

Evaluation of Different Doses and Mode of Application of Ferrous Ammonium Sulphate for Maximizing Rice Production

THESIS

Submitted to

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

In partial fulfilment of the requirements for

The Degree of

MASTER OF SCIENCE

In

AGRICULTURE

(AGRONOMY)

By

SUDHANSHU SHUKLA

(200111013)

Department of Agronomy

College of Agriculture, Jabalpur 482004

Jawaharlal Nehru Krishi Vishwa Vidyalaya Jabalpur,

Madhya Pradesh

2022

CERTIFICATE - I

This is to certify that the thesis entitled “**Evaluation of different doses and mode of application of Ferrous ammonium sulphate for maximizing rice production**” submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (Ag)** in **Agronomy** of the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Sudhanshu Shukla** under my guidance and supervision. The subject of the thesis has been approved by the student’s Advisory Committee and the Director of Instructions JNKVV, Jabalpur (M.P.).

All the assistance and help received during the course of the investigations has been acknowledged by the scholar.

Place: Jabalpur

Dr. S.B. Agrawal

Date:

(Chairman of the Advisory Committee)

THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	Dr. S.B. Agrawal	_____
Member	Dr. K. K. Agrawal	_____
Member	Dr. A.K. Upadhyay	_____
Member	Dr. R.B. Singh	_____

Thesis is approved by







Dr. P.B. Sharma

(The Professor and Head)

Document Information

Analyzed document	sudhnasu agronomy.doc (D141137216)
Submitted	6/24/2022 10:50:00 AM
Submitted by	Sudhanshu Shukla
Submitter email	sudhanshushukla304@gmail.com
Similarity	5%
Analysis address	hod.agronomy.jnk@analysis.arkund.com

Sources included in the report

SA	Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur / Tanjeem agromony 200111022.docx Document Tanjeem agromony 200111022.docx (D141133545) Submitted by: tanjeem.har@gmail.com Receiver: hod.agronomy.jnk@analysis.arkund.com	 5
SA	Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur / Shivangi FFC complete Thesis.docx Document Shivangi FFC complete Thesis.docx (D136419279) Submitted by: shivangiraghuwanshi401@gmail.com Receiver: hod.agronomy.jnk@analysis.arkund.com	 22
W	URL: http://www.ecologyjournal.in/article/view/86/2-3-64 Fetched: 4/16/2022 8:39:11 AM	 7
SA	Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur / THESIS FOR PLAGIARIAM (RICHA SINGH).docx Document THESIS FOR PLAGIARIAM (RICHA SINGH).docx (D121691369) Submitted by: kittoo2015@gmail.com Receiver: hod.agronomy.jnk@analysis.arkund.com	 1
SA	Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur / Atul agro.docx Document Atul agro.docx (D115930360) Submitted by: patelatul567@gmail.com Receiver: bmmourya.jnk@analysis.arkund.com	 1
SA	Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur / Hemanthkumar thesis.pdf Document Hemanthkumar thesis.pdf (D114971184) Submitted by: hemanthgoo1996@gmail.com Receiver: hod.agronomy.jnk@analysis.arkund.com	 1

**JAWAHARLAL NEHRU KRISHI VISHWA VIDYALAYA,
JABALPUR**

Plagiarism Verification

1. Name of the Researcher : **Sudhanshu Shukla**
2. Title of the Thesis : **“Evaluation of Different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing Rice Production”**
3. Faculty : Agriculture
4. Name of the Supervisor : Dr. S. B. Agrawal
5. Official Designation & Address : M.Sc. (Ag.) Student
House no.1014, ward no.7, Khutehi,
Rewa (M.P.) 486001

The above thesis was scanned for similarity detection. The report is as follows

Software used: **Ooriginal**

Date: **24/06/2022**

Similarity Index: **05 %**

Total word count: **22293**

The report is attached for the review by the Researcher/Supervisor

Sign. of Researcher

The plagiarism report of the above thesis has been reviewed by the undersigned. The similarity index is below accepted norms.

The similarity index is above accepted norms because of the following reasons:

.....
.....
.....

The thesis may be considered for submission to the University. The software report is attached

Sign. of Researcher

Sign. of Supervisor with Seal

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

Central Library

Anti-Plagiarism Certificate

Thesis : **“Evaluation of Different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing Rice Production”**

Name of the Author : **Sudhanshu Shukla**

Enrollment Number : 200111013

Department : Agronomy

College : College of Agriculture, Jabalpur

Name of the Advisor : **Dr. S. B. Agrawal**

Date of received for check : 24/06/2022

Chapter wise plagiarism report

Chapter	Percentage of Plagiarism		Remark
Introduction	-	-	-
Review of Literature	-	-	
Material and Methods	-	-	
Result	-	-	
Discussion	-	-	
Summary, Conclusion and Suggestions for further work	-	-	
AVERAGE	-	05%	

I hereby certify that the thesis has been evaluated using Plagiarism Check Software **Original (URKUND)** on **24.06.2022** (Date). The system reported that the thesis has average **05** Percent of plagiarism which is within the **approved** limit and it is **passed** with Dr. (Smt.) Arti Shrivastava

A. Below 10%

B.

C.

D.

Date:

Chairman	Dr. P.B. Sharma
Member	Dr. K. K. Agrawal
Member	Dr. (Smt.) Arti Shrivastava
Member	Dr. Siddharth Nayak

CERTIFICATE - II

This is to certify that the thesis entitled “**Evaluation of different doses and mode of application of Ferrous ammonium sulphate for maximizing rice production**” submitted by **Sudhanshu Shukla** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfilment of the requirements for the degree of “**Master of Science in Agriculture**” in the **Department of Agronomy** has been, after evaluation, approved by the External Examiner and by the Student’s Advisory Committee after an oral examination of the same.

Place: Jabalpur

S.B. Agrawal

Date:

(Chairman of the Advisory Committee)

MEMBERS OF THE ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	Dr. S.B. Agrawal	-----
Member	Dr. K. K. Agrawal	-----
Member	Dr. A.K. Upadhyay	-----
Member	Dr. R.B. Singh	-----
Head of the Department	Dr. P.B. Sharma	-----
Director of Instruction	Dr. Abhishek Shukla	-----

Declaration and Undertaking by the Candidate

I, Sudhanshu Shukla s/o Shri Ashutosh Shukla certify the work embodied in thesis entitled “**Evaluation of different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing Rice Production**” is my own first hand bonafide work carried out by me under the guidance of **Dr. S.B. Agrawal**, Associate Professor, Department of Agronomy, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur during 2021-22.

The matter embodied in the thesis has not been submitted for the award of any other degree/diploma. Due credit has been made to all the assistance and help.

I, undertake the complete responsibility that any act of misinterpretation, mistakes and errors of fact are entirely of my own.

I, also abide myself with the decision taken by my advisor for the publication of material extracted from the thesis work and subsequent improvement, on mutually beneficial basis, provided the due credit is given, thereof and will not include any unauthorized name in research publications.

Place: Jabalpur

(Sudhanshu Shukla)

Date:

**Copyright © Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur
Madhya Pradesh 2021-2022**

Copyright Transfer Certificate

Title of the Thesis : **Evaluation of different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing rice production**

Name of the candidate : Sudhanshu Shukla

Subject : Agriculture

Department : Agronomy

College : College of Agriculture, Jabalpur
Jawaharlal Nehru Krishi Vishwa Vidyalaya,
Jabalpur

Year of thesis submission : 2022

Copyright Transfer

The undersigned **Sudhanshu Shukla** assigns to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, all rights under Copyright Act, that may exist in and for the thesis entitled “**Evaluation of different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing Rice Production**” submitted for the award of M.Sc. (Ag.) Agronomy degree.

Date:

Place: Jabalpur

Dr. S. B. Agrawal
(Major Advisor)

Sudhanshu Shukla
(Student)

ACKNOWLEDGEMENT

Thanks to God for blessed me with the ability to finish my thesis and for providing me with this opportunity to convey my heartfelt gratitude to all those who assisted me in making my study a success.

It brings me great joy and honour to express my sincerest gratitude and reverence to venerable Dr. S.B. Agrawal, Professor, Department of Agronomy, JNKVV, Jabalpur and the most efficient, timely and wise personality. I give him big thanks for keeping my spirits up, being attentive and making helpful recommendations. It would not have been able to accomplish this time-consuming investigation without his assistance.

I would like to thanks and deep sense of gratitude to advisory committee members, Dr. K.K. Agrawal, Professor, Department of Agronomy, Dr. A.K. Upadhyay, Assistant Professor, Department of Soil Science and Dr. R.B. Singh, Professor, Department of Mathematics & Statistics, JNKVV, Jabalpur, for their valuable guidance and timely assistance during the course of this investigation.

I am indeed thankful to Dr. P. B. Sharma, Professor and Head, Department of Agronomy for his proper guidance and extending the required facilities during the course of research work.

I express my warmest feelings with deep sense of gratitude and regards to all respected teacher of the Department of Agronomy Dr. M.L. Kewat, Dr. Namrata Jain, Dr. Amit Jha, Dr. Manish Bhan, Dr. S.K. Vishwakarma and Dr. Arti Shrivastava, without whose benevolent guidance and constant motivation it would not have been possible to complete this project.

I also take the opportunity to thank Dr. P. K. Bisen, Honourable Vice Chancellor, Dr. D. Khare, Dean Faculty of Agriculture and Dr. G. K. Koutu Director of Research Services and Dr. Abhishek Shukla, Director of Instruction, Dr. D. P. Sharma, Director Extension Services and Dr. Sharad Tiwari, Dean College of Agriculture, JNKVV, Jabalpur for providing necessary facilities during the course of investigation.

I express my sincere thanks to my Seniors Shani Gulaiya, Badal Verma, Swati Saraswat, Sahiba Khatoon, Vinay Sahu, and Akash Patel for their kind co-operation throughout this academic programme.

Words fails me to express my appreciation to my best friends Kartik Mandloi, Tanjeem Ansari, Kaminee Singh, Vedant Gautam, Abhishek Singh Jadon, Abhishek Mishra, Vishal Patel, Dheerendra Pratap Singh for their love, care, moral support and help during my thesis programme and also very thankful to all my batchmates.

I think, I am blessed with such a good family I have with me who always supports and motivates me. I would express my gratitude to my dearest grandfather late Shri Chintamani Prasad Shastri, grandmother Manwati Shukla, my father Mr. Ashutosh Shukla, my mother Mrs Sudha Shukla and my sister Manya Shukla for their sincere encouragement and inspiration throughout my research work and lifting me uphill during this phase.

Finally, I record my thanks to all of them who have been praying for my betterment and helped me in this study to make it successful and could not find a separate mention.

Place: Jabalpur

(Sudhanshu Shukla)

Date: 2022

LIST OF CONTENTS

Chapter No.	Title	Page No.
1.	Introduction	1-3
2.	Review of Literature	4-19
3.	Materials and Methods	20-36
4.	Results	37-52
5.	Discussion	53-60
6.	Summary, Conclusions and Suggestions for further work	61-64
7.	Bibliography	65-72
	Appendices	i-v
	Curriculum Vitae	

LIST OF TABLES

Table No.	Title	Page No.
3.1.	Meteorological parameters during rabi season, 2021-22	22
3.2.	Physico-chemical properties of the soil	24
3.3.	Cropping history of the experimental field	25
3.4.	Details of experimental treatments	26
3.5.	Schedule of Agriculture practices during the course of field experimentation	29
3.6.	Analysis of variance	35
4.7	Influence of different FASt treatments on plant population.	37
4.8	Influence of different FASt treatments on plant height	39
4.9	Influence of different FASt treatments on tillers hill ⁻¹ of rice at different time intervals	41
4.10	Influence of different FASt treatments on dry weight hill ⁻¹ of rice at different time intervals	42
4.11	Influence of different FASt treatments on Leaf area index of rice at different time intervals	44
4.12	Influence of different FASt treatments on yield attributing characters	46
4.13	Influence of different FASt treatments on grain yield, straw yield, harvest index	49
4.14	Economic analysis of different FASt treatments	51

LIST OF FIGURES

Figure No.	Title of the Figure	Page No.
1	Meteorological parameters during <i>kharif</i> season, 2021	23
2.	Plan and layout of the experiment	27
3.	Influence of different FAST treatments on plant population of rice at different time intervals	38
4	Influence of different FAST treatments on plant height of rice at different time intervals	39
5.	Influence of different FAST treatments on tillers of rice at different time intervals	41
6.	Influence of different FAST treatments on dry weight of rice at different time intervals	43
7.	Influence of different FAST treatments on Leaf area index of rice at different time intervals	44
8.	Influence of different FAST treatments on yield attributing characters	47
9.	Influence of different FAST treatments on grain yield, straw yield of rice	49
10.	Influence of different FAST treatments on cost of cultivation, GMR and NMR	52

LIST OF PLATES

Plate No.	Title of the Plates	Page No.
1	View of Experimental Field	36

LIST OF ABBREVIATIONS AND SYMBOLS

<u>Abbreviation</u>	<u>Stand for</u>
@	At the rate
ANOVA	Analysis of variance
cm	Centimetre
CD	Critical difference
F value	Fisher's value
d.f.	Degree of freedom
DAT	Day After Transplanting
<i>et al</i>	And co- worker
m	Meter
FASt	Ferrous ammonium sulphate
Fig.	Figure
g	Gram
ha	Hectare
kg	Kilogram
Max.	Maximum
Min	Minimum
M.S. S	Mean Sum of Square
i.e.,	That is
mt	Million tonnes
%	Percentage
Viz.	Namely
° C	Degree Celsius
q	Quintal
RDF	Recommended dose of fertilizer
SEm ±	Standard Error of mean
SSTr	Treatment sum of square
SSE	Error sum of square
SST	Total sum of square
MSR	Replication mean sum of square
MST	Treatment mean sum of square
S.Ed	Standard error of differences between two treatments

MSE

Treatment sum of square

t (0.05)

Tabulated 't' Value at error degree of freedom at $p=0.05$

C.V

Coefficient of variation

INTRODUCTION

Rice (*Oryza sativa* L.) belongs to the family Gramineae (Poaceae). As a cereal grain, domesticated rice is the most widely consumed staple food for over half of the world's human population, especially in Asia and Africa. Rice is the most important food crop with respect to human nutrition and caloric intake, providing more than one-fifth of the calories consumed worldwide by humans. Rice is the leading cereal of the world and more than half of the human race depends on rice for their daily sustenance (Chouhan and Johnson, 2011). Almost 90% of the world's rice is produced and consumed in Asia. It provides 50-80% daily calorie intake to the consumer (*Choudhary et al., 2011*).

Rice can be grown in a variety of soil and climatic conditions. Productivity of rice in India is low in comparison to the productivity of several countries throughout the world. The major constraint in raising rice productivity in the country is that about 90% of the farmed area belongs to small and marginal farmers. Hence, there is an ample scope to increase the productivity of rice in the country. The highest productivity is 6710 kg per ha of China followed by Vietnam (5573 kg /ha), Indonesia (5152 kg/ha), Bangladesh (4375 kg/ha). Moreover, 2 billion people in Asia rely on rice for 60-70 percent of their energy needs, and the demand for rice is increasing every year. According to estimates, the demand for 100 million tonnes in 2010 will climb to 140 million tonnes in 2025. India needs to boost rice output by 3% per year to maintain current food self-sufficiency and fulfil future food demand. (Thiyagarjan and selvaraju, 2001).

The improved technologies for rice cultivation and other interventions which could be adapted to increase the productivity in the country. Rice occupies a pivotal place in Indian agriculture as it's an important staple food crop of India. It account for about 42% of total food grain production and 55% of cereal production in the country. In India, rice is grown in nearly 43.70 mha area with the production of 105.42 MT and productivity of 2412 kg ha⁻¹. India is the second largest producer and consumer of rice in the world. In Madhya

Pradesh, it occupies an area of 2.29 mha with production of 4.23 MT and productivity of 1847 kg ha⁻¹ (Agriculture Statistics at a glance, 2018).

Fe deficiency is one of the most prevalent micronutrient deficiencies in the world, affecting an estimated two billion people (Stoltzfus, *et al.* 1998) and contributing to 0.8 million deaths per year worldwide (WHO 2002). Zn deficiency is a serious nutritional problem, affecting an estimated one third of the world's population (Sandstead, *et al.* 1991) and contributing to 0.8 million deaths per year.

Most Indian soils are deficient in S, Zn, M, Cu, B, Fe and Mo. Rice crops under the Rice-Wheat cropping system (RWCS) struggle with iron and zinc deficiency. Hence, the occurrence of multi micronutrient deficiencies are the new deterrent in façade of the sustainability of the Rice Wheat Cropping System, as farmers are not aware to correct the deficiencies of these yield driven nutrients. Therefore, at many locations resource poor farmers unknowingly started to use a higher amount of N fertilizer than the local recommendation to maintain the past yield level. Balanced nutrition increases a plant's ability to absorb requisite amounts of desired nutrients and thus, improve crop productivity and input use efficiency. One such product which is multinutrient fertilizer FASt claims to increase rice productivity so in this experiment it was observed to test effect of FASt on growth and yield of Rice along with recommended dose of fertilizer (Dwivedi BS *et al.* 2016).

Current crop management strategies addressing Fe deficiency include Fe foliar application, soil application and plant breeding to identify species and development of varieties rich in iron.(Zuo and Zhang, 2011). Iron enrichment by soil application will offer more effective and sustainable pathways to alleviate iron malnutrition.

The iron chlorosis is most severe when the coarse textured soils are brought into wider rice cultivation for the first time. Sometimes severe chlorosis due to Fe-deficiency can lead to complete failure of the rice crop (Katyal and Sharma, 1980). This happens despite the fact that the total iron content in soils is extraordinary high but the amount of plant usable iron is

rather low to moderate and depends on soil properties, cropping pattern and environmental condition.

The deficiency of sulphur is emerging fast in areas where continuously sulphur free fertilizers like DAP, urea etc are being used. Sulphur deficiency is also found more in alkaline, coarse textured, low organic matter soils. The sulphur requirement of rice varies according to the nitrogen supply.

When S becomes limiting, addition of N does not change the yield or protein level of plants. Sulphur is required early in the growth of rice plants. If it is limiting during early growth period followed by tillering finally the yield will be reduced (Blair & Lefroy, 1987).

Ferrous ammonium sulphate ($(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$) is a crystalline water soluble solid containing Iron, Nitrogen, Sulphur and is used mostly in the soils where, Iron is deficient and the soil is neutral to alkaline in nature. Its composition is (Iron: - 14% ,Nitrogen :- 7%, Sulphur : - 8%).It helps to reduce the pH of the soil increasing availability of nutrients and enhances quick & full greening response for Iron when combined with Nitrogen, in lawns, turf grass, vegetables and ornamentals. It eliminates Iron chlorosis by enhancing chlorophyll synthesis. And also helps conditioning alkaline soils to allow uptake of immobilized soluble micronutrient salts. It is compatible with almost all kinds of fertilizers except phosphatic fertilizers. (Agrawal GC *et al.* 1995)

The present investigation entitled “**Evaluation of different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing Rice Production**” was carried out at the Agricultural Engineering Research Farm, JNKVV, Jabalpur, (M.P.) during *kharif* seasons of 2021 with the following objectives:

- i. To find out the suitable dose of ferrous ammonium sulphate (FASt) for enhancing growth and yield of rice.
- ii. To assess the effective method of ferrous ammonium sulphate application for higher yield of rice.
- iii. To find out the economically viable treatment.

REVIEW OF LITERATURE

It is always desirable to study a brief resume of work done before undertaking any scientific investigation on those lines, because this gives scope to formulate new objectives and strategies in experimentation.

Micronutrient deficiencies affecting crop yields are difficult to be corrected due to large temporal and spatial variation in availability, quick conversion and fixation into unavailable form and poor movement of applied micronutrients in soil profile. Soil applied micronutrients are not readily transported to the shoot; similarly foliar applied micronutrients are also inefficiently transported to roots. Therefore, application of micronutrients applied either in soils or on foliage may be successful in enhancing grain yield only under well-defined agro ecosystem. Hence extrapolating results to a new situation is unlikely to be successful without a specific adjustment in the fertilizer schedule.

