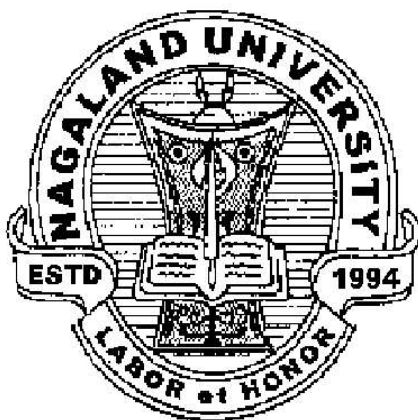




**EFFECT OF PRECISION NITROGEN MANAGEMENT AND
IRRIGATION REGIMES IN RICE - TORIA CROPPING SYSTEM IN
DIMAPUR DISTRICT OF NAGALAND**

THESIS
SUBMITTED

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF
DOCTOR OF PHILOSOPHY
BY

NGANGBAM MONICA DEVI
ADMN. NO. PH 310/20 REGN. NO. PHD/AGR/00455

**DEPARTMENT OF AGRONOMY
SCHOOL OF AGRICULTURAL SCIENCES
NAGALAND UNIVERSITY, MEDZIPHEMA CAMPUS – 797106
JUNE, 2026**

**EFFECT OF PRECISION NITROGEN MANAGEMENT AND
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SYSTEM IN DIMAPUR DISTRICT OF NAGALAND
BY**

Name of Candidate-NGANGBAM MONICA DEVI

Name of Supervisor-PROF. L. TONGPANG LONGKUMER

Submitted

In partial fulfilment of the requirements for the Degree of Doctor of
Philosophy in

Agronomy of Nagaland University

Nagaland University

JULY, 2025

I, NGANGBAM MONICA DEVI, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to School of Agricultural Sciences, Nagaland University for the degree of Doctor of Philosophy in Agronomy.

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The result of the investigation reported in the thesis has not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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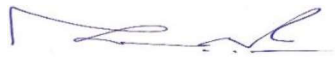
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CERTIFICATE – II

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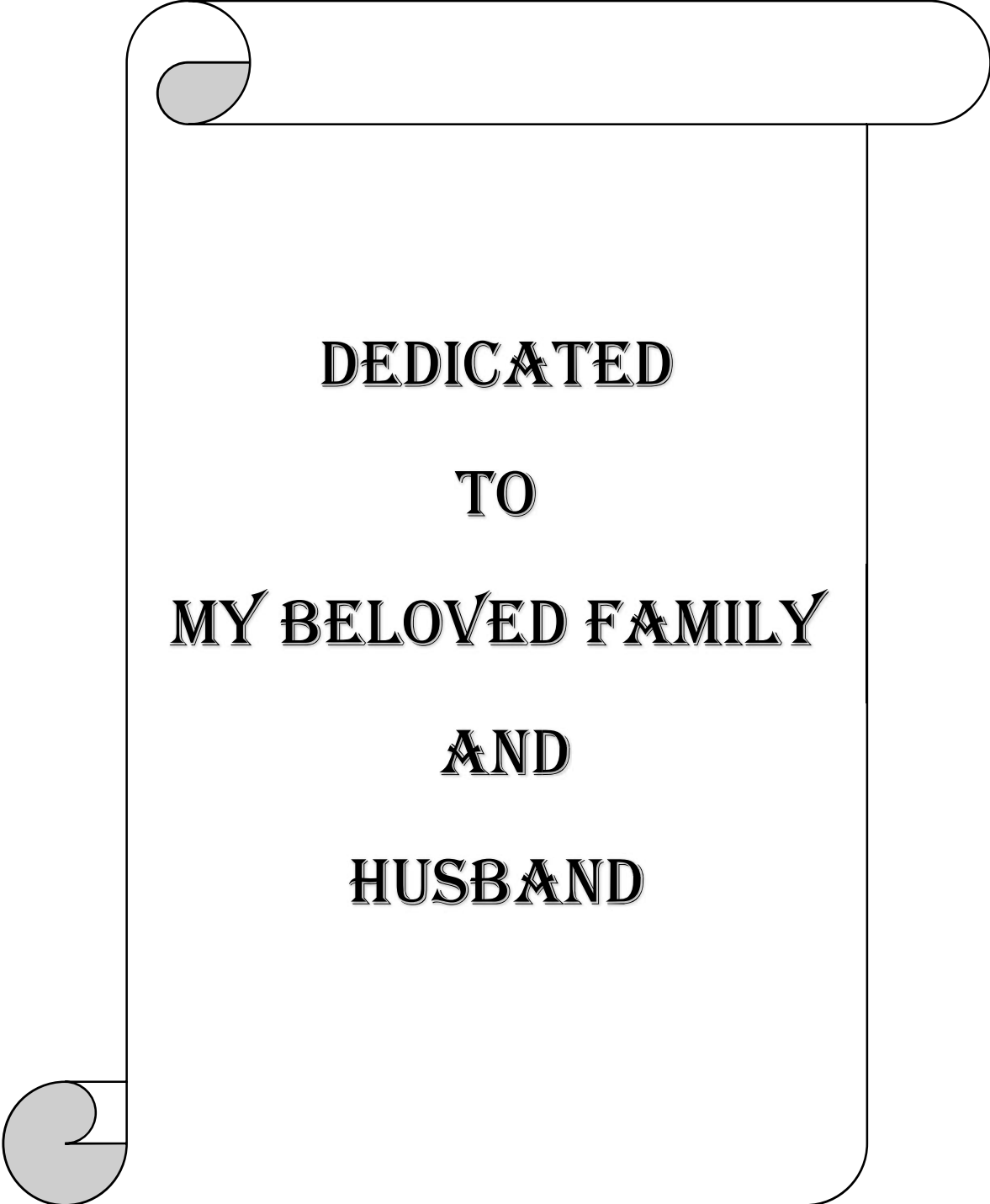
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Date:

(Ngangbam Monica Devi)

Place: Medziphema



DEDICATED
TO
MY BELOVED FAMILY
AND
HUSBAND

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LIST OF ABBREVIATION

%	:	Percent
@	:	At the rate of
₹ ha ⁻¹	:	Rupees per hectare
<	:	less than
AE	:	Agronomic efficiency
B:C	:	Benefit cost
°C	:	Degree Celsius
CD	:	Critical Difference
CGR	:	Crop Growth Rate
CPE	:	Cumulative pan evaporation
DAS	:	Days after sowing
DAT	:	Days after transplanting
DMA	:	Dry matter accumulation
dS m ⁻²	:	Deci Siemen per meter
et al	:	And others
Fig	:	Figure
FP	:	Farmer practices
FYM	:	Farm Yard Manure
g	:	Gram
GS	:	Green seeker
ha	:	Hectare
HI	:	Harvest index
hr	:	Hour
i.e.,	:	That is
ICAR	:	Indian Council Agricultural Research
IW	:	Irrigation Water
kg ha ⁻¹	:	Kilogram per hectare
Kg	:	Kilogram
km	:	kilometer
LAI	:	Leaf area index

LCC	:	Leaf colour chart
Max.	:	Maximum
Min.	:	Minimum
mm	:	Millimeter
MOP	:	Muriate of Potash
MT	:	Million tonnes
mt	:	Metric tonnes
NAR	:	Net assimilation rate
NDVI	:	Normalized Difference Vegetative Index
NE	:	Nutrient Expert
No.	:	Number
NPK	:	Nitrogen Phosphorus Potassium
NS	:	Non-Significant
P ₂ O ₅	:	Phosphorus pentoxide
PE	:	Physiological efficiency
PFP	:	Partial factor productivity
pH	:	Potential of Hydrogen ion concentration
Plant ⁻¹	:	per plant
PNM	:	Precision Nitrogen Management
q	:	Quintal
RDF	:	Recommended Dose of fertilizer
REY	:	Rice equivalent yield
SEm±	:	Standard Error of mean
Sl.no.	:	Serial number
SPAD	:	Soil plant analysis development
SSNM	:	Site specific nutrient management
t ha ⁻¹	:	Tonne per hectare
Viz	:	Namely

ABSTRACT

A field experiment was conducted to study the effect of precision nitrogen management on growth, yield and yield attributes of transplanted rice and irrigation regimes in toria in Dimapur district of Nagaland during *kharif* and *rabi* seasons of 2022-23 and 2023-24 at ICAR Research Farm, Jharnapani, Nagaland Centre. The first experiment was laid out in Randomised Block Design with four numbers of treatment which were replicated thrice. The treatments were N₁-Control, N₂-RDF, N₃-LCC based N management and N₄-SPAD based N management. The data pooled over two years revealed that precision nitrogen management had significant effect on growth, yield attributes and yield of rice. The plant height at 60 (89.94 cm) and 90 DAT (111.04 cm), DMA plant⁻¹ at 30 (7.41g), 60(15.68g) and 90 (28.22g) DAT and number of tillers sq.m⁻¹ at 30 (255.50) and 60 (287.63) DAT were recorded the highest in N₄ followed by N₃. The CGR showed significant effect at 60 and 90 DAT but RGR and NAR were significant at 30 DAT. The highest CGR (13.50 g m⁻² day⁻¹) and (21.18 g m⁻² day⁻¹) at 60 and 90 DAT respectively, RGR (0.0477 g g⁻¹ day⁻¹) and NAR (0.0366 g m⁻² day⁻¹) at 30 DAT were recorded in N₄. Significantly the highest number of panicles m⁻¹ (256.97), panicle length (25.84 cm), weight of panicle (5.45g) and number of filled grain panicle⁻¹ (152.90) were also recorded in N₄ which was followed by N₃ and the lowest was recorded in N₁. The grain yield (4830.83 kg ha⁻¹), AE (64.40 kg kg⁻¹) and PFP (23.19) were significantly highest in N₄ but PE (39.38 kg kg⁻¹) was highest recorded from N₂ i.e. RDF. The available N (259.13 kg ha⁻¹), P (23.61 kg ha⁻¹) and K (164.36 kg ha⁻¹) were also observed to be the highest in N₄. The precision nitrogen management showed highly significant effect on nutrient uptake by both grain and straw of rice. The highest N uptake by grain (68.48 kg ha⁻¹) and straw (29.60 kg ha⁻¹), P uptake by grain (8.85 kg ha⁻¹) and straw (10.02 kg ha⁻¹) and K uptake by grain (22.54 kg ha⁻¹) & straw (79.85 kg ha⁻¹) were recorded highest from the treatment N₄ i.e. SPAD based N management and lowest nutrient uptake was recorded from control plot. In terms of economics, cost of cultivation was recorded highest in N₂-RDF but the highest gross return (₹ 114910.33 ha⁻¹), net return (₹ 71241.60 ha⁻¹) and B:C (1.64) was recorded in N₄. The second experiment was laid out in Split- Plot Design

keeping the four residual treatments of nitrogen management in the main plot and three Irrigation regimes in the sub plot. There were 12 numbers of treatment with 3 replications. The three irrigation treatments were I₁- Control, I₂- IW: CPE=0.8 and I₃- IW: CPE=1. The irrigation regimes had significant effect on growth, yield and quality of toria whereas the residual effect of nitrogen management on toria did not show any significant effect. The plant height at 30(22.04 cm), 60(43.86 cm) and 90 (98.87 cm) DAS were recorded to be significantly highest in I₃. The highest DMA was observed in I₃ and significant effect was recorded at 45 DAS (5.26 g) and 60 DAS (6.81g). The irrigation regimes did not significant effect on CGR, RGR and NAR at 15-30 DAS but showed significant effect at 30-45 DAS and 45-60 DAS. The highest CGR, RGR and NAR at 30-45 (4.47 g m⁻² day⁻¹, 0.0238 g g⁻¹ day⁻¹ and 0.0020 g m⁻² day⁻¹) and at 45-60 (3.45 g m⁻² day⁻¹, 0.0106 g g⁻¹ day⁻¹ and 0.0010 g m⁻² day⁻¹) were recorded from treatment I₃- IW: CPE=1 and the lowest was recorded from control plot i.e. IW: CPE =0. The maximum primary branches plant⁻¹ at 30 and 60 DAS (4.38 and 5.85) and secondary branches plant⁻¹ at 30 and 60 DAS (6.69 and 12.52) was recorded from I₃- IW: CPE=1 and the lowest was recorded from control plot i.e. IW: CPE =0. The no. of siliqua plant⁻¹(77.64), length of siliqua (6.52 cm), weight of siliqua (3.50) and no. of seed siliqua ⁻¹ (18.81), grain yield (1449.38 kg ha⁻¹), straw yield (2455.41 kg ha⁻¹), oil content (37.30%) and oil yield (541.76 kg ha⁻¹) were also recorded highest in I₃. The highest NPK uptake was recorded in treatment I₃. The highest cost of cultivation was recorded in N₁I₁(₹26013 ha⁻¹). N₄I₃ recorded maximum gross return (₹86481.58 ha⁻¹), net return (₹59583.58 ha⁻¹) and B:C (2.22). The sustainability index of rice and toria were 1.09 and 0.998 respectively. The average system productivity of the rice-toria cropping system was 7477.43 kg ha⁻¹.

Keywords: PNM, Irrigation regimes, rice - toria cropping system, growth, yield, economics.

CHAPTER I

INTRODUCTION

INTRODUCTION

Rice (*Oryza sativa* L.) is the most widely grown cereal in the world after wheat and maize. The crop occupies a significant position in the culture, tradition and heritage of many Asian countries. Most of the rice in tropical countries is produced in irrigated and rainfed lowland areas. Irrigated rice system accounts for 78% of all rice production and 55% of total rice area, mostly concentrated in alluvial floodplains, terraces, inland valleys, and details in the humid and sub-humid of sub tropics and tropics in Asia. Rice is the most important cereal food crop to feed the ever-growing population, however, the average yield in Asia is low compared to global average yield (Haider, 2018). There is a limited scope for further expansion in cultivated area under cropping in Asia. However, sustainable intensification of land for crop production and increase in crop productivity could help the current and future food demand.

Rice plays a major role in diet, economy, employment, culture and history. It is the staple food for more than 65% of Indian population contributing approximately 40% to the total food grain production, thereby, occupying a pivotal role in the food and livelihood security of people.

Total global rice production was 776.46 MT in 2022 and the production has been increased to 800 MT which represent an increase of 23.54 MT of rice production in 2023 (Anonymous, 2023 a). After China, India grows rice in 47.82 m ha with production of 137.83 million tonnes and average productivity of 2.88 tonnes ha⁻¹ (Anonymous, 2020). The crop is grown in highly diverse conditions ranging from hills to coasts. In Nagaland, rice is grown throughout the state and covers an area of 2,11,130 ha with a production of 5,54,669 mt out of which upland rainfed condition occupies an area of 90,496 ha with a production of 1,79,227 mt in 2022-23 (Anonymous, 2023 b).

Nitrogen (N) is the most important limiting factor, after water deficit, for biomass production in natural ecosystems. In paddy field systems, N fertilization can provide plants a sufficient N supply to achieve the potential grain yield under the vested meteorological conditions. Inadequate N application leads to a decrease in leaf

area chlorophyll contents, leaf photosynthesis, biomass production and the loss of yields and qualities. During the past century, the global consumption of nitrogen has seen a steady increase. Consumption of fertilizer-N increased from 0.6 MT in 1965–66 to 17.4 MT in 2015–16; the country has emerged to be the second largest producer and consumer of nitrogen in the world. There exists a vast scope to increase N consumption further in India, as the current per hectare N consumption at 89.7 kg is still very low compared to many developed and even neighbouring developing countries. Based on current pricing policy and growth trends, it is estimated that the demand and supply of N in India by 2030 would be 23.45 and 18.76 MT, respectively, leaving a gap of 4.69 MT. (Tewatia and Chanda, 2017).

Nitrogen (N) stands as the foremost essential nutrient in rice production across the globe. Tailoring N–fertilizer application based on demand and thorough in-situ examination can significantly enhance rice production (Bo *et al.*, 2020). This approach not only boosts yield by enhancing grain filling quality, increasing tiller numbers, and improving plant vitality, but also maintains and regulates the physiological processes of rice (The *et al.*, 2021). The fixed rate and predetermined timing of nitrogen application might need to be revised to align effectively with the actual nitrogen requirements of the crop. Excessive nitrogen application can lead to extreme plant height, susceptibility to pest infestations, lodging, inadequate canopy light, reduced fertility rates, and delayed maturation (Ali *et al.*, 2017). Furthermore, it can elevate nitrogen losses through various processes (Li *et al.*, 2017), ultimately leading to a lower recovery efficiency of N of about 30% (Baral *et al.*, 2021). The recovery efficiency of N of significant cereal crops betrays a relatively low rate of around 33%, as reported by Chaudhary *et al.* (2019). Applying precision and decision supportive tools for nitrogen management become imperative to solve these challenges. Precision nitrogen management employs a range of tools and technologies to collect data on spatial and temporal variations within a field, which is then utilized to align inputs following the distinct conditions of each specific location within the field. The foundation of precision nitrogen management lies in adhering to the ‘4 R’s Principle, which involves administering fertilizers at the right rate, at the right time, by the right way of application, and by utilizing the right fertilizer source.

The split doses according to the crop requirement are needed to be analysed under aerobic rice cultivation. So, optimization of nitrogen level as well as split doses to different crop growth stages is more important to produce higher grain yield. Split nitrogen (N) fertilizer applications can play an important role in a nutrient management strategy that is productive, profitable and environmentally responsible. Dividing total nitrogen application into two or more splits can help growers enhance nutrient efficiency, promote optimum yields and mitigate the loss of nutrients.

To improve the nitrogen use efficiencies various practices are followed such as use of nitrification inhibitor-controlled release nitrogenous fertilizer, deep placement of nitrogenous fertilizers etc. There are also different types of gadgets available for improving nitrogen use efficiency such as leaf colour chart (LCC) and crop sensors like SPAD meter, which can indirectly estimate crop N status of the growing crops and help to define time and quantity of in-season fertilizer N top dressings in aerobic rice.

The LCC is an easy-to-use and inexpensive diagnostic tool for monitoring the relative greenness of a rice leaf as an indicator of the plant N status (Alam *et al.*, 2005) used to guide the application of fertilizer N to maintain an optimal leaf N content for achieving high rice yield with effective N management. Leaf N status of rice is closely related to photosynthetic rate and biomass production, and it is a sensitive indicator of changes in crop N demand within a growing season. A tool to rapidly assess leaf N status and thereby guide the application of fertilizer N to maintain an optimal leaf N content can consequently be vital for achieving high rice yield with effective N management.

The soil-plant analysis development (SPAD) meter is a low-cost, rapid, simple, and non-destructive apparatus for diagnosis of crop N nutrition that has facilitated research in plant physiological ecology during the past few decades. It is widely used to monitor leaf N status of many crops, including cotton, durum wheat and maize (Singh *et al.*, 2011) and irrigated rice. However, the successful use of SPAD meters can be affected by many factors such as variety, year, growth stage, leaf thickness, leaf positions and the measurement point on the leaf. The chlorophyll meter which measures leaf greenness, can predict the need for N top-dressing at per panicle

initiation and panicle differentiation for rice, meter reading is given in company-defined SPAD values that indicate relative chlorophyll contents. The chlorophyll meter or SPAD offers a new strategy for synchronizing N application with actual crop demand in rice. The chlorophyll meter can be used to monitor plant N status in the field and to determine the right time of N top dressing in rice.

The monocropping system of rice (*Oryza sativa*) cultivation is practiced in the northeast hill region of India (Das *et al.*, 2018) but this system has led to depletion in soil fertility and productivity of the soil, increased infestation of pest, diseases and weed. In India, rice-based cropping system is a major food production system with rice as the first food crop. Diversity of rice-based cropping system with inclusion of pulses or legumes and oilseeds in summer fallows is one of the options for horizontal expansion, as pulses are known to improve soil organic matter through biological nitrogen fixation, root exudates, leaf shedding and below ground biomass.

The spread and extent of rice-based cropping systems across the country and more precisely in eastern India is predominant and diversified as well (Mahapatra *et al.*, 2012). Rice-based cropping systems also produce and emit dominant greenhouse gas (methane) that largely controlled by water and residue management practices. Further, the importance of prevailing rice-based cropping system is losing due decrease in productivity. So, identification of suitable rice-based cropping systems with higher resource use efficiency is required for improving profitability and employment generation in agriculture. Diversification has been well reported as an alternate option for sustaining the land productivity and enhancing farm income for achieving a stable agricultural development.

India is one of the four major players in the global oilseeds or vegetable oils scenario, being one of the important oil growers, producers, importers and exporters (De and Sinha, 2011). Rapeseed-mustard is the second-most important oilseed crop in India, next only to soybean, with almost one-fourth share in both area and production (Jat *et al.*, 2019). The area for cultivation of rapeseed-mustard is 9.18 million hectares with a production of 12.26 mt in 2023. However, its average productivity is 1444 kg ha⁻¹ (GOI, Ministry of Agriculture, 2020). The total area for cultivation in Nagaland is

15070 ha with a production of 15,978 tonnes and productivity of 1060 kg ha⁻¹. India would need 58 mt of oilseeds by 2020 for maintaining minimum edible oil requirement.

Application of irrigation at regular interval with proper nutrient management is the other two most critical inputs which can substantially increase yield of rapeseed and mustard. Irrigation scheduling is important factor affecting the mustard yield as too much water application leads to its wastage, whereas scanty water application may lead to reduction in yield. Scheduling water supply and appropriate nutrient management at the most critical growth stage would boost plant production efficiency, produce quality, nutrient use efficiency and water use efficiency. The crop receiving only two irrigations at pre-flowering and pod-filling stages produced 33% more seed than non-irrigated crops (Yadav *et al.*, 2010). Irrigation scheduling is one of the important managerial activities and affects the effective and efficient utilization of water by crops. It optimizes agricultural production with minimizing yield loss due to water shortage and improving performance and sustainability of any irrigation system through conserving the moisture (Saini *et al.*, 2023a).

As we all know that, N fertilizers like urea are essential for enhancing crop yields and meeting global food demand. But continuous use can lead to numerous negative consequences including soil degradation, environmental pollution and increased greenhouse gas emissions. In order to overcome these problems sustainable agricultural practices such as crop rotation, cropping system, use of slow-release fertilizers and precision nitrogen management are critical in managing nitrogen use effectively. PNM is crucial for balancing agricultural productivity with environmental responsibility, economic viability and compliance with regulations.

There is a shortage of water during winter (*rabi*) season as there is less rainfall in north eastern state specially Nagaland. So, most of fields are keeping fallow after the harvest of the *kharif* crop. Irrigation based on irrigation regimes (IW:CPE ratio) is necessary as determines the process to decide when to irrigate the crop and how much water is to be applied to increase the soil productivity which can increase the economics of the farmer.

Keeping in view, the scope and significance of different dose of nutrient and irrigation in cropping system, the experiment entitled **“Effect of precision nitrogen management and irrigation regimes in rice- toria cropping system in Dimapur District of Nagaland”** was proposed to be undertaken with the following objectives:

1. To study the effect of nitrogen management practices on growth and yield of rice.
2. To study the effect of irrigation regimes on growth and yield of toria and,
3. To study on economic and sustainability of rice-toria cropping system in Dimapur District of Nagaland as influenced by precision by N management in rice and irrigation scheduling in toria.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

A field experiment entitled “Effect of precision nitrogen management and irrigation regimes in rice - toria cropping system in Dimapur District of Nagaland” was conducted at ICAR Research Farm, Jharnapani, Nagaland Centre. The research work done in India and elsewhere in recent years on the effect of precision nitrogen management on the growth, phenological and yield parameters of rice and effect of irrigation regimes on growth, yield attributes, yield and quality of toria and other crops are also reviewed in this chapter.