It is well established that among the micronutrients, particularly iron is one of the most essential plant nutrients. Iron is involved in the activation of several enzymes system including the one that is responsible for chlorophyll formation. Further, rice is considered very susceptible to Fe deficiency, especially when grown under upland condition (Fageria *et al.*, 2011).

The Fe content of green plant tissues is low in comparison with the macronutrient and generally in the order of about 100 mg kg⁻¹ in the dry matter. In cereal grains, tubers and root crops, it is often considerably low. Total soil iron is thus always in excess of crop requirement. According to Lindsay (1974), most agriculture crops require less than 0.5 mg kg⁻¹ available iron in soil (in the plough layer) while, the total Fe level is about 2 per cent or 20,000 mg kg⁻¹. Any problem of iron deficiency is due to iron unavailability. Iron is absorbed by plant root in the form of Fe²⁺, Fe³⁺ and organically complexed Fe chelate. The Fe²⁺ is more stable and available for incorporation into bio-molecular structures. Total iron content of the plant is

not a true indicator of the iron status of the plant but Fe²⁺ give good picture about iron status (Katyal and Sharma 1980).

A brief review of literature pertaining to the present investigation entitled “**Evaluation of different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing Rice Production**” has been presented in this chapter under different sub-headings.

2.1 Iron in soils

2.1.1 Total iron in soils

2.1.2 Available iron in soils

2.2 Iron in plant nutrition

2.3 Effect of iron on growth and growth parameters

2.4 Effect of iron on yield and yield components

2.5 Effect on economics

2.1 Iron in soils

2.1.1 Total iron in soils

Rai *et al.* (1972) Reported that available iron, zinc, manganese, molybdenum, copper and boron in shallow black soils of Madhya Pradesh in the districts of Betul, Chindwara and Seoni were determined by chemical methods. These soils contained sufficient amount of manganese, molybdenum, copper and boron, but some soils were deficient in iron and zinc. The percentage of samples deficient in iron was 40.5 in Betul, 46.7 in Chindwara and 14.5 in seoni districts.

Dubey *et al.* (1983) estimated iron content in salt affected black soils of western Madhya Pradesh. The total iron in the soils was fairly high which could be attributed to the presence of iron bearing minerals. The content generally decreased with the depth of the profile.

Mengel and Kirkby (1982) reported that iron makes up about 5 per cent by weight of the earth's crust and is invariably present in all soils. The major part of soil Fe usually occurs in the crystal lattices of many minerals. The primary minerals in which Fe is present include the ferromagnesium silicates such as olivine, augite, hornblende and biotite. These minerals along with biotite micas constitute the major Fe source in igneous rocks. Primary iron oxides which occur in many soils include haematite (Fe_2O_3), limonite (FeTiO_3) and magnetite (Fe_3O_4). In sedimentary rocks, iron oxides and siderite (FeCO_3) are usually the most common primary iron forms. Iron may also be present in secondary mineral lattices in soils and it is an essential element in a large group of clay minerals. As weathering proceeds, iron originally present in the easily weatherable ferromagnesium primary minerals appears in illitic clay minerals. The high stability of primary iron oxides means that during oxidative weathering, Fe oxides accumulate as hydrous oxides in clay fraction. Thus, in soils, at an advanced stage of oxidative as in the case of lateritic soils, these oxides together with Al-oxides and kaolinite predominate in the profile.

Kumar *et al.* (1981) studied the total iron content in soils of Kumaon and Garhwal Himalayas which ranged from 3.20 to 9.50 per cent, 2.25 to 4.15 per cent and 2.0 to 4.05 per cent in Bhageshwar, Ganur and Ranichuri soils, respectively. The total iron content was higher in subsurface horizons than in surface layers, which was due to illuviation of iron from surface to subsurface layer.

El-Falaky (1981) reported that the average values of total iron content in alluvial, sandy and calcareous soils were 5.77, 1.26 and 1.77 per cent, respectively.

Ghugre and Sonar (1984) conducted a field experiment on a calcareous Vertisols to study the effect of soil water treatments (control, field capacity and saturation) for 15 days prior to sowing on yield and iron nutrition of two rice cultivars grown under upland condition at Rahuri, MPAU

(Maharashtra). They revealed that soil saturation (daily two irrigations) for 15 days prior to sowing of rice increased the availability of Fe in soil as a result of reduction in pH and Eh of saturated soil.

According to Mured and Fischer (1988), the total Fe content in soils ranged from less than 1 to greater than 20 per cent with an average value of 3.2 per cent Netherland.

2.1.2 Available iron in soils

Rajkumar *et al.* (1990) studied the depth-wise distribution of four available micronutrients in soil series of Bundelkhand region of Madhya Pradesh and reported that available Fe and Mn increased with depth.

Sakal and Singh (2001) observed an overall deficiency of iron in Indian soils. In Karnataka about 39 per cent soils are deficient in iron.

The deficiency of iron is quite common in calcareous soils because of its low availability. Under conditions of satisfactory aeration, iron is found in most soils, principally as precipitates of oxides and phosphates. The occurrence of iron oxides, magnetite, goethite, hematite, limonite and lepidocrite has been recorded in soils (Brown,1960). The availability of these oxides in soils is determined by the changes in pH, oxidation reduction potential and the presence of soluble complexing agent. Available iron in Indian soils varies from 0.09 to 225 ppm (Kanwar and Randhawa,1974).

Babarai and Patel (1980) found an increase in the availability of iron at 10 ppm of iron, to soils. The effect was more pronounced as the incubation period was increased up to 42 days.

Welp *et al.* (1983) found that the soil with high organic matter (>2% carbon) and especially under alkaline conditions, the concentration of organic Fe-chelates can reach values up to 10^{-4} to 10^{-3} M. However, in well-aerated soil inorganic matter, Fe concentration in the soil solution ranged from 10^{-8} to 10^{-7} M and thus is lower than the required amount for adequate plant growth.

Shukla *et al.* (2020) reported that recent analysis of Indian soils revealed an average deficiency level of 36.5% for Zn, 23.2% for B, 12.8% for Fe, 7.1% for Mn, 4.2% for Cu and 28.5% for S in soils of intensively cultivated Indo-Gangetic Plain (IGP) of India. The concentration of available Zn, B, Fe, Mn, Cu and S varied from 0.01 to 3.27, 0.01 to 3.51, 0.19 to 55.7, 0.05 to 49.0, 0.01 to 5.29 and 1.01 to 108 mg kg⁻¹, respectively.

The availability of iron in soils is a fraction of a number of properties, including texture, CaCO₃ content, organic matter and the amount of Fe in the solid form, which is equilibrium with those in the soil solution. A very small proportion of soil total Fe is available for higher plants. The total concentration of ionic Fe³⁺ and Fe²⁺ are extremely low (10⁻¹⁰ M or lower) in the aerated media maintained in the physiological pH range (Lindsay, 1974). He separated 77 Colorado soils into iron deficiency and non-deficiency categories and indicated that no response to iron fertilizer was obtained when DTPA extractable iron exceeded 4.5 ppm.

Cottenie *et al.* (1982) demonstrated that the critical limit of DTPA extractable soil iron more than 4.5 ppm Fe is considered adequate.

2.2 Iron in plant nutrition

Chaney *et al.* (1972) reported that reduction of Fe³⁺ (ferric ion) to Fe²⁺ (ferrous ion) is found to be obligatory, before it can be absorbed by the plants. Katyal and Sharma (1980) identified higher amount of iron in chlorotic leaves of paddy in comparison to green leaves. In order to overcome the elusive behaviour of iron they analysed for active iron Fe²⁺ or dilute acid extractable iron using 1-10 Orthophenonthroline and reported that chlorotic plant contain less of Fe²⁺ than green plants.

Basanna (1982) reported that Fe²⁺ was generally greater in green leaves (lower leaves) than chlorotic (upper) leaves. The total iron content was generally more in chlorotic (top) leaves than green (lower) leaves of paddy in medium black soils at Agricultural College farm, Dharwad.

In plant leaves, Bergmann (1992) stated that the critical deficiency concentration (CDC) of iron ranged from 30 to 50 ppm on dry weight basis. The CDC was presumably considerably higher in fast growing meristematic and expanding tissue.

Marschner (1991) declared that the critical concentration of Fe in leaves is usually in the range between 50 and 150 mg kg⁻¹ dry weight.

Krishnamurthy and Raj (1975) reported that application of organic matter to calcareous soils under waterlogged conditions increased the ferrous iron content of soils. The formation of ferrous iron in waterlogged soils was attributed to the reducing compounds and carbon dioxide produced in the course of anaerobic decomposition or fermentation of added organic matter. Such substances dissolve insoluble ferric iron compounds in the soils and reduce them to the ferrous form.

The most of the iron found in leaves is located in the chloroplast (Seckback, 1982). Terry and Low (1982) reported that three-fifth of the total iron content in rapidly growing leaves of sugarbeet was in the thylakoid membrane, one-fifth in the chloroplast and stroma and remaining one-fifth in the extra-chloroplast. Much of the iron in the leaf was in the ferric form. Some of the iron in the leaf, however, must be present in the soluble form since several enzymatic processes required Fe (II) e.g. haem synthesis (Rebeiz and Lascelles, 1982).

Chen and Barak (1982) stated that a major problem with foliar application is the poor translocation of applied iron within the plants. The main disadvantages of foliar sprays are possible deleterious effects on plant foliage and the need for repeated application under same conditions

2.3 Effect of iron on growth and growth parameters

Syed *et al.* (2020) reported that Plant height was found to increase with increase the levels of ferrous ammonium sulphate (FASt). The highest height (105.17 cm) was noticed in the T4 treatment due to soil application of FASt

@35kg/ha however it was on par with soil application of FAST @ 25kg/ha. (104.58cm) and 20kg/ha.(100.58cm).

A field experiment was carried out to judge the mode of iron application on the performance of direct seeded upland rice in which plant height (61.9 cm) increased due to basal application of FeSO₄ @ 15 kg ha⁻¹ along with 1.0% foliar spray at 35 DAS. However, it was significantly at par with foliar spray of 0.1% Fe EDTA at 25 and 35 DAS (59.7 cm) (Sarangi *et al.*, 2006).

Yadav *et al.* (2011) in an aerobic rice experiment studied the influence of basal and foliar Fe application methods and noticed more plant height (87.1 cm) with application of iron sulphate @ 100 kg ha⁻¹ followed by 50 kg ha⁻¹ as basal + two foliar sprays of 2% iron sulphate (86.2 cm).

Gill and Walia (2013) observed noticeable increase in the plant height of direct seeded basmati rice with increase of foliar sprays of 1% FeSO₄ from 1 to 4 (96.53 to 98.69 cm) compared to single foliar spray and control (92.11 cm).

Kumar *et al.* (2015) observed significantly higher plant height with two (104.23 cm) and three (105.93 cm) foliar sprays of 2.0 % iron sulphate. However, lower plant height (100.18 cm) was produced in case of control plot and was at par with basal application of iron sulphate and combination of basal application with one foliar spray of iron sulphate or chelate.

Baishya *et al.* (2016) at Langol studied the influence of combination of foliar sprays of micronutrients on aerobic rice. Foliar application of micronutrients particularly Fe at 2% (98.71 cm) had significant positive effect on plant height over the control (90.25 cm).

Gill and Walia (2013) carried out a field experiment in sandy loam soils (pH:8.1, EC:0.4 dS/m) of Ludhiana (Punjab), to study the effect of foliar feeding of micronutrients on growth and yield of direct seeded aromatic rice during the *kharif* seasons of 2010 and 2011. They reported that application of four sprays of 0.5 % MnSO₄ or four sprays of 1 % FeSO₄ at 40, 50, 60 and 70 days after sowing were at par and recorded significantly higher plant height

(101.6 and 101.3 cm), dry matter (15.0 and 15.1 t/ha), Leaf area index (3.3 and 3.6), effective tillers/m² (312.7 and 291.8), panicle length (26.2 and 26.0 cm) and spikelets/panicle (72.9 and 73.5), grains/ panicle (142.5 and 140.5) and 1000 seed weight (21.9 and 22.0g) compared to control during both the years.

Basal and foliar Fe application methods was observed by Yadav *et al.* (2011) in rice, wherein they noticed higher total tillers m⁻² with application of iron sulphate @ 50 kg ha⁻¹ as basal + 2 foliar sprays of 2% iron sulphate (513) at 90 DAS compared to basal application of iron sulphate @ 50 kg ha⁻¹(488).

Deficiency of Fe is one of the widely known disorders of upland rice (Haon *et al.* 1993). Fe and Zn applications increased dry matter production during tillering, panicle initiation and maturity stages (Sakal & Sinha, 1983). Fe application @ 19 kg ha⁻¹ with usual dose of N, P, K, significantly increased yield, leaf number, leaf area, straw yield, tiller number and grain size in Nigeria (Agboda and Fube, 1983).

Highest number of tillers m⁻² (381.2) was recorded by Kumar *et al.* (2015) from three foliar sprays of 2.0% iron sulphate followed by 3 foliar sprays of 0.5% iron chelate (373.5) over the other treatments. However, soil application of iron and soil application along with single foliar spray did not prove effective in improving tiller count of aerobic rice (310) and were at par with the control (279.3).

Yadav *et al.* (2011) conducted a field experiment to study the effect of mulching and iron nutrition on productivity at IARI, New Delhi. Iron fertilization @100 kg FeSO₄/ha as basal or 50 kg FeSO₄/ha as basal + two foliar sprays of 2 % FeSO₄ recorded significantly higher panicles/m², panicle length, number of filled grains per panicle and grain weight per panicle as compared to other treatments.

Saranghi *et al.* (2006) in a field experiment studied the mode of iron application on the performance of direct seeded upland rice and noticed significantly higher dry matter (1069 g m⁻²) with combination of FeSO₄ @ 15

kg ha⁻¹ and foliar spray at 35 DAS. Foliar spray alone with 0.1% Fe EDTA at 25 and 35 DAS also produced similar dry matter (1014 g m⁻²).

The application of N180, P90 & K60 along with 25 kg ha⁻¹ iron sulphate as basal application increased plant dry matter at active tillering (68.7 g m⁻²), panicle initiation (524 g m⁻²), flowering (919 g m⁻²) and at harvesting (1600 g m⁻²) with iron application compared to the control (53.3, 388, 652 and 1232 g m⁻²) in aerobic rice (Rakesh *et al.*, 2012).

Among different iron sulphate sprays on direct seeded rice, Gill and Walia (2013) noticed higher dry matter accumulation with 4 sprays of FeSO₄ 1.0% at 40, 50, 60 and 70 days (149.45 q ha⁻¹) significantly superior over all other treatments, but remained at par with three sprays of FeSO₄ 1.0% at 50, 60 and 70 days (150.06 q ha⁻¹) and two sprays of FeSO₄ 1.0% at 60 and 70 days (148.52 q ha⁻¹) of direct seeded basmati rice.

Kumar *et al.* (2015) observed aerobic rice with different sources and mode of iron application. Significantly higher dry matter was accumulated with 2 (1153.6 g m⁻²) and 3 (1229.8 g m⁻²) foliar sprays of 2.0% iron sulphate. However, lower dry-matter (948.4 g m⁻²) was produced in case of control plot and was at par with basal application of iron sulphate (981.2 g m⁻²) and combination of basal application with one foliar spray of iron sulphate or chelate (985.1 and 982.4 g m⁻²).

Sinha and Sakal (1983) carried out a pot experiment at Department of Soil Science and Agricultural Chemistry, Rajendra Agricultural University, Samastipur (Bihar) to examine the effect of Fe as FeSO₄.7H₂O and ferric citrate on rice in sandy loam soil (calcareous) having pH 8.3, EC 0.22 dS/m and available Fe 4.50 ppm. They reported that soil application of Fe either through FeSO₄.7H₂O or ferric citrate progressively enhanced the dry matter yield of rice (variety IR 20) at tillering, panicle initiation and maturity stages. The effect of Fe @ 10 ppm in form of ferric citrate was better than 20 ppm Fe through FeSO₄.7H₂O in respect to dry matter production.

Prasad and Rajkumar (1992) recorded the significant increase in dry matter yields and iron uptake by rice in calcareous soil of Bihar due to the application of iron in the form of FeSO₄ as well as Fe-chelates.

In a pot culture experiment rice seed were treated with ferrous sulphate and ferrous chelate fertilizers. Among the treatments seed soaking with chelate solution of 0.05 Fe-EDTA recorded highest dry matter (3.65 g pot⁻¹) followed by 0.5M (3.38 g pot⁻¹) and 0.25M FeSO₄.7H₂O (3.35 g pot⁻¹) solutions which were statistically at equivalence with control (3.21 g pot⁻¹) (Meena *et al.*, 2013).

Kumar *et al.* (2015) observed higher LAI at all the stages of crop with 3 foliar sprays of 2 % iron sulphate (tillering-2.65, panicle initiation-3.84 and flowering-4.80). Lower values of LAI were recorded with control plot (tillering-2.42, panicle initiation-3.50 and flowering-4.03) which was lower than 2 foliar sprays of either 2 % iron sulphate (tillering- 2.45, panicle initiation- 3.83 and flowering- 4.77).

Mahajan and Khurana (2014) studied direct seeded rice with foliar treatments of Fe, KNO₃ alone and in combination sprays at different stages of rice crop. At flowering stage, significant response for LAI (5.41) with sequential foliar spray of Fe (2s) + KNO₃ (1s) was noticed and was lowest in control (4.03).

Significantly higher leaf area index (2.99) with four sprays of FeSO₄ 1.0% was observed by Gill and Walia (2013) over all other treatments, but was statistically similar with three and two sprays of FeSO₄ 1.0 % of direct seeded basmati rice (2.87 and 2.65).

Kumar *et al.* (2015) in aerobic rice, noticed more CGR (10.89 g m⁻² day⁻¹) with 3 foliar sprays of 2.0 % iron sulphate, followed by 3 foliar sprays of 0.5% iron chelate (358.65), which was significantly higher over the control (7.39 g m⁻² day⁻¹) and basal application of iron sulphate (7.68 g m⁻² day⁻¹).

Maximum CGR (10.95 g m⁻² day⁻¹) was observed by Das *et al.* (2016) in aerobic rice experiment with 3 foliar application of 2 % FeSO₄ at tillering,

pre flowering and flowering stages compared to control ($9.25 \text{ g m}^{-2} \text{ day}^{-1}$) and basal application of $25 \text{ kg FeSO}_4 + 5 \text{ t/ha FYM}$ but was statistically at par with 3 foliar application of 1 % FeSO_4 at tillering, pre flowering and flowering stages ($10.69 \text{ g m}^{-2} \text{ day}^{-1}$).

2.4 Effect of iron on yield and yield components

Increasing trend of effective tillers m^{-2} was obtained with increase in number of sprays of FeSO_4 1.0% from 1 to 4 sprays. Higher tillers (276.76) were recorded with 4 foliar sprays of FeSO_4 1.0% at 40, 50, 60 and 70 days in direct seeded basmati rice (Gill and Walia, 2013)

Yadav *et al.* (2011) in an aerobic rice experiment noticed higher panicles m^{-2} (341.5) with application of iron sulphate @ 100 kg ha^{-1} or 50 kg ha^{-1} as basal + 2 foliar sprays of 2% iron sulphate (335.8) which helped in increase of grain and straw yields of aerobic rice.

Among different methods of micronutrient application *i.e.*, seed pelleting, seed soaking and soil application for aerobic rice crop in a study by Sridhara *et al.* (2012) significantly higher panicles plant^{-1} were observed with soil application of 5 g of FeSO_4 and 20g of ZnSO_4 (17.5).

The yield attributing characters of rice *i.e.* number of effective tillers m^{-2} were higher due to the incubated mode of application of FeSO_4 and ZnSO_4 . The FeSO_4 application rate @ 5 and 10 kg ha^{-1} did not affect the growth and yield characters of rice (Kulandaivel *et al.*, 2003).

Yogesh *et al.* (2013) with aerobic rice cultivation recorded more productive tillers (35.33) with combined application of RDF + FYM 10 t ha^{-1} + FeSO_4 @ 12.5 kg ha^{-1} + VAM + *Azospirillum* + PSB and it resulted in 76.5 per cent higher tillers as compared to farmers practice (20.0) and it was at par with application of RDF + FYM 10 t ha^{-1} + FeSO_4 @ 12.5 kg ha^{-1} (29.33).

Kumar *et al.* (2015) in aerobic rice, noticed more effective tillers (366.2) with 3 foliar sprays of 2.0 % iron sulphate, followed by 3 foliar sprays of 0.5%

iron chelate (358.65), which was significantly higher over the control (264.3) and basal application of iron sulphate (265.7).

Rakesh *et al.* (2012) studied the influence of different doses of N, P & K along with 25 kg ha⁻¹ iron sulphate on aerobic rice of which application of 180:90:60:25 kg NPK and FeSO₄ ha⁻¹ recorded highest number of grains panicle⁻¹ (91).

Kriem *et al.* (1991) found that number of panicles m⁻², number of grains per panicle and panicle weight increased significantly with an increase in the levels of ferrous sulphate. These results were further confirmed by Singh *et al.* (1992). Dravid and Goswami (1987); Biswas and Tewatia (1988) and Bhattacharya (1992) found an improvement in the rice yield attributing characters like panicle length, fertility percentage and test weight due to the levels of ferrous sulphate. Similar results were also reported by Singh *et al.* (1996).

Baishya *et al.* (2016) at Langol Research Farm of ICAR Research complex for North Eastern Hill Region (NEHR), Manipur studied the influence combination of foliar sprays of micronutrients on aerobic rice. Foliar application of micronutrients particularly Zn and Fe had significant positive effect on filled grains panicle⁻¹ (82.33 and 63.08) over control (70 and 61.92).

In an aerobic rice experiment at Bengaluru by Sunil *et al.* (2014) reported lower chaffyness (7.9%) with integrated package of agro techniques *i.e.*, RDF+FYM+ Biofertilizers + FeSO₄+Integrated weed management practices which resulted in higher panicle length.

Syed *et al.* (2020) reported that Panicle length was found to increase with increase the levels of ferrous ammonium sulphate (FASt). The highest panicle length (25.08cm) was noticed in the T4 treatment due to soil application of FASt @35kg/ha however it was on par with soil application of FASt @ 25kg/ha. (24.77cm) and 20kg/ha.(23.50cm).

Rakesh *et al.* (2012) studied the influence of varying fertility levels of N, P & K along with 25 kg ha⁻¹ iron sulphate in aerobic rice and found that there

was no significant difference in 1000 grain weight. However, the test weight was increased along with increase in nutrient levels. Maximum 1000 grain weight (26.9 g) was recorded with the application of 180:90:60:25 kg N, P, K and Fe ha⁻¹.

Influence of combination of foliar sprays of micronutrients on aerobic rice was experimented, particularly Fe at 2% (28.48 g) which had significant positive effect on 1000 grain weight compared to control (26.58 g) (Baishya *et al.*, 2016).

Belavanaki (1979) noticed a significant increase in the grain yield and 1000-grain weight of sorghum due to soil application of 10 kg ferrous sulphate per hectare.

Jatav *et al.* (2008) conducted a pot experiment on sodic soils to test the two levels of irrigation water and four levels of zinc and iron on rice. They recorded higher grain (3.46, 8.52 and 9.57 per cent) and straw (5.76, 5.71 and 14.42 per cent) yield, with application of FeSO₄.7H₂O @ 200, 334 and 648 mg FeSO₄.7H₂O/pot, respectively. Fe being a component of important enzymes systems involved in N metabolism, chlorophyll development and other metabolic activities may increase and regulate vegetative growth and yield.

Kumar *et al.* (2013) studied the effect of iron, zinc, and manganese levels on yield and yield attributing characters of rice at Banaras Hindu University, Varanasi. Among these tested micronutrients, iron application @ 15 kg/ha had produced the significantly highest grain yield (50.90 q/ha and 51.27 q/ha) and straw yield (100.40 q/ha and 101.31 q/ha) during both years of experiment followed by iron application @ 30 kg/ha with on an average increase of 8.60 and 7.88 per cent more grain and straw yields over control.

The results on Naguib *et al.* (2007) indicated that application of recommended dose of NPK (150:75:75 kg/ha) along with basal application of zinc (25 kg/ha), FeSO₄ (5kg/ha) + 1 % FeSO₄ spray at 25 DAS had

significantly increased the grain yield (6069 kg/ha) and straw yield (7270 kg/ha) in direct seeded rice.

The foliar sprays of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ with 0.5 % level on different rice cultivars showed that there was increase in grain yield of different rice cultivars from 74.7-77.5 q ha⁻¹ as compared to control (67.8-71.4 q ha⁻¹) as studied by Dhaliwal *et al.* (2010).

Stalin *et al.* (2011) observed that foliar application of multi-component fertilizer in combination with Fe at 0.5 per cent level at panicle initiation stage increased the yield of rice crop from 55 to 59 q ha⁻¹ due to better Fe absorption, thereby helping in effective translocation to storage organs.

Jhadhav *et al.* (2014) recorded highest grain yield (3 t ha⁻¹) with recommended dose of NPK and FYM with soil application of both the micronutrients *i.e.* FeSO_4 and ZnSO_4 @ 10 kg ha⁻¹ each and they noticed comparable yield (2.97 t ha⁻¹) with foliar applications of both the micronutrients *i.e.* FeSO_4 and ZnSO_4 at 20 and 45 DAS along with RDF and FYM.

In an experiment by Yadav *et al.* (2011) aerobic rice revealed that both soil and foliar spray of Fe conjointly resulted in better yield compared to their sole application. Application of 50 kg ha⁻¹ + two foliar spray of 2% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ resulted in higher grain yield (5.10 t ha⁻¹) compared to sole soil application of 100 kg $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ha⁻¹ (5.02 t ha⁻¹) and three foliar spray of 2% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ (4.95 t ha⁻¹).

Shaygany *et al.* (2012) from direct seeded rice reported that five and three foliar sprays of formulation containing Fe @ 0.6 g L⁻¹ at heading and ripening stages significantly increased the grain yield of rice crop. The grain yield with five and three foliar sprays increased up to 58.6 q ha⁻¹ and 53.2 q ha⁻¹ as compared to control (44.0 q ha⁻¹).

Sharma and Lal (1992) reported that among the individual micronutrient treatments in loamy sand soil of Rajasthan, the highest grain and straw yield of wheat were obtained due to the application of FeSO_4 at the

rate of 50 kg per hectare. Grain yield of wheat increased by 22.7 per cent due to application of 50 kg FeSO₄ per hectare over control.

Misra and Venkateswarlu (1981) investigated that the grain yield of wheat increased significantly from 5.02 to 6.06 t /ha with soil and foliar application of 20 kg /ha FeSO₄.

Bameri *et al.* (2012) revealed that foliar application of iron sulphate significantly increased plant height, yield attributes and yield of wheat over control.

2.5 Effect on economics

Some experiments revealed that both soil and foliar spray of Fe conjointly resulted in better returns compared to their sole application. Application of 50 kg ha⁻¹ + 2 foliar spray of 2% FeSO₄.7H₂O resulted in higher net returns (57940 ₹ ha⁻¹) and benefit cost ratio (1.06) and was comparable to sole soil application of 100 kg FeSO₄.7H₂O ha⁻¹ (56962 ₹ ha⁻¹ and 1.04) and 3 foliar spray of 2% FeSO₄.7H₂O (56137 ₹ ha⁻¹ and 1.02) (Yadav *et al.*, 2011).

In an aerobic rice experiment, different doses of N, P& K along with 25 kg ha⁻¹ iron sulphate was used. Application of 180:90:60 kg NPK and 120:60:40 kg NPK ha⁻¹ recorded a benefit cost ratio of 1.64 and 1.63 respectively. Though the gross returns were higher with the treatments containing FeSO₄, these treatments had recorded highest B:C ratios because of higher grain yield due to application of FeSO₄ (Rakesh *et al.*, 2012).

Gross returns, net returns and B:C ratio were higher with three foliar sprays of 2% iron sulphate (88470, 52970 ₹ ha⁻¹ and 1.49) compared to three foliar sprays of 0.5% of iron chelate (86030, 44680 ₹ ha⁻¹ and 1.08) in a trial conducted at IARI, New Delhi (Kumar *et al.*, 2015).

Baishya *et al.* (2016) at Langol Research Farm of ICAR Research complex for North Eastern Hill Region (NEHR), Manipur studied the influence combination of foliar sprays micronutrients on aerobic rice. Among the

different micronutrient spraying practices application of 2% iron sulphate foliar spray recorded highest net returns of 18787 \square ha-1 compared to control (10852 \square ha-1).

Application of ferrous sulphate to the cereal based intensive cropping system has become an uncompromising agronomic input management practice (Mengel and Kirkby 1987; Khattak, 1988; Alam and Azmi, 1989)

MATERIAL AND METHODS

As described in the chapter introduction, the current inquiry was organized and carried out within the scope of the issue under study, with objectives established to achieve the solutions to the problem indicated. Under the climatic conditions of Jabalpur (M.P.), an experiment was done during the kharif season of 2021 to study the "**Evaluation of different doses and mode of application of ferrous ammonium sulphate for maximizing rice production** " the material utilized and procedures used throughout the study are cited in this chapter and detailed under the respective headings.

3.1 Experimental site

During the kharif season of 2021, the experiment was carried out at Agricultural Engineering Research Farm, College of Agriculture Engineering, JNKVV, Jabalpur (M.P.). The field chosen for experiments had a homogeneous terrain and has no weeds that were particular to this area. On the study farm, all physical resources, such as labour, agrochemicals, equipment and irrigation water, were readily available as needed. The laboratory investigations were conducted at the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, in the Department of Agronomy, College of Agriculture, Jabalpur.

3.2 Climate

The Jabalpur district in Madhya Pradesh in India, is located between 23°90' North latitude and 79°58' East longitude, with an average altitude of approximately 411.78 meters (1350.18 ft.) above mean sea level and a total area of 5198 km². As per the National Agricultural Research Program, Jabalpur is located in the "Kymore Plateau and Satpura Hill " agro-climatic zone. As per a recent concept proposed by National Bureau of Soil Survey and Land Use Planning, Nagpur, this area is located in agro ecological sub region No. 10.1, which is a sub humid (dry) eco-region (Malwa plateau, Vindhyan Scarp Land and Narmada Valley). Temperatures extremes vary between from 5-6°C in December and January to maximum 46°C in May and

June. This region climate is divided into three seasons: Kharif (rainy) from middle June to September, Rabi (winter) from October to March and Zaid (summer) from April to mid- June. The average annual rainfall in the Jabalpur area is 1350 mm. The monsoon normally starts in the third week of June and ends by the end of September, or even as late as the first week of October. During the months of December to February, Rabi showers might occur in the area. The relative humidity ranges between 20 and 35% during zaid and 50 to 60 % during Rabi seasons, while it exceeds maximum values of 80 to 95 % during Kharif season.

3.3 Weather condition

The statistics on the weather conditions during the crop growing season of the ongoing study, including maximum weekly temperatures ranges from (26.8 to 35.7°C) and minimum weekly temperatures ranges from (10.5 to 25.4°C), maximum and minimum relative humidity morning (75 to 95 %) and evening (33 to 85 %), sunshine hours (0.2 to 9.0 hour) and total seasonal rainfall (462.1 mm) received with 43 rainy days. During the crop's entire growing period, the crop is exposed to a total of 118.2 hours of sunlight. The weekly metrological data were collected during the crop season at the meteorological observatory at the College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh and these are graphically shown in Table 1 and figure 1.

The weather parameters Viz., relative humidity, maximum and minimum temperature, wind velocity and sunshine hours etc. did not deviate much from the mean values of the reverence parameters during the same time. Though the scale of rainfall was less during the crop season (growing to harvesting) its distribution was not uniform. As a result, it favored crop for proper establishment and then further crop growth, development and yield. At this point, these conditions were also quite pleasant. All the weather conditions were practically favorable for proper growth, development and yield of crop.

Table 3.1: Weekly meteorological observation

SMW	T	T min.	Sun	Rainfall	RH	RH	Wind	Vapour	Vapour	Evapo.	Rainy
	max.(°C)	(°C)	Shine hrs.	(mm)	Morning (%)	Evening (%)	Speed	Pressure (MM) Mor	Pressure (MM) Eve	(mm)	days
24	31.7	23.9	4.0	12.0	84	62	6.0	20.3	21.1	4.3	2
25	33.5	23.9	4.3	73.2	87	63	6.3	21.4	21.1	4.6	3
26	33.6	24.7	4.7	38.6	86	61	4.3	21.9	23.1	4.1	3
27	35.7	26.7	4.7	15.0	75	50	5.3	21.1	19.7	5.5	1
28	33.3	25.1	5.5	33.2	85	58	3.3	22.7	21.8	4.2	2
29	33.4	25.4	5.5	35.4	84	70	3.9	22.8	22.1	3.8	3
30	27.7	23.8	0.2	130.4	95	85	5.7	22.0	22.5	2.6	5
31	26.8	23.4	0.3	43.7	91	84	8.0	21.0	21.7	1.7	6
32	28.5	24.2	0.5	11.1	90	79	6.2	22.2	22.6	1.7	2
33	32.6	24.7	4.9	42.3	89	71	3.3	22.6	21.8	3.7	3
34	30.7	24.7	2.6	2.2	87	67	4.3	22.2	21.5	2.4	0
35	31.6	24.5	5.1	2.5	86	68	3.4	22.1	21.9	3.0	0
36	31.4	24.1	4.1	35.7	91	78	3.5	22.6	22.4	3.0	4
37	30.0	23.8	2.3	100.8	93	81	3.0	22.5	23.0	3.1	4
38	30.9	23.6	4.7	16.3	89	68	3.1	21.7	22.7	2.5	2
39	31.9	24.1	5.6	3.8	88	62	3.3	22.4	21.4	2.5	1
40	32.9	23.7	8.2	0.0	84	58	2.3	22.0	20.9	3.7	0
41	33.3	20.0	8.6	0.0	84	48	1.5	18.8	17.1	3.8	0
42	31.9	19.9	8.1	67.0	88	48	2.8	19.4	16.2	3.8	2
43	30.7	16.0	8.3	0.0	87	41	1.4	14.5	12.6	2.7	0
44	28.7	11.0	9.0	0.0	84	33	1.4	10.7	9.6	2.6	0
45	28.7	10.5	7.8	0.0	84	34	1.2	10.4	9.5	2.2	0
46	27.6	12.8	4.9	0.0	85	45	2.4	12.0	12.5	1.8	0
47	29.1	15.0	4.3	1.8	87	46	1.6	13.3	13.3	1.8	0

Source: Meteorology observatory JNKVV Jabalpur (M.P.)

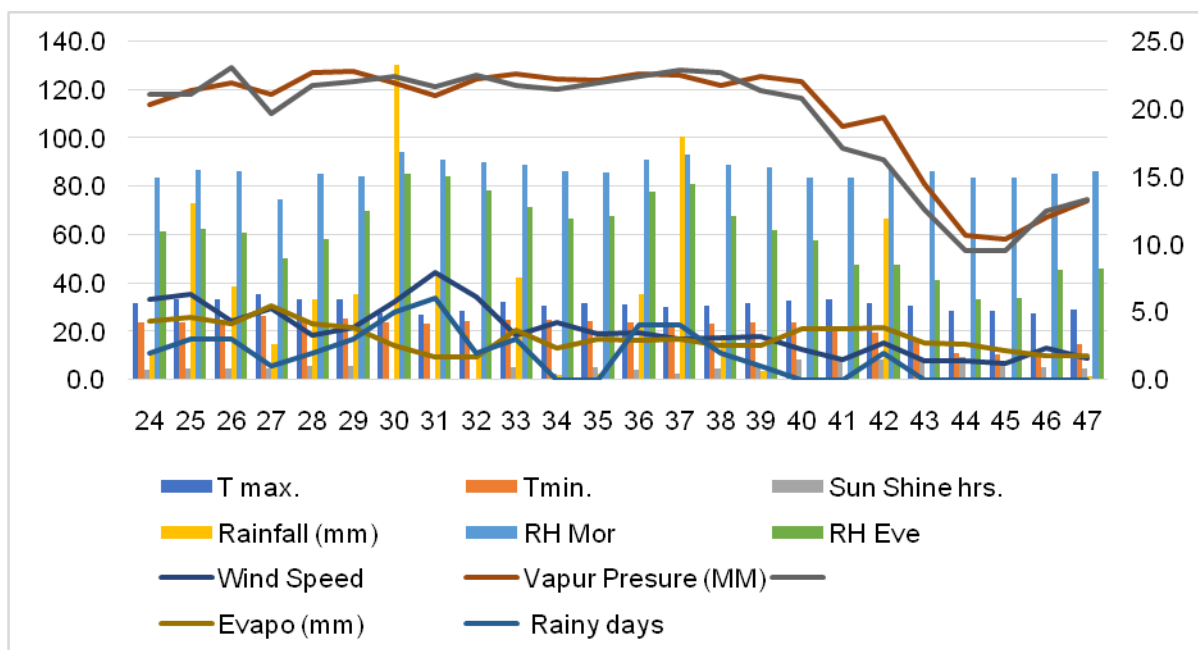


Fig 1. Graphical representation of weekly meteorological observation during kharif season 2021

3.4 Soil

The soil in the Jabalpur region is classified as 'Vertisol' according to the United States soil classification system. It has a medium to deep depth range and is black in colour. It expands when moist and contracts when dry. As a result of these traits, the soil develops enormous fissures on the surface during the summer. The soil of the experimental field may be contaminated with a variety of weeds depending on the season, crop planted, and management strategies utilized throughout the research.

To examine the texture and intrinsic soil fertility condition of the experimental region, eight soil samples were randomly taken from 0-15 cm depth using a soil screw auger before transplanting and fertilizer application to measure the physio-chemical parameters. The composite sample was created by combining several soil samples (4). The combined sample was dried and powdered using a pestle and mortar before being subjected to further investigation. A sufficient quantity of soil from the composite sample was taken and examined using conventional procedures for the analysis of

Physico-chemical characteristics of the soil in the laboratory of the Department of Agronomy, College of Agriculture, JNKVV, Jabalpur.

Table 3.2. Physico-chemical properties of the experimental soil

Constituents	Value	Interpretation	Method of analysis
Physical properties			
Sand (%)	30.18	Clay loam	International pipette method (Piper, 1967)
Silt (%)	20.13		
Clay (%)	46.27		
Chemical analysis			
Soil pH	7.1	Neutral	Glass electric pH meter (Piper, 1967)
Organic carbon (%)	0.58	Medium	Walkey and Black rapid titration method (Walkey and Black, 1934)
Electrical conductivity (dS m ⁻¹)	0.27	Medium	Solu-bridge method (Black, 1956)
Available N (kg ha ⁻¹)	238.14	Low	Alkaline permanganate method (Subbaiah and Asija, 1956)
Available P ₂ O ₅ (kg ha ⁻¹)	16.17	Medium	Calorimeter method (Olsen et al., 1954)
Available K ₂ O (kg ha ⁻¹)	305.12	Medium	Flame photometer method (Chapman and Pratt, 1961)
Available iron (Fe) (ppm)	8.5	Medium	Spectrophotometer method
Available (SO ₄) ²⁻ (ppm)	7.3	Low	Flame photometer method

It is clear from the data of soil analysis (Table.3.2) that the soil of experimental site was clay loam texture. Organic carbon (0.58 %), available nitrogen (238.14 kg ha⁻¹), available phosphorus (16.17 kg ha⁻¹), available potassium (305.12 kg ha⁻¹) and available iron (8.5 ppm) were all in the middle range. In response, the soil was neutral in reaction (pH 7.1) and the soluble salt content (0.27 dS m⁻¹) were below the hazardous limit.

3.5 Cropping history of experimental field

The cropping history of the experimental field during the last three years is presented in table 3.3. It is evident from the information provided in the table that rice-wheat cropping system was followed in the experimental field during both the seasons with a uniform dose of fertilizers administered to the soil. It means that the fertility of the soil in the field was uniform.