2.1 Effect of precision nitrogen management on growth parameters of rice

2.1.1 Growth parameters

2.1.1.1 Plant height

Prakash *et al.* (2014) conducted an experiment during 2012 and 2013 at Kolasib District of Mizoram on the response of rice (*Oryza sativa* L) varieties to different levels of nitrogen. Plant height and dry matter production were the highest with ‘Bhalum 3’ at 90 kg N/ha.

Kumar *et al.* (2017) from Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu revealed that significantly higher plant height (103.37cm) was recorded with application of 150 kg N ha⁻¹ on sandy loamy soils.

Lone *et al.* (2017) at Srinagar evaluated Pusa Sugandh-3 rice variety with different nitrogen management aspects and four real-time N management treatments, after taking in to account the overall results of all the observed parameters, the LCC 4@ 20 kg N ha⁻¹ treatment proved superior to all the treatments in plant height (96.96 cm).

Kutikuppala and Singh (2018) revealed that maximum plant height of direct seeded rice was noticed at 60 DAS with nitrogen application at LCC value 5.0 followed by LCC value 4.0 during *kharif* season on sandy clay loam soils at Varanasi, Uttar Pradesh.

Goudra *et al.* (2019) conducted a field study during *kharif* 2017 at Zonal Agricultural Research Station, UAS, Bengaluru in sandy loam soil. The results revealed that nitrogen management through SPAD recorded significantly higher plant height (72.2 cm), number of tillers (45.8 hill⁻¹) and total dry matter (136.2 g hill⁻¹).

Naik *et al.* (2019) stated that higher plant height of maize was recorded with nitrogen application through LCC-5 compared to lower LCC values during *rabi* on sandy loamy soils of Tirupati, Andhra Pradesh.

Rao *et al.* (2019) conducted an experiment at Annamalai University Experimental farm, Annamalainagar to study the effect of different organic manures with graded dose of nitrogen in the growth and yield of rice and the residual effect on succeeding green gram in rice–greengram cropping system. They observed that the growth and yield attributes of rice crop *viz.*, plant height, number of tiller hill⁻¹, LAI at tillering, productive tillers hill⁻¹, thousand grain weight, grain and straw yield were favourably influenced by combined application of inorganic and organic.

Seth *et al.* (2019) conducted an experiment for two years from *Rabi* (wheat) season of 2015-16 through *Kharif* (rice) season of 2017 at Experimental Farm of Rice and Wheat Research Centre, Malan. Results revealed that nutrient management practices, N-rich plot in which 150% of recommended nitrogen was significantly produced taller plants and higher dry matter accumulation in wheat.

Shankar *et al.* (2020) conducted an experiment during 2014-2015 and 2015-2016 at farmers' field situated at Binuria village of Birbhum district of West Bengal under the red and lateritic belt of West Bengal. The study revealed that application of N₈₀P₄₀K₄₀Zn₂₅S₂₀ (T₁) during *Kharif* and N₁₂₀P₆₀K₆₀Zn₂₅S₂₅ (T₁) in boro season, the two seasons of experimentation was essential for improving growth attributes, yield components and productivity of high yielding variety (HYV) and hybrid rice.

Sowmya *et al.* (2023) conducted a field experiment during *rabi*, 2021-22 on sandy clay loam soils of Agricultural Research Station, Nellore, Andhra Pradesh to study the effect of precision nitrogen management on growth and yield of rice. The experimental results indicated that the precision nitrogen management practices significantly influenced the growth and yield rice and found that the application of

nitrogen through LCC-5, NDVI- 0.8 and SPAD-40 were on a par with the farmers practices.

Sridhar *et al.* (2019) conducted a field experiment during rabi 2016-17 and 2017-18 at Agricultural Research Institute Main Farm, Rajendranagar, Hyderabad, on a clay loam soil to study the effect of alternate wetting and drying irrigation on rabi rice under varied nitrogen levels. Among nitrogen levels, application of 200 kg N ha⁻¹ resulted in higher physiological growth parameters of rice which was on par with application of 160 kg N ha⁻¹.

2.1.1.2 Number of tillers m⁻²

Lee *et al.* (2010) found that tiller number increased significantly by top dressing at the tillering stage. It was reported that nitrogen management at LCC value of 4 (150 kg N ha⁻¹) produced significantly higher tillers (369.3/m²) at maximum tillering stage than LCC value 3 with 90 kg N ha⁻¹.

Yoshida *et al.* (2010) established positive relationships between nitrogen absorbed by the plant and number of tillers produced and also observed a significant difference due to basal and additional nitrogen fertilization.

Ghosh *et al.* (2013) conducted an experiment at Kharagpur during the *kharif* seasons of 2010 and 2011. In comparison of results obtained with low rates of N top dressing (15 kg N ha⁻¹) at low SPAD (S34) values, farmer fertilizer practice, and control treatments, it was observed that the number of tillers m⁻² showed an increasing tendency when receiving higher doses of N top dressing (25 or 35 kg N ha⁻¹) at higher SPAD (S36 and S38) values. Tiller production benefited from the higher rate of N application at a higher SPAD value.

Thirunavukkarasu and Vinoth (2013) reported that N application through LCC critical value 4 recorded higher number of tillers per plant in rice at panicle initiation stage compared to RDF during *kharif* on sandy loam soils of Madurai, Tamil Nadu.

Duttarganvi *et al.* (2014) conducted an experiment at Raichur during *Kharif* to study the effect of Leaf Colour Chart (LCC) and Soil and Plant Analysis Development meter (SPAD) based nitrogen (N) management on growth and yield of lowland rice

(*Oryza sativa* L). It was found that N application based on LCC values @ 5 (120 kg ha⁻¹) and SPAD @ 37.5 (120 kg ha⁻¹) were more beneficial which enhanced the growth and yield of the lowland rice. They also found that better growth parameters were significantly recorded when N requirement for rice was applied based on LCC @ 5 (120 kg ha⁻¹) and SPAD @ 37.5 (120 kg ha⁻¹).

Satpute *et al.* (2015) conducted a field experiment at the Institute of Agriculture, Visva-Bharati during rainy season of 2009. Significant increase in the tiller production was observed with nitrogen application at higher LCC values ranging from 3 to 5 being significantly superior particularly at latter stages of growth (60 and 80 DAT).

Das and Sahu (2015) reported maximum number of tillers per plant of rice with N application through LCC as compared to farmers practice during *kharif* season on sandy loam (alluvial) soils of Dinajpur, West Bengal.

Kumar *et al.* (2017) revealed that higher number of tillers (400) was recorded with the application of SSNM (Nutrient Expert) but was on par with SSNM (LCC) which recorded 383 tillers m⁻² on silty clay soils of College of Agriculture, Raipur, Chhattisgarh.

Mannade *et al.* (2017) revealed that higher number of tillers was recorded with the application of nitrogen through SSNM (Nutrient Expert) which was on par with SSNM (LCC) on black silty clay soils of Raipur, Chhattisgarh.

Rajesh *et al.* (2017) conducted a field experiment during 2011-12 to study the response of rice varieties on morpho-physiological and yield under two nitrogen levels 120 kg N ha⁻¹, 60 kg N ha⁻¹ as main treatments and twenty-six rice genotypes as sub treatments. Among the nitrogen treatments application of 120 kg N ha⁻¹ recorded significantly higher values for morpho-physiological parameters such as number of tillers hill⁻¹.

2.1.1.3 Dry matter production plant⁻¹

Sharma (2011) recorded the maximum dry matter accumulation at 80 DAT with green seeker NDVI sufficiency index of 0.85 (9.84 t ha⁻¹) as threshold as compared to

SPAD meter-based N management using fixed threshold 42.5 (7.59 t ha⁻¹) in PR118 cultivar during *kharif* at Punjab Agricultural University, Ludhiana.

Mohanty *et al.* (2015) revealed that STCR based nitrogen management produced significantly higher dry matter production of wheat as compared to nitrogen application through green seeker, RDF and SPAD during *rabi* on sandy loam soils of Delhi.

Premalatha (2017 a &b) revealed that N application at LCC threshold value 3 resulted in the highest dry matter accumulation plant⁻¹ (38.14 g) compared to LCC value 4 (29.35g) in rice during *kharif* on clayey soils of Dharwad, Karnataka.

Barad *et al.* (2018) observed that the dry matter accumulation plant⁻¹ (22.76g) of wheat was significantly higher with the application of nitrogen through SPAD threshold value 40 as compared to SPAD threshold value 35 during *rabi* on black calcareous soils of Junagadh, Gujarat.

Application of nitrogen at LCC value 4.0 was found significantly superior in increasing dry matter production of rice at harvest compared to control during *kharif* on calcareous loamy soils at Samastipur, Bihar (Kumar *et al.*, 2018)

Sunawan *et al.* (2018) recorded the highest dry matter production (68.47g clump⁻¹) at 77 Days of planting with increasing levels of N from 45 to 180 kg N ha⁻¹ in an experiment conducted in Indonesia.

2.1.1.4 Leaf area index

Sen *et al.* (2011) noticed highest leaf area index of rice at 60 DAT with N application through LCC value 5 over RDF during *Kharif* on sandy clay loamy soils of Varanasi, Uttar Pradesh.

Gill and Singh (2013) conducted a field experiment at Punjab Agricultural University, Ludhiana and revealed that application of 125% RDN produced the highest leaf area index (3.6) over other treatments.

Reena *et al.* (2017) carried out a field experiment at G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarkhand, during the winter (*rabi*) season

of 2014–15. The study aimed to investigate the effect of leaf colour chart (LCC) and chlorophyll meter (SPAD meter) based nitrogen management on wheat crop. Significant increase in LAI was observed at 90 DAS with application of RDN i.e., 150 kg N ha⁻¹ (2.9) however, it was comparable with SPAD threshold value 40 (2.7).

Budhathoki *et al.* (2018) conducted an experiment at agronomy farm Lamjung campus, Sundar bazar, Nepal and reported the highest leaf area index (6.41) with nutrient expert but it remained on par with LCC based application (5.47).

2.1.1.5 Growth indices

Shivashankar *et al.* (2023) carried out an experiment on sensor-based precision nitrogen management in maize at main agriculture research station, University of Agricultural Sciences, Dharwad, during *kharif* 2020 and 2021. Among precision nitrogen management practices, nitrogen application at SI of 96-100% recorded significantly higher DMA and growth indices (AGR and CGR) as compared to other treatments throughout the growth period.

Ali *et al.* (2017 a) revealed that different N management techniques had a favourable impact on crop and relative growth rates (CGR and RGR) of transplanted rice Crop growth rate (21.01 g m⁻² day⁻¹), and relative growth rate (0.072 g day⁻¹) were obtained with N application based on LCC value 4 (4 splits; 132 kg N ha⁻¹).

2.1.1.6 Days to 50 per cent flowering

Shrestha *et al.* (2018) lucidly claimed that interaction effect of different nitrogen levels and plant population on days to tasselling and silking of maize was non-significant on sandy loam soils of Nepal.

Veer *et al.* (2016) reported that Days to 50 % tassel and silk emergence of maize significantly responded to different N management strategies and observed slightly higher number of days to 50 % tasselling and silking when N was applied at fixed time interval 9 compared to LCC score-based N application on silty clay loam soils of Pantnagar, Uttarakhand

2.1.1.7 Days to maturity

With respect to flowering, there was a non - significant difference between farmers practice and precision-based N management practices, but there is a difference of 2 to 3 days in flowering, which could be due to different doses of nitrogen application to different treatments in direct seeded rice during *kharif* on black loam soils of Raichur, Karnataka (Gurupadappa, 2018).

2.2 Effect of precision nitrogen management on yield attributes of rice

Krishnakumar and Haefele (2013) from the experiment conducted on sandy loam soils during *kharif* at International Rice Research Institute (IRRI) Farm, Laguna, Philippines, reported higher panicle length of rice with nitrogen application through LCC threshold value 5.0 compared to other LCC values.

Liu *et al.* (2013) experimented on super rice at Yangzhou University's research farm in Jiangsu Province, China. Grain yield increased by 5.7-6.1%, 6.0-6.6%, and 12.4-14.5%, respectively, under continuous flooding (CF) -site-specific nutrient management (SSNM), alternate wetting and drying (AWD)- farmer's N practice (FNP) and AWD-SSNM treatments as compared to (CF)-FNP. Under SSNM, the number of spikelets panicle⁻¹ was substantially higher than under FNP. The AWD-SSNM treatment had the highest percentage of filled grains and harvest index, the lowest for the CF-FNP treatment, and intermediate for the CF-SSNM and AWD-FNP treatments.

Prakash *et al.* (2014) conducted an experiment during 2012 and 2013 at Kolasib District of Mizoram on the response of rice (*Oryza sativa* L) varieties to different levels of nitrogen. Panicles m⁻², filled grains panicle⁻¹, grain (4.50 tons/ha) and straw yield and nitrogen uptake by grain and straw were also significantly higher with 'Bhalum 3'. Increasing levels of nitrogen enhanced panicles/m², filled grains/panicle, grain and straw yield and nitrogen uptake by grain and straw only up to 90 kg N/ha.

Ali *et al.* (2017 b) from their experiment on sandy loam soils of Allahabad, Uttar Pradesh, concluded that there was a significant increase in productive tillers hill⁻¹ in transplanting rice with N application through LCC threshold value 4 compared to LCC threshold value 3 during *kharif*.

Rajesh *et al.* (2017) conducted a field experiment during 2011-12 to study the response of rice varieties on morpho-physiological and yield under two nitrogen levels 120 kg N ha⁻¹, 60 kg N ha⁻¹ as main treatments and twenty-six rice genotypes as sub treatments. Among the nitrogen treatments application of 120 kg N ha⁻¹ recorded significantly maximum number of panicles hill⁻¹, number of filled grains hill⁻¹, filled grain percentage, 1000 grain weight and grain yield.

Jahan *et al.* (2018 a) revealed that significantly higher number of productive tillers m⁻² of rice was recorded with N application through LCC $\leq$ 3.0 value during winter in rice on non-calcareous soils of Mymensingh, Bangladesh.

Shrestha *et al.* (2018) conducted an experiment on elderly aged hybrid rice seedlings in Lamjung, Nepal, using Nutrient-Rice Expert and other precision nutrient management practises. NE (109:35:41), outperformed the other five treatments, including government advice, GR (80:60:40), farmers' field practice, FFP (67:36:20), LCC (56 N) + FFP (36 P:20 K), NE (109 N) + FFP (36 P:20 K), and LCC (56 N) with NE (35 P; 41 K), in terms of growth, yield attributing characteristics, yield, and economic analysis; NE(N) was followed by FFP (P and K).

Goudra *et al.* (2019) conducted a field study during kharif 2017 at Zonal Agricultural Research Station, UAS, Bengaluru in sandy loam soil. The results revealed that nitrogen management through SPAD recorded significantly higher productive tillers hill⁻¹ (36.1), panicle length (24.5 cm) and test weight (25.07 g) ultimately resulted in higher grain (7353 kg ha⁻¹) and straw yield (9151 kg ha⁻¹).

Sairam *et al.* 2020 reported that the treatments with 75% RDN along with 25% vermicompost recorded better results in terms of yield attributes, namely, number of panicle m⁻² (213.3), panicle length (24.5 cm), number of spikelet's panicle⁻¹ (140.7), number of filled grain panicle⁻¹ (123.3) and grain and straw yields of 5.18 t ha⁻¹ and 7.3 t ha⁻¹, respectively

Mohanta *et al.* (2021) conducted field trials in sandy loam soil in the red and lateritic belt (Ultisols) of West Bengal, India to determine the productivity and profitability of *kharif* rice. Different doses of N: P₂O₅:K₂O kg ha⁻¹ were applied and it was concluded that State recommendation (80:40:40), LCC (79.6:40:40), NE

(118:37:51), and Green Seeker (92.9:37:51) increased effective tillers over farmer's practice (68:46:37) by 4.36, 7.8, 16.40, and 22.88%, respectively.

Sadhukhan *et al.* (2023) conducted a field experiment on zero-till direct seeded rice (DSR) in India's Indo Gangetic plain to investigate the various nutrient management options used in DSR in a detailed manner. Conservation agriculture (direct rice seeding) paired with a site-specific smart nutrient management strategy Nutrient Expert (NE), LCC, soil test based fertiliser prescription enhanced seed and biomass production significantly. Nutrient management in the field, notably with N, P, and K increased rice grain yield by 12%.

2.3 Effect of precision nitrogen management on efficiencies indices

Huang *et al.* (2008) experiment was carried out on real-time N management (RTNM) by using various chlorophyll meter (SPAD) criteria. N-recovery efficiency (56.9%) and internal N-use efficiency (78.6 kg kg⁻¹) were discovered to be significantly higher under SPAD 38 and 11 control, respectively. Agronomic efficiency of N and partial factor productivity of applied N was found to be highest (19.4 kg kg⁻¹ and 91.5 kg kg⁻¹, respectively) with SPAD value of 35.

Zhang *et al.* (2013) stated that with partial factor productivity of N (PFP N) of roughly 40 kg grain kg⁻¹ applied N globally, N-use efficiency is still poor. This is partly because farmers applied enormous amounts of N fertilizer at the beginning of the rice plant's growth cycle, before the roots had fully formed. Due to the applied N's loss, which is a mobile nutrient, more water and land pollution as well as greenhouse gas (GHG) emissions ensue.

Ghosh *et al.* (2013), evaluated fixed time N management (FTNM), with real-time N management (RTNM), and one control. The RTNM was combination of three SPAD threshold (SPAD: 34, 36 and 38) and three N levels (15, 25 and 35 kg ha⁻¹) for top dressing when the SPAD value of rice leaf falls below the threshold. The grain yield of RTNM was similar to that of FTNM, although with a lower N application rate. When compared to FTNM, SPAD 36 with 35 and 25 kg N ha⁻¹ top-dressing could save N fertilizer by 20 to 35% without reducing grain output. The use of SPAD meters for N management boosted agronomic N usage efficiency at high yield levels. When

compared to farmers' practices (12 kg grain/kg N), agronomic N use efficiency was quadrupled (24.7 kg grain kg⁻¹ N) using SPAD 34.

Ghosh *et al.* (2017) recorded highest grain yield (4483 kg ha⁻¹) by maintaining SPAD index of 40 up to heading stage by applying 25 kg N ha⁻¹ while saving of 22.5 kg N ha⁻¹ (18.8%), increased AEN by 58.5%, REN by 15.1% and PFPN by 26.4% compared to farmer's practice.

Suresh *et al.* (2017a) conducted a field experiment on a sandy loam soil during kharif season of 2012 with a view to study the effect of Site-specific nitrogen management in rice on nutrient uptake, N use efficiency and grain yield. The result revealed that a considerable opportunity to increase yield, N use efficiency (NUE) and nutrient uptake through improved N management with LCC and SPAD values.

Ghosh *et al.* (2017) concluded that top-dressing 25 kg N ha⁻¹ at medium SPAD (S36 in rice and S40 in wheat) under RTNM could produce comparable grain yield in rice and 13.4% higher grain yield in wheat while saving 33.3% N fertilizer, respectively, over the conventional FTNM in rice-wheat cropping system. Over FTNM, it enhanced AEN by 58.5% and REN by 32.2% in rice, and by 58.5% and 15.1% in wheat. According to the current study, the SPAD threshold value might help maintain the desired soil available N and leaf N status during the crucial growth stages of rice and wheat. Based on research findings, researchers strongly recommend topdressing with 25 kg N ha⁻¹ at SPAD threshold values of 37.5 in rice and 41.8 in wheat for boosting grain yield and N use efficiency in the lateritic acid belt of eastern India.

Wang *et al.* (2020) conducted 87 on-farm trials in the main agro ecological areas in Northeast China. By drastically reducing N and P fertilizer inputs and improving nutrient management, the results demonstrated that NE had overall and considerable advantages over FP in terms of agronomic and environmental benefits. In comparison to farmer's practice (FP), NE increased grain yield and N uptake by maize by 8.4% and 6.6%, respectively. For rice, it achieved equal yield performance and 3.0% higher N uptake, which led to significantly higher N-use efficiency.

Baral *et al.* (2021) conducted a field experiment in western Terai of Nepal during 2017–2018 to identify the appropriate decision support tool for improving NUE and grain yields. N fertilizer application guided by decision support tools had a significant effect on grain yields. UDP produced the highest grain yield among the treatments. In addition, GS produced a significantly higher agronomic N use efficiency (ANUE), partial factor productivity of N (PFPN), apparent N recovery (ANR), and utilization efficiency of N (UEN) compared to RP.

Singh *et al.* (2018) found that Green Seeker-guided dose during maximal tillering or second irrigation stage resulted in grain yield in wheat that were comparable to the general advice of 120 kg N ha⁻¹ and higher fertilizer N use efficiency.

2.4 Effect of precision nitrogen management on yield of rice.

Houshmand far and Kimaro (2011) compared LCC value 4 with different doses of split applications. Highest grain yield (4226 kg ha⁻¹) with 7% increase over recommended splits method was obtained at 25 kg N ha⁻¹ applied each time with a total application of 100 kg N ha⁻¹. However, highest grain yield (8544 kg ha⁻¹) with GRH-1 genotype was achieved with a total application of 150 kg N ha⁻¹ in 5 splits. However, there was no significant difference with 4 splits of 35 kg N ha⁻¹ each.

Yoseftabar *et al.* (2012) conducted an experiment to study the effect of split application of nitrogen fertilizer on SPAD values in hybrid rice (GRH1). The results showed that SPAD values increased significantly with nitrogen fertilizer. The result also revealed that timing of nitrogen application can apply four or three times at different growth stage-based crop need and SPAD threshold and crop-growing condition at each location and N application method based on growth diagnosis helped in saving N applied fertilizer and increasing grain yield.

Ghosh *et al.* (2013) conducted an experiment to study the effect of chlorophyll meter (SPAD meter) based N management on growth, productivity and agronomic N use efficiency of rice (cv. IR 36) in lateritic soil of India during the wet season of 2010 and 2011. The results revealed that SPAD 36 with 35 and 25 kg N ha⁻¹ top-dressing could save N fertilizer by 20 to 35% compared to one fixed time N management

without reducing grain yield and agronomic N use efficiency can be increased at high yield level using SPAD meter-based N management.

Kumar *et al.* (2014) reported that application of 125%RDF with 5.0 t ha⁻¹ vermicompost increased the number of panicles (20.5 %), panicle length (23.12 %), panicle weight (13.02 %), 1000 grain weight (12.90 %), grain yield (31.15 %) and straw yield (37.12 %) over control where no fertilizer or vermicompost was applied.

Das and Sahu (2015) conducted an experiment for assessing nitrogen scheduling in *Kharif* rice through soil test based and leaf colour chart (LCC) based nitrogen top-dressing. The study observed that 9.5 to 13 per cent yield increase over the farmers' practice was obtained through LCC based nitrogen application coupled with soil test-based P and K application over the couple of years of experiment. Rice yield in soil test-based fertilizer application was found to be at par with that of LCC based application.

Satpute *et al.* (2015) concluded that there was a gradual significant increase in grain yield of rice variety MTU 7029 with higher LCC values of nitrogen application ranging from 3 to 5 where the grain yield at LCC 5 was 46.2 and 19.9% more over the grain yield at LCC 3 and LCC 4, respectively. Similarly, grain yield at LCC 4 was 22.0% higher over grain yield at LCC 3.

Suresh *et al.* (2015) conducted a field experiment on a sandy loam soil during *kharif* season of 2012 with a view to study the LCC and SPAD based nitrogen management in rice on and grain yield, N concentration in leaf and Nutrients uptake. The critical SPAD value of 41 with 30 kg N ha⁻¹ and critical LCC value of 4.5 with 30 kg N ha⁻¹ were found to be suitable for guiding N application to achieve the highest yield

Singh *et al.* (2016) conducted an experiment to study the fertilizer nitrogen management in irrigated transplanted rice under dynamic threshold greenness of leaves. The study showed that the grain yield of rice, N uptake and fertilizer N use efficiency measured with N management following threshold leaf greenness pf 0.5 units less than LCC-N_{rich} were at par with the SPAD meter- based 90 % sufficiency

index approach and were better than the blanket fertilizer recommendation in the region.

Baraki *et al.* (2016) concluded that rice yield and yield components were significantly affected by time of nitrogen applications. Highest grain yield, number of productive tillers plant⁻¹, plant height and harvest index were recorded with the application of 33% of the recommended dose at sowing, 34% of the recommended dose at tillering and 133% of the recommended dose at early panicle initiation.

Swamy *et al.* (2016) carried out a field experiment during *rabi* 2014-15 at University of Agricultural Sciences, Raichur, Karnataka, India to study nitrogen management in sweet corn (*Zea mays saccharata* L.) using simple hand-held decision tools. They reported highest fresh cob yield with husk (15.65 t ha⁻¹) of sweet corn with RDF which was however, comparable with green seeker based NDVI at 0.8 (14.4 t ha⁻¹).

Qureshi *et al.* (2016) conducted an experiment on clay loam soils of G.B. Pant University of Agriculture and Technology, Pantnagar and found that Nutrient Expert recommended fertilizer under LCC based SSNM registered more straw yield (7284 kg ha⁻¹) compared to RDF (7084 kg ha⁻¹).

Krishna *et al.* (2017) conducted field trial and recorded higher grain yield (49.8 q ha⁻¹) in wheat with RDF, but remained in parity with site specific nutrient management + green seeker (45.7 q ha⁻¹) on sandy loam soils of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar.

Suresh *et al.* (2017a) conducted a field experiment on a sandy loam soil during kharif season of 2012 with a view to study the effect of Site specific nitrogen management in rice on nutrient uptake, N use efficiency and grain yield. Results revealed that LCC threshold value of 4.5 recorded significantly increased grain yield (5879 kg ha⁻¹) but it remained on par with SPAD values < 41 (5869 kg ha⁻¹).

Budhathoki *et al.* (2018) recorded maximum straw yield (6.52 t ha⁻¹) with Nutrient Expert tool but it remained on par with LCC based nitrogen fertilizer

+nutrient expert (PK) (5.72 t ha^{-1}) at Agronomy farm of Lamjung campus, Sundar bazar, Nepal during rainy season.

Hemalatha and Singh (2018) conducted an experiment during *Kharif*, 2016 and 2017 in sandy clay loam soils of experimental field at Banaras Hindu University, Varanasi, Uttar Pradesh to find out the effect of leaf colour chart based nitrogen and weed management practices on growth and yield of direct seeded rice. The yield of the rice was observed significantly higher with application of nitrogen @ LCC < 5 (N_4).

Latha *et al.* (2019) conducted a field experiment at College Farm, Agricultural College, Bapatla during 2015-16 and 2016-17 of both *kharif* and *rabi* seasons. The work concluded that the application of INM + 50% RDN+ 25% N through FYM + 25% N through neem cake produced significantly higher grain yield and straw yield of rice.

Singh (2019) conducted an on-farm trial for two *kharif* and *rabi* seasons of 2014-15 and 2015-16 to study the effect of site-specific nutrient management on yield and nutrient uptake in rice *Oryza sativa* (L)-wheat *Triticum aestivum* (L) cropping system at Bichpuri, Agra. It revealed that recommended dose of NPK resulted in significantly higher grain and straw yield of rice and wheat as compared to farmer fertilizer practice. Farmer fertilizer practice and state recommended dose of NPK fertilizers recorded 12.7 and 34.0 % lower wheat grain yield than the SSNM (N, P, K, S, B, and Zn) treatment.

Bhavana *et al.* (2020) conducted a field experiment during *Kharif* with an objective to study the possibility of improving N-use efficiency by applying fertilizer N as per need of crop using leaf colour chart (LCC) in transplanted rice. Among all the treatments, with regard to nitrogen use efficiency indices, highest efficiency was observed in T_7 {120 kg RDN at LCC 4} followed by recommended practice. LCC based nitrogen application was found to be effective in improving rice yields with limited nitrogen supply on plant need basis.

Kumar *et al.* (2021) conducted a field experiment conducted at RARS Nandyal during *Kharif* season of 2017 to study the precision nitrogen management in rice crop, grown under conservation agriculture. Green Seeker directed N application recorded

highest grain (5.5 t ha^{-1}) and straw yield (8.4 t ha^{-1}) compared to all the treatments followed by LCC based N application (5.2 t ha^{-1}). By using green seeker 45 kg N ha^{-1} was saved as compared to RDN.

Mohanta *et al.* (2021) reported that N management treatments influenced filled grains panicle⁻¹ of “Pratikhya” *Kharif* rice. The treatment GS recorded significantly higher filled grains panicle⁻¹ than other treatments, namely, FP, SR, LCC, and NE-based nitrogen management. GS which was statistically comparable to NE, registered a significantly higher grain yield than other treatments like FP, SR, and LCC. The yield enhancement in GS and NE was 19.2% and 14.7% over FP, respectively.

Borah *et al.* (2024) conducted a field experiment carried out at Instructional cum Research farm, Assam Agricultural University, Jorhat to study the performance of direct seeded Sali rice under different nitrogen management practices viz., green seeker, leaf colour chart and nano nitrogen during *kharif* season of 2021. Results revealed that application of site-specific nitrogen management with the help of green seeker and leaf colour chart could increase the yield of direct seeded rice in the most economical way with efficient utilization of nutrient.

Swamy *et al.* (2016) during *rabi* 2014-15 at University of Agricultural Sciences, Raichur, Karnataka, India to study nitrogen management in sweet corn (*Zea mays saccharata* L.) using simple handheld decision tools. They reported that significantly highest harvest index was recorded with RDF (44.7%), but it remained on par with green seeker based NDVI at 0.8 (44%) on sandy loamy soils during *rabi* in sweet corn.

Jahan *et al.* (2018b) obtained highest harvest index (44.64%) in rice with Soil analysis-based N management which was statistically on par with SPAD value ≤ 35 (43.84%) at Bangladesh Agricultural University, Mymensingh, Bangladesh on silty loam soils.

Kutikuppala and Singh (2018) conducted an experiment at BHU, Varanasi on sandy clay loam soils and reported that harvest index of direct seeded rice (39.72%) significantly increased with increase in LCC threshold values from 3 to 5 when compared to RDF (36.04%).

Patil *et al.* (2018) carried out the field experiment on medium black soil during *kharif* 2016 & 2017 at Agricultural Research Station, Gangavathi to study the effect of nitrogen management through LCC and SPAD meter on growth and yield in direct seeded rice. The highest harvest index (0.45 %) in direct seeded rice was recorded from LCC threshold 5 followed by SPAD meter threshold 40 (0.44 %).

2.5 Effect of precision nitrogen management on Nutrient Status in soil and plant

2.5.1 Post-Harvest Soil Nutrient Status

Krishnakumar and Haefele (2013) in the experiment conducted at International Rice Research Institute (IRRI) Farm, Laguna, Philippines on rice during *kharif* on sandy loam soils reported that higher post-harvest soil available N and P was recorded in N application through LCC threshold value 5.0 compared to other LCC values.

Rao *et al.* (2016) reported that the status of available N, P, K in soil after harvest of maize was increased with increase in the rate of N application from 120 to 300 kg N ha⁻¹ during *rabi* on sandy clay loam soils of Bapatla, Andhra Pradesh

Deepthi (2015) recorded higher post-harvest available soil nitrogen, and phosphorus after harvest of rice with increase in nitrogen application rate from 100 to 150 kg N ha⁻¹ during *kharif* on clay soils of Parbhani, Maharashtra.

2.5.2 Nutrient content and uptake by plant.

Swamy *et al.* (2016) noticed that application of 150 kg N ha⁻¹ in three splits significantly resulted in higher N uptake of *rabi* sweet corn followed by LCC threshold value 5.0 and green seeker based NDVI of 0.8, whereas it was the lowest in control on sandy loam soils of Raichur, Karnataka.

Bhat *et al.* (2017) conducted an experiment at Research farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, in silty clay loam soil to study the LCC based N management on yield, nutrient uptake and soil available status in two rice genotypes (Jhelum and SR-2) under irrigated conditions. The results revealed that yield and NPK uptake were significantly higher in LCC ≤ 5 @ 30 and 20 kg N ha⁻¹ as compared to other LCC levels (LCC ≤ 4 and 3 @ 30 and 20 kg N ha⁻¹) and recommended nitrogen level.

Upadhyay *et al.* (2018) conducted an experiment at the Agricultural Research Farm Banaras Hindu University during 2013-14 and 2014-15 to study the effect of time and rate of panchagavya application and recommended dose of fertilizer (RDF) on growth, nutrient content and productivity of transplanted rice (*Oryza sativa*.L). They revealed that 120% RDF significantly increased the N, P and K content in grain and straw over 60,80 and 100 % RDF

Nandan *et al.* (2020) conducted a field experiment during *kharif* of the year 2016 at the Research Farm of Dr. Rajendra Prasad Central Agricultural University, Pusa (Samastipur), Bihar. Nutrient uptake by crop was higher in 160 kg N/ha than other two lower doses.

Karthik *et al.* (2023) conducted an experiment during the monsoon season of 2018 to evaluate the precision nitrogen management using SPAD meter in improving N uptake as well as soil fertility status in rice crop under direct seeded condition at Agriculture Research Farm, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India during the monsoon season. Results revealed that FTNM among N management practices have recorded highest leaf N content as well as N uptake.

Pratap *et al.* (2024) conducted a field experiment during rainy (*kharif*) seasons of 2019 and 2020 at ICAR-Indian Agricultural Research Institute, New Delhi to monitor the effect of precision nitrogen (N) and water management options on yield and nutrient acquisition in grain and straw of direct-seeded rice (DSR, basmati) (*Oryza sativa* L.) and the results showed significant highest grain yield (9.2%) in NE® + SPAD meter-based N application over RRN; the N, P and K uptake in grain also spiked by 22.1, 42.1 and 31.7%, respectively.

2.6 Effect of Precision nitrogen management on economics of rice

The ultimate aim in any agriculture practice is to obtain maximum returns per rupee invested. This also gives the information about the optimum level of input that could be recommended to obtain maximum profit. Some of the reviews pertaining to above aspects are given below.

Duttarganvi *et al.* (2011) recorded the highest net returns (Rs.30,278 ha⁻¹) with SPAD threshold value 37.5 which was on par with LCC threshold value 5.0 (Rs. 29,929 ha⁻¹).

Das *et al.* (2015) concluded that N management using LCC increased 9.5-13 % grain yield over the farmer's practice along with soil test. The fertilizer application based on soil test the grain yield was found at par with N management using LCC. However, LCC based N application saves farmers from pointless use of nitrogenous fertilizers and fetches an additional income of Rs.7500 ha⁻¹ compared to farmers' method.

Mohanty *et al.* (2015) reported net returns (Rs. 42724 ha⁻¹) and benefit-cost ratio (1.66) were increased with STCR in wheat which was statistically on par with green seeker for net returns (Rs. 42525 ha⁻¹) and B: C ratio (1.64).

Swamy *et al.* (2016) reported nitrogen application based on NDVI-threshold value 0.8 recorded higher gross return (Rs.117591 ha⁻¹), net return (Rs.85684 ha⁻¹) and B: C ratio (3.69) in sweet corn over both SPAD threshold value 40 and green seeker based NDVI threshold value 0.6 at Agricultural Research Station, Raichur.

Haque *et al.* (2018) revealed the highest net returns (Rs. 31524 ha⁻¹) and B: C ratio (2.13) was obtained with the application of nitrogen based on nutrient expert tool (70% N) + remaining N as guided by green seeker (105:63:105kg NPK ha⁻¹) in wheat crop during rabi season at Bhagalpur, Bihar.

Goudra *et al.* (2019) conducted a field study during *kharif* 2017 at Zonal Agricultural Research Station, UAS, Bengaluru in sandy loam soil. The results revealed that nitrogen management through SPAD was also recorded highest gross return (₹ 124021 ha⁻¹) and net return (₹75062 ha⁻¹).

Billa *et al.* (2020) reported that higher productivity and profitability could be obtained with NDVI value 0.8 with the application of 120 kg N ha⁻¹ during *kharif* on sandy loam soils of north coastal zone of Andhra Pradesh.

Nandan *et al.* (2020) conducted a field experiment during *kharif* of the year 2016 at the Research Farm of Dr. Rajendra Prasad Central Agricultural University,

Pusa (Samastipur), Bihar. The results rested in its economic studies, wherein treatment with 160 kg N/ha fetched higher gross returns, net return and finally B:C ratio than other two doses.

Velmurugan *et al.* (2021) conducted an experiment on NU and other changing N doses at Bloomsdale Research Farm, ICAR- CIARI, Port Blair, and two farmers' fields. The total cost of NU sprayed plots was greater than NPK addition, with an additional cost of INR 249, 339, and 339 incurred on application of NU spray, respectively. However, the additional monetary advantage of 12-16% higher yield over RDF addition was INR 10082, 11679, and 7937, respectively.

Attri *et al.* (2022) conducted an experiment in the irrigated subtropics of the Jammu region, and the results showed that 75% recommended N+ recommended P K Zn + 2 foliar sprays of NU each @ 2ml l⁻¹ of water recorded a numerically higher value for net returns to the tune of INR 79,305 ha⁻¹ with the highest B: C of 1.7 when compared to other treatments.

Singh *et al.* (2023) grew wheat in an experimental field at Kanpur, India to examine the efficacy of NU. Crops produced with 75% NPK + nano N and nano P spray at 30 and 45 DAS had the highest B: C (2.36) with a cost of cultivation of 72548 (INR ha⁻¹) and a net return of 98529.2 (INR ha⁻¹).

2.7 Effect of irrigation regimes on growth parameters of toria

Piri *et al.* (2011) reported significant effect of irrigation and sulphur level application on dry matter accumulation of mustard crop. At 45 DAS, dry matter accumulation was not significantly affected due to different irrigation regimes while at 90 DAS, one and two irrigations being at par, significantly increased dry matter per plant of Indian mustard over no irrigation in both years of the study. At harvest, two irrigations resulted in significantly higher dry matter accumulation than single irrigation or no irrigation.

Rafiei *et al.* (2011) conducted a field experiment at Takestan (Iran) with four irrigation regimes viz., irrigation after 70 mm, 100 mm, 130 mm and 160 mm evaporation from Class-A pan evaporimeter and reported that among the irrigation

treatments, irrigation after 70 mm evaporation from Class-A pan resulted into significantly higher plant height (138.3 cm) as compared to other irrigation treatments.

Dudwal *et al.* (2013) observed from Kanpur (U.P.) that application of three irrigations at branching, flowering and siliqua development (IB + F + SD) significantly increased the plant height, primary and secondary branches per plant and number of leaves per plant of mustard over IB + F, IB + SD, IF + SD, IB, IF, ISD and I₀ (Control) treatments.

Singh (2014) reported maximum plant height, number of branches (primary and secondary), dry matter accumulation, 50 percent flowering and 80 percent maturity under irrigated condition as compared to no irrigation.

Trivedi *et al.* (2014) conducted an experiment at Zonal Agricultural Research Station, Morena (M.P), found that application of two irrigations in mustard crop at flower initiation and siliquae formation stage significantly increased the plant height, branches plant⁻¹, siliquae plant⁻¹, seed siliquae⁻¹ and 1000-seed weight of mustard.

Verma *et al.* (2014) studied the response of mustard varieties to irrigation scheduling and found significantly higher plant height, branches per plant⁻¹ (primary and secondary), dry matter accumulation plant⁻¹, number of siliquae plant⁻¹, number of seed siliqua⁻¹, length of siliqua and 1000-seed weight recorded with two irrigation (two irrigation at branching + siliqua formation) as compared to single (one irrigation at siliqua formation), and no irrigation treatment.

Roy *et al.* (2017) conducted an experiment at Sher-e-Bangla Agricultural University, Dhaka, to evaluate the effect of irrigation scheduling and they observed that two irrigations applied at 25 and 53 days after sowing significantly increased the plant height and number of primary and secondary branches plant⁻¹ of rapeseed (*Brassica napus*) compared to no irrigation and one irrigation at 25 days after sowing.

Singh *et al.* (2017b) carried out an experiment during the rabi season of 2013-14 at N. E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar to study the effect of irrigation scheduling and hydrogel levels on the growth, yield attributes, yield, WUE and economics of Indian mustard. The

result revealed that plant height, dry matter accumulation, yield attributes, seed yield, WUE and benefit- cost ratio were higher at 0.6 IW/CPE ratio and hydrogel.

Jat *et al.* (2018) performed an experiment during *rabi* season of 2013-14 to 2015-16 at Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar in the north-Gujarat agro-climatic region. They revealed that irrigation with IW: CPE =0.8 gave significantly higher growth and yield attributes, namely plant height, number of primary branches per plant, number of siliquae per plant, number of seeds per siliqua, seed yield, oil yield, production efficiency and economic efficiency of mustard.

Kumar *et al.* (2019a) carried out an experiment at the Instructional-cum-Research Farm, Assam Agricultural University, Jorhat, during two consecutive seasons of 2016-17 and 2017-18. The experiment was laid out in a split-plot design with 3 replications to evaluate the growth, yield and uptake of mustard under and nutrient management practices. Results revealed that IW: CPE = 1.60 recorded the highest growth parameters plant height, dry matter accumulation and number of branches plant⁻¹, yield attributes, yield and harvest index and nutrient uptake of N, P and K.

Singh *et al.* (2019 a, b and c) performed an experiment for two consecutive *rabi* seasons during 2014-15 and 2015-16 at Norman E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar to evaluate the growth and yield parameters of yellow sarson (*Brassica rapa* L.) affected by different irrigation levels, planting methods and mulching. Higher numbers of leaves per plant and dry matter accumulation in leaves and stem were significantly higher at 1.2 IW: CPE over 0.6 and 0.3 IW: CPE in both the seasons.

Barick *et al.* (2020) conducted an experiment during *rabi* season of 2017-18 at the Instructional Farm, Jaguli, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal to study the effect of irrigation levels and methods of sowing on production potential of rapeseed (*Brassica campestris* L. Prain). The study revealed that the growth attributes viz. plant height, leaf area index, dry matter production and crop growth rate of rapeseed were recorded to be maximum under I₄(IW: CPE=1.0).

Bindhani *et al.* (2020 a.b &c) carried out an experiment on growth and yield of hybrid mustard as influenced by irrigation scheduling and nitrogen management at the Central Research Farm, Bidhan Chandra Krishi Vishwavidyalaya, Mohanpur, West Bengal during *rabi* season (2017-18) in alluvial soil having medium soil fertility. Revealed that maximum growth parameter like plant height, dry matter accumulation, CGR of hybrid mustard crop were recorded with IW/CPE=1.2 irrigation level and the yield variation due to irrigation regimes was to the tune of 13.35 to 17.14%.

Rana *et al.* (2020) conducted an experiment to evaluate the effect of sulfur fertilization and irrigation scheduling on mustard hybrids. They observed that individually irrigation scheduling at 0.8 IW/CPE, mustard variety 'PAC 432' and sulfur application at 60 kg ha⁻¹ reported to have maximum plant height, number of primary and secondary branches, dry matter accumulation.

Rathore *et al.* (2020) conducted a field experiment to study the effect of irrigation scheduling and use of superabsorbent polymers on growth, seed and water productivity, soil moisture dynamics in Indian mustard under semi-arid conditions. The results showed that plant growth parameters, yield attributes, seed yield and oil yield were recorded from IW: CPE=0.8.

Maurya *et al.* (2022) conducted a field experiment during *Rabi* season of year 2019-20 at Integrated Farming System Research Unit farm in Banda University of Agriculture and Technology, Banda (U.P. - 210001) India to study the response of various mustard varieties to different irrigation scheduling treatments through critical growth stage approach. Higher growth attributing characters at different crop stages and at harvest viz. plant height, number of primary & secondary branches, leaf area index, plant dry matter, crop growth rate, relative growth rate and net assimilation rate were recorded in.

Singh *et al.* (2022) conducted a field experiment at research farm (Agronomy) of Pacific College of Agriculture, Udaipur, during the *rabi* season of 2018–19, named response of select mustard (*Brassica juncea* L.) cultivars to varied irrigation schedules based on IW/CPE ratios. They concluded that irrigation at IW/CPE ratio 0.8

considerably increased plant height at maturity, the number of green leaves per plant, and the number of branches per plant.

Thakur *et al.* (2022) conducted an experiment during *rabi* season of 2020-2021 at Water Management Farm, CSKHPKV, Palampur to find out the effect of irrigation levels and management practices on growth and yield of different Brassica species. The results revealed that application of three irrigations significantly increased the plant height, dry matter accumulation, seed and stover yield of Brassica species as compared to two irrigations.

Naragund *et al.* (2023) carried out an experiment during winter (*Rabi*) seasons of 2019–20 and 2020–21 at Agronomy Farm, Anand Agricultural University, Anand, Gujarat to assess the influence of irrigation scheduling and nitrogen management on crop growth and development of Indian mustard [*Brassica juncea* (L.) Czern]. The results showed that, growth traits of mustard, viz. height of plant, dry matter accumulation, crop growth rates, leaf area and leaf area index were significantly enhanced by scheduling irrigation at 0.8 IW/CPE ratio and application of 50% RDN through chemical fertilizer + 50% RDN through vermicompost among nitrogen management treatments.

Saini *et al.* (2023a &b) carried out a field experiment during *rabi* season of 2021-22 on loamy sand of Agronomy Instructional Farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar, Gujarat to assess the impact of levels of irrigation and nitrogen with & without mulch on growth, yield attributes, yield, field water use efficiency and economics of mustard. The results indicated that significantly higher growth and yield parameters viz., plant height at harvest (195.6, 191.9 cm), dry matter accumulation at harvest (46.69, 49.26 g/plant), CGR and RGR were recorded.

2.8 Effect of irrigation regimes on yield attributes of toria

Thakur (2013) reported that 2 irrigations at 40 and 75 DAS resulted in significantly higher the number of siliquae plant⁻¹, seeds siliqua⁻¹, 1000-seed weight, seed yield, stover yield, biological yield and harvest index of Indian mustard than that of one irrigation at 40 DAS and rainfed.

Bharat *et al.* (2019) conducted an experiment to study the effect of irrigation scheduling and hydrogel application in Indian mustard (*Brassica juncea* L.) of Jammu region, India. Irrigation scheduling at 0.8 and 0.6 IW/CPE resulted in significant increase in the yield attributes, oil yield and seed yield of Indian mustard during first and second year of experimentation besides concomitant increase in the water use efficiency of Indian mustard than control and other treatments.

Konwar *et al.* (2019) conducted a field experiment during *rabi* 2016-2017 and 2017-18 at Assam Agricultural University, Jorhat to find out the optimum irrigation scheduling and to evaluate the suitable planting geometry of rapeseed (*Brassica rapa* var. *dichotoma*) under system of rapeseed intensification. Three irrigations applied at flower initiation, 50% flowering and at siliqua development stage recorded the highest yield attributes viz., number of branches plant⁻¹, siliquae plant⁻¹, number of seeds siliqua⁻¹, highest seed and stover yield.