Table 3.3 Cropping history of experimental field

Year	Cropping system		Fertilizer dose (NPK kg ha ⁻¹)	
	<i>Kharif</i>	<i>Rabi</i>	<i>Kharif</i>	<i>Rabi</i>
2018-19	Rice	Wheat	120:60:40	120:60:40
2019-20	Rice	Wheat	120:60:40	120:60:40
2020-2021	Rice	Wheat	120:60:40	120:60:40

3.6 Experimental details

During the kharif of 2021, the experiment was replicated three times using a randomized block design (RBD) with eight treatments. The treatments and symbols used are detailed below and the layout design is displayed in Figure 2.

Table 3.4: Treatment details: 8 FAST treatments

Treatments	Treatment doses
T ₁	RDF- Recommended dose of fertilizer (N:P:K) (120:60:40)
T ₂	RDF + FAST @ 15kg/ha for soil application
T ₃	RDF + FAST @ 25kg/ha for soil application
T ₄	RDF + FAST@ 35kg/ha for soil application
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT

3.6.1 Layout of the experiment

Other experimental details

Gross plot size	:	5.0 m × 4.0 m
Net plot size	:	4.60 m × 3.60 m
Distance between replications	:	1.0 m
Distance between plots	:	0.50 m
Total number of plots	:	24
Distance between rows	:	20 cm
Crop and Variety	:	Rice and Kranti
Seed rate	:	40 Kg
Recommended dose of fertilizers	:	N-120, P ₂ O ₅ -60, K ₂ O-40(kg/ha)

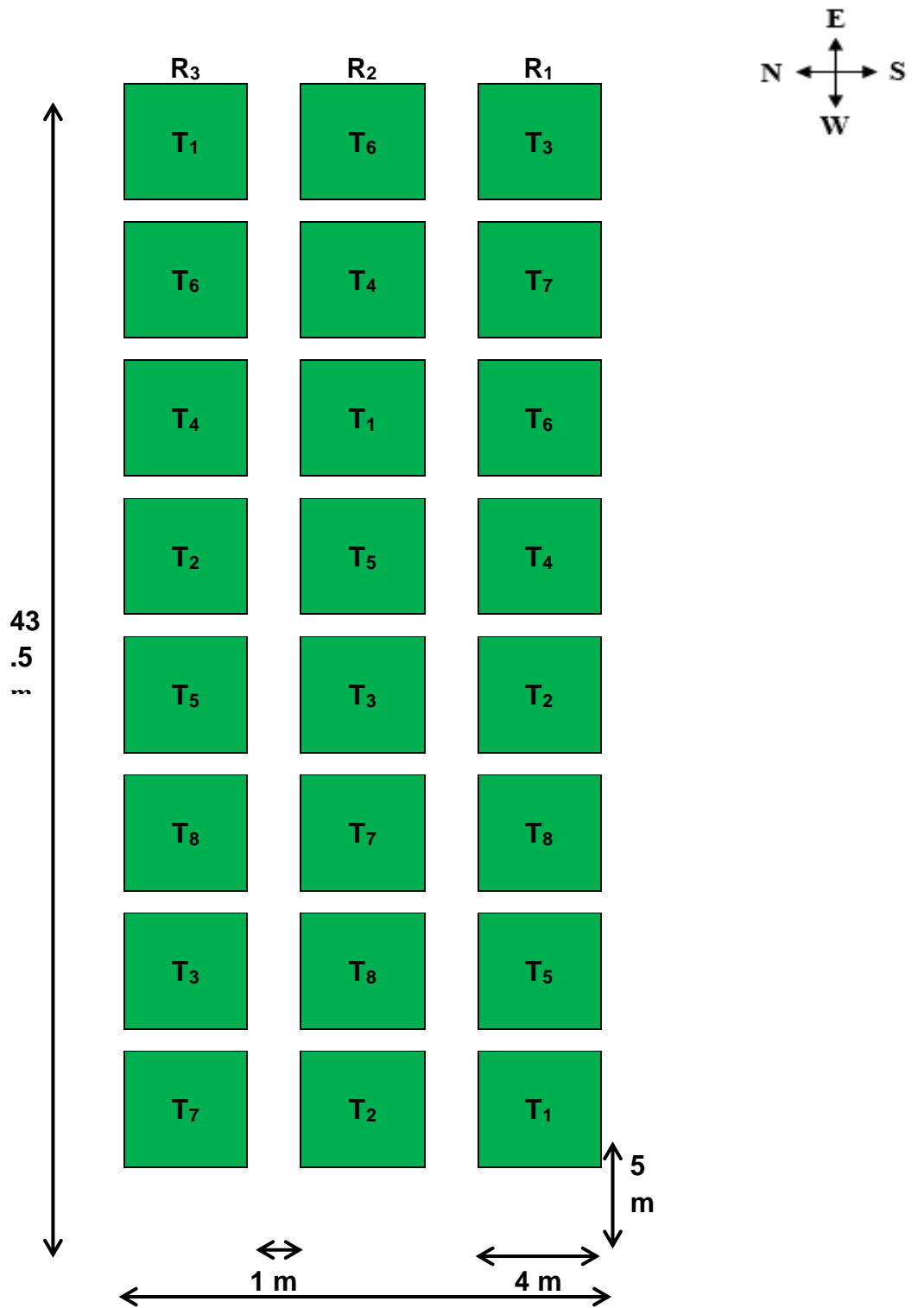


Fig. 2. Plan and Layout of Experiment

3.6.2 Crop variety - Kranti

Kranti is a mid-maturing (120 days) variety that grows well in Madhya Pradesh. The "Kranti" cultivar is semi dwarf (115-130 cm), non-lodging, fertilizer sensitive, and has bold grains. Test weight (1000 grains weight) is around 25-30 g. Under appropriate agronomic management, Kranti has a yield potential of 55-60 q ha⁻¹.

3.7 Schedule of agronomic operations

The many field activities carried out during the current inquiry are listed in chronological sequence.

3.7.1 Nursery Management

To prepare the land for the nursery, two cross harrowing's with a disc harrow were employed, after which FYM was scattered evenly over the nursery field at a rate of 10 tonnes ha⁻¹ and the nursery field was levelled with a planker. Weeds, stones and stubbles were removed manually from nursery beds. The nursery bed was 15 meters long, 1 meter wide and 15 cm. high. The seeds were treated with carbendazim at a rate of 2g kg⁻¹ seed prior to sowing. Dry seeds were sown in the bed and covered with FYM. The irrigation was applied to ensure proper germination of seeds in nursery bed.

3.7.2 Land preparation of main field

The field was cultivated using a tractor-drawn cultivator in the summer after harvesting the previous wheat crop, followed by two cross harrowing's to break up clods and mix the crop residues in the soil. The primary need for preparing a field of transplanted rice is to puddling of field. Water was filled into the field up to a depth of 12-15 cm and the soil was puddled with the help of a cage wheel puddler. Following that, individual plot demarcations were established according to the layout design by building 45 dykes using moist soils collected from the border area between the plots. On the 12th of July, 2021, the layout of the experiment plan was completed according to the design provided in the in the table 3.5.

Table 3.5: Schedule of field operations done during the course of investigation.

S.NO.	Field Operation	Date
1.	Land preparation for nursery	17.06.2021
2.	Preparation of nursery bed and sowing of seeds	18.06.2021
3.	Land preparation for main field cultivator once disc harrow twice	08.07.2021 10.07.2021
4.	Puddling, levelling and Fertilizer application	12.07.2021
5.	Layout of experiment	12.07.2021
6.	Transplanting	13.07.2021
7.	Spraying of FAS _t at 25 DAT	07.08.2021
8.	Spraying of FAS _t at 45 DAT	28.08.2021
9.	Top dressing of urea at tillering stage	15.08.2021
10.	Top dressing of urea at panicle initiation stage	07.09.2021
11.	Harvesting of crop	15.11.2021
12.	Threshing and winnowing	23.11.2021

3.7.3 Fertilizer application

Urea, single super phosphate, and muriate of potash were used to apply the recommended doses of plant nutrients (nitrogen, phosphorus, and potassium) at 120:60:40 kg NPK ha⁻¹, respectively. Before transplanting, half of the nitrogen (60 kg N ha⁻¹) and the full doses of phosphorus (60 kg P₂O₅ ha⁻¹) and potassium (40 kg K₂O ha⁻¹) were applied as basal application and the remaining 50% nitrogen was applied into two equal splits and top-dressed during the tillering and panicle initiation stages of the crop and soil application of ferrous ammonium sulphate also applied @ 25 kg ha⁻¹ at the time of field preparation.

3.7.4 Transplanting

In all plots, two seedlings per hill were manually transplanted at a planting geometry of 20 cm × 15 cm when they were 25 days old.

3.7.5 Spraying of FASt

It has been done by making solution of 500 g FASt in 100 liter of water for 0.50% concentration. And for 0.25% concentration, 250 g of FASt in 100 liter of water should be dissolved. Therefore spraying with the help of knap sack sprayer at 25 and 45 DAT.

3.7.6 Plant protection

No plant protection measures were used since the crop was not infested with insects, pests and diseases during the course of investigation.

3.7.7 Harvesting

Individual plots were harvested manually with a sickle once the grains in the panicles had fully matured. The crop plants in the border area were first harvested. Two rows on both sides and two hills from both ends of each plot were harvested separately to eliminate the border effect. The net plots were then harvested individually and sun dried in the field for three days. The bundles were then individually wrapped, labelled, and weighed. Each net plot's produce was then taken to the threshing floor separately for threshing.

3.7.8 Winnowing and threshing

Each plot's produce was manually threshed by beating it with wooden sticks. After that, a hand-operated winnower was used to separate the grains from the chaff. Each plot's grains were weighed separately.

3.8 Observations on crop

3.8.1 Pre-harvest observations

3.8.1.1 Plant population m⁻² (20 DAT and harvest)

Initial and final plant population of crop was counted at 20 days after transplanting (DAT) and just before the harvesting. It was taken from five predetermined sites in each plot, which were marked with pegs on either side of the meter square.

3.8.1.2 Plant height (cm)

Five randomly selected plants were measured in centimeters from the ground level to the tip of the new leaf till flag leaf stage (30, 60, 90 DAT and harvest). The plant height was measured up to the lower node of the panicle after panicle emergence (90 DAT and at harvest) and the mean plant height was calculated by dividing the total plant height by the number of plants and represented in centimeters.

3.8.1.3 Tillers hill⁻¹ (30, 60, 90 DAT and harvest)

The number of tillers from five randomly chosen hills plot⁻¹ was counted at 30, 60, 90 DAT and harvest. Then the number of tillers hill⁻¹ was calculated.

3.8.1.4 Leaf area

Three leaves were taken from the five selected hills of each plot to measure their leaf area (LA) at 60 and 90 DAT. With the help of leaf area meter, the LA was measured and a mean was calculated.

3.8.1.6 Dry matter (g hill⁻¹)

At 30, 60, 90 DAT and harvest, plant samples were taken. These samples were sun-dried then dried at 68°C in oven until a constant weight was reached. On an electronic balance, the dry weight was recorded. The average was calculated in terms of dry matter per plant.

3.8.1.7 Leaf area index (LAI)

The leaf area or assimilatory area over a certain ground area is referred to as LAI. At 60 and 90 DAT, it was figured out. At 60 DAT, three leaves from five plants were randomly selected from the upper, middle and bottom portions of the plants from each treatment. These leaves were placed in polybags according to their treatment and the area of three leaves was measured using a leaf area meter. It was then multiplied by the number of leaves plant⁻¹ and the mean leaf area plant⁻¹ was calculated. The mean leaf area plant⁻¹ at 90 DAT was calculated using a similar technique. Then the leaf area index was calculated using formula proposed by Gardner et al. (1985).

$$\text{Leaf area index} = \frac{\text{Total leaf area of the crop}}{\text{Total ground area under the crop}}$$

3.8.2 Post harvest observations

3.8.2.1 Effective tillers (hill⁻¹)

Fertile tillers are those that have grain-bearing panicles. From five randomly selected hills plot⁻¹, the number of effective tillers hill⁻¹ was counted. Later the mean number of effective tillers hill⁻¹ was estimated.

3.8.2.2 Length of panicle (cm)

Five panicles from selected hills in each plot were removed at the time of harvesting. From the base to the tip of each panicle length was measured. After that, the average panicle length was determined and shown in centimeters.

3.8.2.3 Filled grains panicle⁻¹

The filled grains from the five panicles selected for observations were counted to determine the number of filled grain panicle⁻¹. The mean number of filled grains panicle⁻¹ was calculated by dividing the total number of filled grains by the number of panicles..

3.8.2.4 Chaffy grains

As with the previous observation, chaffy grains were calculated by subtracting the sound grains from the total grains collected from five randomly selected panicles. After that, the mean number of chaffy grains panicle⁻¹ was calculated.

3.8.2.5 Test weight

Grain samples were collected from each net plot grain yield and 1000 grains were counted manually. After that, these grains were sun dried and the weight was recorded using an electronic scale. Thereafter, the average 1000 grain weight was calculated and given in gram.

3.8.2.6 Biological yield (kg ha⁻¹)

The grain and straw yield combinedly form biological yield. The samples from each net plot were dried in the sun till constant weight is achieved and expressed in kg ha⁻¹

$$\text{Biological yield} = \text{grain yield} + \text{straw yield}$$

3.8.2.7 Grain yield (kg ha⁻¹)

After winnowing and cleaning, the grain yield of each net plot was weighted separately on a double pan balance and recorded as grain yield kg plot⁻¹. The grain yield kg ha⁻¹ was calculated by multiplying the factor with grain yield kg plot⁻¹.

3.8.2.8 Straw yield (kg ha⁻¹)

Each plot's straw yield was calculated by subtracting the grain yield from the biological yield of that plot. The values so obtained were converted into straw yield (kg ha⁻¹) by multiplied with a factor to get the straw yield (kg ha⁻¹).

3.8.2.9 Harvest index (HI)

It is the ratio of economic yield to the biological yield and is expressed in percentage. It was calculated as per the formula proposed by Synder and Carlson (1984).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.9 Economics of treatments

The current market price of inputs used in cultivation under different treatments and produce under different treatments (grain and straw) were used to calculate the cost of production and economics for each treatment. The information is in Appendix-I. The net income was calculated by subtracting the cost of cultivation from the gross monetary returns (Rs. ha⁻¹).

Different values were determined for each treatment and presented in table below.

3.9.1 Cost of cultivation

The cost of cultivation for each treatment is computed using various inputs utilised to grow the crop under various treatments on a one-hectare basis.

3.9.2 Gross monetary returns (GMR)

The values obtained from the crop produced under each treatment were estimated as gross monetary returns (GMR) per hectare based on the recent market price of the product (both grain and straw).

$$\text{Gross monetary returns} = \text{value of grain} + \text{value of straw}$$

3.9.3 Net monetary returns (NMR)

The net monetary return (NMR) per hectare under each treatment was computed by subtracting the cost of cultivation from the gross monetary return of that same treatment.

$$\text{Net monetary returns} = \text{Gross monetary returns} - \text{Cost of cultivation}$$

3.9.4 Benefit-cost ratio (B: C)

The benefits obtained for each rupee invested under various treatments were computed as follows:

$$\text{Benefit cost ratio} = \frac{\text{Gross monetary return (Rs ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs ha}^{-1}\text{)}}$$

3.10 Statistical Analysis

The data from the numerous observations were tabulated and then statistically analysed according to analysis of variance (ANOVA) methods, with the F test used to assess the treatment. To assess the differences between treatment means, a critical difference (CD) was computed for each character at a 5% level of significance. Before carrying out analysis of variance, the data on weed population and weed dry weight were square root transformed, i.e., $\sqrt{x+0.5}$ and only transformed values were compared.

Table 3.6: Analysis of Variance

S. No.	Source of variation	d.f.	S.S	M.S. S	F cal.	F tab.		Level of significance
						5%	1%	
1.	Replication	(r-1) =2						
2.	Treatment	(t-1) =7						
3.	Error	(r-1) (t-1) =14						
	Total	(rt-1) = 23						

Where r = number of replications

t = number of treatments

$$SEm = \sqrt{\frac{Ems}{r}}$$

$$S. Ed. = SEm \times \sqrt{2}$$

$$CD = S.Ed \times t (0.05) (edf)$$

Where,

SEm± = Standard error of treatment means

S. Ed± = Standard error of difference between treatment means

C.D. = Critical difference

R = Replication

Edf = Error degree of freedom



Plate No. 1 View of Experimental Field

RESULTS

A field experiment entitled “**Evaluation of different doses and mode of application of Ferrous Ammonium Sulphate for maximizing rice production**” was carried out under field conditions during *kharif* 2021 at the Agriculture Engineering Research Farm, JNKVV, Jabalpur (M.P.) and are presented in this chapter. Experimental data were statistically analysed and apportioned under various heads and subheads, presented in tables and illustrated through figures wherever necessary. The results were described critically with the use of data under the following heads.

4.1 Studies on crop Growth

Data in relation to the effect of various treatments on Plant population, plant height, tillers per hill, dry matter production and leaf area index were recorded at different time of interval and presented under following subheads.

4.1.1 Plant population (m⁻²)

Data with respect to plant population recorded at 20 DAT and harvest of crop are given in Table 4.11. and bar diagram depicted by Fig. 3. Analysis of data shows that various treatments of FAST had no significant impact on plant population and it was statistically found at par in all the plots, regardless of treatments at 20 DAT and harvest.

Table 4.11. Effect of different doses and mode of application of FAST treatments on plant population of rice at different time of intervals.

Treatment numbers	Treatments	Plant population (No of hills m ⁻²)	
		20 DAT	Harvest
T ₁	RDF- Recommended dose of fertilizer	31	28
T ₂	RDF + FAST @ 15kg/ha for soil application	32	29
T ₃	RDF + FAST @ 25kg/ha for soil application	32	30
T ₄	RDF + FAST @ 35kg/ha for soil application	34	32
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	32	30
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	33	31
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	31	28
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	32	29
	SEm±	0.99	1.08
	CD at 5%	NS	NS

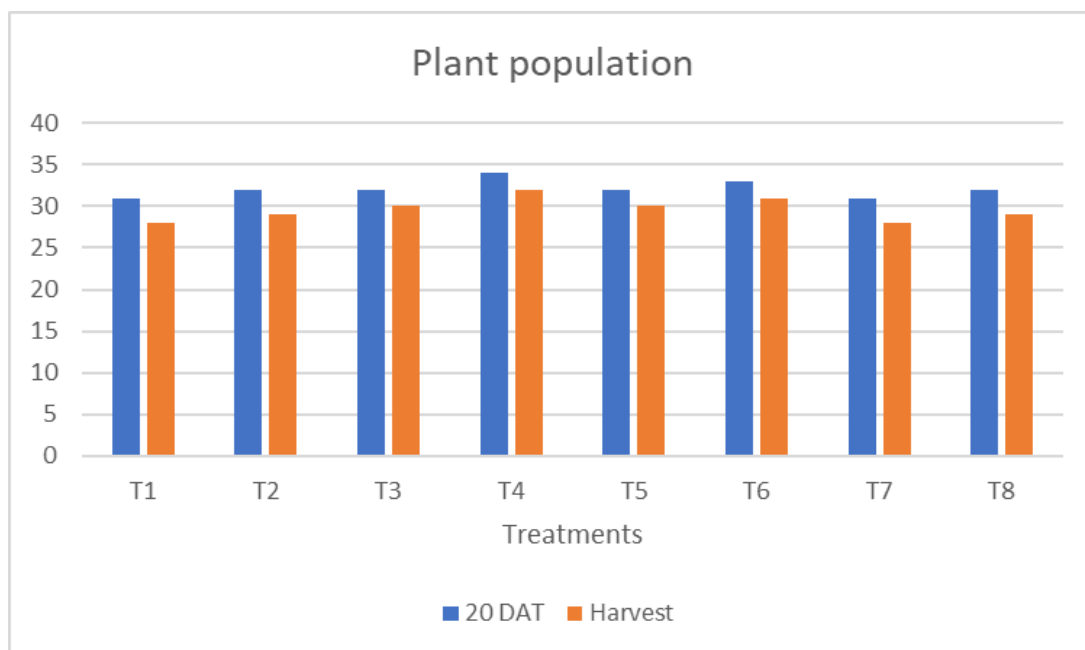


Fig. 3. Effect of different doses and mode of application of FASt on plant population at different time of intervals.

4.1.2 Plant height (cm)

Data pertaining to plant height were recorded at different time of intervals consisted of 30, 60, 90 DAT and at harvest of crop under different treatments of FASt are presented in Table 4.12 and depicted in Fig. 4. It is apparent from the data that the plant height gradually increased with successive growth stages up to 60 days at a faster rate, and thereafter it slow down between 60 and 90 DAT and further height of plant slightly reduced when crop was harvested. Significant differences were noticed among the treatments with regard to plant height at 30 DAT and subsequent growth stages. The treatment T4 that consisted of soil application of FASt @ 35 kg ha⁻¹ with RDF registered the highest plant height (56.5 cm) however it was found at par with T6 that received RDF with 2 foliar application of FASt @ 0.50% at 25 and 45 DAT (53.1 cm). However, control plot T1 which received only RDF recorded lowest plant height (42.8 cm) among all the treatments. Similar trend was also observed for plant height at 60, 90 DAT and harvest of crop.

Table 4.12. Effect of different doses and mode of application of FAST on plant height at different time of intervals.

Treatment numbers	Treatments	Plant height (cm)			
		30 DAT	60 DAT	90 DAT	Harvest
T ₁	RDF- Recommended dose of fertilizer	42.8	82.1	90.3	90
T ₂	RDF + FAST @ 15kg/ha for soil application	46.7	86.8	102.6	102.1
T ₃	RDF + FAST @ 25kg/ha for soil application	50.9	95.4	106.7	105.9
T ₄	RDF + FAST @ 35kg/ha for soil application	56.5	105.5	112.5	112.2
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	51.7	100.8	106.1	105.7
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	53.1	103.3	108.1	107.9
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	50.6	99.8	102.9	102.3
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	51.2	100.2	106.5	106.1
	SEm±	1.17	1.43	1.48	1.47
	CD at 5%	3.56	4.34	4.51	4.51

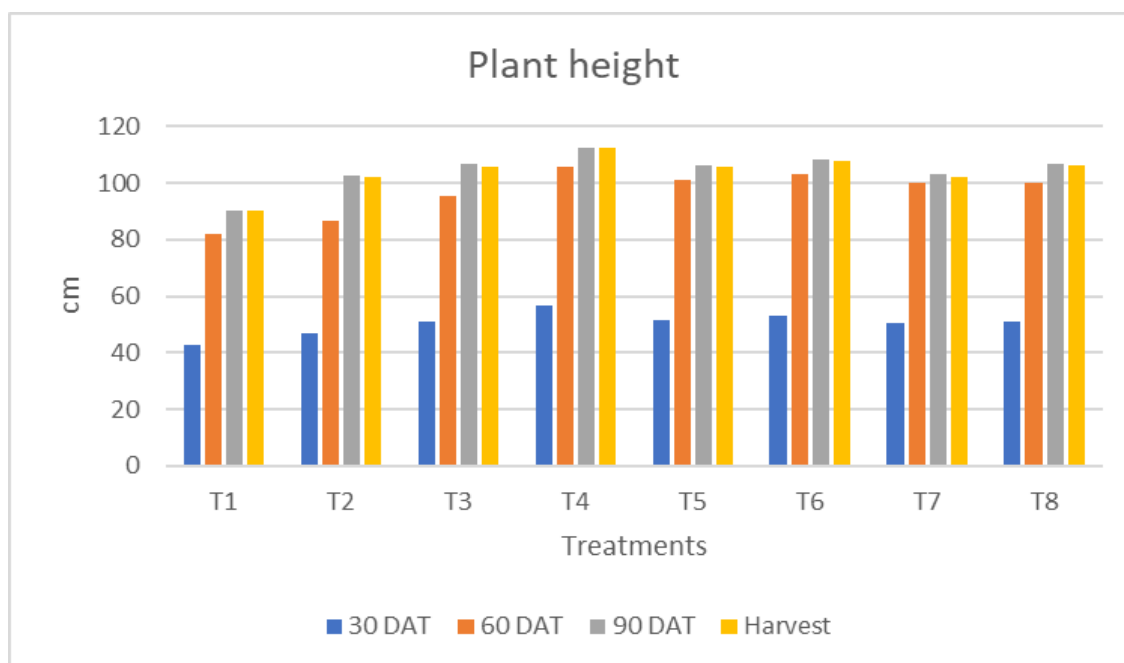


Fig. 4. Effect of different doses and mode of application of FAST on plant height at different time of intervals.

4.1.3 Tillers hill⁻¹

The number of tillers per hill as affected by different treatments at different intervals of growth (30, 60, 90 DAT and at harvest) are presented in Table 4.13 and depicted through Figure 5. Result showed significant variation in number of tillers per hill due to different levels of FAST at all the intervals of growth. It is cleared from the data that tillers expanded rapidly in all treatments till 90 DAT, with growth being substantially faster between 30 and 60 DAT. After 90 days, there was no obvious rise in the number of tillers. At harvest, tillers hill⁻¹ was slightly reduced in numbers. The controlled plot had the minimum number of tillers hill⁻¹ and it was increased appreciably in plots supplemented with FAST either in the form of soil application or foliar sprays. The minimum numbers of tillers (5.4 hill⁻¹) were occurred under controlled plot T1 where only RDF was given. However soil application of FAST @15kg ha⁻¹ with RDF in treatment T2 marginally increases the no. of tillers (6.4 hill⁻¹). The treatment T4 that received soil application of FAST @35kg ha⁻¹ with RDF bears maximum tillers (7.8 hill⁻¹) and proved significantly superior over all the treatments however it was found at par with the treatment T6 which received foliar application of 2 spray of 0.50% FAST at 25 and 45 DAT with RDF. The trend was continued at 60, 90 DAT as well as harvest of crop.

Table 4.13. Effect of different doses and mode of application of FAST on tillers hill⁻¹ at different time of intervals.

Treatment numbers	Treatments	Tillers (hill ⁻¹)			
		30 DAT	60 DAT	90 DAT	Harvest
T ₁	RDF- Recommended dose of fertilizer	5.4	7.9	8.0	7.7
T ₂	RDF + FAST @ 15kg/ha for soil application	6.4	8.6	8.9	8.8
T ₃	RDF + FAST @ 25kg/ha for soil application	6.8	9.7	9.7	9.4
T ₄	RDF + FAST @ 35kg/ha for soil application	7.8	10.4	11.1	11.0
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	6.4	9.2	9.4	9.4
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	6.9	9.4	9.8	9.3
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	6.2	8.6	8.8	8.7
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	6.3	8.8	9.0	9.0
	SEm±	0.38	0.14	0.43	0.31
	CD at 5%	1.14	0.42	1.31	0.94

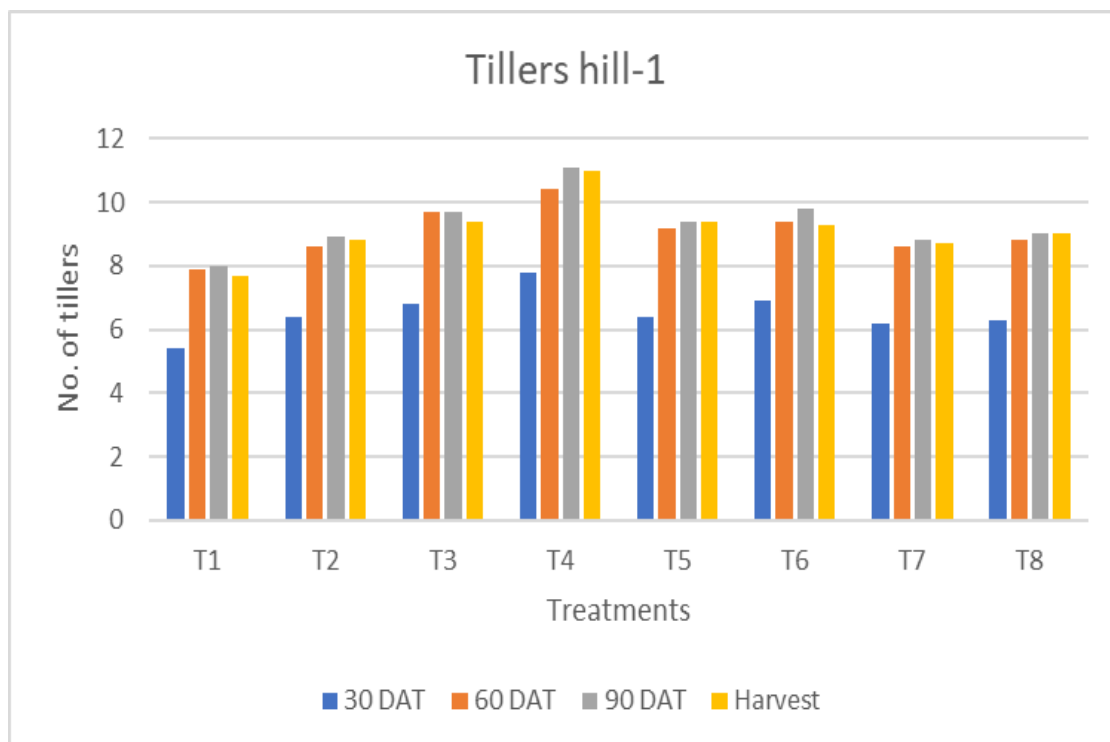


Fig. 5. Effect of different doses and mode of application of FAST on tillers/hill at different time of intervals.

4.1.4 Dry weight hill⁻¹

Dry matter production is the best indicator of crop growth. Perusal of the data revealed that FAST nutrition significantly influenced the dry matter production of rice at 30, 60, 90 DAT and at harvest (Table 4.14 and Figure 6). Data with respect to dry weight hill⁻¹ indicated that it was lowest at 30 DAT, which increased with time, and was highest at harvest, with the rate of growth in dry weight per hill being highest between 30, 60 and 90 DAT. The controlled plot produced the least dry matter over all the treatments, however it was increased in plots which were treated with ferrous ammonium sulphate. Controlled plot received only RDF and it produced least amount of dry matter (10.8 g hill⁻¹). However, the soil application of FAST @ 35kg ha⁻¹ with RDF produced maximum amount of dry matter production (12.2 g hill⁻¹) and it was outperformed among all the treatments and it was at par with the foliar application of 2 spray of 0.50% FAST at 25 and 45 DAT along with the RDF (11.8 g hill⁻¹). Similar trends were also observed in 60, 90 DAT and harvest.

Table 4.14. Effect on dry weight of plant hill⁻¹ as influenced by different doses and mode of application of FAST in rice at different time of intervals.

Treatment numbers	Treatments	Dry weight (g hill ⁻¹)			
		30 DAT	60 DAT	90 DAT	Harvest
T ₁	RDF- Recommended dose of fertilizer	10.8	42.8	75.7	76.7
T ₂	RDF + FAST @ 15kg/ha for soil application	10.9	43.7	77.2	79.4
T ₃	RDF + FAST @ 25kg/ha for soil application	11.3	48.8	80.1	82.2
T ₄	RDF + FAST @ 35kg/ha for soil application	12.2	54.8	84.8	86.5
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	11.4	47.6	79.2	80.7
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	11.8	50.2	81.9	83.8
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	10.5	43.5	76.9	77.9
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	10.9	45.4	78.6	80.8
	SEm±	0.19	1.81	1.25	0.72
	CD at 5%	0.59	5.51	3.81	2.20

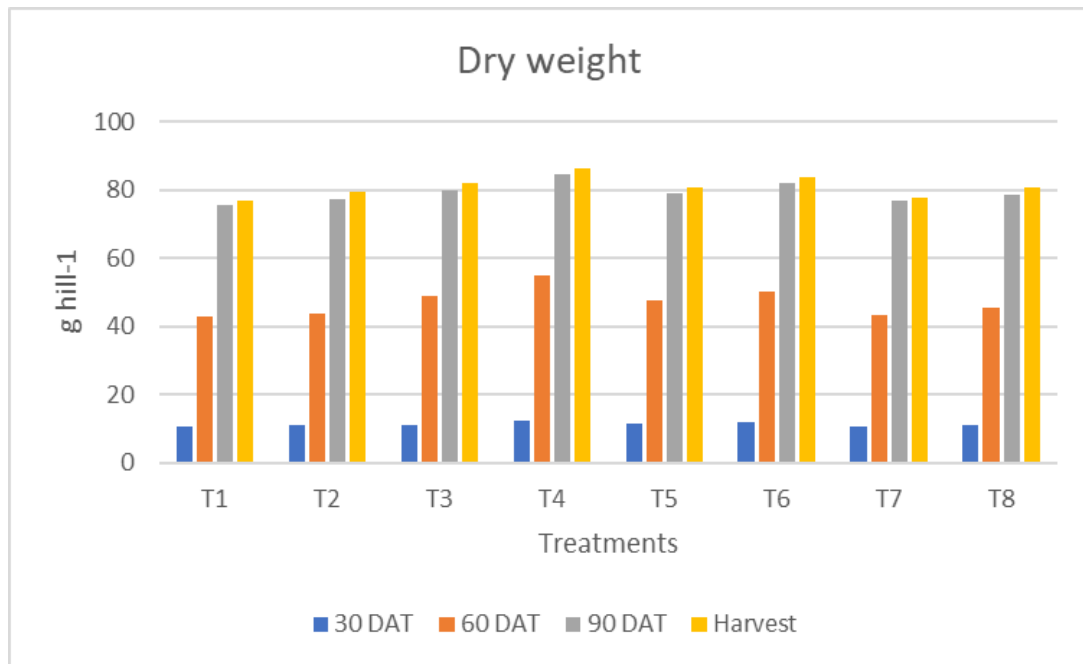


Fig. 6. Effect of different doses and mode of application of FAST on plant dry weight at different time of intervals.

4.1.5 Leaf area Index

The leaf area index (LAI) at 60 and 90 DAT was significantly influenced by different treatments. The LAI was highest at 60 DAT and after that LAI was slightly reduced at 90 DAT, according to data in Table 4.15 and Figure 7. The controlled plot had minimum LAI and it was increased markedly in plots receiving different FAST treatments. At 60 DAT, The controlled plot recorded minimum LAI (3.72) which is supplemented with RDF only. However the soil application of FAST @ 35kg ha⁻¹ with RDF recorded maximum LAI (4.02) and it outperformed all the treatments. Similar pattern was also noted at 90 DAT..

Table 4.15. Effect of different doses and mode of application of FASt on LAI at different time of intervals.

Treatment numbers	Treatments	LAI	
		60 DAT	90 DAT
T ₁	RDF- Recommended dose of fertilizer	3.72	3.67
T ₂	RDF + FASt @ 15kg/ha for soil application	3.82	3.79
T ₃	RDF + FASt @ 25kg/ha for soil application	3.89	3.85
T ₄	RDF + FASt @ 35kg/ha for soil application	4.02	3.96
T ₅	RDF + 2 Spray of FASt 0.25% at 25 and 45 DAT	3.91	3.84
T ₆	RDF + 2 Spray of FASt 0.50% at 25 and 45 DAT	3.94	3.89
T ₇	RDF + 1 Spray of FASt 0.25% at 25 DAT	3.83	3.80
T ₈	RDF + 1 Spray of FASt 0.50% at 25 DAT	3.87	3.79
	SEm±	0.019	0.013
	CD at 5%	0.059	0.040

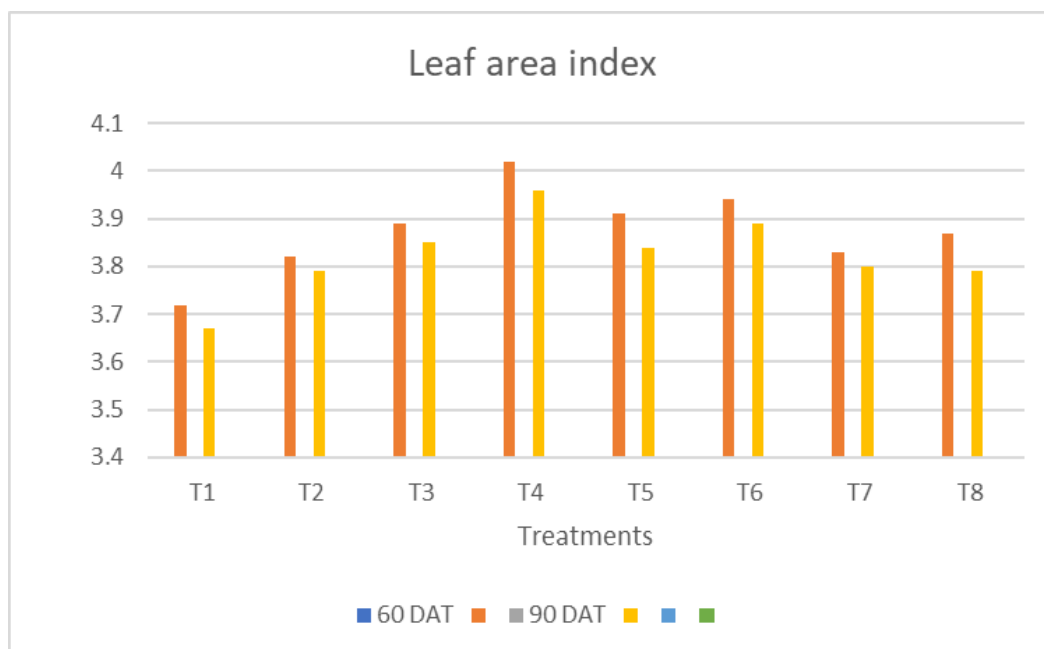


Fig. 7. Effect of different doses and mode of application of FASt on Leaf area index at different time of intervals.

4.2 Studies on yield attributes

4.2.1 Effective tillers (hill⁻¹)

Data in relation to effective tillers hill⁻¹ are presented in Table 4.16. It is obvious from the data, that Treatment T₁ having RDF application only recorded minimum number of effective tillers (7.0 hill⁻¹) at harvest, which were increased in plots getting either soil or foliar application of FAS_t. The soil application of FAS_t @ 15kg ha⁻¹ with RDF increased the number of effective tillers and further increase in dose of FAS_t corresponding increased the effective tillers. However soil application of FAS_t @ 35kg ha⁻¹ with RDF recorded maximum effective tillers (10.1 hill⁻¹) and proved significantly superior over all the doses of FAS_t.

4.2.2 Panicle length (cm)

Data pertaining to panicle length are presented in Table 4.16. It is clear from the data that the length of panicle increases with increase in dose of FAS_t up to highest level i.e. 35kg/ha as soil application. The highest dose of FAS_t (35kg ha⁻¹ as soil application) recorded highest length of panicle (24.98cm) and proved statistically superior over rest of the treatments except treatment T₃. However among the methods of application, soil application proved to be better its superiority over foliar spray at different concentrations and both methods of application superior over T₁ (RDF alone). The Treatment with 2 spray at higher concentration i.e. 0.50% at 25 and 45 DAT with RDF registered higher panicle length of 23.67 cm over single spray either with 0.50% or 0.25%. Shortest panicle length (21.83cm) was recorded in plot with RDF only.

4.2.3 Grains panicle⁻¹

The numbers of grain panicle⁻¹ as affected by the various FAS_t treatments are shown in Table 4.16. The data presented in table showed that the controlled plot (applied with RDF only) had the minimum numbers of grains panicle⁻¹ (141) which was significantly lower as compared to other treatments. However soil application of FAS_t @ 35kg ha⁻¹ with RDF recorded

maximum number of grain panicle⁻¹ (178) and it was outperformed over all the treatments, The number of grains panicle⁻¹ ranged between 152-165 in rest of the treatments.

4.2.4 Test weight

1000 grain weight (test weight) is an important yield attribute which provides information regarding the grain filling efficiency. The data presented in Table 4.16 clearly shows that there is no significant impact on test weight of different FASt treatments and irrespective of treatments it was statically at par in all the treatments with value ranges from 27.15 - 28.52 g.