Barick *et al.* (2020) carried out an experiment during *rabi* season of 2017-18 at the Instructional Farm, Jaguli, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal to study the effect of irrigation levels and methods of sowing on production potential of rapeseed (*Brassica campestris* L. Prain). The result revealed that the yield attributes viz. primary branches plant⁻¹, siliqua plant⁻¹, seeds siliqua⁻¹ and test weight (g) and yield of rapeseed were recorded to be maximum under I₄(IW:CPE= 1.0) which recorded 55.69% increase in yield over control (I₁).

Rana *et al.* (2020) carried out an experiment to evaluate the effect of sulphur fertilization and irrigation scheduling on mustard hybrids in Varanasi, India during *Rabi* seasons (Oct–March) of 2015–16 and 2016–17. Results revealed that individually irrigation scheduling at 0.8 IW: CPE recorded number of primary and secondary branches, number of siliquae plant⁻¹, number of seeds siliqua⁻¹, siliqua length and seed yield.

Das *et al.* (2021) conducted an experiment at the Instructional-cum-Research (ICR) farm of Assam Agricultural University, Jorhat in 2013-14. The results of the experiment revealed that three irrigations at 20 DAS, flowering and siliqua formation

stage performed better than those with one irrigation at flowering and rainfed crop in response to physiological traits and biological yield.

Bhukhar *et al.* (2022 a&b) conducted an experiment at 2018 during the *Rabi* season of 2018 at S.K.N. College of Agriculture, Jobner (Rajasthan) . Results revealed that the scheduling of drip irrigation at 0.8 IW/CPE ratio recorded significantly higher plant height, dry matter accumulation, siliquae per plant, seeds per siliqua, test weight and seed yield over 0.4 IW/CPE ratios, which was statistically at par with 0.6 IW/CPE ratio.

Kumar *et al.* (2022) conducted an experiment at Agriculture Research farm, Rama University, Kanpur during *rabi* season of 2021-22 to study the effect of Irrigation and Sowing time on Growth and Yield of Indian Mustard (*Brassica juncea* L.) in central plain zone of UP. Among the treatments, it was found that mid sowing time 15th November, and Irrigation schedule 20, 35, 50 DAS have best result in terms of growth, development, yield and quality of mustard crop.

Saini *et al.* (2023 a&b) carried out a field experiment during rabi season of 2021-22 on loamy sand of Agronomy Instructional Farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar, Gujarat to assess the impact of levels of irrigation and nitrogen with & without mulch on growth, yield attributes, yield, field water use efficiency and economics of mustard. The results indicated that significantly higher yield parameters viz number of primary branches per plant (5.50, 5.58), number of siliquae plant⁻¹ (277.0, 279.3) and number of seeds siliqua⁻¹ (13.50, 13.48) were recorded with irrigation scheduled at 1.0 IW/CPE.

2.8 Effect of irrigation regimes on seed and stover yield of toria.

Yadav *et al.* (2010) reported that the seed and straw yields of mustard were significantly affected due to irrigation regimes. The application of two irrigations resulted in 24.2 per cent and 8.8 percent increase in seed yield and 20.1 percent and 12.4 percent in straw yield over one irrigation applied at pod development stage and flower initiation stage, respectively.

Piri (2012) studied the effect of irrigation scheduling on black mustard and reported that the application of two irrigations significantly increased seed yield, biological yield and harvest index than one and no irrigation in black mustard in clay loam soil.

Sarma and Das (2017) carried out a field experiment on irrigation and fertilizer effects on productivity, quality, water use and economics of Yellow Sarson [*Brassica rapa* (L.) var. *trilocularis*] to study the effect of irrigation and fertilizer on Yellow Sarson with four irrigation regimes and three level of fertilizer. Results showed that two irrigations at flowering- and pod formation stage also recorded 6.8, 11.6 and 46.9 percent higher yield over single irrigation at flowering, single irrigation at pod formation and rainfed crop.

Deka *et al.* (2018) conducted an experiment during 2014-15 in the *Rabi* season at Instructional Cum Research Farm of Assam Agricultural University, Jorhat, Assam, India to find the effect of different irrigation schedule and fertilizer levels on seed yield, oil content and nutrient uptake in late sown toria (*Brassica campestris* var. *toria*) grown after sali rice. Result revealed that application of different irrigation and fertilizers has significantly increased the yield of late sown toria over control. Out of different irrigation schedule, application of 6 cm irrigation at 25 and 50DAS recorded the higher seed yield (9.55 q ha^{-1}) which is 16.60, 23.11 and 37.10 percentage higher over the other irrigation schedules i.e. 6 cm irrigation at siliqua formation stage (50 DAS), 6 cm irrigation at pre flowering stage (25DAS) and rainfed respectively.

Shivram *et al.* (2018) conducted an experiment at Azad University of Agriculture & Technology, Kanpur and revealed that 3 irrigations at 30-35 DAS, flowering and siliqua development gave significantly higher seed yield, stover yield and biological yield than that of two irrigations at (30-35 DAS and flowering or 30-35 DAS and siliqua development) and single irrigation at 30-35 DAS or flowering. These clearly indicated that the yield of Indian mustard increased with increasing intensity of irrigation and responded better up to three irrigations at different crop growth stages.

Singh *et al.* (2019a,b&c) conducted an experiment for two consecutive winter (*rabi*) seasons of 2014–15 and 2015–16 at G.B. Pant University of Agriculture and

Technology, Pantnagar to evaluate the effect of irrigation levels, planting methods and mulching on growth, yield, water-use efficiency, economics and nutrient uptake in yellow sarson (*Brassica rapa* L.). Results showed that maximum plant height, total dry matter, yield attributing characters, seed and stover yields, nutrient uptake by seed and stover, net returns and benefit: cost ratio were recorded from 1.2 IW/CPE ratio followed by 0.9 IW/CPE ratio. Higher water-use efficiency (WUE) was recorded with irrigation at 0.9 IW/CPE ratio, which was at par with 1.2 IW/CPE ratio.

Singh *et al.* (2019 a,b&c) conducted an experiment for two consecutive *rabi* seasons during 2014-15 and 2015-16 at Norman E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar to evaluate growth and yield parameters of yellow sarson (*Brassica rapa* L.) affected by different irrigation levels, planting methods and mulching. Results revealed that significantly seed yield of yellow sarson increased significantly up to 0.9 IW/CPE ratio as compared to remained irrigation levels.

Singh *et al.* (2021 a&b) carried out an experiment during winter seasons of 2014–15 and 2015–16 at crop research farm of Pantnagar, India to evaluate the effect of irrigation levels, planting methods and mulching on nutrient uptake, yield, quality, water and fertilizer productivity of field mustard (*Brassica rapa* L.) at sandy loam soil. Results revealed that irrigation at 1.2 irrigation water/ cumulative pan evaporation ratio (IW/CPE ratio) resulted in higher yield, N, P, K, and S uptake by plant, oil quality and fertilizer productivity and this irrigation level was at par with 0.9 IW/CPE ratio during 1st year of study when there was good amount of winter rainfall.

Bhindani *et al.* (2020a,b&c) conducted an experiment during *Rabi* season of 2017-18 at Central Research Farm, Gayespur, Nadia, under Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal to study the effect of irrigation and nitrogen levels on performance of hybrid mustard. The study revealed that maximum seed yield (2016 kg/ha) was achieved in IW: CPE=1.0 followed by IW: CPE =1.2. The highest oil content was observed in IW: CPE =1.2. The highest WUE and biological yield of mustard was observed in IW: CPE =1.0 and IW: CPE=0.8, respectively.

Maurya *et al.* (2023) conducted a field experiment during *Rabi* season of year 2019-20 at Integrated Farming System Research Unit farm in Banda University of Agriculture and Technology, Banda (U.P. - 210001) India to study the response of various mustard varieties to different irrigation scheduling treatments through critical growth stage approach. Higher yield (grain yield, straw yield, biological yield and harvest index) along with B: C ratio was recorded under treatment irrigating the crop for two times during rosette and pod formation.

2.9 Effect of irrigation regimes on quality of toria

Yadav *et al.* (2010) observed that the irrigation applied at siliquae development stage recorded significantly higher oil content (40.80%). However, the maximum oil yield was produced with irrigation at flower initiation + seed development stage, which might be owing to higher yield.

Verma *et al.* (2014) studied the response of mustard varieties to irrigation scheduling and reported that oil content was not significantly influenced due to irrigation scheduling. However, oil yield (856 kg/ha), and protein content (25.47%) were influenced significantly due to irrigation scheduling. Higher oil yield was recorded with two (irrigation at branching + siliqua formation), which was significantly superior over single irrigation and no irrigation treatment. The minimum oil yield was recorded under no irrigation schedule treatment.

Ray *et al.* (2015) found that the two irrigations applied in mustard crop at flower initiation (30 DAS) and siliqua development stages (60 DAS) increased oil content in seed (40.88 %) as compared to single irrigation at flower initiation (30 DAS) or at siliqua development stages (60 DAS), while working in clay loam soil.

Das *et al.* (2019) conducted a field experiment during the *rabi* season of 2013-14 at Instructional Cum Research farm of Assam Agricultural University, Jorhat, Assam, India to study the response of rapeseed (*Brassica campestris* var. toria) varieties to varying levels of irrigation under late sown conditions. Results revealed that highest oil yield 594 kg ha⁻¹ was recorded from irrigations at 20 days after sowing (DAS), flowering and siliqua formation stages.

Singh *et al.* (2022) conducted a field experiment at research farm (Agronomy) of Pacific College of Agriculture, Udaipur, during the rabi season of 2018–19, named response of select mustard (*Brassica juncea* L.) cultivars to varied irrigation schedules based on IW/CPE ratios. Significant increase in the quantity of siliquae & seeds per plant and highest seed production of 20.33 q ha⁻¹ and oil content was recorded with an IW/CPE ratio of 0.8 as opposed to 0.4.

2.10 Effect of irrigation regimes on nutrient content in plant

Singh (2014) reported maximum N, P and K content in seeds and stover with irrigation over no irrigation. However, the N, P and K uptake by seeds and straw, and the total N, P and K uptake were significantly more with irrigation than that without irrigation.

Verma *et al.* (2014) found N uptake was influenced significantly due to irrigation schedule. Significantly higher N uptake (87.35 kg / ha) was recorded with two irrigation (irrigation at branching + siliqua formation) which was significantly superior over single irrigation and no irrigation. The minimum N uptake was recorded under no irrigation schedule treatment.

Bhatt and Kushwaha. (2019) carried out an field experiment during *rabi* season of 2015-16 to analyse the effect of different irrigation schedules on water use efficiency and nutrient uptake of yellow mustard (*Brassica juncea* L.) cv. Pant Pili Sarson-1, at Norman E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar. Maximum uptake of nutrients by crop was observed under IW: CPE 0.75 associated with deep water table condition (90±1.5 cm) using sprinkler method of irrigation.

Niwas *et al.* (2020) conducted a field experiment during *rabi* season of 2017-18 at Agronomy Research Farm of Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya, Uttar Pradesh, India. The results revealed that irrigations either at 1.0 IW/CPE ratio or at critical growth stages (CRI, TRS, LJS, FRS, MKS & DS) recorded maximum yield potential (45.40 to 46.00 q ha⁻¹ grain yield and 65.83 to 66.29 q ha⁻¹ straw yield), enhanced nutrient uptake (Nitrogen 72.68 kg ha⁻¹, Phosphorus 18.03 kg ha⁻¹ and Potassium 16.97 kg ha⁻¹) in grain of wheat.

Barman *et al.* (2023) conducted an experiment to evaluate effects of deficit irrigation scheduling (DIS) and different Agri-Horti System (AHS) on nutrient uptake, quality and fertilizer productivity of Indian mustard under sandy loam soil. Results revealed that among different levels of irrigation scheduling, 0.6 IW (irrigation water)/Cumulative pan evaporation (CPE) ratio resulted in higher amount of total N, P, K and S uptake which remained significantly superior over 0.4 IW/CPE and rainfed treatments. They also revealed that Indian mustard could be suitably irrigated with 0.6 IW/CPE ratio to achieve higher nutrient uptake, quality and fertilizer productivity under moringa based AHS.

Meena *et al.* (2023) conducted a field experiment to study the effect of irrigation scheduling and foliar application of thiourea on nutrient concentration, uptake and water use efficiency of mustard. The results revealed that drip irrigation at 0.6 IW/CPE ratio recorded significantly higher nitrogen, phosphorus, sulphur concentration and their uptake in mustard, water use efficiency as well as protein content as compared to surface irrigation, sprinkler and drip irrigation at 0.4 IW/CPE ratio.

Saini *et al.* (2023 a) carried out a field experiment during rabi season of 2021-22 on loamy sand of Agronomy Instructional Farm, C. P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar, Gujarat to assess the impact of levels of irrigation and nitrogen with & without mulch on growth, yield attributes, yield, field water use efficiency and economics of mustard. The N (54.80 kg/ ha), P (7.36 kg/ ha) and K (15.71 kg/ha) after harvest were found to be highest in IW: CPE =1.

2.10 Effect of irrigation regimes on economics of toria

Piri *et al.* (2011) studied the effect of irrigation levels on yield analyses and water use efficiency of Indian mustard and founded that application of two irrigations at 45 DAS and 90 DAS significantly increased gross returns (37655 ₹ ha⁻¹), net returns (25362 ₹ ha⁻¹) and B: C ratio (2.06).

Gupta and Tomar (2015) carried out an experiment during Rabi season 2013-14 at Rajasthan, DRMR (ICAR) Bharatpur. The crop recorded higher gross return, net return

and benefit cost ratio in improved technologies as compared to the farmers using traditional practices of cultivation.

Jat *et al.* (2017) reported from the experiment with 5 irrigation (viz., no irrigation, 0.4 -IW/CPE, 0.6 - IW/CPE, 0.7 - IW/CPE and 0.8 - IW/CPE) scheduling. Experiment results revealed that maximum gross return (99658 ₹ ha⁻¹), net returns (72318 ₹ ha⁻¹) and B: C ratio (3.69) was recorded under 0.8 - IW/CPE irrigation scheduling for Indian mustard.

Singh *et al.* (2017 a&b) study the effect of front line demonstrations on mustard varieties were conducted at farmer's field in the NICRA village Chomakot, Kota district of Rajasthan, during 2011-12 to 2015-16. Observed the frontline demonstrations recorded higher mean gross return (65249 ₹ ha⁻¹) and mean net returns (45589 ₹ ha⁻¹) with average B: C ratio (3.42) compared to the local checks.

Barick *et al.* (2020) studied the effect of irrigation levels of rape-seed (*Brassica campestris* L. Prain) with four irrigation levels (viz., rainfed, IW: CPE of 0.6, IW: CPE of 0.8, IW: CPE of 1.0). It was found that irrigation levels (IW: CPE of 1.0) recorded maximum gross return (39016.64 ₹ ha⁻¹), net return (18823.98 ₹ ha⁻¹), and B: C ratio (1.94) over other control.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation entitled “**Effect of precision nitrogen management and irrigation regimes in rice-toria cropping system in Dimapur district of Nagaland.**”) was conducted at the experimental farm of ICAR, Jharnapani, Nagaland during the *Kharif* and *Rabi* season of 2022-2023 and 2023-2024. In this chapter, the experimental geographical site, weather conditions, experimental materials and methodology used to record different observations of the parameters have been discussed.

3.1 General information

3.1.1 Site of the experiment

The experimental field is geographically located at 25° 45' 43" N latitude and 95° 53' 04" E longitude at an altitude of 310 m above the mean sea level (MSL). The site comes under Mid Tropical Hills (AZ52).

3.1.2 Climatic and weather conditions during the experiment period

The climatic conditions of Jharnapani falls under the sub-tropical climatic zone and is subjected to extreme of weather conditions *i.e.*, extremely hot summer and cold winter. The region lies in humid sub- tropical region with an average rainfall ranging from 2000-2500 mm annually. The rainy season usually starts from April and extends up to the end of September. The mean temperature varied from 21-33°C during summer while minimum temperature seldom goes down to 8°C in winter owing to high atmospheric humidity.

The detailed meteorological data of Jharnapani of different weather parameters recorded during the period of investigation is presented in Table 3.1(a&b) and shown graphically in Fig 3.1(a&b).

The average weekly maximum and minimum temperature recorded was 30°C and 18°C during the first year of investigation, June 2022-February 2023 while

Table 3.1(a) Average weekly meteorological data recorded during the cropping system (2022-23 and 2023-24)

Standard meteorological week	Temperature		Relative Humidity		Rainfall (mm)	Wind speed (km hr ⁻¹)	Sunshine hour
	Max. °C	Min. °C	Max. %	Min. %			
24	30.3	23.3	95	74	46.7	0.872	1.3
25	31.2	23.4	95	75	34.8	0.824	1.8
26	33.3	24.9	93	68	9.9	1.313	4.5
27	34.2	24.7	91	66	77.1	1.569	7.2
28	34.1	24.5	90	69	22.9	1.464	6.9
29	33.9	24.5	92	75	135.3	1.357	3.4
30	31.8	23.2	96	70	135.3	1.024	3.6
31	33.6	23.9	93	68	48.8	1.259	3.1
32	33.3	23.9	96	71	114.7	1.205	5.1
33	33.6	24.2	91	72	27.5	1.286	6.1
34	34.1	24.5	94	68	64.2	1.039	4.1
35	32.7	24.3	93	68	9.0	0.945	4.6
36	33.4	24.4	89	67	21.7	1.423	4.9
37	31.9	23.5	91	72	42.8	1.042	4.1
38	33.5	24.0	91	65	15.3	0.964	5.6
39	32.8	23.2	91	70	81.2	1.024	6.3
40	31.9	23.5	95	74	31.0	0.672	4.4
41	31.8	22.7	91	71	2.9	0.810	5.0
42	30.9	20.6	94	65	19.7	1.010	5.9
43	28.1	19.9	95	71	41.0	1.127	4.7
44	29.8	17.1	96	60	0.0	0.963	8.0
45	29.3	16.7	96	57	0.0	0.867	8.2
46	27.9	14.6	98	56	0.0	0.971	8.2
47	27.7	12.8	96	52	0.0	0.913	8.0
48	27.8	14.3	96	67	0.0	0.932	7.4
49	27.6	12.0	95	49	0.0	0.944	8.0
50	26.4	11.3	96	50	0.0	0.843	7.0
51	25.7	11.0	96	51	0.2	0.704	6.4
52	22.7	11.2	97	60	15.2	0.595	3.9
1	23.2	9.2	97	50	0.0	0.782	6.9
2	25.4	8.8	96	55	0.0	0.114	6.9
3	22.8	7.0	94	45	0.0	0.791	5.7
4	24.9	6.9	93	45	0.0	0.804	6.0
5	27.0	10.4	93	46	0.0	0.868	6.2
6	25.6	10.2	94	53	0.0	1.156	3.7
7	26.9	11.0	91	43	0.0	1.337	5.3
8	29.0	15.1	93	51	0.0	1.513	3.4

Source: ICAR Research Complex for NEH Region, Jharnapani, Nagaland

**Table 3.1. (b) Average weekly metrological data during the cropping system
(2022-23 and 2023-24)**

Standard meteorological week.	Temperature		Relative Humidity		Rainfall (mm)	Wind speed (km hr ⁻¹)	Sunshine hour
	Max. °C	Min. °C	Max. %	Min %			
24	30.3	23.3	95	74	46.7	0.872	1.3
25	31.2	23.4	95	75	34.8	0.824	1.8
26	33.3	24.9	93	68	9.9	1.313	4.5
27	34.2	24.7	91	66	77.1	1.569	7.2
28	34.1	24.5	90	69	22.9	1.464	6.9
29	33.9	24.5	92	75	135.3	1.357	3.4
30	31.8	23.2	96	70	135.3	1.024	3.6
31	33.6	23.9	93	68	48.8	1.259	3.1
32	33.3	23.9	96	71	114.7	1.205	5.1
33	33.6	24.2	91	72	27.5	1.286	6.1
34	34.1	24.5	94	68	64.2	1.039	4.1
35	32.7	24.3	93	68	9.0	0.945	4.6
36	33.4	24.4	89	67	21.7	1.423	4.9
37	31.9	23.5	91	72	42.8	1.042	4.1
38	33.5	24.0	91	65	15.3	0.964	5.6
39	32.8	23.2	91	70	81.2	1.024	6.3
40	31.9	23.5	95	74	31.0	0.672	4.4
41	31.8	22.7	91	71	2.9	0.810	5.0
42	30.9	20.6	94	65	19.7	1.010	5.9
43	28.1	19.9	95	71	41.0	1.127	4.7
44	29.8	17.1	96	60	0.0	0.963	8.0
45	29.3	16.7	96	57	0.0	0.867	8.2
46	27.9	14.6	98	56	0.0	0.971	8.2
47	27.7	12.8	96	52	0.0	0.913	8.0
48	27.8	14.3	96	67	0.0	0.932	7.4
49	27.6	12.0	95	49	0.0	0.944	8.0
50	26.4	11.3	96	50	0.0	0.843	7.0
51	25.7	11.0	96	51	0.2	0.704	6.4
52	22.7	11.2	97	60	15.2	0.595	3.9
1	23.2	9.2	97	50	0.0	0.782	6.9
2	25.4	8.8	96	55	0.0	0.114	6.9
3	22.8	7.0	94	45	0.0	0.791	5.7
4	24.9	6.9	93	45	0.0	0.804	6.0
5	27.0	10.4	93	46	0.0	0.868	6.2
6	25.6	10.2	94	53	0.0	1.156	3.7
7	26.9	11.0	91	43	0.0	1.337	5.3
8	29.0	15.1	93	51	0.0	1.513	3.4

Source: ICAR Research Complex for NEH Region, Jharnapani, Nagaland

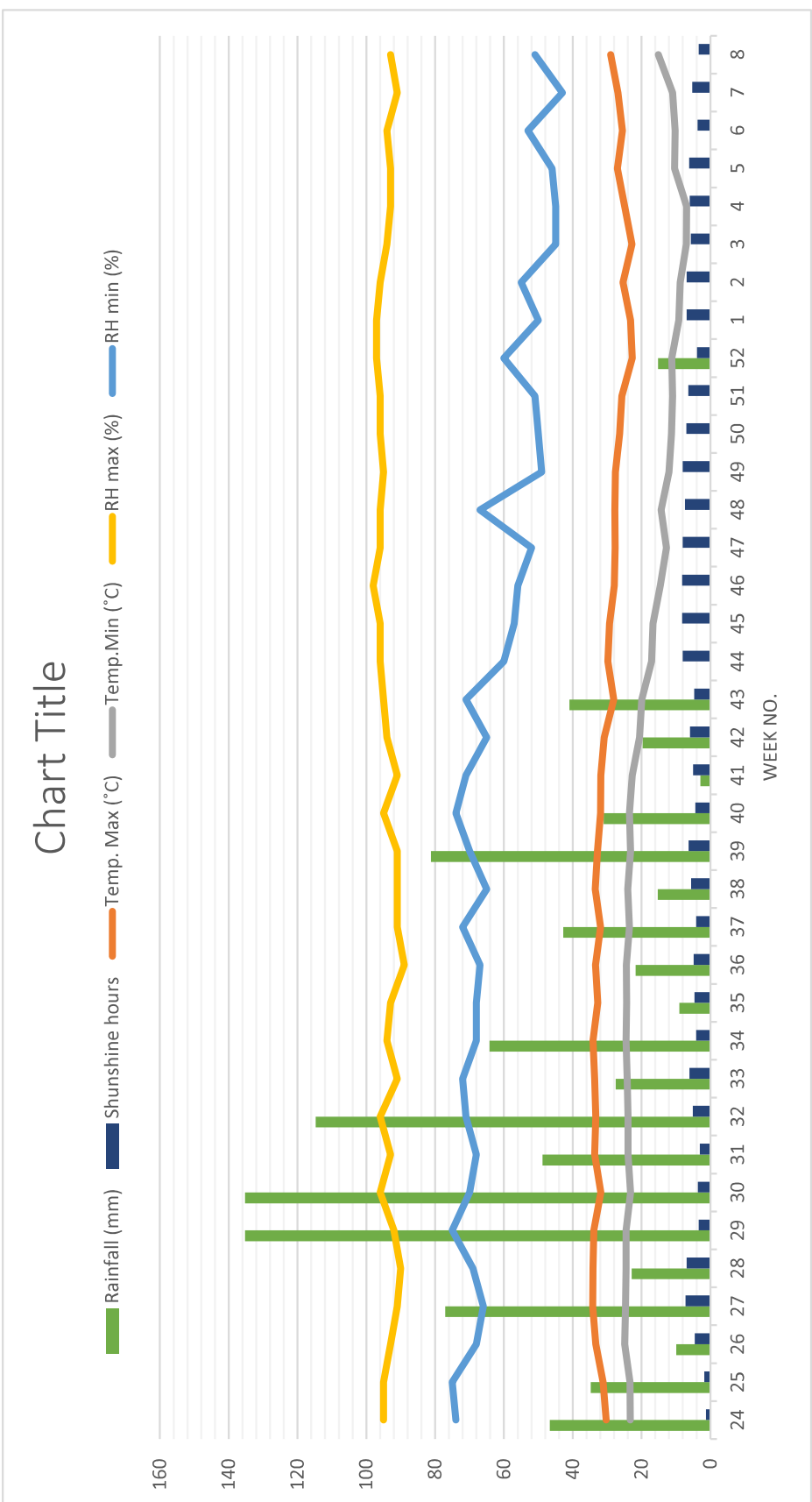


Fig 3.1(a) Meteorological data during the cropping season (2022-23)