Table 4.16. Effect of different doses and mode of application of FASt on yield attributing characters

Treatment numbers	Treatments	Yield attributing characters			
		Effective tillers hill ⁻¹	Panicle length (cm)	Grains Panicle ⁻¹	Test weight (g)
T ₁	RDF- Recommended dose of fertilizer	7.0	21.83	141	27.15
T ₂	RDF + FASt @ 15kg/ha for soil application	8.4	22.67	152	27.44
T ₃	RDF + FASt @ 25kg/ha for soil application	8.8	23.84	164	28.22
T ₄	RDF + FASt @ 35kg/ha for soil application	10.1	24.98	178	28.52
T ₅	RDF + 2 Spray of FASt 0.25% at 25 and 45 DAT	8.6	22.55	163	27.48
T ₆	RDF + 2 Spray of FASt 0.50% at 25 and 45 DAT	8.8	23.67	165	28.44
T ₇	RDF + 1 Spray of FASt 0.25% at 25 DAT	8.3	22.12	154	27.16
T ₈	RDF + 1 Spray of FASt 0.50% at 25 DAT	8.5	22.41	158	27.78
	SEm±	0.08	0.42	2.15	0.58
	CD at 5%	0.23	1.28	6.53	NS

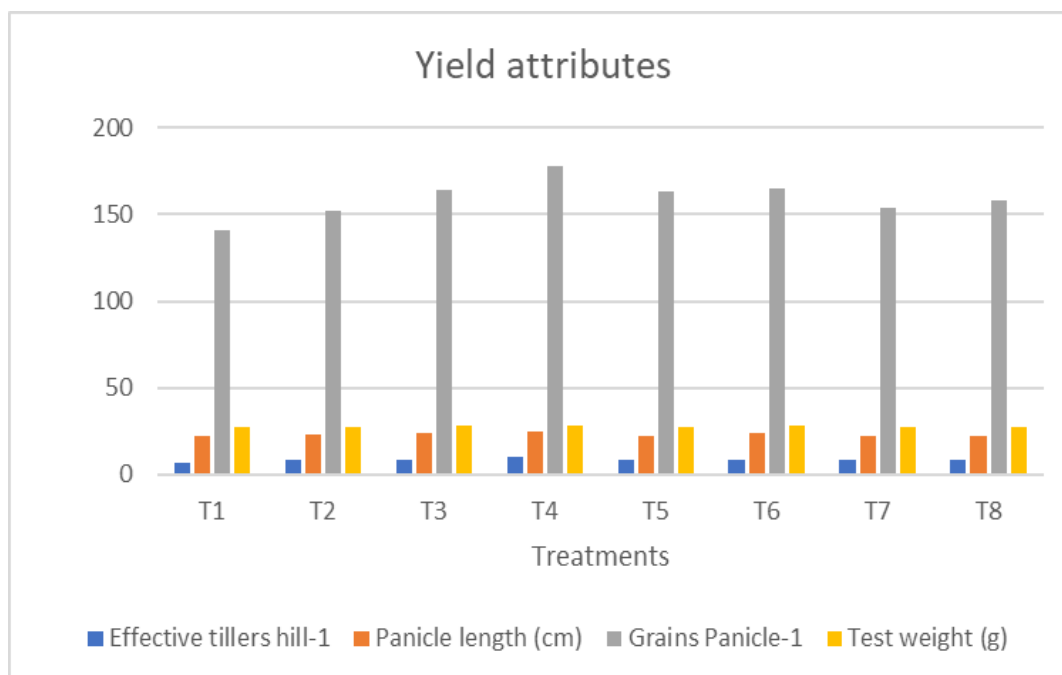


Fig. 8. Effect of different doses and mode of application of FAST on Yield attributes at different time of intervals.

4.3 Studies on yield

4.3.1 Grain Yield (kg ha^{-1})

Grain yield is a function of effective tillers, filled grains and 1000-grain weight. The data on grain yield of rice as influenced by different treatments is presented in Table 4.17 and depicted graphically in Fig 9. Maximum grain yield of (5188kg ha^{-1}) was recorded under T₄ (RDF+ 35 kg FAST as soil application) and proved significantly superior over rest of the treatments. Moreover the soil application of 25kg FAST with RDF and 2 spray of 0.50% of FAST at 25 and 45 DAT with RDF proved statistically equally good for grain yield. And proved superior over lower dose (15kg ha^{-1}) and single application of FAST sprays with 0.50% and 0.25%. Lowest grain yield (3269kg ha^{-1}) was recorded in T₁ which was consisted with RDF only. Thus it could be calculated that the application of FAST proved beneficial for grain production and may be applied either in the form of soil or foliar application.

4.3.2 Straw Yield (kg ha⁻¹)

Straw yield represents the vegetative growth of the crop. The straw yield was obtained from converting the yield plot wise under each treatment. The values thus obtained were subjected to statistical computation and mean data are presented in table 4.17 and depicted in fig 9. The recommended dose of fertilizer along with the FASt @ 35kg ha⁻¹ proved significantly superior over rest of the treatments. Moreover other treatments consisted of FASt either in the form of soil or foliar application proved superior over RDF alone. Hence the lowest straw production (6566kg ha⁻¹) was observed under T₁ (RDF alone).

4.3.3 Harvest index (%)

Harvest index shows the physiological efficiency of plants to convert the fraction of photo assimilates to grain yield. The appraisal of the data on harvest index was calculated in each treatment and presented in Table 4.17. It is clear from the data that under various FASt treatments minimum value of harvest index was found in controlled plot and it was further increased with the application of FASt either increase in dose or change in method of application. Whereas the lowest value of 33.33 was observed under T₁ (RDF only). And the maximum value of harvest index (38.85) was computed in plot that was treated with soil application of FASt @ 35kg ha⁻¹ with RDF.

Table 4.17. Effect of different doses and mode of application of FAST on grain yield, straw yield and harvest index

Treatment numbers	Treatments			
		Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest Index (%)
T ₁	RDF- Recommended dose of fertilizer	3269	6566	33.33
T ₂	RDF + FAST @ 15kg/ha for soil application	4381	7142	38.01
T ₃	RDF + FAST @ 25kg/ha for soil application	4632	7348	38.66
T ₄	RDF + FAST @ 35kg/ha for soil application	5188	8167	38.85
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	4451	7248	38.04
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	4620	7365	38.54
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	4322	7083	37.88
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	4390	7260	37.68
	SEm±	83.75	46.95	
	CD at 5%	254.04	142.42	

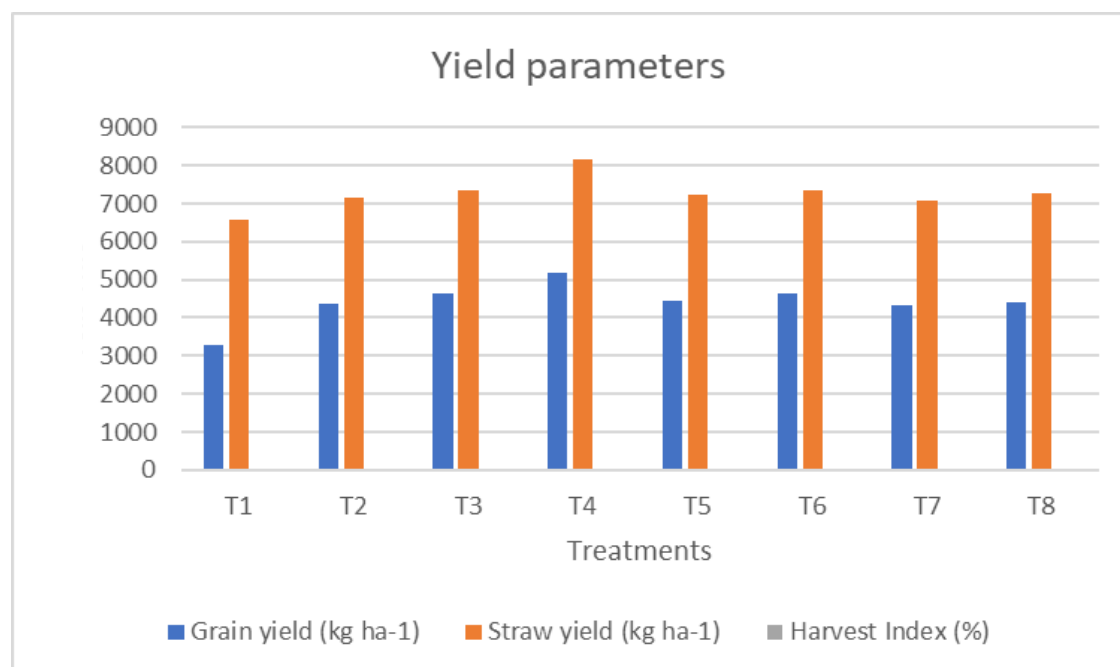


Fig. 9. Effect of different doses and mode of application of FAST on Yield parameters at different time of intervals

Studies on economics

The cost of cultivation, gross monetary returns, net monetary returns, and benefit-cost ratio (profitability per rupee of investment) were calculated under various treatments.

4.4.1 Cost of cultivation

The cost of cultivation was calculated for each treatment using current market rates for several common and variable agro-inputs which were used during the crop growing period. The data thus obtained are presented in Table 4.18 and illustrated through bar diagram as in Fig. 10. It is obvious from the data that lowest value of cost of cultivation (Rs. 38433 ha⁻¹) was found under T₁ (consisted of RDF only). Whereas, maximum value of cost of cultivation (Rs. 43333 ha⁻¹) was recorded under the plot which was supplemented with soil application of FAST @ 35kg ha⁻¹ with RDF.

4.4.2 Gross monetary returns (GMR)

The significant variation in production of grain and straw yields brought about significant variations in gross returns and data obtained from that are presented in Table 4.18 and depicted through bar diagram as in Fig 10. Based on current market price, the gross monetary return determined by using economic produce (seed) and straw.

It is cleared from the data that plot supplemented with RDF only had minimum GMR (Rs.71946 ha⁻¹).The maximum GMR (Rs. 111927 ha⁻¹) was in the plot receiving soil application of FAST @ 35kg ha⁻¹ with RDF.

4.4.3 Net monetary returns (NMR)

The net monetary return (NMR) was calculated after subtracting the cost of cultivation (CoC) from the GMR of each treatment. The plot with the RDF only had lowest NMR (Rs. 33513 ha⁻¹), which increased considerably in plots receiving FAST either as soil application or foliar application, as shown by the data. However the value of maximum NMR (Rs. 68594 ha⁻¹) was recorded in the plot supplemented with the soil application of FAST @ 35kg

ha⁻¹ with RDF, followed by the plot (Rs. 59992 ha⁻¹) consisted with the 2 foliar spray of FAST @ 0.50% at 25 and 45 DAT with RDF.

4.4.4 Benefit-cost ratio (B:C ratio)

Table 4.18 shows the benefit-cost ratio as influenced by different doses and methods of application of FAST treatments. The lowest value (1.87) of B-C ratio was computed under T₁ plot where RDF applied only. And increased significantly in the plots receiving different FAST treatments. The plot with the soil application of FAST @ 35kg ha⁻¹ with RDF had the maximum B-C ratio (2.58) which was closely followed by the plot with 2 foliar sprays of FAST @ 0.50% at 25 and 45 DAT with RDF (2.50).

Table 4.18. Economic analysis of different FAST treatments.

Treatment numbers	Treatments	Cost of Cultivation (Rs ha ⁻¹)	Gross monetary returns (Rs ha ⁻¹)	Net monetary returns (Rs ha ⁻¹)	Benefit cost ratio
T ₁	RDF- Recommended dose of fertilizer	38433	71946	33513	1.87
T ₂	RDF + FAST @ 15kg/ha for soil application	40533	94762	54229	2.33
T ₃	RDF + FAST @ 25kg/ha for soil application	41933	99988	58055	2.38
T ₄	RDF + FAST @ 35kg/ha for soil application	43333	111927	68594	2.58
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	39703	96268	56565	2.42
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	39773	99765	59992	2.50
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	39068	93523	54455	2.39
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	39103	95060	55957	2.43

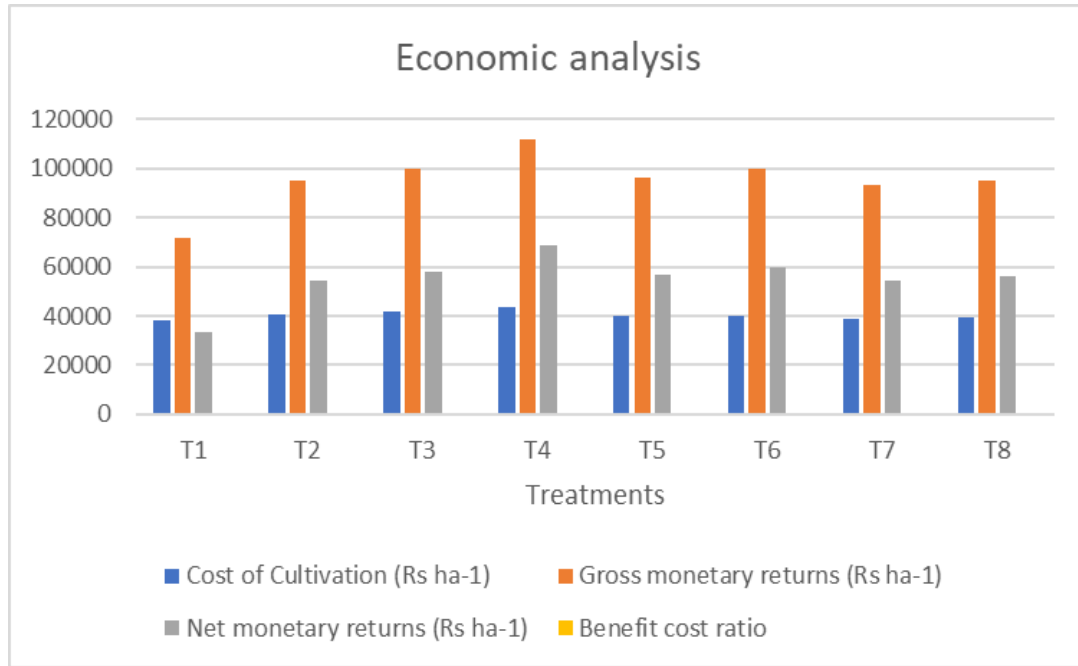


Fig. 10. Effect of different doses and mode of application of FASt on economics

DISCUSSION

The effective performance of rice growth and yield (phenotype) depends on the interaction of micronutrient and environment. Micronutrient refers to specific plant character and the major environmental factors including soil physical, chemical and biological properties along with climatic parameters like temperature, sunshine, rainfall etc. under any particular set of agro-climatic condition. Exploitation of maximum yield potential of a micronutrient depends on agronomic manipulation of local environment, specially the edaphic factors. The growth and development of rice crop are often subjected to suffer from moisture and nutrient stress, more particularly micronutrients deficiency, in addition to the deficiency of essential nutrient elements. In general, the micronutrient status of rice growing belt of Varanasi division indicated that more than 40% soils are deficient in available Fe content (Tripathi, 1993). Poor grain filling and spikelet sterility are often the most significant factors responsible for low yield of rice in the belt due to nutrient stress.

Different crop parameters such as plant population, plant height, tillers per hill, leaf area index, dry weight per hill, and seed yield were discussed in the previous chapter. The purpose of this chapter is to discuss the possible causes of some of the key research findings provided in the previous chapter. In order to reach a proper conclusion, the results acquired and given in the previous chapter are briefly examined in the following pages. The conclusions of this study have been examined in light of other researchers' findings as well as data collected on numerous factors throughout the field trial. Accordingly the present investigation entitled **“Effect of different doses and mode of application of FAST for maximizing rice production”** An attempt has been made in this chapter to discuss the possible causes of variation due to

experimental factors on different attributes duly supported by available literature.

5.1 Edaphic variation

The magnitude of crop growth in a given area is mostly determined by the soil type and qualities. According to data on Physico-chemical parameters of soil, the soil in the experimental field was clay loam with consistent fertility and soil reactivity (table 2). These traits abound in the soils of the Jabalpur region. As a result, the current investigation's conclusions might be applied to similar soil conditions in this area.

5.2 Weather variation

Weather conditions have always had considerable impact on any crop and rice is no exception. Rice requires moderate temperature, solar radiation and rainfall with direct influence on its yield (Yoshida, 1981). Weather elements such as maximum and minimum temperatures, rainfall (intensity and duration), relative humidity, and sunshine hours all play an effective role in crop productivity during the crop season. Except for rainfall, the meteorological conditions remained rather consistent throughout the crop growth season. During the crop season, the weather conditions were ideal for proper rice growth and development

5.3 Effect on crop Growth

5.3.1 Plant population

Data on plant population was collected at 20 DAT and harvest. The plant population was unchanged by different FASt treatment. In all of the plots, it was nearly identical. Because the FASt treatments had no significant effect on young seedlings, the population in all of the plots was nearly identical regardless of treatments.

5.3.2 Plant height

Plant heights varied substantially as a result of several FAST treatments applied at different time intervals (30, 60, 90 and harvest). The plot with the soil application of FAST @ 35kg ha⁻¹ with RDF reported highest plant height and it was at par with 2 foliar spray of FAST @ 0.50% at 25 and 45 DAT with RDF, Because foliar application of micronutrient significantly increased the plant height which might be attributed to the adequate supply of micronutrient, contributed to accelerate the enzymatic activity and auxin metabolism in plants (Sudha and Stalin, 2015). The young seedlings recorded better root growth, cell division and cell enlargement due to increased photosynthetic rate subsequently increasing the plant height. These results are in agreement with the finding of Rasool *et al.*, (2015). The higher plant height with combined application of micronutrients through soil and foliage might be ascribed to availability of nutrients in adequate amount with balanced proportion, resulted in improved crop establishment with better root development. These results are in conformity with the findings of Sudhakar *et al.* (2006). Yadav (2012) reported that levels and methods of FeSO₄ significantly influenced the plant height of aerobically grown rice. The application of FeSO₄ @100 kg ha⁻¹ recorded significantly higher plant height over control at 60 DAS. Similar findings were stated by Baishya *et al.* (2016), Syed *et al.* (2020).

5.3.3 Tillers hill⁻¹

Favourable temperature and sunshine hours during early tillering period coupled with higher rate of plant growth might have triggered higher number of vegetative primordia, which in turn resulted in higher number of tillers. The minimum numbers of tillers were recorded under controlled plot due to non availability of micronutrients. However the plot with soil application of FAST @ 35kg ha⁻¹ with RDF followed by the plot supplemented with 2 foliar spray of FAST 2 0.50% at 25 and 45 DAT with RDF recorded higher number of tillers. The combined soil or foliar spray of zinc and iron application favoured

positive effect on number of tillers hill⁻¹. This might be due to improved metabolic activity with micronutrients that enhanced the floral primordia development in many tillers. The results are in accordance with the findings of Khanda and Dixit (1996) and Jena et al. (2006), who reported that micronutrients favour higher production and conversion of vegetative tillers into reproductive tillers. Similar results were noted by Yadav *et al.* (2011), Kumar *et al.* (2015).

5.3.4 Dry weight (g hill⁻¹)

Different FASt treatments had significant role in dry weight at different time of intervals hill⁻¹. Dry matter production was increased progressively from sowing to harvest. The lowest dry matter was obtained with no application of micronutrients that was in the plot supplemented with RDF only. This indicates that the combined application has helped towards balanced availability of nutrients throughout the crop growth period. The highest dry weight was produced by the plot comprised of soil application of FASt @ 35kg ha⁻¹ with RDF followed by the plot having 2 foliar spray of FASt @ 0.50% at 25 and 45 DAT with RDF. The combined soil or foliar application of iron along with recommended dose of fertilizer produced the higher dry matter production. The enhanced availability of nutrient especially iron, might have lead to better accumulation of photosynthates in the form of dry matter. This confirmed the findings of Asewar et al. (2000) and Pal et al. (2008). Application of sufficient amount of NPK nutrients along with ferrous sulphate could have enhanced the photosynthetic activity of the crop and ultimately the dry matter production. Similar findings were noted by Sarangi *et al.* (2006), Meena *et al.* (2013), Sinha and Sakal (1983).

5.3.5 Leaf area index

Leaf area index is an important plant growth index determining the capacity of plant to trap solar energy for photosynthesis and has marked influence on growth of plant. Leaf area index affected biomass production in any crop, and its relationship to biological yield was well known in cereals. Depending on the leaf's orientation, LAI is a significant character. Vertically oriented leaves showed a higher rate of photosynthesis than horizontally oriented leaves. Photosynthesis rates depend on the LAI and canopy structure, and the rate of photosynthesis per unit area. Rice varieties with upright leaves and better output were discovered to be more productive than older kinds. The LAI was minimum in the controlled plot consisted of RDF only because of absence of micronutrients (FASt) and the maximum LAI was recorded at the plot supplemented with soil application of FASt @ 35kg ha⁻¹ with RDF. However it was followed by the plot consisted of 2 foliar spray of FASt @ 0.50% at 25 and 45 DAT with RDF. Similar output were observed by the Gill and Walia (2013), Mahajan and Khurana (2014).

5.3 Effect on yield attributes

Different FASt treatments had a considerable impact on all yield attributing features, such as effective tillers, panicle length and grains panicle⁻¹. All these characters were lower in controlled plots which were supplemented with RDF only and this cause is happened due to unavailability of FASt. However Soil application of FASt @ 35kg ha⁻¹ with RDF had highest values of yield attributing characters such as effective tillers, panicle length and grains panicle⁻¹ and it is followed by the foliar spray of FASt @ 0.50% at 25 and 45 DAT with RDF, Because FASt increases the nutrient uptake capacity of plants and make them available the macro nutrients by chelation process. Similar findings were recorded by Sridhara *et al.* (2012), Yogesh *et al.* (2013).

In case of effective tillers hill^{-1} micronutrient management practices exerted significant influence on number of effective tillers hill^{-1} . The effective tillers hill^{-1} was significantly higher with soil application of FASt, which was however, comparable with foliar application of FASt. Maximum number of effective tillers were recorded in plot supplemented with soil application of FASt @ 35 kg ha^{-1} with RDF, because FASt supply the macronutrient uptake by chelationing the major nutrients of soil. However it was followed by the foliar spray of FASt @ 0.50% at 25 and 45 DAT with RDF and it shows higher number of effective tillers because iron reduce chlorosis in plant and induce the photosynthetic process which result in more tillers. Significantly lesser number of effective tillers m^{-2} was associated with non-supply of micronutrients. Similar results were noted by Kulandaivel *et al.* (2003), Sridhara *et al.* (2012) and Yogesh *et al.* (2013).

In case of panicle length there was a significant difference among different treatments. Lowest panicle length was observed in controlled plot which was consisted of RDF only. And significant increment was recorded with increasing FASt treatment because iron make chelation with major soil nutrients and make available to the plants. Higher panicle length was observed in plot with the soil application of FASt @ 35 kg ha^{-1} with RDF followed by 2 foliar spray of FASt @ 0.50% at 25 and 45 DAT with RDF, due to iron that enhance the photosynthates in plants. These results were accordance with Sunil *et al.* (2014), Syed *et al.* (2020).

In case of grains panicle⁻¹ distinct disparity was noticed in the number of grains panicle⁻¹ due to micronutrient management practices. The increase in number of grains panicle⁻¹ may be ascribed to better nutrition due to combined soil or foliar application of micronutrient fertilizer along with recommended dose of fertilizers. With regard to micronutrient management practices, soil application of FASt @ 35 kg ha^{-1} with RDF registered higher number of grains panicle⁻¹ which was however, comparable with foliar application of FASt @ 0.50% at 25 and 45 DAT with RDF. These results might

be due to better translocation of accumulated photosynthates to the sink, because iron help in photosynthesis process. The minimum number of filled grains panicle⁻¹ was associated with non-application of any micronutrient that was controlled plot with RDF only. These results are in accordance with the findings of Kriem *et al.* (1991), Singh *et al.* (1996), Rakesh *et al.* (2012) and Baishya *et al.* (2016).

In case of test weight (1000 grain weight) there was no significant difference among the treatments of soil and foliar application of FAS_t. A slight increase in 1000 grain weight could be due to efficient participation of zinc in the number of metabolic processes involved in the production of healthy seed. Similar results were also reported by Abid *et al.* (2011), Rakesh *et al.* (2012).

5.4 Grain and straw yield

Rice grain and straw yields were significantly different as a result of different FAS_t treatments. Effective tillers, panicle weight, number of grains panicle⁻¹ and number of fertile spikelets panicle⁻¹ are the main features of yield. The controlled plot had minimum grain yield and straw yield due to non availability of micronutrient, resulting in poor growth parameters and yield attributing traits and finally grain yield was reduced. Among all the treatments plot supplemented with soil application of FAS_t @ 35kg ha⁻¹ with RDF had maximum grain yield and straw yield. However it was followed by 2 foliar spray of FAS_t @ 0.50% at 25 and 45 DAT with RDF, because Soil application of FeSO₄ recorded significantly higher grain yield and it can be attributed to better improvement on growth and yield parameters through adequate availability of major and micro nutrients in soil, which in turn, favourably influenced physiological processes and build up of photosynthates (Tabassum *et al.*, 2013). Soil application iron along with recommended dose of fertilizers resulted in higher grain yield and straw yield when compared to foliar spray of iron over control. This result was conformity with those of Jadhav *et al.* (2014). Increased leaf area, more light interception and enhanced dry matter

production noticed with FYM incorporation might resulted into significant increase in straw yield. These results confirm the findings of Singh et al. (2001), Mankotia and Shekhar (2007) and Shekara et al. (2010). Similar findings were noted by Jatav *et al.* (2008), Shaygany *et al.* (2012) and Kumar *et al.* (2013).

5.5 Harvest index

Harvest index of rice was significantly influenced by micronutrient management practices to a considerable extent. There was no significant difference in harvest index among the treatments with soil or foliar application of zinc and iron along with recommended dose of fertilizers. Lowest harvest index was recorded at controlled plot consisted with RDF only and the highest harvest index associated with soil application of FAST indicated the optimum vegetative growth and better source sink relationship. Similar output were observed by (Chaudhary and Sinha, 2007).

SUMMARY, CONCLUSION AND SUGGESTION FOR FURTHER WORK

6.1 SUMMARY

Rice is the most important cereal crop grown in tropical and subtropical regions of the world and it is the most widely consumed staple food for over half of the world's human population, especially in Asia and Africa. In India, rice is grown in nearly 43.70mha area with the production of 105.42 MT and productivity of 2412 kg ha⁻¹. The low productivity of rice in India is attributed by several factors including imbalance nutrition. Balanced nutrition especially application of iron and sulphur to the rice crop is one of the important inputs that can enhance productivity to a great extent. Most Indian soils are deficient in S, Zn, M, Cu, B, Fe and Mo. Rice crops in a Rice-Wheat cropping system (RWCS) struggle with iron and zinc deficiency. One such product which is multinutrient fertilizer FAST claims to increase rice productivity so in this experiment it is tried to test effect of FAST on growth and yield of Rice along with recommended dose of fertilizer. Ferrous ammonium sulphate ((NH₄)₂Fe(SO₄)₂.6H₂O) is a crystalline water soluble solid containing (Iron: - 14% ,Nitrogen :- 7%, Sulphur : - 8%). Keeping the above facts in view, the current study was conducted to determine suitable dose of FAST either as soil or foliar application for effective and higher grain production of rice.

The present investigation entitled “**Evaluation of different doses and mode of application of Ferrous Ammonium Sulphate for Maximizing Rice production**” was carried out at the Agricultural Engineering Research Farm, JNKVV, Jabalpur, (M.P.) during *kharif* seasons of 2021 with the following objectives:

- i. To find out the suitable dose of ferrous ammonium sulphate (FAST) for enhancing growth and yield of rice.
- ii. To assess the effective method of ferrous ammonium sulphate application for higher yield of rice.

- iii. To find out the economically viable treatment.

The current study was conducted on clay loam soil with a medium organic carbon level, low available nitrogen, Medium phosphorus, and potassium content, and a neutral response of pH (7.1). Through urea, DAP, and MOP, a uniform dose of 120 kg N, 60 kg P₂O₅, and 60 kg K₂O was applied to all plots. Half of total N and full doses of P₂O₅ and K₂O were applied as a basal, while the remaining half dose of N was top dressed in two equal splits at active tillering (30 DAT) and panicle initiation stage (60 DAT). The experiment was carried out in randomized block design with 3 replications and 8 treatments. Seedlings of rice variety "Kranti" were cultivated in nursery and transplanted into main field on 13th July 2021 at a planting geometry of 20 cm × 15 cm in 5.0 m x 4.0 m plots size after thorough puddling and levelling. For the transplanting 20 days old seedlings of rice are used. Plant population was recorded at 20 DAT and harvest. Growth parameters like plant height, number of tillers hill⁻¹, dry weight hill⁻¹ were recorded at 30, 60, 90 DAT and harvest and leaf area index was recorded at 60 and 90 DAT. Yield attributing traits (effective tillers hill⁻¹, , panicle length, grains panicle⁻¹ and test weight) were recorded before harvest. The yield (grain and straw) was then calculated treatment wise. Finally, from the data collected, the harvest index and the economic feasibility of the treatments had been determined. Data tabulation and statistical analysis were performed to check the significance of the various treatments. Results are summarized as below.

6.1.1 Effect on crop

The data related to plant population was recorded at 20 DAT and harvest. It was not affected significantly due to different FASt treatments. It was practically same in all the treatments including controlled plot and the plots supplemented with FASt either as soil or foliar application. In the transplanted rice, growth parameters (plant height, number of tillers per hill,

dry matter production) were significantly influenced by the different FAST treatments. All these growth parameters were higher in FAST treated plots comparatively to controlled plot. The plot supplemented with soil application of FAST @ 35kg ha⁻¹ with RDF recorded superior values of all growth parameters and outperformed over all the treatments and it was found at par with the 2 foliar spray of FAST @ 0.50% at 25 and 45 DAT along with the RDF. In case of LAI it varied significantly in the different treatment of FAST with maximum LAI at 60 DAT when applied with the soil application of FAST @ 35kg ha⁻¹ and thereafter decline.

Different FAST treatments had a significant impact on yield attributing traits such as effective tillers hill⁻¹, panicle length, and grains panicle⁻¹. The highest yield attributing traits were observed under the plot consisted of FAST @ 35kg ha⁻¹ with RDF. However controlled plot with RDF only registered minimum values of all the yield attributing traits. Whereas, varied FAST treatments had no significant effect on the test weight (1000 grain weight), and it was statistically the same in all plots regardless of FAST treatment.

Both grain and straw yield were affected significantly due to different FAST treatments. The grain and straw yields were higher under all the plots receiving FAST either as soil or foliar application in comparison to controlled plots. Soil application of FAST @ 35kg ha⁻¹ with RDF recorded highest grain and straw yield followed by 2 foliar spray of FAST @ 0.50% at 25 and 45 DAT with RDF. Controlled plot with RDF only shows the lowest grain yield and straw yield. The harvest index was optimum for FAST @ 35kg ha⁻¹ with RDF as compared to remaining treatments and was minimal for controlled plots.

6.1.2 Economic viability of treatments

Among all the treatments FAST applied @ 35kg ha⁻¹ was the economically viable treatment. The maximum cost of cultivation, gross monetary returns, net monetary returns and B:C ratio were under soil application of FAST @ 35 kg ha⁻¹ with RDF followed by 2 foliar spray of FAST @ 0.50% at 25 and 45 DAT along with RDF.

6.2 Conclusions

Based on the results of the experiment conducted, the following broad conclusions were drawn:

1. Soil Application of ferrous ammonium sulphate (FASt) @ 35kg ha⁻¹ with recommended dose of fertilizer (RDF) was found suitable for enhancing growth and yield of rice.
2. Soil application of FASt @ 35kg ha⁻¹ was found more effective method comparatively foliar application of FASt @ 0.25% and 0.50%.
3. The maximum net monetary return (Rs 68594 ha⁻¹) and B:C ratio(2.58) was recorded with the application of FASt @ 35 kg for soil application with RDF, followed by (Rs. 59992 ha⁻¹) with the application of 2 spray of 0.50% at 25 and 45 DAT with RDF and B:C ratio (2.50).

6.3 Suggestions for further work

The following suggestions for future research could be made based on the results of the current investigations.

1. The investigation should be carried out for *kharif* season under various agro-climate circumstances in order to adhere to the current results.
2. Efficiency of other micronutrient fertilizer may be tested along with the FASt.
3. To determine which rice varieties are vulnerable to FASt, these treatments must be tried on popular varieties of rice in the region.
4. It is necessary to do more analysis to examine the effects of various FASt concentrations on assimilate growth and the relationship between the source and sink using radio labelled carbon.

BIBLIOGRAPHY

- Abid M, Ahmad N, Jahangir M and Ahmad I. 2011. Effect of Zinc, Iron and Manganese on growth and yield of rice (*Oryza sativa* L.); Pakistan *Journal of Agriculture Sciences* 39(3):19-27.
- Agboda AA and Fube HN 1983 Effect of iron on yield and performance of upland rice in South-West Nigeria. *Fertilizer Research*. 4(2): 119-126.
- Agrawal GC, Sidhu AS, Sekhon NK, Sandhu KS and Sur HS. 1995 Puddling and N management effects on crop response in a rice-wheat cropping system. *Soil Till. Res.*; 36:129-139.
- Agricultural Statistics at a Glance. 2018. Directorate of Economics and Statistics, Department of Agriculture and Co-operation, Govt. of India, New Delhi. 78-85.
- Alam SM and Azmi AR 1989 Effect of P and Fe on the growth and content of P and Fe by rice plants. *Pak. J. Agric. Engg. Vet. Sci.* 5(1-2): 35
- Asewar BV, Dahiphale VV, Chavan GV, Katare NB and Sontakke, JS 2000. Effect of ferrous sulphate on grain yield of upland basmati rice. *Journal of Maharashtra Agricultural Universities*. 25 (2): 209-210.
- Babarai CJ and Patel CL. 1980. Effect of application of iron, farm yard manure and sulphur on the availability of iron in medium black calcareous soils at different moisture regimes. *J. Indian Soc. Soil Sci.*, 28 : 302-306.
- Baishya LK, Sarkar D, Ansari MA, Singh KR, Meitei CB and Prakash N. 2016. Effect of micronutrients, organic manures and lime on bio-fortified rice production in acid soils of Eastern Himalayan region. *Ecology, Environment and Conservation*. 22 (1): 199-206.
- Bameri M, Abdolshahi R, Mohamadi NG, Yousefi K and Abatabaie SM. 2012. Effect of different microelement treatments on wheat (*Triticum aestivum*) growth and yield. *International Research Journal of Applied and Basic Sciences*.3 (1):219-223.
- Basanna KT. 1982. Physiological studies on iron uptake efficiency in three groundnut (*Arachis hypogaea* L.) genotypes. *M. Sc. (Agri.) Thesis*, Univ. Agric. Sci., Bangalore, Karnataka (India).
- Belavanaki LN. 1979 . Effect of iron and zinc on yield chemical composition of sorghum and their residual effect on succeeding maize crop. *M. Sc. (Agri.) Thesis*, Univ. Agric. Sci., Bangalore, Karnataka (India).
- Bergmann, W. (1992) Nutritional Disorders of Plants: Developments, Visual and Analytical Diagnosis. Gustav Fischer Verlag Jena, New York.

- Bhattacharya. 1992. Identification and inheritance of efficient zinc absorption in rice. *Crop Sci.* 31:61-63.
- Biswas BC and Tewatia RK 1988. Role of micronutrients in intensive cropping areas. *Fert. News.* 29(10): 27-36.
- Blair GJ & Lefroy RDB. 1987. Sulphur cycling in tropical soils and the agronomic impact of increasing use of S free fertilizers, increased crop production and burning of crop residue. In: *Proceedings of the Symposium on Fertilizer Sulphur Requirements and Sources in Developing Countries of Asia and the Pacific* (pp. 12-17). FADI- NAP, FAO, TSI and ACIAR Bangkok, Thailand
- Brown, G. (1953) The occurrence of lepidocrocite in some British soils: *J. Soil Sci.* 4, 220-229.
- Chaney RL, Brown JC and Tiffin LO. 1972. Obligatory reduction of ferric chelates in iron uptake by soybean genotypes. *J. Plant Physiol.*, 50 :208-213.
- Chaudhary SK and Sinha NK. 2007. Effect of levels of nitrogen and zinc on grain yield and their uptake in transplanted rice. *Oryza.* 44 (1): 44-47.
- Chen Y and Barak P. 1982. Iron nutrition of plants in calcareous soils. *Adv. Agron.* 35 : 217-240.
- Choudhary N, Ahuja U, Jain RK, Kumari P and Batan KR. 2011. Morphological and molecular variability in weedy rice of Haryana. *Asia Journal of Agriculture Research* (5): 250-259.
- Chouhan BS, Johnson DE. 2011. Row spacing and weed control timing affects yield of aerobic rice. *Field Crops Research* 121: 226-231.
- Cottenie A, Veriloo L, Kiens L, Velghe G and Camerlynck R. 1982. *Chemical Analysis of Plant and Soils.* State University, Ghent, Belgium.
- Das L, Kumar R, Kumar V, Kumar V and Kumar N. 2016. Effect of moisture regimes and levels of iron on growth and yield of rice under aerobic condition. *The Bioscan.* 11(4): 2475-2479.
- Dhaliwal, S. S., Sadana, U. S., Khurana, M. P. S., Dhadli, H. S. and Manchanda, J.S. 2010. Enrichment of rice grains with zinc and iron through fertifortification. *Indian J Fert*6: 28-35.
- Dravid MS and Goswami NN. 1987. Effect of farm yard manure P and Zn on dry matter yield and uptake of P, K, Zn and Fe by rice under non- saline and saline conditions. *J. Nuclear Agric. Bio.* 16: 201-205.
- Dubey DD, Khedkar S and Singh OP. 1983. Forms of iron in salt affected black soils of Western part of Madhya Pradesh. *J. Indian Soc. Soil Sci.*, 31: 320-324.