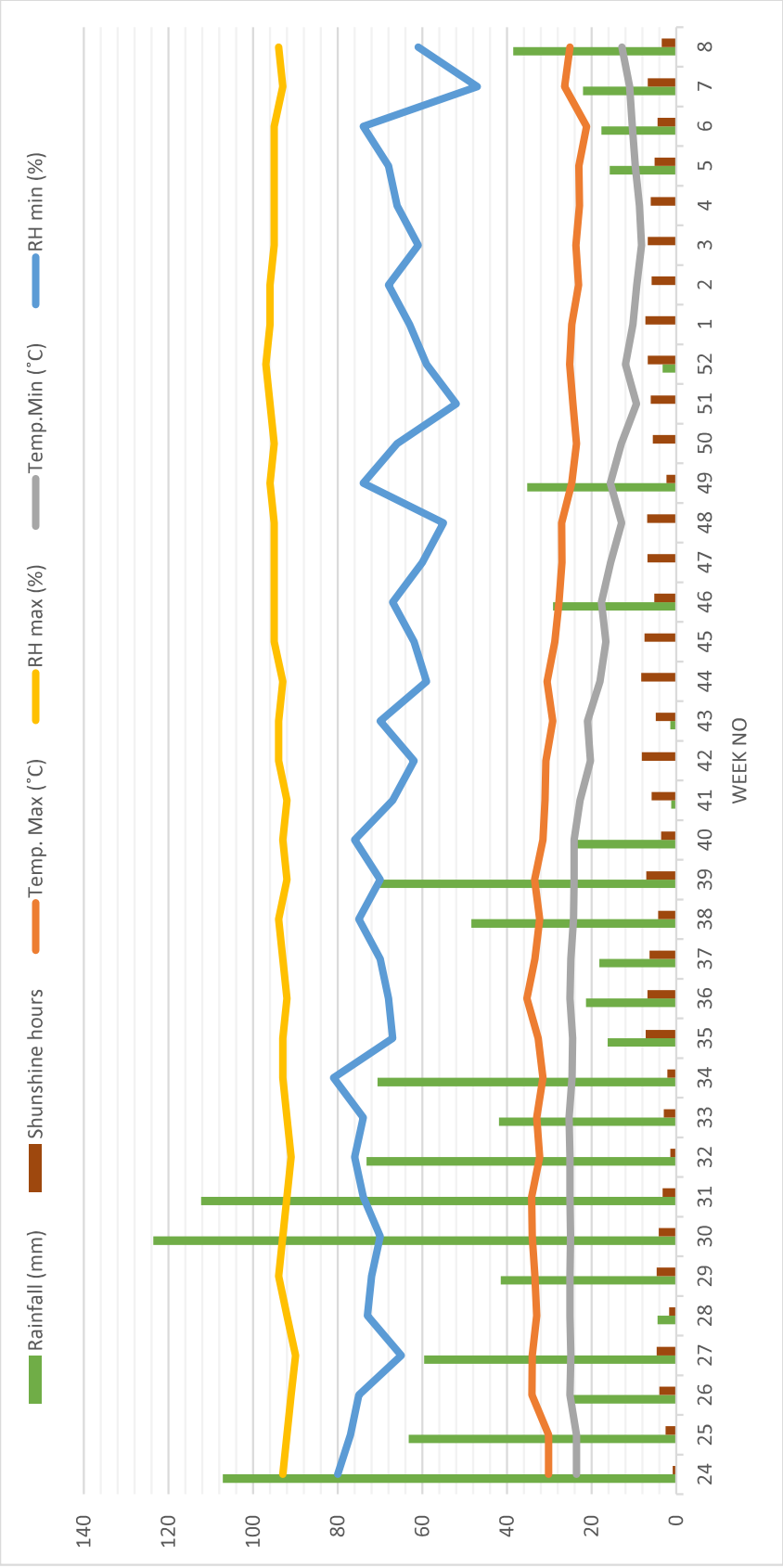


Fig 3.1(b) Meteorological data during the cropping season (2023-24)

29.3°C and 18.9°C during the second year of investigation, June 2023-February 2024. The mean weekly maximum and minimum relative humidity recorded was 94% and 64% during the first year, June 2023-February 2024 while 93.7 % and 67.8% during the second, June 2023-February 2024. The mean weekly sunshine hours during the period of experimentation were 6 hrs during the first year, June 2022-February 2023 and 5.1hrs during the second year, June 2023-February 2024. The average weekly amount of rainfall received during the first and second year, was 28 mm and 29.1 mm respectively. The average weekly amount of wind speed for first and second year was 1 km hr⁻¹ and 0.3 km hr⁻¹, respectively.

3.1.3 Cropping history of the experimental site

The details of the crops grown and cropping system adopted on the experimental site for the last few years are shown in the Table 3.2.

Table 3.2: Cropping history of the experimental site

Sl. No.	Year	Season		
		<i>Kharif</i>	<i>Rabi</i>	<i>Zaid</i>
1.	2020	Rice	Toria	Green gram
2.	2021	Rice	Toria	Green gram

3.1.4 Details of the experimental soil condition

To study the physio- chemical properties of the soil, the respective soil samples were collected randomly from the experimental field at a depth of 0-15 cm by soil auger before sowing of the crop. Likewise, soil samples were collected from each plot after harvesting of the main crop to know the fertility status during both the years of investigation. The collected soil samples were dried in the shade area, grind and sieved through 2 mm sieve and were used for the estimation of Available nitrogen, phosphorus, potassium, pH, organic carbon and EC of the soil samples by the standard methods as given in Table 3.3. The details of the initial physico-chemical properties of the experimental field re shown in Table 3.3

Table 3.3: Initial soil fertility status of the experimental field

Characteristics	Method followed	2022-23		2023-24	
		Content	Remark	Content	Remark
Soil texture	International pipette method (Piper, 1966)	Sand: 52.87% Silt: 27.1% Clay: 20.66%	Sandy loam	Sand: 53.47% Silt: 27.3% Clay: 20.10%	Sandy loam
Soil pH	Glass electrode pH meter (Jackson, 1973)	5.03	Acidic	5.39	Acidic
Organic carbon (%)	Titrimetric determination (Walkley and Black method, 1934)	0.64	Medium	0.67	Medium
EC (ds/m)	Conductivity bridge (Jackson, 1973)	0.65	Medium	0.66	Medium
Available soil nitrogen (kg ha⁻¹)	Alkaline potassium permanganate method (Subbiah and Asija, 1956)	285.82	Medium	287.47	Medium
Available soil phosphorus (kg ha⁻¹)	Bray's No. 1 method (Bray and Kurtz, 1945)	22.15	Medium	22.86	Medium
Available soil potassium (kg ha⁻¹)	Neutral normal ammonium acetate method (Hanway and Heidal, 1952)	132.55	Medium	136.39	Medium

3.2 Details of the experimental techniques

3.2.1 Experimental design and layout

The first experiment was laid out in Randomised Block Design (RBD) with four number of treatments which were replicated thrice. The second experiment was laid in Split Plot Design (SPD) consisting effect of residual nitrogen management in the main plot and three irrigation regimes in the sub-plot and were replicated thrice. The detailed plan of layout of the experiments for both the years are presented in Fig 3.2(a&b)

3.2.2 Detail layout of the experiment

The details of the experiment are given below:

1. Crop-I	- Rice
i. Variety	- RCM-9
ii. Spacing	- 20 cm × 10 cm
iii. Recommended fertilizer dose	- 80-40-40 kg ha ⁻¹ (NPK)
iv. Experimental design	- Randomised Block Design (RBD)
v. Number of treatments	- 4
vi. Number of replications	- 5
vii. Total number of plots	- 20
viii. Gross experimental area	- 14m x 10.5m
ix. Net experimental area	- 12.5m x 9m
x. Block border	- 1 m
xi. Plot border	- 0.5 m
2. Sequential Crop-II	- Toria
i. Variety	- TS- 67
ii. Spacing	- 30 cm × 5-10 cm
iii. Recommended fertilizer dose	-50-60-20: kg ha ⁻¹ (N,P ₂ O ₅ , K ₂ O)
iv. Experimental design	- Split Plot Design (SPD)
v. Main plot	- 4
vi. Sub- plot	- 3

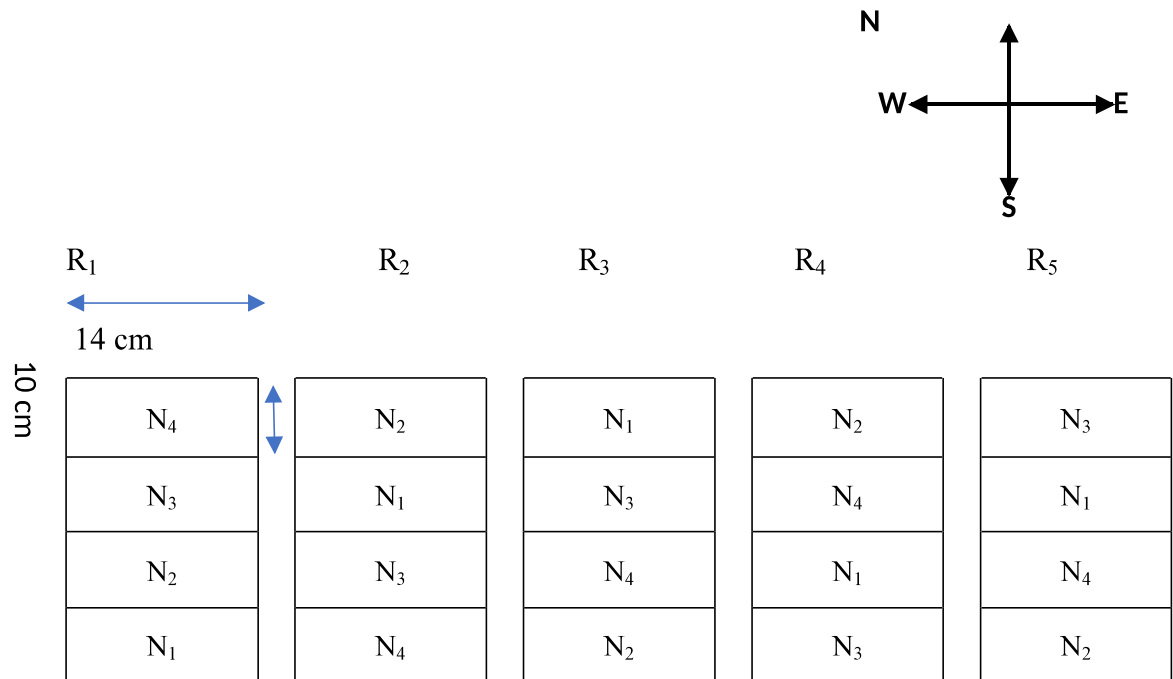


Fig 3.2(a) Layout of the first experiment (Rice)

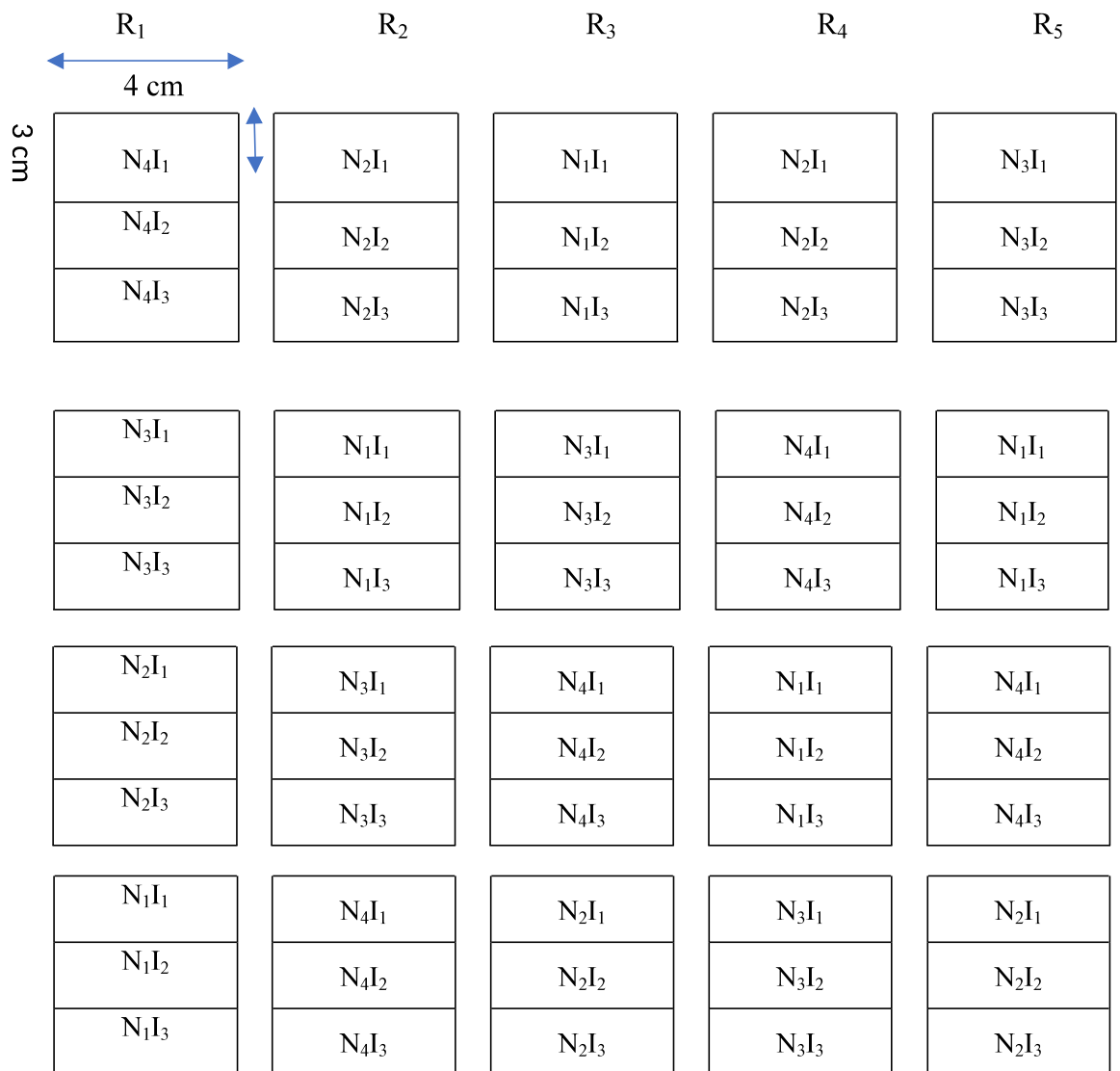


Fig 3.2(b) Layout of the second experiment (Torio)

vii.	Total number of treatments	-12
viii.	Number of replications	- 5
ix.	Total number of plots	- 60
x.	Gross experimental area	- 4 m × 3 m
xi.	Net experimental area	- 3m × 2.5 m
xii.	Block border	- 1 m
xiii.	Plot border	- 0.5 m

3.2.3 Treatment details

The details of the treatments of the first experiment along with symbols used to represent are given below:

Precision nitrogen management

N₁ - Control

N₂ - Split application of N (3 split) – 80 kg ha⁻¹

(50 % at FLP (Basal) + 25 % at Maximum tillering stage + 25 % at PI)

N₃ – Leaf colour chart (LCC) based N application

(The LCC critical value will be maintained at 4-5 and 15kg ha⁻¹ of N will be applied)

N₄ - SPAD (Chlorophyll meter) based N application

(The SPAD value will be maintained at 36 and 15kg ha⁻¹ of N will be applied)

The details of the treatments for second experiment in the main and sub-plots along with symbols used to represent are given below:

Main plot

The four residual treatments (nitrogen management practices) in rice were imposed on toria.

Sub plot

Irrigation regimes

I₁-No irrigation (control)

I₂-IW: CPE = 0.8

I₃-IW: CPE =1.0

3.2.4 Details of the experimental crop

3.2.4.1 Rice variety- RCM-9

Rice (*Oryza sativa* L.) belongs to the family Poaceae. RCManiphou-9 is a mutant culture of Punshi, a high yielding variety released in 2000 in Manipur. It is also known by different local synonyms like Punshi mutant, M-58, M-50, M-15, Charongphou and Niphuthokpi. RCM-9 is suitable for irrigated or waterlogged (5-15 cm) low land with medium to high soil fertility, early to medium and early to late planting for main *kharif*. It is slightly short day and is suitable for the main and late seasons. It matures in 135 to 140 days depending on sowing time. It has a high tillering ability (15-20/hill) and long panicles with 300-450 spikelets, distinguishing from other cultivars by its well-exserted profuse whitish panicles at the flowering stage. It has tolerance to blast. Its yield ranges from 5 to 7 t/ha.

3.2.4.2 Toria variety-TS- 67

Toria belongs to the family Brassicaceae. It is released in the year 2015-2016 in AAU, Jorhat. This variety is suitable for cultivation in the Northeastern region of India, particularly in the context of a rice- toria cropping sequence. It is known to be tolerant to White Rust and Alternaria blight, making it a good choice for regions where these diseases are prevalent. Plant type is semi erect and medium in height with a duration of 90-95 days. It has a potential yield of 10-12 q/ha. The oil content of TS-67 typically ranges from 44 % to 46%.

3.2.5 Calendar of agronomic management operations

The dates and operations from the initial field preparation to final crop harvest have been presented below in the Table 3.4.

Table 3.4: Calendar of agronomic management practices

Sl. No.	Operations	Year- 2022-23	Year- 2023-24
		Date	
1	Land preparation		
	Nursery bed preparation	13.06.2022	15.06.2023
	Sowing of seed in nursery bed	15.06.2022	17.06.2023
	Ploughing of main field	9.07.2022	11.07.2023
2	Layout	10.07.2022	12.07.2023
3	Puddling and levelling	11.07.2022	13.07.2022
4	Bunding	12.07.2022	14.07.2022
5	Fertilizer application as basal	14.06.2022	16.06.2023
6	Transplanting	15.07.2022	17.07.2023
7	Weeding	25.07.2022	28.07.2023
8	Irrigation	26.07.2022	29.07.2023
9	1 st biometric observation	15.08.2022	17.08.2023
10	2 nd biometric observation	16.09.2022	17.09.2023
11	Weeding	21.08.2022	24.08.2023
12	3rd biometric observation	16.10.2022	17.10.2023
13	Harvesting	2.11.2022	4.11.2023
14	Threshing and winnowing	9.11.2022	11.11.2023
15	Ploughing through rotavator	12.11.2022	15.11.2023
16	Lay out	13.11.2022	16.11.2023
17	Fertilizer application for toria	15.11.2022	17.11.2023
18	Sowing of toria	16.11.2022	18.11.2023
19	First irrigation after sowing	16.11.2022	19.11.2023
20	Thinning and earthing up	6.12.2022	8.12.2023
21	Hand weeding	12.12.2022	13.12.2023
22	1 st biometric observation	16.12.2022	18.12.2023
23	2 nd biometric observation	16.01.2023	18.01.2024
24	Weeding	25.01.2023	26.01.2024
25	3 rd biometric observation	16.02.2023	18.02.2024
26	Harvesting	22.02.2023	24.02.2024
27	Threshing and winnowing	28.02.2023	29.02.2024

3.2.7 Agronomic practices

The details of various agronomic practices, inter-cultural operations and laboratory analysis carried out during the period of investigation are given below.

3.2.7.1.a Nursery bed preparation for rice

Nursery bed was prepared after puddling the land. Seed bed of 1.47 sq. m was prepared for sowing of seed. The seed was soaked in the plastic tub by putting the seed in the gunny bags for one day. Next day, the seeds were spread in the plastic sheet in the floor and cover with the gunny bags and kept for 1 day in order to germinate the seed. The pre germinated seed were sown in the prepared bed. Irrigation was given to maintain the saturated condition of the nursery bed. Transplanting was done when the seedling was 30 days old.

3.2.7.1. b Field preparation for rice

The field was ploughed thoroughly by tractor drawn disc plough at first followed by power tiller or rotavator. The plot of the experiment was laid out in field as per the design. Bunds were made in order to keep the standing water upto 5-15 cm. After 20 days the field was ploughed by the power tiller. The puddling was done manually in order to make the soil softer and which also help in increasing the soil moisture of the soil. All the weeds, stubbles, waste, etc. were removed from the field and levelling was done.

3.2.7.2 Fertilizer application

The nutrient was applied in the form of Urea (nitrogen), Single Super phosphate (phosphorus) and Muriate of Potash (potassium) as per the treatment. In treatment N₂ nitrogen were applied in three split doses, half of the urea were applied as a basal, one-fourth at the tillering stage and the remaining one-fourth at the panicle initiation stage. In treatment N₃ and N₄, 20kg ha⁻¹ N were applied as a basal. After 30 DAT, nitrogen level was checked through LCC and SPAD meter. When the nitrogen level was below the threshold level (LCC=4, SPAD= 36), then nitrogen was applied

in the treatment plots. The entire amount of phosphorus and potassium were applied as per recommended dose in the plots except control plot at the time of transplanting.

3.2.7.3 Transplanting

The seedling were uprooted from the nursery bed and kept in the field when the seedlings were 30 days old. On next day, transplanting was done manually in the main field by maintaining the row spacing of 20 cm.

3.2.7.4 Weeding and irrigation

Weeding was done at 45 DAT manually followed by 65 and 90 DAT. Irrigation was given as and when required by the crops through pipes. Since the experiment was conducted in the *kharif* season only three irrigations were applied.

3.2.7.5 Plant protection measures

Systematic field assessment was done to observe and control was done for the pest and diseases in the experimental crop.

3.2.7.6 Harvesting and threshing

The crop was harvested at maturity as the panicles turn brown in colour coupled with yellowish straw. Harvesting was done manually with the help of sickle. From the net plot area, the crop was harvested treatment wise. Then the harvested crop was sun dried for 5-6 days. It was manually threshed and winnowed. The grains were dried properly and weight was recorded as per treatment and converted into kg ha⁻¹. Similarly, the straw was also dried properly in the sun and weight was recorded as per treatment.

3.2.7.7 Land preparation of succeeding crop

After harvesting of *kharif* crop, each plot was divided into three plots to conduct an experiment on three different irrigation regimes during *rabi* season. The land was ploughed manually and making a line furrow with the help of spade maintaining a row spacing of 30 cm.

3.2.7.8 Fertilizer application

A recommended dose of 50-60-20 kg ha⁻¹ N, P and K was applied as a basal before sowing. Half dose of nitrogen and full dose of phosphorus and potassium was applied as a basal in each plot. Remaining half dose of nitrogen was applied at 30 DAS of toria.

3.2.7.9 Sowing

The seed rate of 5-6 kg ha⁻¹ was sown in line maintaining a spacing of 10 cm between the plants and row spacing of 30 cm by placing the seed at a depth of 3 cm.

3.2.7.10 Intercultural operations

Intercultural operation like weeding and thinning was done manually and earthing up by spade at 45DAS. Second and third weeding was done as and when required.

3.2.7.11 Irrigation

Irrigation was given for all the treatments at the time of sowing. But after 30 DAS irrigation was given in the treated plot in terms of IW:CPE ratio. IW was taken as 3 cm and evaporation was checked from the weather data. In I₂ and I₃ treatments, irrigation was given at IW:CPE ratio of 0.8 and 1 respectively.

3.2.7.12 Harvesting and threshing

Harvesting of crop was done when the siliqua turns 80% brown coloured and harvested from the net plot area leaving the border rows and 0.5 m row length from both sides. The plants were harvested manually by pulling out from the ground and tied into the bundles separately representing different plots. The bundles were drying in the sun for one week. The threshing was done in the floor by crushing with feet. The seeds and straw were separated by winnowing and weighed separately.

3.3 Collection of experimental data (Biometric Observation)

The five plants were selected randomly and were tagged from the net plot and observations on growth parameters of the crop were recorded on 30 days intervals. Destructive sampling was taken from the border row. To analyze the effectiveness of different treatments, data on various growth and yield attributing parameters by regular plant sampling was carried in both the years. The technique used and the details of the observation are narrated as.

3.3. Rice

3.3.1 Growth attributes

3.3.1.1 Plant height (cm)

Plant height was recorded from the five tagged samples. It was measured from the ground level up to the tip of the flag leaf at 30 and 60 DAT and up to the base of the panicle at 90 DAT. The average plant height was carried out and expressed in centimeter (cm).

3.3.1.2 Plant population m⁻²

Plant population per metre square was measured from the selected area by using quadrat of 1m x 1m in the net plot area. The plant under that area was counted as plant population.

3.3.1.3 Number of tillers m⁻²

In each net plot area, one square metre was selected and marked. The number of tillers were counted from this area and expressed as total number of tillers per m⁻² at each stage of observations (30 and 60 DAT).

3.3.1.4 Dry matter accumulation (g plant⁻¹)

For measuring the plant dry matter accumulation, five plants were selected from outside the net plot area but not from extreme border row and cut at the

ground level at 30, 60 and 90 DAT and dried in the sun for 24 hours. Then the samples were kept in the oven @ 60°C till the constant weight was obtained and their weight was recorded. The average weight was taken from the five dry plant sample and the weight was expressed in g plant⁻¹.

3.3.1.5 LCC measurement

The LCC developed by the National Rice Research Institute (NRRI) is a modified version of LCC developed by International Rice Research Institute with strips of six shades of green colour showing increasing intensity of colour with increasing number was used in the study. Five disease-free rice plants were randomly selected from each plot. The topmost fully expanded leaf was placed on the top of the leaf colour chart and the colour of the middle part of the leaf was graded according to the corresponding colour strip on the LCC. During measurement, the leaf being measured was kept under the shade of the body to avoid the colour variance caused by sunlight. The LCC readings were taken at 7days intervals starting from 30 days after transplanting of rice until initiation of the flowering stage during morning (8 AM-10 AM) or afternoon (2-4 PM) under the shade of the body in order to avoid the influence of the sunlight. Unusually tall or short plants, wet and widely spaced leaves were avoided. When the colours of five leaves fell below a threshold of shade 4 on the LCC, the nitrogen was top dressed on the same day.

3.3.1.6 SPAD measurement

Soil Plant Analysis Development (SPAD) Chlorophyll meter (model SPAD 502 of Minotta co., Japan) was calibrated by switching on the meter with no leaf in the sample slot, followed by completely closing the measuring head until a beep sound was heard. The meter was, thus, calibrated and ready for measurements. Five disease-free rice plants were randomly selected from each plot. The SPAD readings were taken at 7days intervals starting from 30 days after transplanting of rice until initiation of the flowering stage during morning (8 AM-10 AM) or afternoon (2-4 PM) under the shade of the body in order to avoid the influence of the sunlight. SPAD meter reading was recorded from the uppermost fully expanded leaf midway between leaf base and leaf

tip. The data was recorded when leaves were on the plant. The selected leaf was inserted into the sample slot of measuring head of chlorophyll meter to make sure that the sample was completely covered by the receiving window. The measuring head was kept completely closed until a beep sound was heard which indicated that measurement was over and the value appeared on the display. The chlorophyll reading was automatically saved in the meter. The head was opened and the reading for next leaf was taken in the same way. The average of all the SPAD meter readings for a plot was then noted. The average of all the SPAD readings for a plot was noted. After noting the average SPAD values of the plot, the meter was cleared for the next set of reading by pressing the "all data clear" button. When the SPAD readings of five leaves fell below a threshold value 36, the nitrogen was applied on that day.

3.3.1.7 Crop growth rate ($\text{g m}^{-2} \text{ day}^{-1}$)

Crop growth rate (CGR) ($\text{g m}^{-2} \text{ day}^{-1}$) at 0-30 DAT, 30-60 DAT and 60-90 DAT was calculated by using the dry matter accumulation (g) of plant from each plot at 30, 60 and 90 DAT with the following formula (Watson, 1956):

$$\text{CGR} = \frac{W_2 - W_1}{(t_2 - t_1)S}$$

Where, W_1 and W_2 are the dry weights of plants at t_1 and t_2 , respectively. S is the land area (m^2) over which dry matter was recorded.

3.3.1.8 Relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$)

The Relative growth rate (RGR) ($\text{g g}^{-1} \text{ day}^{-1}$) at 0-30 DAT, 30-60 DAT and 60-90 DAT was also calculated using the data of dry matter accumulation (g) of plant from each plot at 30, 60 and 90 DAT with the following formula (Blackman, 1919):

$$\text{RGR} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are the dry matter produced by a gram (g) of existing dry matter in

the day at a time t_1 and t_2 , respectively.

3.3.1.9 Net assimilation rate ($\text{g m}^{-2} \text{ day}^{-1}$)

The Net assimilation rate ($\text{g m}^{-2} \text{ day}^{-1}$) at 0-30 DAT, 30-60 DAT and 60-90 DAT also calculated using the data of dry matter accumulation (g) of plant from each at 30, 60 and 90 DAT with the following formula (William 1946):

$$NAR = \frac{(W_2 - W_1) \times (\ln L_2 - \ln L_1)}{(t_2 - t_1) \times (L_2 - L_1)}$$

Where,

L_1 and W_1 are leaf area and dry weight of the plant, respectively at time t_1 ,

L_2 and w_2 are leaf area and dry weight of the plant respectively at time t_2 .

3.3.1.10 Leaf area index (LAI)

Leaf area index is the ratio of leaf area to ground area occupied by the crop plant. Leaf area index was worked out using the following formula (Watson 1952).

$$\text{Leaf area index} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

3.3.1.11 Relative water content (RWC) (%)

One green leaf was collected as fully developed and expanded topcoat. The sample was kept in the polythene bag to minimize water loss and then kept the polythene bag immediately in cooler bag. The leaf was cut into fine pieces about 5-10 cm and took the fresh weight immediately in the electronic balance. The leaf tissue was transferred in Petri dish with the presence of distilled water and covered with the petri dish cap. The petri dish was kept in the refrigerator for 4 hours, after 4 hours extra moisture from hydrated and fully liviged leaf tissue are sieved. The hydrated fully turgid leaves tissue was measured. The turgid leaf tissues were kept in hot air oven at 100°C for 1 day (24 hours). The dry weight of leaves was measured after proper drying. RWC was calculated by using the following formula:

$$RWC = \frac{FW-DW}{TW-DW} * 100$$

Where, FW, TW and DW are fresh weight, turgid weight and dry weight of the leaf tissue.

3.3.2 Phenological parameters

3.3.2.1 Days to 50% flowering

Days to 50 per cent flowering was recorded when 50 per cent of plants in net plot area flowered based on visual assessment and expressed in days.

3.3.2.2 Days to maturity

The days required to attain maturity stage i.e., one third of pods in the plants, and one third of seeds in the pods turned brown colour, were recorded and expressed in days.

3.3.3 Yield and yield attributes

3.3.3.1 Number of panicles m⁻¹

From each net plot area, the number of ears bearing tillers were recorded from tagged plant, the average was calculated and expressed in number of panicles m⁻².

3.3.3.2 Panicle length (cm)

Panicle length was measured from the healthy five tagged plant. The panicle length was measured from the base to the top of individual panicle. The average was calculated and expressed in centimeter (cm).

3.3.3.3 Weight of panicle (g)

From the tagged plants, five panicles were selected randomly for measuring the weight of the panicle. The average was computed and expressed in gram (g).

3.3.3.4 Number of unfilled grains panicle⁻¹

For each plot, five panicles were selected randomly from the tagged plants. The numbers of unfilled grains panicle⁻¹ was counted and the average was recorded.

3.3.3.5 Number of filled grains panicle⁻¹

For each plot, five panicles were selected randomly from the tagged plants. The numbers of filled grains panicle⁻¹ was counted from selected panicle and the average was recorded.

3.3.3.6 1000 grain weight (g)

1000 grains were counted from yield of each plot separately after proper sun dry to a constant weight and the weight was recorded and expressed in gram.

3.3.3.7 Grain yield (kg ha⁻¹)

The harvested plants were sun dried and the grains were manually separated by threshing. The separated grains were sundried properly to bring down moisture content to 14 % and the weight was recorded. From this yield per hectare was computed and expressed in kg ha⁻¹.

3.3.3.8 Straw yield (kg ha⁻¹)

After the grains were properly threshed, the straws were gathered from each plot and sun-dried and yield per plot was recorded and the yield per hectare was recorded and expressed in kg ha⁻¹.

3.3.3.9 Harvest index (%)

Harvest Index is the ratio of economic yield to biological yield. Harvest index was calculated by using the formula given by Donald (1962).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (grain yield)(kg ha}^{-1}\text{)}}{\text{Biological yield (grain + straw yield)(kg ha}^{-1}\text{)}} \times 100$$

3.4. Observation for sequential crop toria

3.4.1. Growth attributes

3.4.1.2 Plant height (cm)

Five plants were randomly selected from the net plot area of each plot and tagged to record the plant height at 30, 60 and 90 DAS. The plant height was measured from the ground level up to the tips of the plant. The average of these five plants was recorded as the plant height and expressed in centimeter.

3.4.1.2 Plant population at 20 DAS (m⁻²)

Plant population per square meter area in each plot was counted using 0.25 m² quadrat placed at random two spots. The data from these two spots were doubled for conversion into per m² and expressed in number metre⁻².

3.4.1.3 Dry matter accumulation plant⁻¹ (g)

Five random plants were uprooted from outside the net plot area. The plant samples were dried in the sun for 24 hrs and in the next day it was kept in the oven for drying at 65 ± 5°C till the sample at constant dry weight. The average was taken from the five sample and recorded as the dry matter accumulation plant⁻¹ which is expressed in gram (g).

3.4.1.4 Leaf area index (LAI)

Leaf area index is the ratio of leaf area to ground area occupied by the crop plant. Leaf area index was worked out using the following formula (Watson et al., 1952).

$$\text{Leaf area index} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

3.4.1.5 Number of primary branches plant⁻¹

From selected five tagged plants, primary branches were counted from the

branches arising directly from the main stem. The average was taken from these plants and recorded as number of primary branches plant⁻¹.

3.4.1.6 Number of secondary branches plant⁻¹

Secondary branches were recorded from the selected five tagged plants as a branch that was developed from the primary branches. The average was taken from these plants and recorded as number of secondary branches plant⁻¹.

3.4.1.7 Crop growth rate (g m⁻² day⁻¹)

Crop growth rate (CGR) (g m⁻² day⁻¹) at 0-30 DAT, 30-60 DAT and 60-90 DAT was calculated by using the dry matter accumulation (g) of plant from each plot at 30, 60 and 90 DAT with the following formula (Watson, 1956):

$$\text{CGR} = \frac{W_2 - W_1}{(t_2 - t_1)S}$$

Where, W₁ and W₂ are the dry weights of plants at t₁ and t₂, respectively. S is the land area (m²) over which dry matter was recorded.

3.4.1.8 Relative growth rate (g g⁻¹ day⁻¹)

The Relative growth rate (RGR) (g g⁻¹ day⁻¹) at 0-30 DAT, 30-60 DAT and 60-90 DAT was also calculated using the data of dry matter accumulation (g) of plant from each plot at 30, 60 and 90 DAT with the following formula (Blackman, 1919):

$$\text{RGR} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

Where, W₁ and W₂ are the dry matter produced by a gram (g) of existing dry matter in the day at a time t₁ and t₂, respectively.

3.4.1.9 Net assimilation rate (g m⁻² day⁻¹)

The Net assimilation rate (g m⁻² day⁻¹) at 0-30 DAT, 30-60 DAT and 60-90 DAT

also calculated using the data of dry matter accumulation (g) of plant from each at 30, 60 and 90 DAT with the following formula (William 1946):

$$NAR = \frac{(W_2 - W_1) \times (\ln L_2 - \ln L_1)}{(t_2 - t_1) \times (L_2 - L_1)}$$

Where

L_1 and W_1 are leaf area and dry weight of the plant, respectively at time t_1 ,

L_2 and w_2 are leaf area and dry weight of the plant respectively at time t_2 .

3.4.2. Yield attributes

3.4.2.1 Number of siliquae plant⁻¹

From all the tagged five plants of all the plots, number of siliquae were counted and the average number of siliquae was recorded and used for statistical analysis.

3.4.2.2 Length of siliqua (cm)

From the selected five tagged plants of all the plot, five siliquae were selected randomly and length of each siliqua was measured in centimeter from the joint of the stalk to the tip of the beak of the siliqua. The average of five siliqua was recorded

3.4.2.3 Weight of siliqua plant⁻¹ (g)

In order to measure the weight of the siliqua plant⁻¹, five siliquae were randomly selected from each plot of the tagged plant. and weight was measured in gram and average values were recorded.

3.4.2.4 Number of seed siliqua⁻¹

Five selected siliquae were selected from the tagged plant of each plot in order to record the number of seed. The number of seed was counted from each siliqua and the average values was recorded for analysis.

3.4.2.5 Test weight (g)

The seed from the five tagged plants were collected from each plot and thousands of seeds were separated and weighed in gram after drying to 14% moisture.

3.4.2.6 Seed yield (kg ha⁻¹)

After drying and cleaning, the seeds were properly dried in the sun. The seeds of each plot were weighed and recorded in kilogram which was converted into kg ha⁻¹.

3.4.2.7 Stover yield (kg ha⁻¹)

After threshing, the crop biomass was dried separately for each plot followed by weighing of the biomass in kilogram which was converted into kg ha⁻¹.

3.4.2.8 Harvest index (%)

Harvest index was calculated by using the formula given by Donald (1962).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (grain yield)}(\text{kg ha}^{-1})}{\text{Biological yield (grain + straw yield)}(\text{kg ha}^{-1})} \times 100$$

3.4.3 Yield quality

3.4.3.1 Seed oil content (%)

For oil extraction, seeds of 5g from each treatment plot were taken. The seeds were fine grinded and placed in a thimble containing acetone. Then, the thimbles were arranged and placed in Soxhlet extraction unit as per the method described by A.O.A.C., 1975 for one and half hours by maintaining the different temperature range during the extraction procedure. The extraction was then transferred to weighed flask and the weight was taken. The formula used for estimation of oil content in seeds was as follows:

$$\text{Oil content (\%)} = \frac{W_2 - W_1}{X} \times 100$$

Where, W_1 = weight of the empty flask (g)

W_2 = weight of the empty flask + weight of oil (g)

X = weight of the sample taken for extraction (g)

3.4.3.2 Oil yield (kg ha^{-1})

The estimated oil yield kg ha^{-1} was carried out by multiplying the seed yield by oil content in the seed.

Oil yield (kg ha^{-1}) = Seed yield x Oil content (%) in the seed

3.4.4 Soil analysis

The soil samples were collected treatment wise from the experimental field before sowing and after harvesting of the main crop. The collected soil samples were shade dried, ground and sieved through 2 mm sieve for further use for analysis of soil texture, pH, bulk density, soil organic carbon and available soil nitrogen, phosphorus and potassium.

3.4.4.1 Soil texture

Soil texture was determined by international pipette method as outlined by Piper (1966).

3.4.4.2 Soil pH (soil reaction)

Soil pH was determined in soil: water (1:2) ratio by digital pH meter (Jackson, 1967).

3.4.4.3 Electrical conductivity (dS m^{-1})

Electrical conductivity of the clear soil water (1:2.5) extract was determined using electric conductivity (dSm^{-1}) bridge (Jackson, 1973).

3.4.4.4 Soil organic carbon (%)

Organic carbon of soil was determined by rapid titration method as described by Walkley and Black method (1934) and the results were expressed in terms of percentage.

3.4.4.5 Available nitrogen (kg ha^{-1})

The available soil nitrogen was determined by alkaline potassium permanganate method proposed by Subbiah and Asija (1956). The procedure involves determination of ammonia liberated on distillation of alkaline potassium permanganate solution using 'Kel Plus' nitrogen distillation machine. This serves as an index of the available soil nitrogen and the data is calculated in terms of kg ha^{-1} .

3.4.4.6 Available phosphorus (kg ha^{-1})

Available phosphorus was determined by using Bray's No. 1 method as outlined by Bray and Kurtz (1945). In this method, soil was extracted using $0.03 \text{ N NH}_4\text{F} + 0.025 \text{ N HCL}$ (pH 3.5) and available phosphorus was estimated colorimetrically using ascorbic acid method where ammonium molybdate and stannous chloride was added to the filtered extract. The intensity (% transmittance) of characteristic blue colour in the solution gives the measure for the concentration of P in the test solution, which was read in the spectrometer at 660 nm wavelength. After getting % transmittance of the P in the test solution, concentration of P was read from the standard curve. The results were expressed in kg ha^{-1} . The procedure is primarily meant for soils which is moderate to strongly acidic with pH around 5.5 or less.

3.4.4.7 Available potassium (kg ha^{-1})

The available potassium was extracted from 5 g of soil by shaking with 25 ml of neutral ammonium acetate (pH 7) solution for 5 minutes and the extract was filtered immediately using dry Whatman No. 1 filter paper and then potassium concentration in the extract was determined by using Flame Photometer (Hanway and Heidal, 1952). The data is expressed in terms of kg ha^{-1} .

3.4.5 Chemical analysis of plant

3.4.5.1 N, P and K content in grain and straw (%)

After harvesting, plants were randomly selected, dried and threshed properly for each plot. The grains and straw were separated, air dried and then finally oven dried at a temperature 65°C. The samples were ground to powder and subjected to chemical estimation for N, P and K content using the following methods.

Nutrient	Method
Nitrogen	Modified Kjeldhal method as described by (Black, 1965)
Phosphorous	Vanado-molybdate-phosphoric acid method (Jackson, 1973)
Potassium	Flame photometer (Chapman and Pratt, 1961)

3.4.5.2 N, P and K uptake in grain and straw (kg ha⁻¹)

Nutrient uptake by crop is the amount of nutrient taken up by the crop. Nutrient uptake in grain and straw was estimated by multiplying percentage nutrient content in their respective grain or straw with grain or straw yield. The crop nutrient uptake was computed using the formula below:

$$\begin{aligned} &\text{Nutrient uptake in grain (kg ha}^{-1}\text{)} \\ &= \frac{\text{Percent nutrient content in grain (\%)} \times \text{Grain yield (kg ha}^{-1}\text{)}}{100} \end{aligned}$$

$$\begin{aligned} &\text{Nutrient uptake in straw (kg ha}^{-1}\text{)} \\ &= \frac{\text{Percent nutrient content in straw (\%)} \times \text{Straw yield (kg ha}^{-1}\text{)}}{100} \end{aligned}$$

3.5 Efficiency Parameter

3.5.1 Water use efficiency (WUE)

Water use efficiency is the ratio of crop yield (Y) to the amount of water depleted by the crop in the process of evapotranspiration. It is expressed in kg ha⁻¹cm.

$$WUE = \frac{Y}{ET}$$

Where, Y = Yield Kg ha⁻¹

ET = Evapotranspiration (cm)

3.5.2 Partial Factor Productivity (PFP)

Partial factor productivity is the ratio of total output to a single input like output/input, output/machine, output/capital, or output/energy. The output and input of PFP can be expressed in the same unit of measure or output per rupee invested in the input.

$$PFP = \frac{\text{Total output}}{\text{Single input}}$$

3.5.3 Agronomic efficiency (AE)

Agronomic efficiency is the additional grain yield produced due to application of nutrients over unfertilized control per unit of nutrient applied. It is expressed in kg kg⁻¹

$$AE = \frac{GY_n - GY_0}{N_a}$$

Where, GY_n = Grain or economic yield with nutrient

GY₀ = Grain or economic yield without nutrient

N_a = Nutrient applied

3.5.4 Physiological efficiency (PE)

Physiological efficiency is the additional biological yield produced due to application of nutrient uptake over unfertilized control. It is expressed in kg kg⁻¹.

$$PE = \frac{BY_n - BY_0}{NU_n - NU_0}$$

Where, BY_n = Biological yield with nutrient

BY₀= Biological yield without nutrient

NU_n=Nutrient uptake with nutrient

NU₀=Nutrient uptake without nutrient

3.5.5 Sustainability index (SI)

Sustainability index indicates how sustainable a management practice.

It can be computed by

$$SI = \frac{\bar{Y} - \sigma}{Y_{\max}}$$

Where, $\bar{Y}$ =Average yield of the management practice over years

σ = Standard deviation of yield of the management practice over years

$Y_{\max}$ = Observed maximum yield of the experiment

3.5.6 System productivity

System productivity will be calculated in terms of rice equivalent yield (REY).

$$REY = \frac{\text{Yield of toria (kg ha}^{-1}\text{)} \times \text{price of toria (₹ kg}^{-1}\text{)}}{\text{Price of rice (₹ kg}^{-1}\text{)}}$$

System productivity = REY + Yield of rice (kg ha⁻¹)

3.6 Economic analysis

Economics of different treatments was worked out as per existing market prices.

3.6.1 Cost of cultivation (₹ ha⁻¹)

The cost of cultivation was calculated as per item wise cost incurred in each treatment.

3.6.2 Gross return (₹ ha⁻¹)

Gross return for each treatment was calculated by multiplying the values of economic produce with the prevailing support price of output.