- Dwivedi BS, Singh VK, Meena MC, Dey A, Datta SP. 2016. Integrated nutrient management for enhancing nitrogen use efficiency. *Indian J Fertil*; 12:62-71.
- El-Falaky AA. 1981. Studies on iron in some soils of Egypt. *Ph. D. Thesis*, Faculty of Agriculture, Cairo. University. Egypt.
- Fageria NK, Carvalho GD, Santos AB, Ferreira EPB and Knupp AM. (2011). Chemistry of Lowland Rice Soils and Nutrient Availability. *Communications in Soil Science and Plant Analysis*, **42**: 1913–1933.
- Ghughre RV and Sonar KR. 1984. Effect of pre-sowing soil water treatments on yield and iron nutrition of upland rice grown on calcareous *Vertisols*. *Journal of Plant Nutrition*, **7**(1-5): 201-209
- Gill JS and Walia SS. 2013. Effect of foliar application of iron, zinc and manganese on direct seeded aromatic rice (*Oryza sativa* L.); *Indian Journal of Agronomy*, **59**(1): 80-85.
- Haon NT, Rao UP and Siddiq EA. 1993. Genetic tolerance to iron chlorosis in rice. In *Genetic aspects of plant mineral nutrition* (J P Randal Eds) Kluwer academic publication, Netherland pp. 327-333,
- Jhadhav KT, Lokhande DC and Asewar BV. 2014. Effect of ferrous sulphate and zinc sulphate management practices on rice under aerobic condition. *Advanced Research Journal of Crop Improvement*. **5**(2):131-135.
- Jatav MK, Kumar P, Verma RC and Raigar PR. 2008. Efficiency of zinc and iron on yield attributes, yield and total uptake of NPK in grain and straw of wheat in treated saline sodic soil, irrigated with sodic water. *International Journal of Tropical Agriculture*, **26**(2): 121-126.
- Jena PK, Rao CP and Subbaiah HG. 2006. Effect of zinc management practices on growth, yield and economics in rice. *Crop Production*. **43** (4): 326-328.
- Kanwar JS and Randhawa NS. 1974. *Micronutrients Research in Soil and Plants in India - A Review*, ICAR Publication, New Dehli.
- Katyal JC and Sharma BD. 1980. New technique of plant analysis to resolve iron chlorosis. *Plant and Soil*, **55** (1) : 105-109.
- Khanda CM and Dixit L. 1996. Effect of zinc and nitrogen fertilization on yield and nutrient uptake of summer rice (*Oryza sativa*). *Indian Journal of Agronomy*. **41** (3): 368-372.
- Kriem HM, Abdel-Mottaleb MA, El-Fouly MM and Notal OA. 1991. Response to micronutrient fertilization of different formulations under the soil conditions. *Egyptian J. Physio. Sci.* **15**(1-2): 131-140

- Krishnamurthy R and Raj D. 1975. Effect of lime, organic matter and fertilizers on the availability of various forms of iron in acid alluvial soils. *Madras Agric. J.*, 62 : 439-444.
- Kulandaivel S, Mishra BN, Mishra PK. 2003. Direct and residual effect of levels of zinc and iron and their mode of application on productivity of rice-wheat cropping system. *Annals of Agricultural Research*. 24 (2): 221-226.
- Kumar A, Sen A and Dev CM. 2013. Effect of iron, zinc and manganese levels on yield and yield attributing characters of rice. *BIOINFOLET*,10(3B): 924-929.
- Kumar S, Omnavar PK, Sachin RS and Sharma RB. 1981. Iron status of some soils of Kumaon and Garhwal Himalaya. *J. Indian Soc. Soil Sci.*, 29 : 266-267.
- Kumar V, Kumar D, Singh YV and Raj R. 2015. Effect of iron fertilization on dry-matter production, yield and economics of aerobic rice (*Oryza sativa*). *Indian Journal of Agronomy*. 60 (4): 547-553.
- Lathika Mandal, Maiti D and Bandyopadhyay P. 2009. Response of zinc in transplanted rice under integrated nutrient management in new alluvial zone of West Bengal. *Oryza*. 46(2): 113-115.
- Lindsay WL. 1974. Role of chelations in micronutrient availability. *Plant Roots and its Environment*, Ed. E. W. Larson, University Press of Virginia, Charlottesville, pp. 507-524.
- Mahajan G and Khurana MPS. 2014. Enhancing productivity of dry-Seeded Rice (*Oryza sativa* L.) in North-West India through foliar application of Iron and Potassium Nitrate. *VEGETOS*. 27 (2): 301-306.
- Mankotia BS and Shekhar J. 2007. Integrated nutrient supply and seed rate for direct seeded rainfed upland rice (*Oryza sativa*) in mid hills of Himachal Pradesh. *Indian Journal of Agricultural Sciences*. 77(9): 604-606.
- Marschner H. 1991. *Symposium summary and future research areas*. Y. Chen and Y. Hadar (Eds.). Iron nutrition and Interactions in Plants, pp. 365- 372. Kluwer Academic publishers, Dordrecht.
- Meena BL, Rattan RK and Datta SP. 2013. Efficacy of Seed Treatment in Ameliorating Iron Deficiency in Aerobic Rice on a Calcareous Soil. *Journal of the Indian Society of Soil Science*. 61 (2) 1: 47-152.
- Mehla DS and Panwar DVS. 2000. Effect of organic and inorganic fertility levels on yield and yield components of scented rice. Extended Summary: International Conference on Managing Natural Resources, New Delhi, 14-18 February 2000, 2: 330-331.

- Mengel K and Kirkby EA. 1982. Principles of Plant Nutrition, Third Edition. International Potash Institute, Switzerland.
- Misra NM and Venkateswarlu S. 1981. Effect of soil VS foliar application of certain micronutrients on wheat Var. Kalyan Sona. *Food Farming. And Agriculture.*, 14 : 57-59.
- Mori S, Nishizawa N, Hayashi H, Chino M, Yoshimura E and Ishihara J. 1991. Why are young rice plants highly susceptible to iron deficiency?. *Plant and Soil.*130:143-156.
- Mured E and Fischer WR. 1988. The geobiochemical cycle of iron. In : J. W. Stuck, B. A. Goodman and U. Schwertmann (Eds), *Iron in soils and clay minerals*, Reidel, Dordrecht, The Netherlands, pp. 1-18.
- Naguib YN, Hussein MS, El-Sherbeny S.E, Khalil MY and Lazari D. 2007. Response of *Ruta graveolens* L. to sowing date and foliar micronutrients. *Journal of Applied Science Research.* 3 (11): 1534-1543.
- Nayyar VK, Takkar PN, Bansal RL, Singh SP, Kaur NP and Sadana US. 1990. Micronutrients in Soils and Crops of Punjab. Research bulletin, Department of Soils, P.A.U, Ludhiana, India.
- Pal S, Datta SP, Rattan RK and Singh AK. 2008. Diagnosis and amelioration of iron deficiency under aerobic rice. *Journal of Plant Nutrition.* 31(5): 919 – 940.
- Patel DP, Munda AD, Ghosh GC, P.K., Borodoloi JS and Manoj Kumar. 2010. Evaluation of yield and physiological attributes of high-yielding rice varieties under aerobic and flooded-irrigated management practices in mid-hills ecosystem. *Agricultural Water Management.* 97 (9): 1269-1276.
- Prasad B and Rajkumar VK. 1992. Effect of Fe- chelates on iron diffusion, growth and iron nutrition of rice in calcareous soils. Nation. Sem. On Development in Soil Sciences, Indian Society of Soil Sciences, held at CRIDA Hyderabad from 26th-29th November, pp. 55.
- Qu LQ, Yoshihara T, Ooyama A, Goto F, Takaiwa F. 2005. Iron accumulation does not parallel the high expression level of ferritin in transgenic rice seeds. *Planta.* 222: 225–233.
- Rahman MT, Jahiruddin M, Humayan MR, Alam MJ & Khan AA. (2008). Effect of Sulphur and Zinc on Growth, Yield and Nutrient Uptake of Boro Rice (Cv. BrriDhan 29) . *J. Soil. Nature.*, 2, 10-15.
- Rai MM, Pal AR, Chiman BP, Shitoley DB, Vakil P.1972. Available micronutrient status of shallow black soils of Madhya Pradesh. Publisher: Indian Society Of Soil Science. Print ISSN: 0019-638X. Online ISSN: 0974-0228.

- Rajkumar, Nayyar, V.K., Sidhu, G.S. and Deshmukh, S.N. (1990). Distribution of available micronutrient cations in some dominant soil series in different physiographic units of Bundelkhand region of Madhya Pradesh. *Journal of the Indian Society of Soil Science* 38(2): 410-415.
- Rakesh D, Reddy PRR and Pasha ML. 2012. Response of aerobic rice to varying fertility levels in relation to iron application. *Journal of Research ANGRAU*. 40 (4): 94-97.
- Rasool R, Singh P and Akhter S. 2015. Growth, yield attributes and yield of rice as affected by age of seedling and time of nitrogen application under temperate conditions. *Indian Journal of Ecology* 42(1): 143-147.
- Rebeiz CA and Lascelles J. 1982. Biosynthesis of pigments in plants and bacteria. PP.699-772. In 'Photosynthesis* by Goundjee (Ed.), Vol. 1, Energy Conversion by Plant and Bacteria. Academic Press, New York.
- Sakal, R, Singh, A.P., Sinha, R.B. & Bhogal, N.S., Annual progress reports. ICAR All India Coordinated Scheme of Micro-and Secondary Nutrients in Soils and crops of Bihar, Res. Bull, Department of Soil Science, RAU, Samastipur, Bihar, India (2001)
- Sakal R and Sinha RB. 1983. P and K nutrition of rice as influenced by Zn and Fe application. *Madras Agric. J.* 79(7): 458-461.
- Sandstead HH. 1991. Zinc deficiency: a public health problem? *Am J Dis Child.* 145:853-9.
- Saranghi SK, Sharma HC, Singh K, Singh Y, Singh CS and Singh KK. 2006. Studies on the iron application and growth regulators on the performance of direct seeds upland rice (*Oryza sativa* L.) varieties under rain fed condition. *Annals of Agricultural Research New Series*, 27(3): 213-219.
- Seckback J. 1982. Ferreting out the secretes of plant ferritin. A review. *J. Plant Nutr.*, 5:369-394.
- Shaygany J, Peivandy N and Ghasemi S. 2012. Increased yield of direct seeded rice (*Oryza sativa* L.) by foliar fertilization through multi-component fertilizers. *Archives of Agronomy and Soil Science*. 58 (10): 1091-1098.
- Sharma SK and Lal FH. 1992. Effect of micronutrient fertilization on yield and nutrient contents of wheat in loamy soils of Rajasthan. *Nation. Sem. on Development in Soil Sciences*, Indian Society of Soil Sciences, held at CRIDA Hyderabad from 26th-29th November, pp. 108-109.
- Shekara BG, Sharanappa and Krishnamurthy N. 2010. Effect of irrigation schedules on growth and yield of aerobic rice (*Oryza sativa*) under varied levels

- of FYM in Cauvery command area. *Indian Journal of Agronomy*. 55 (1): 35-39.
- Sridhara CJ, Shashidhar HE, Gurumurthy KT and Ramachandrappa BK. 2012. Effect of genotypes and method of establishment on root traits, growth and yield of aerobic rice. *Agricultural Science Digest*. 32 (1): 13.
- Shukla AK, Behera SK, Singh VK, Prakash C, Sachan AK, Dhaliwal SS, et al. (2020) Pre-monsoon spatial distribution of available micronutrients and sulphur in surface soils and their management zones in Indian Indo-Gangetic Plain. *PLoS ONE* 15(6): e0234053. <https://doi.org/10.1371/journal.pone.0234053>
- Singh K, Raj L and Ghose RL. 1996. Zinc translocation to wheat roots and its implications for a phosphorus/zinc interaction in wheat plants. *J. Plant Nutr.* 13:1499-1512.
- Singh K, Deo C, Bohra JS, Singh JP and Singh RN. 1992. Effect of iron carriers and compost application on rice yield and their residual effect on succeeding wheat crop in Entisol. *Annals of Agricultural Research*. 13(2): 181-183.
- Singh G, Wade LJ, Singh RK, Nayak R, Singh BB and Singh ON. 2001. Nutrient management for rainfed lowland rice and its effect on succeeding lentil crop. *Oryza*. 38 (3&4): 123-126.
- Sinha RB and Sakal R. 1983. Effect of zinc and iron application in calcareous soil on zinc and iron nutrition of rice. *Journal of the Indian Society of Soil Science*, 31(4): 527-533.
- Stoltzfus, R. J. and Dreyfuss, M. L. 1998. Guidelines for the use of iron supplements to prevent and treat iron deficiency anaemia. *Washington, DC: ILSI Press*.
- Sudha S and Stalin P. 2015. Effect of zinc on yield, quality and grain zinc content of rice genotypes. *International Journal of Farm Sciences* 5(3): 17-27.
- Sudhakar PC, Singh JP, Yogeshwar Singh and Raghavendra Singh. 2006. Effect of graded fertility levels and silicon sources on crop yield, uptake and nutrient-use efficiency in rice (*Oryza sativa*). *Indian Journal of Agronomy*. 51 (3): 186-188.
- Sunil CM and Shankarlingappa BC. 2014. Influence of integrated package of agrotechniques on quality parameters of aerobic rice. *Journal of Agronomy*. 13(2): 58-64.
- Syed SA, Patil PR, Karanje SV, Karpe AH and Gharge PV (2020) Effect of multinutrient fertilizer FAST (Ferrous, Ammonium, Sulphate) on growth, yield contributing characters and yield of rice DOI: 10.22271/chemi.2020.v8.i3d.9233

- Terry N and Low G. 1982. Leaf chlorophyll content and its relation to the intra-cellular localization of iron. *J. Plant Nutr.*, 5*301-310.
- Thiyagarjan and selvaraju. 2001. Water saving in rice cultivation in India. In proceedings of an international workshop on water saving rice production system, Nanjing university. 15-45.
- Tripathi SD. 1993. Micronutrient status of rice growing belt of Varanasi division with special reference to zinc and iron. Ph. D. thesis, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India.
- Welp G, Herms U and Bummer D. 1983. Influence of soil reactions, redox conditions and organic matter on the phosphate content of soil solutions. *Zpflanzen Bodenk*, 146 : 38-52.
- World Health Organization (WHO). World Health Report Reducing Risks, Promoting Healthy Life. WHO: Geneva, Switzerland. 2002.
- Yadav GS, Shivay YS and Kumar D. 2011. Effect of mulching and iron nutrition on productivity, nutrient uptake and economics of aerobic rice (*Oryza sativa* L.). *Indian Journal of Agronomy*, **56**(4): 365-372.
- Yadav GS. 2012. Influence of mulching and iron nutrition on aerobic rice grown under aerobic rice-wheat cropping system. Ph.D. thesis submitted to Division of Agronomy Indian Agricultural Research Institute, New Delhi-12
- Yogesh TC, Viswanath AP and Thimmegowda P. 2013. Yield and Economics of Aerobic Paddy with Application of Zinc, Iron and Microbial Inoculants. *Journal of Environmental Science, Computer Science and Engineering & Technology*. 2 (1): 100-104.
- Yoshida S. Fundamentals of rice Crop Science, Int. Rice Research Institute, Los Banos, Philippines, pp. 269, 1981.
- Zuo Y and Zhang F. 2011. Soil and crop management strategies to prevent iron deficiency in crops. *Plant and Soil*, **339**: 83-95.

APPENDICES

Appendix – I

Procedure for calculation of cost of cultivation per hectare area basis of rice under different treatments

A. Common cost of cultivation under all treatments (per hectare area basis)

S. No.	Particulars	Input(ha ⁻¹)	Cost Unit ⁻¹ (Rs)	Cost (Rs ha ⁻¹)
A	Nursery Management			
I	Harrowing with cultivator and levelling	1 pass	500/hr	125
II	Preparation of Nursery beds, seed treatment and sowing of seed	2 man day	300	600
III	Cost of seed	40 kg	50/kg	2000
IV	Seed treatment by fungicide	80 g	900/kg	72
V	Cost of Fertilizers			
	Nitrogen	120 kg	12/kg	144
	Phosphorus	60 kg	32/kg	192
	Potassium	40 kg	10/kg	40
B	Land Preparation			
I	Harrowing with cultivator	1 pass	500/hr	1250
II	Puddling and levelling by tractor driven rotavator	1 pass	750/hr	750
III	Uprooting and transplanting of seedling	30 men days	300	9000
C	Fertilizer			
I	Cost of fertilizer	120 kg N	12/kg	1440
		60 kg P ₂ O ₅	32/kg	1920
		40 kg K ₂ O	10/kg	400
II	Application Charges	1man days	300	300
D	Irrigation through tube well (Including application charges)	600 + 2man day	300/day	1200
E	Harvesting, Bundling	20 men days	300/day	6000
F	Threshing and Winnowing	10 men days	300/day	3000
G	Land rent	6 months	20000/year	10000
	Total			38433

**[B]. Estimation of variable cost of cultivation of different FAST treatments
(on hectare⁻¹ area basis)**

Treatment Numbers	Treatments	Commercial dose	Unit price (Rs. L ⁻¹ or kg)	Cost (Rs. ha ⁻¹) including application charges (Rs. 400 ha ⁻¹)
T ₁	RDF- Recommended dose of fertilizer	-	0	0
T ₂	RDF + FAST @ 15kg/ha for soil application	15kg/ha	140	2500
T ₃	RDF + FAST @ 25kg/ha for soil application	25kg/ ha	140	3900
T ₄	RDF + FAST @ 35kg/ha for soil application	35kg/ha	140	5300
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	250g/ha	140	470
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	500g/ha	140	540
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	250g/ha	140	435
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	500g/ha	140	470

[C]. Estimation of total cost of cultivation under different FAST treatments (per hectare area basis)

Treatment numbers	Treatments	Common cost of cultivation (Rs. ha⁻¹)	Cost of cultivation with treatment (Rs. ha⁻¹)
T ₁	RDF- Recommended dose of fertilizer	38433	38433
T ₂	RDF + FAST @ 15kg/ha for soil application	38433	40533
T ₃	RDF + FAST @ 25kg/ha for soil application	38433	41933
T ₄	RDF + FAST @ 35kg/ha for soil application	38433	43333
T ₅	RDF + 2 Spray of FAST 0.25% at 25 and 45 DAT	38433	39703
T ₆	RDF + 2 Spray of FAST 0.50% at 25 and 45 DAT	38433	39773
T ₇	RDF + 1 Spray of FAST 0.25% at 25 DAT	38433	39068
T ₈	RDF + 1 Spray of FAST 0.50% at 25 DAT	38433	39103

[D]. Economic analysis of different FAST treatments in rice

T. No.	Grain yield (Kg ha⁻¹)	Value of Grain (Rs. ha⁻¹)	Straw yield (Kg ha⁻¹)	Value of Straw (Rs. ha⁻¹)	Gross monetary returns (Rs. ha⁻¹)	Total Cost of cultivation (Rs. ha⁻¹)	Net monetary returns (Rs. ha⁻¹)	B:C Ratio
T ₁	3269	65380	6566	6566	71946	38433	33513	1.87
T ₂	4381	87620	7142	7142	94762	40533	54229	2.33
T ₃	4632	92640	7348	7348	99988	41933	58055	2.38
T ₄	5188	103760	8167	8167	111927	43333	68594	2.58
T ₅	4451	80303	7248	7248	96268	39703	56565	2.42
T ₆	4620	89020	7365	7365	99765	39773	59992	2.50
T ₇	4322	86440	7083	7083	93523	39068	54455	2.39
T ₈	4390	87800	7260	7260	95060	39103	55957	2.43

Price of grain = Rs.20 kg⁻¹

Price of straw = Rs. 1 kg⁻¹

Appendix-III

[A]. Mean sum of square for different growth parameters

S. No.	Source of variance	D.f.	Plant height (cm)				Number of tillers hill ⁻¹			
			30 DAT	60 DAT	90 DAT	Harvest	30 DAT	60 DAT	90 DAT	Harvest
1.	Treatment	7	50.81	202.50	301.98	301.98	1.41	3.47	3.62	3.67
2.	Replication	2	9.68	14.36	24.5	50	0.58	0.74	0.92	1.47
3.	Error	14	4.14	6.15	10.5	21.42	0.24	0.31	0.39	0.63

[B]. Mean sum of square for plant population and dry matter accumulation

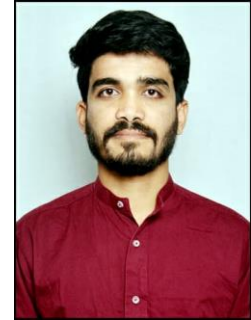
S. No.	Source of variance	D.f.	Plant population (No. of hill m ⁻²)		Dry matter accumulation (g m ⁻²)			
			20 DAT	Harvest	30 DAT	60 DAT	90 DAT	Harvest
1.	Treatment	7	0	0.71	0.95	49.91	26.89	30.13
2.	Replication	2	2	2.88	0.27	23.12	11.04	3.69
3.	Error	14	0.85	1.23	0.11	9.90	4.73	1.58

[C]. Mean sum of square for the yield attributing characters and yields

S. No.	Source of variance	d.f.	Effective tillers hill ⁻¹	Panicle length (cm)	Grains panicle ⁻¹	Test weight (g)	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
1.	Treatment	7	3.06	3.37	358.23	0.75	442693	188845
2.	Replication	2	1.21	1.24	32.48	1.72	65551	29233.6
3.	Error	14	0.52	0.53	13.92	0.74	28093.3	12528.7

CURRICULUM VITAE

The author of this thesis Mr. Sudhanshu Shukla S/o Shri Ashutosh Shukla was born 30th June, 1996 at Rewa (Madhya Pradesh). He passed the High School Examination in the year 2011 with 72.16% from Model Higher Secondary School, Rewa (M.P.) and Higher Secondary Examination in the year 2013 acquiring 74% marks from Model Higher Secondary School, Rewa (M.P.). He joined the College of Agriculture, Rewa Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur in the year 2016 and successfully completed the degree of B.Sc. (Ag.) on 26th June, 2020 with (7.68 OGPA out of 10.00 point scale).



After completing graduation, he was selected for M.Sc. (Ag.) degree programme in Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur through JNKVV and RVSKVV Joint Entrance Examination, in 2020 for specialization in Agronomy. He has successfully completed all the course requirements for Master's degree with First Division securing an OGPA of out of 10 point scale.

For the fulfillment of the Master's degree programme, he was allotted a research problem entitled "Evaluation of different doses and mode of application of FAST for maximizing rice production". This is duly completed by him and presented in the form of this thesis