3.6.3 Net return (₹ ha⁻¹)

Net return of each treatment was calculated by subtracting the total cost of cultivation from the gross return.

$$\text{Net return} = \text{Gross return} - \text{Total cost of cultivation}$$

3.6.4 Benefit Cost ratio

Benefit cost ratio was estimated by using the formula:

$$B:C = \frac{\text{Net return}}{\text{Cost of cultivation}} \times 100$$

3.7 Statistical analysis

Data obtained from various studies were statistically analyzed in randomised block design and split plot design using the technique of Analysis of Variance as described by Gomez and Gomez (1984). Pooled analysis of data were also carried out to establish the trend of the treatments applied following Gomez and Gomez (1984). The significance differences were tested by 'F' test. Critical difference of different groups of treatments and their interactions at 5 per cent probability level were calculated whenever 'F' test was significance.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The field experiment entitled “Effect of precision nitrogen management and irrigation regimes in rice- toria cropping system in Dimapur District of Nagaland” was carried out during *kharif* and *rabi* seasons of 2022-23 and 2023 -24 on sandy loam soil at ICAR Research Farm, Jharnapani, Nagaland. Various biometric observations influenced by different precision nitrogen management on growth, phenological, physiological parameters, yield attributes and yield of rice and different irrigation regimes on growth, yield attributes, physiological parameters, yield, oil contents and seed yield of toria crop were studied. The laboratory analysis on content and uptake of N, P and K by the crops, physio-chemical properties of soil after the harvest of both the crops were recorded. The results obtained are presented in this chapter with the help of data, illustration, diagram, wherever necessary.

4.1 Effect of precision nitrogen management on growth parameters of rice

4.1.1 Plant height (cm)

Data relevant to the average plant height is presented in Table 4.1 and graphically presented in Fig. 4.1. The plant height of the rice was recorded at 30, 60 and 90 DAT. At 30 DAT precision nitrogen management do not show any significant effect on the plant height in both the year. But at 60 and 90 DAT, precision nitrogen management show significant effect on plant height in both the years and pooled data. The data of plant height was comparatively higher in second year as compared to first year data.

At 60 DAT, the maximum plant height (89.67 cm and 90.19 cm) was recorded from SPAD based N application followed by LCC based N application (88.48 cm and 89.25 cm) and split application of N (85.54 cm and 86.31 cm) in both the years. The lowest plant height was recorded from control at 60 DAT. At 90 DAT, the highest plant height (110.50 cm and 111.53 cm) was also recorded from N₄ i.e. SPAD based N application followed by LCC based N application (109.53 cm and 110.74 cm) and N₂ (107.65 cm and 108.88 cm). The pooled data also implied significant effect by precision nitrogen management.

This might be due to synchrony in application of nitrogen with crop nitrogen demand which led to increased cell division and elongation which increases the inter nodal length sequentially increase the plant height. Similar outcome was made by Suresh *et al.* (2017 a&b), Goudra *et al.* (2019), Bhattarai *et al.* (2024). The highest plant height might also be attributed to applied nitrogenous fertilizer which accelerated the metabolic and physiological activity of the plant and put up more growth by assimilating more amounts of major nutrients and ultimately increased the plant height. These results are in close conformity with finding of Pramanik and Bera (2013) and Kumar *et al.* (2017).

4.1.2 Plant population m⁻²

The data relevant to plant population m⁻² of rice as influenced by precision nitrogen management is presented in Table 4.2. It is observable from the data that the precision nitrogen management did not show any significant variation at 30 and 60 DAT.

4.1.3 Number of tillers m⁻²

The data related to number of tillers m⁻² of rice as influenced by precision nitrogen management is presented in table 4.3. and graphically presented in Fig. no.4.2. It is evident from the data that the precision nitrogen management significantly affected number of tillers at 30 and 60 DAT in both the years and in pooled data also.

At 30 DAT, the treatment N₄ recorded the highest number of tillers (248.00 and 249.67) in both the years but was found to be statistically at par with LCC based N management. The lowest was recorded from the treatment N₁. Similarly at 60 DAT, the highest number of tillers (277.10 and 278.49) was recorded from the SPAD based N application followed by LCC based N application and split application of N in both years observation and in pooled also. The lowest number of tillers (147.47 and 148.25) from the control plot i.e. N₁.

The higher rate of N application at higher SPAD value was beneficial for tiller production. This might be due to favourable effect of N on cell division and tissue

organization that ultimately improved tiller formation at tillering stage. Ghosh *et al.* (2013) and Rajesh *et al.* (2017). This might also be due to better availability of nutrients from applied nitrogen fertilizer and supply of soil nitrogen over time and space to balance the requirements of crops by applying the right amount of nitrogen at right time. This result is in conformity with Singh *et al.* (2017a&b).

4.1.4 Dry matter accumulation plant⁻¹ (g)

The data relevant to dry matter accumulation plant⁻¹ as influenced by precision nitrogen management is presented in Table 4.4. It is evident from the data that the precision nitrogen significantly influenced on dry matter accumulation at 0-30, 30-60 and 60-90 DAT. The data of second year was higher than the first year data.

At 0-30 DAT, the maximum dry matter accumulation (7.20 and 7.51 g) was recorded from the SPAD based N application but found to statistically at par with LCC based N application in both the years. At 30-60 DAT, SPAD based N application was found to be superior and recorded maximum dry matter accumulation (14.16 and 14.29g) and found to be statistically at par with LCC based N application (13.18 and 13.40 g) in both the years. At 60-90 DAT, the data revealed that maximum dry matter accumulation was recorded in treatment N₄ (27.99 and 28.38 g) which was statistically at par with treatment N₃ (26.85 and 27.37g) in both years of experiment. At all the stages, the lowest dry matter accumulation was recorded from the control plot i.e N₁. in both years observations.

Leaf area is increased due to synchronization of applied nitrogen between crop demand and supply leads to development of more and more chlorophyll pigments which lead to increase specific leaf weight and result in higher light interception, root development, leaves development and plant height and thus resulted in better dry matter production. Similar finding was also made by Ghosh *et al.* (2013) and Goudra *et al.* (2019).

4.1.5 Crop growth rate (g m⁻² day⁻¹)

The data relevant to Crop growth rate as influenced by precision nitrogen

management is presented in Table 4.5. It is observed from the data that the precision nitrogen management had no significant effect on crop growth rate at 0-30 DAT while a significant increased on crop growth rate was found at 30-60 and 60-90 DAT for both the years and pooled data also.

At 30-60 DAT, the highest crop growth rate was recorded from the SPAD based N application (13.25 and 13.75) followed by LCC based N application and split application of N in both the years. Similarly, at 60-90 DAT highest crop growth rate was recorded from the treatment N₄ followed by N₃ and N₂. In both years, the lowest crop growth rate was recorded from the control plot i.e. N₁.

Since the crop growth rate is basically the accumulation of total dry matter production over a given period of time and area, it is assumed that the more accumulation rate of total dry matter was the cause of the higher crop growth rate. SPAD Meter practice can optimize nitrogen application rates, ensuring that the crop receives the appropriate amount of nitrogen at the right time and in the right place. This can lead to improved nitrogen use efficiency and a higher CGR. This is in conformity with the findings of Malviya *et al.* (2018), Shivashankar *et al.* (2022) and Nayak *et al.* (2023).

4.1.6 Relative growth rate ($\text{g g}^{-1}\text{day}^{-1}$)

The data relevant to relative growth rate as influenced by precision nitrogen management is presented in Table 4.6. It is observed from the data that the precision nitrogen management showed significant effect on relative growth rate at 0-30 DAT but did not show any significant effect on relative growth rate at 30-60 and 60-90 DAT in both the years and pooled data also. The data of first year was higher than the second year data. At 0-30 DAT, the maximum relative growth rate was recorded from the SPAD based N application (0.0661 and 0.0298) followed by LCC based N application (0.0624 and 0.0278) and RDF (0.0545 and 0.0247) in both years of experiment.

Table 4.1 Effect of precision nitrogen management on plant height (cm) of rice at 30 days interval

Plant height (cm)	30 DAT			60 DAT			90 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	53.45	53.67	53.56	82.25	83.38	82.82	103.37	104.81	104.09
N ₂	55.36	55.66	55.51	85.54	86.31	85.93	107.65	108.88	108.26
N ₃	57.31	57.50	57.41	88.48	89.25	88.86	109.56	110.74	110.15
N ₄	59.68	59.77	59.72	89.67	90.19	89.93	110.55	111.53	111.04
SEm±	2.37	2.43	1.70	0.18	0.19	0.13	0.10	0.15	0.09
CD (P=0.05)	NS	NS	NS	0.62	0.65	0.40	0.35	0.53	0.28

Table 4.2 Effect of precision nitrogen management on plant population m⁻² of rice at 30 days interval

Plant population	30 DAT			60 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled
N ₁	12.71	12.92	12.82	13.35	13.70	13.53
N ₂	13.74	13.98	13.86	14.52	14.60	14.56
N ₃	14.67	14.92	14.80	14.82	14.69	14.75
N ₄	15.26	15.42	15.34	15.92	15.99	15.96
SEm±	1.11	1.33	0.87	1.30	1.32	0.93
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Where, N₁- Control,

N₂- Split application of N,

N₃- LCC based N application and

N₄- SPAD based N application.

Table 4.3 Effect of precision nitrogen management on number of tillers m⁻² of rice at 30 days interval

Number of tillers m ⁻² .	30 DAT			60 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled
N ₁	142.11	144.00	143.06	147.47	148.25	147.86
N ₂	223.41	225.78	224.59	243.24	246.27	244.75
N ₃	245.65	246.33	245.99	257.49	258.59	258.04
N ₄	248.00	249.67	248.83	277.10	278.49	277.80
SEm±	3.26	3.76	2.49	4.90	4.98	3.49
CD (P=0.05)	11.30	13.02	7.67	16.95	17.23	10.76

Table 4.4 Effect of precision nitrogen management on dry matter accumulation plant⁻¹ (g) of rice at 30 days interval

DMA plant ⁻¹ (g)	0-30 DAT			30-60 DAT			60-90 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	4.51	4.66	4.59	11.19	11.93	11.56	22.29	23.05	22.67
N ₂	5.14	5.55	5.34	12.29	12.96	12.62	24.77	25.43	25.10
N ₃	6.23	6.85	6.54	13.18	13.40	13.29	26.85	27.37	27.11
N ₄	7.20	7.51	7.36	14.16	14.29	14.23	27.99	28.38	28.19
SEm±	0.30	0.31	0.21	0.33	0.34	0.24	0.37	0.40	0.27
CD (P=0.05)	1.04	1.06	0.66	1.15	1.16	0.73	1.28	1.39	0.84

Where, N₁- Control,

N₂- Split application of N,

N₃- LCC based N application and

N₄- SPAD based N application

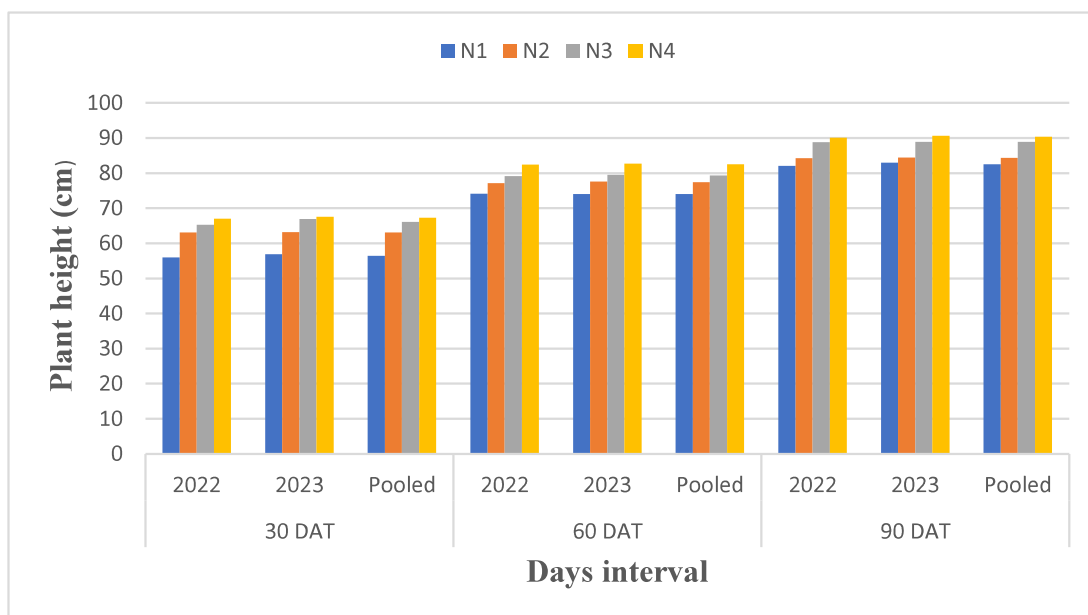


Fig. 4.1 Effect of precision nitrogen management on plant height of rice at 30 days interval

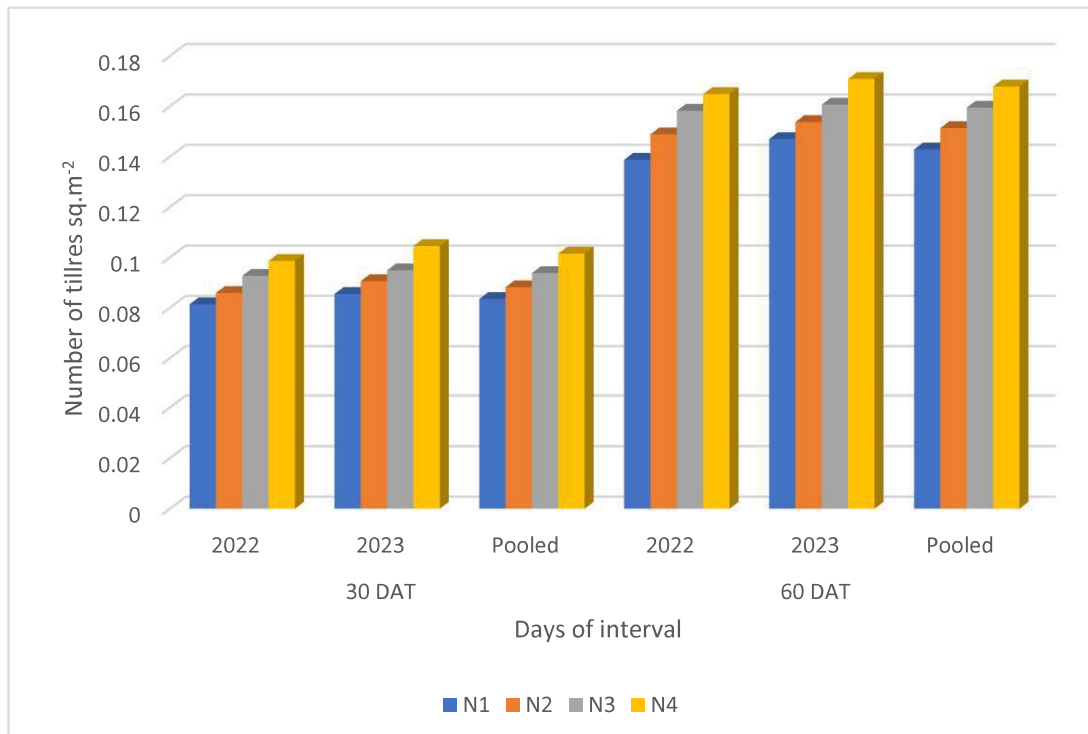


Fig 4.2 Effect of precision nitrogen management on number of tillers sq. m of rice at 30 days interval

In both year observation, the lowest relative growth rate was recorded from the control plot (0.0502 and 0.0228).

The increases in RGR due to the above treatments might be due to stimulating effects of organic manures thus enhancing crop growth. These results are in close agreement with those of Nayak *et al.* (2023) and Malviya *et al.* (2018).

4.1.7 Net assimilation rate ($\text{g m}^{-2} \text{ day}^{-1}$)

The data related to net assimilation rate as influenced by precision nitrogen management is presented in Table 4.7. It is evident from the data that the precision nitrogen management showed significantly influenced on net assimilation rate at 0-30 DAT but did not show any significant effect on net assimilation rate at 30-60 and 60-90 DAT in both the years and pooled data also. The data of second year was higher than the first year data.

At 0-30 DAT, the maximum net assimilation rate was recorded the highest from the SPAD based N application (0.0366 and 0.0367) followed by LCC based N application (0.0341 and 0.0354) and split application of N (0.0283 and 0.0296) in both years. In both year observation, the lowest relative growth rate was recorded from the control plot (0.0258 and 0.0261).

It is profoundly clear that split nitrogen application coordinated with crop demand in precision N management utilizing SPAD and LCC led to improved nitrogen availability, which in turn increased growth and produced higher growth indices. The results are also in agreement with Kumar *et al.* (2019), Mohapatro and Shankar (2022) and Shivashankar *et al.* (2023).

4.1.8 Leaf Area Index

The data relevant to leaf area index as influenced by precision nitrogen management is presented in Table 4.8 and graphically presented in Fig 4.3. It is observed from the data that the precision nitrogen management significantly influenced on leaf area index at 30 and 60 DAT in both the years and pooled data also.

At 30 DAT, SPAD based N application recorded significantly maximum leaf area index (0.0986 and 0.1045) followed by LCC based N application and split application of N in both the years and the lowest leaf area index was recorded from the control plot in both the years. Similarly, at 60 DAT also SPAD based N application recorded highest leaf area index (0.1649 and 0.1583) but was found to be statistically at par with LCC based N application (0.0938 and 0.1607). From both years of data observation, the lowest leaf area index (0.1388 and 0.1470) was recorded from the control plot.

A high dose of nitrogen application can prolong the life of leaves, resulting in a higher LAI. However, it is important to note that excessive nitrogen application can lead to adverse effects such as lodging, nutrient imbalances, and environmental pollution. Therefore, the nitrogen dose should be optimized based on the specific requirements of the rice crop, taking into account factors such as soil fertility, water availability, and climate conditions Sen *et al.* (2011) and Mohanta *et al.* (2021).

The increase in leaf area index might be due to increased nitrogen levels which favoured higher uptake of nutrients by crop, that lead to rapid development in the cell number and elongation which ultimately lead to increased number and size of the leaves and these results are in close conformity with Gupta *et al.* (2011), Ghosh *et al.* (2013) Mathukia *et al.* (2014), Haque and Haque (2016), Reena *et al.* (2017)., and Sowmya *et al.* (2023).

4.1.9 Relative water content (%)

The data relevant to relative water content as influenced by precision nitrogen management is presented in Table 4.9 and graphically presented in Fig.4.4. It is evident from the data that the precision nitrogen management showed highly significant effect on relative water content on 30, 60 and 90 DAT. The observation of second year data was comparatively higher than the first year.

At 30 DAT, SPAD based N management recorded the maximum relative water content (66.97 and 67.54 %) but it was found to be statistically at par with LCC based

N management (65.28 and 66.90 %) and RDF (63.07 and 63.20 %) in both the years. The lowest relative water content was recorded from the control plot. At 60 DAT, SPAD based N management was found to be superior and recorded the maximum relative water content (82.40 and 82.69 %) and found to be statistically at par with LCC based N management (79.53 and 79.53 %) and RDF (77.14 and 74.06 %) in both the years. At 90 DAT, data revealed that the highest relative water content (90.11 and 90.67 %) was recorded under the SPAD based N management which was found to be statistically at par with all the remaining treatments. At all the stages, the minimum relative water content was recorded from the control plot in both the years of observation.

The maximum relative water content observed under precision nitrogen management results from optimized nutrient availability, increase plant growth, improved water use efficiency, and reduced nitrogen loss. Implementing precision agriculture techniques not only increases the crop yield but also supports effective management of water resources, crucial for sustainable agricultural practices. The interconnectedness of nutrient management, plant health, and water retention emphasizes its importance in modern agriculture.

4.2 Effect of precision nitrogen management on phenological parameters of rice

4.2.1 Days to flowering

The data relevant to the number of days to flowering as influenced by the precision nitrogen management is presented in the Table 4.10. It is evident from the data that precision nitrogen management did not show any significant effect in both the years of observation and in pooled data also.

4.2.2 Days to maturity

The data relevant to the number of days to maturity as influenced by the precision nitrogen management is presented in the Table 4.11. It is observed from the data that precision nitrogen management did not showed significant effect on Days to maturity in both the years of observation and in pooled also.

Table 4.5 Effect of precision nitrogen management on CGR of rice at 30 days interval

CGR	0-30 DAT			30-60 DAT			60-90 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	7.52	7.77	7.64	11.62	11.87	11.74	17.96	18.92	18.44
N ₂	8.57	9.24	8.91	11.98	12.21	12.09	20.74	20.98	20.86
N ₃	10.59	11.42	11.00	12.24	12.34	12.29	22.09	22.72	22.41
N ₄	12.12	12.59	12.36	13.25	13.75	13.50	21.28	21.07	21.18
SEm±	2.23	2.28	1.59	0.15	0.18	0.12	0.51	0.60	0.39
CD (P=0.05)	NS	NS	NS	0.50	0.64	0.36	1.77	2.07	1.21

Table 4.6 Effect of precision nitrogen management on RGR of rice at 30 days interval

RGR	0-30 DAT			30-60 DAT			60-90 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	0.0502	0.0228	0.0362	0.0305	0.0126	0.0216	0.0221	0.0098	0.0159
N ₂	0.0545	0.0247	0.0396	0.0292	0.0123	0.0207	0.0236	0.0099	0.0166
N ₃	0.0624	0.0278	0.0451	0.0244	0.0103	0.0174	0.0228	0.0098	0.0163
N ₄	0.0661	0.0298	0.0477	0.0246	0.0107	0.0177	0.0203	0.0085	0.0144
SEm±	0.0005	0.0003	0.0003	0.0087	0.0034	0.0047	0.0006	0.0029	0.0015
CD (P=0.05)	0.0017	0.0011	0.0009	NS	NS	NS	NS	NS	NS

Where, N₁- Control,

N₂- Split application of N,

N₃- LCC based N application and

N₄- SPAD based N application.

Table 4.7 Effect of precision nitrogen management on NAR of rice at 30 days interval

NAR	0-30 DAT			30-60 DAT			60-90 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	0.0258	0.0258	0.0258	0.0108	0.0106	0.0107	0.0107	0.0108	0.0108
N ₂	0.0283	0.0296	0.0289	0.0105	0.0102	0.0103	0.0115	0.0113	0.0114
N ₃	0.0341	0.0354	0.0348	0.0099	0.0105	0.0102	0.0114	0.0109	0.0111
N ₄	0.0366	0.0366	0.0366	0.0103	0.0102	0.0102	0.0111	0.0105	0.0107
SEm±	0.0005	0.0007	0.0004	0.0029	0.0048	0.0028	0.0032	0.0002	0.0016
CD (P=0.05)	0.0017	0.0023	0.0013	NS	NS	NS	NS	NS	NS

Table 4.8 Effect of precision nitrogen management on leaf area index (LAI) of rice at 30 days interval

Leaf area index	30 DAT			60 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled
N ₁	0.0814	0.0855	0.0835	0.1388	0.147	0.1429
N ₂	0.0859	0.0906	0.0882	0.1489	0.1538	0.1514
N ₃	0.0927	0.0949	0.0938	0.1583	0.1607	0.1595
N ₄	0.0986	0.1045	0.1015	0.1649	0.1709	0.1679
SEm±	0.00063	0.00055	0.00042	0.0029	0.0028	0.0021
CD (P=0.05)	0.0022	0.0019	0.0013	0.0104	0.0098	0.0063

Where, N₁- Control,

N₂- Split application of N,

N₃- LCC based N application and

N₄- SPAD based N application.

Table 4.9 Effect of precision nitrogen management on relative water of rice at 30 days interval

RWC (%)	30 DAT			60 DAT			90 DAT		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	55.95	56.90	56.43	74.09	74.06	74.07	82.02	82.97	82.50
N ₂	63.07	63.20	63.13	77.14	77.60	77.37	84.22	84.44	84.33
N ₃	65.28	66.90	66.09	79.15	79.53	79.34	88.78	88.94	88.86
N ₄	66.97	67.54	67.26	82.40	82.69	82.54	90.11	90.67	90.39
SEm±	3.05	3.55	2.34	2.19	2.23	1.56	3.44	3.93	2.61
CD (P=0.05)	10.57	12.29	7.22	7.57	7.73	4.82	11.90	13.61	8.05

Where, N₁- Control,

N₂- Split application of N,

N₃- LCC based N application and

N₄- SPAD based N application.

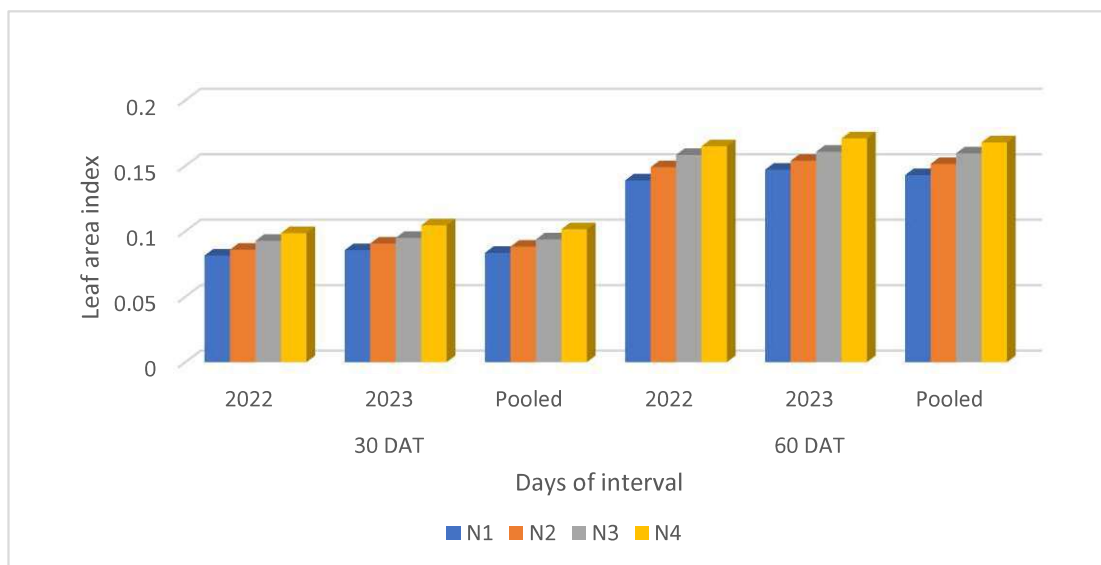


Fig. 4.3 Effect of precision nitrogen management on leaf area index (LAI) of rice at 30 days interval

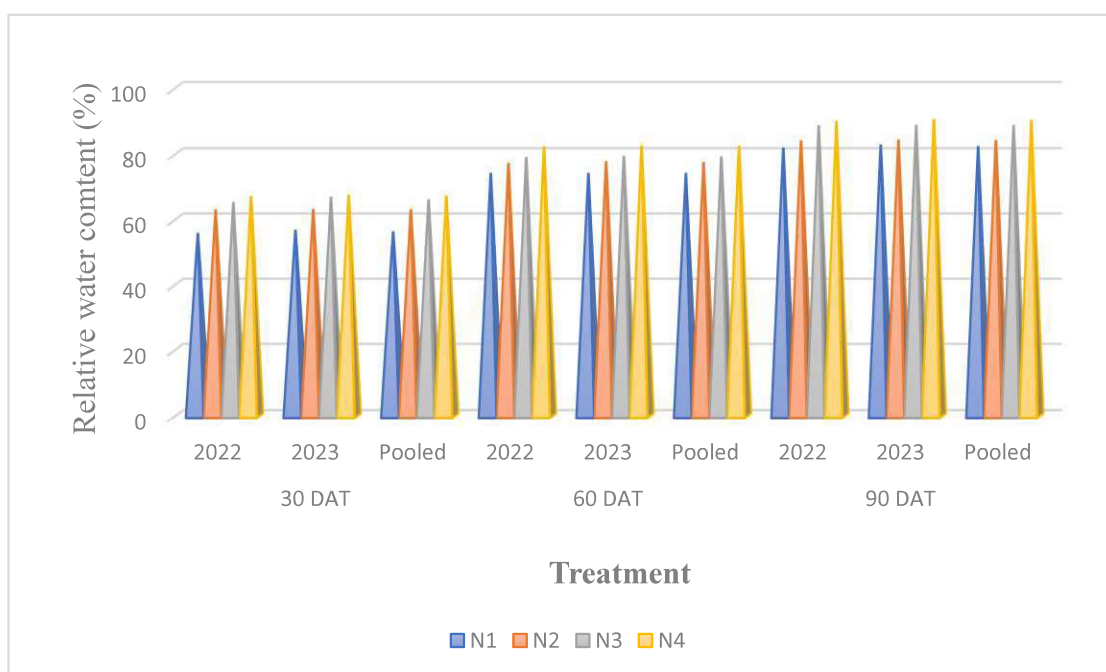


Fig. 4.4 Effect of precision nitrogen management on relative water content of rice at 30 days interval

4.3 Effect of precision nitrogen management on yield attributes and yield of rice

4.3.1 Number of panicles m⁻²

The data relevant to the number of panicles sq.m⁻¹ as influenced by precision nitrogen management is presented in Table 4.11. and graphically presented in Fig 4.5. It is evident from the data that precision nitrogen management significantly enhanced on number of panicles sq.m⁻¹ in both years of data observation.

SPAD based N application found to be superior and recorded highest number of panicles m⁻² (255.39 and 258.56) followed by LCC based N application and RDF in both the years of observation. The lowest was recorded from the treatment N₁ i.e. control plot.

The highest number of panicles increases with precision nitrogen management was might be owing to uptake of nitrogen as per crop need which had substantial role to play in photosynthesis and tillering of rice and later converted to productive tillers, whereas the treatments RDF received higher dose of N and might have produced higher number panicles m⁻². Similar outcomes were reported by Tabar (2012), Satpute *et al.* (2015), Ali *et al.* (2017) Dinesh *et al.* (2017), Goudra *et al.* (2019) and Yadav *et al.* (2023).

4.3.2 Panicle length (cm)

The data relevant to the number of panicles sq.m⁻¹ as influenced by precision nitrogen management is presented in Table 4.12 and graphically presented in Fig 4.6. It is evident from the data that precision nitrogen management showed significant effect on panicle length(cm) in both years of data observation.

SPAD based N application found to be superior and recorded longest panicle length (25.73 and 25.94 cm) but was found to be statistically at par with LCC based N application (25.29 and 25.55 cm) and split application of N in both the years of observation. The lowest was recorded from the treatment N₁ i.e. control plot.

Similar results were also made by Goudra *et al.* (2019) and (Yadav *et al.* (2023).

4.3.3 Weight of panicle (g)

The data pertinent to the weight of panicle as influenced by precision nitrogen management is presented in Table 4.12. and Fig 4.6. It is evident from the data that precision nitrogen management show significantly affected on weight of panicle (g) in both years of data observation.

SPAD based N application found to be superior and recorded highest weight of panicle (5.26 and 5.63 g) followed by LCC based N application (4.62 and 4.84 g) split application of N in both the years of observation. The lowest was recorded from the treatment N₁ i.e. control plot.

The increase in weight of panicle was might be due to constant and suitable availability of nitrogen during the late growth stages (panicle initiation to flowering) which resulted in translocation of carbohydrates, proteins and mineral nutrients from different sources during the grain filling stage and directed to the formation of a greater number of filled grains and large sized grains leading to increased grain weight panicle⁻¹. Similar results were reported by Sen *et al.* (2011), Jain (2016) and Sheeraz *et al.* (2017).

4.3.4 Number of unfilled grains panicle⁻¹

The data relevant to the number of unfilled grain panicles⁻¹ as influenced by precision nitrogen management is presented in Table 4.12. It is evident from the data that the precision nitrogen management did not show any significant effect on number of unfilled grains panicle⁻¹ in both years of data observation.

4.3.5 Number of filled grain panicle⁻¹

The data relevant to the number of filled grain panicles⁻¹ as influenced by precision nitrogen management is presented in Table 4.12. It is evident from the data that precision nitrogen management showed significant effect on number of filled grain panicle⁻¹ in both years of data observation. The number of filled grain panicle⁻¹ of second year was comparatively higher than the first year.

Table 4.10. Effect of precision nitrogen management on phenological parameters of rice.

Treatment	Days to flowering				Days to maturity		
	2022	2023	Pooled		2022	2023	Pooled
N ₁	81.40	81.50	81.45		119.26	119.35	119.31
N ₂	82.18	82.58	82.38		120.27	120.35	120.31
N ₃	80.03	80.35	80.19		118.03	118.59	118.31
N ₄	79.55	79.88	79.71		117.49	117.99	117.74
SEm±	1.32	1.34	0.94		1.30	1.32	0.93
CD (P=0.05)	NS	NS	NS		NS	NS	NS

Table 4.11 Effect of precision nitrogen management on number of panicles sq. m⁻¹, panicle length and weight of panicle of rice

Treatment	Number of panicles m ⁻²			Panicle length (cm)			Weight of panicle (g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	121.67	125.11	123.39	23.26	24.60	23.93	3.63	3.75	3.69
N ₂	224.93	229.00	226.96	24.35	25.49	24.92	3.65	3.91	3.78
N ₃	232.11	234.53	233.32	25.29	25.55	25.42	4.62	4.84	4.73
N ₄	255.39	258.56	256.97	25.73	25.94	25.84	5.26	5.63	5.45
SEm±	1.20	1.27	0.87	0.15	0.17	0.11	0.10	0.12	0.08
CD (P=0.05)	4.14	4.38	2.68	0.51	0.60	0.35	0.34	0.41	0.24

Where, N₁-Control, N₂-Split application of N, N₃- LCC based N application and N₄- SPAD based N application

SPAD based N application was found to be superior and recorded maximum number of filled grain panicle⁻¹ (152.29 and 153.51) followed by LCC based N application (143.29 and 145.33) and split application of N in both the years of observation. The lowest was recorded from the treatment N₁ i.e. control plot.

The increased in number of filled grain plant⁻¹ in precision nitrogen management is might be due to the application of N through precision nitrogen management which enhanced photosynthetic capacity and promoted carbohydrate accumulation in culms and leaf sheaths and also contributed to spikelet production during early panicle formation stage and decreased the sterility percentage consequently increased number of filled grains panicle⁻¹ during the late panicle formation stage as nitrogen have played an important role in grain filling. The control plot without application of nitrogen could not meet the nitrogen need of the crop particularly during its reproductive period resulting in lower number of spikelet's and filled grains panicle⁻¹. The findings are in accordance with the findings of Satpute *et al.* (2015), Suresh *et al.* (2015) and Premalatha (2017).

Adequate N supply during reproductive growth phase was possibly liable in increasing the yield parameters and yield of the crop. Higher yield attributes were attributed by higher plant height, increased number of tillers and higher total dry matter accumulation. The higher values of yield attributing characters might be attributed to the tendency of nitrogen in accelerating growth, photosynthetic activity and translocation efficiency for photosynthates to sink. This higher yield attributes under precision nutrient management practices were added due to enhanced growth attributes viz., plant height, number of tillers, leaf area and SPAD values which reflected in significantly higher total dry matter accumulation. The results were accordance with the findings of Duttarganvi *et al.* (2014), Goudra *et al.* (2019), Sow *et al.* (2023) and Bhattarai *et al.*, (2024)

4.3.6 1000 grain weight (g)

The data relevant to the test weight as influenced by precision nitrogen management is presented in Table 4.12. It is evident from the data that precision

nitrogen management had no show significant effect on test weight in both years of data observation.

4.3.7 Grain yield (kg ha⁻¹)

The data relevant to grain yield as influenced by precision nitrogen management is presented in Table 4.13 and graphically presented in Fig 4.7. It is observed from the data that precision nitrogen management significantly influenced the grain yield in both years of data observation.

SPAD based N application was found to be superior and recorded maximum grain yield (4823.33 and 4838.33 kg ha⁻¹) followed by LCC based N application (4526.67 and 4550.00 kg ha⁻¹ and split application of N in both the years of observation. The lowest was recorded from the treatment N₁ i.e. control plot.

The increase in grain yield might be due to the nutrients that were released from the organic fertilizer which favoured the higher nutrient availability and nutrient uptake and thus increased the yield. These are similar as reported by Bejbaruah *et al.* (2013), Bhatt *et al.* (2017) and Nayak *et al.* (2023).

This might also be due to timely and adequate supply of nitrogen as per the crop need that led to better crop root & shoot growth and greater nitrogen use efficiency which ultimately improved growth attributing characters like number of tillers, leaf area in different parts of plant which resulted in better translocation of photosynthates from source to sink during the crop growth. Similar results were also reported by Ghosh *et al.* (2013), Syeda *et al.* (2014), Ali *et al.* (2015), Mohanty *et al.* (2015), Liu *et al.* (2015), Prabhudev *et al.* (2017), Pateel *et al.* (2017) and Suresh *et al.* (2017) and Sowmya *et al.* (2023).

4.3.8 Straw yield (kg ha⁻¹)

The data relevant to straw yield as influenced by precision nitrogen management is presented in Table 4.14. It is observed from the data that precision nitrogen management did not show significant effect on straw yield in both years of data observation.

4.3.9 Harvest index (%)

The data relevant to harvest index as influenced by precision nitrogen management is presented in Table 4.13. It is observable from the data that precision nitrogen management had no show significant effect in both years of data observation.

4.4. Effect of precision nitrogen management on efficiency parameters.

4.4.1 Agronomic efficiency (kg kg⁻¹)

The data relevant to agronomic efficiency as influenced by precision nitrogen management is presented in Table 4.14 and graphically presented in Fig 4.8. It is observable from the data that precision nitrogen management showed significant effect on agronomic efficiency in both years of data observation.

SPAD based N management was found to be superior and recorded maximum agronomic efficiency (62.22 and 66.58 kg kg⁻¹) followed by LCC based N management (37.78 and 47.02 kg kg⁻¹) and RDF in both the years of observation.

Agronomic efficiency is a product of nutrient recovery from mineral or organic fertilizer and the efficiency with which the plant uses each additional unit of nutrient. Agronomic efficiency values observed with the treatment SPAD based nitrogen management was due to application of lesser quantity of fertilizer nitrogen and higher grain yield per unit quantity of nitrogen. This result was in accordance with Patil *et al.* (2018) and Goudra *et al.* (2021)

4.4.2 Physiological efficiency (kg kg⁻¹)

The data relevant to physiological efficiency as influenced by precision nitrogen management is presented in Table 4.14 and graphically presented in Fig 4.8. It is observable from the data that precision nitrogen management showed significantly increased on physiological efficiency in both years of data observation.

Split application of N was found to be superior and recorded maximum physiological efficiency (38.50 and 40.25 kg kg⁻¹) which was found to be statistically

at par with LCC based N application (36.57 and 38.20 kg kg⁻¹) in both the years of observation.

Higher N-use efficiency under precision N management could have resulted from timely application of N in synchronization with crop demand, but a low N-use efficiency in blanket recommendations indicates its inefficiency and waste of valuable N input. Similar outcomes were also reported by Ghosh *et al.* (2013) and Ghosh *et al.* (2020).

4.4.3 Partial factor productivity

The data related to partial factor productivity as influenced by precision nitrogen management is presented in Table 4.14 and graphically presented in Fig 4.8. It is evident from the data that precision nitrogen management showed significant effect on partial factor productivity in both years of data observation.

SPAD based N application was found to be superior and recorded maximum partial factor productivity (23.15 and 23.23) followed by LCC based N application (21.73 and 21.84) and control plot in both the years of observation. Here, the lowest partial factor productivity was recorded from the treatment split application of N.

It was mainly because of application of lower quantity nitrogen as per the crop demand and higher yield per unit quantity of nitrogen was reduced. Results are in conformity with Xu *et al.* (2012), Zhang *et al.* (2013) and Harish *et al.* (2018).

Table 4.12 Effect of precision nitrogen management on number of filled grain panicle⁻¹, number of unfilled grain panicle⁻¹ and 1000 grain weight

Treatment	Number of filled grain panicle ⁻¹			Number of unfilled grain panicle ⁻¹			1000 grain weight (g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	117.33	123.39	120.36	23.26	23.66	23.46	23.79	23.87	23.83
N ₂	134.55	136.12	135.34	24.19	24.90	24.55	24.17	24.24	24.20
N ₃	143.29	145.33	144.31	24.60	24.92	24.76	24.46	24.52	24.49
N ₄	152.29	153.51	152.90	25.37	25.90	25.63	24.83	24.90	24.86
SEm±	0.81	0.84	0.58	1.01	1.02	0.72	0.50	0.56	0.38
CD (P=0.05)	2.79	2.89	1.79	NS	NS	NS	NS	NS	NS

Table 4.13 Effect of precision nitrogen management grain yield, straw yield and harvest index of rice

Treatment	Grain yield (kg ha ⁻¹)			Straw yield (kg ha ⁻¹)			Harvest index (%)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	3838.33	3844.67	3841.50	5373.33	5380.67	5377.00	41.67	41.74	41.70
N ₂	4231.67	4343.00	4287.33	5443.33	5469.33	5456.33	43.74	44.25	43.99
N ₃	4526.67	4550.00	4538.33	5551.67	5563.33	5557.50	45.00	45.02	45.01
N ₄	4823.33	4838.33	4830.83	5623.33	5664.33	5643.83	46.17	46.21	46.19
SEm±	10.45	10.87	7.54	122.64	122.84	86.79	2.12	2.13	1.50
CD (P=0.05)	36.17	37.62	23.24	NS	NS	NS	NS	NS	NS

Where, N₁-Control, N₂- Split application of N, N₃- LCC based N application and N₄- SPAD meter-based N application

Table 4.14 Effect of precision nitrogen management on agronomic, physiological efficiency and partial factor productivity

Treatment	AE (kg kg ⁻¹)			PE (kg kg ⁻¹)			PFP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	0.00	0.00	0.00	0.00	0.00	0.00	13.82	13.84	13.83
N ₂	4.92	6.23	5.57	38.50	40.25	39.38	3.81	3.91	3.86
N ₃	37.78	47.02	42.40	36.57	38.20	37.39	21.73	21.84	21.79
N ₄	62.22	66.58	64.40	35.84	34.61	35.22	23.15	23.23	23.19
SEm±	0.95	1.08	0.72	1.69	1.85	1.26	0.0229	0.0395	0.0228
CD (P=0.05)	3.29	3.74	2.22	5.86	6.42	3.87	0.0792	0.1368	0.0703

Where,

- N₁- Control,
- N₂- Split application of N,
- N₃- LCC based N application and
- N₄- SPAD meter-based N application

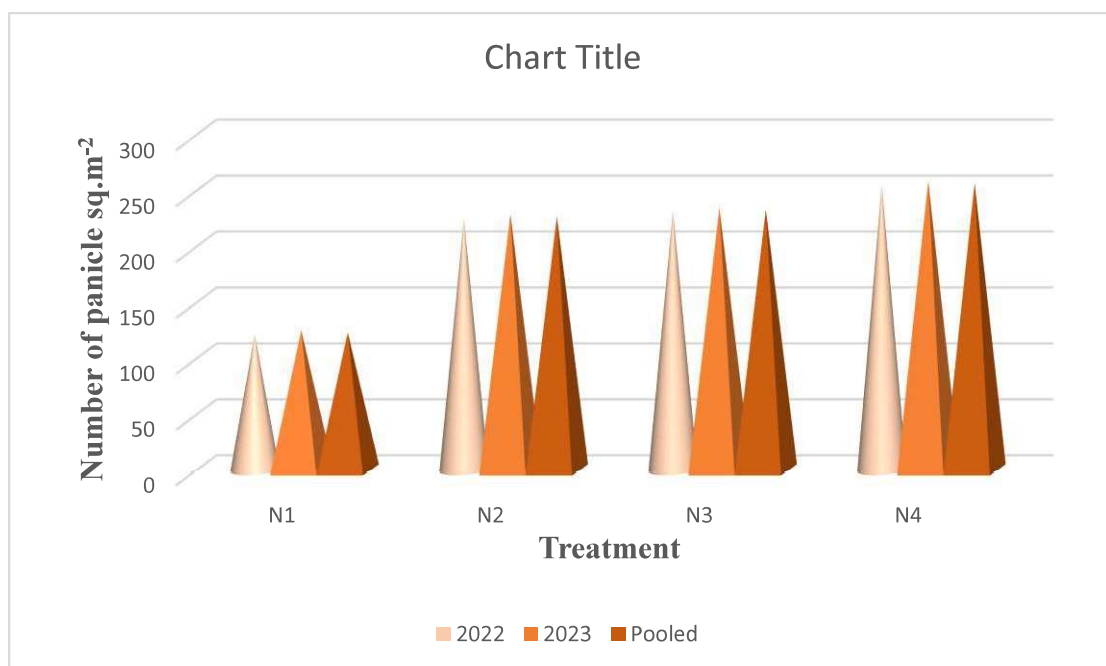


Fig. 4.5 Effect of precision nitrogen management on number of panicle m⁻²

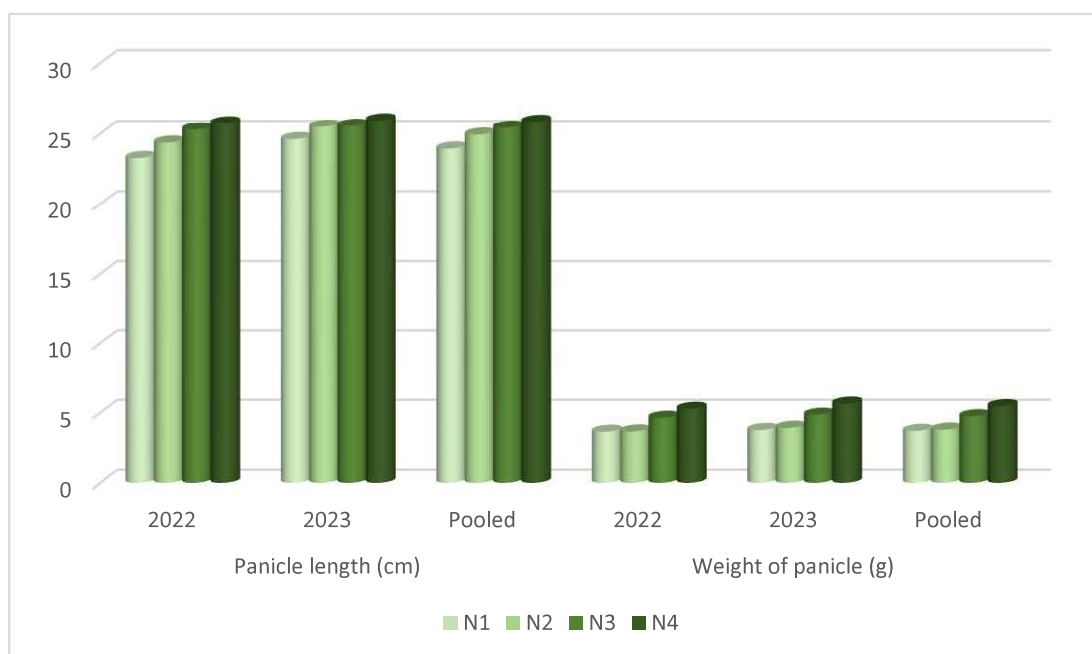


Fig. 4.6 Effect of precision nitrogen management on panicle length (cm) and weight of panicle (g)

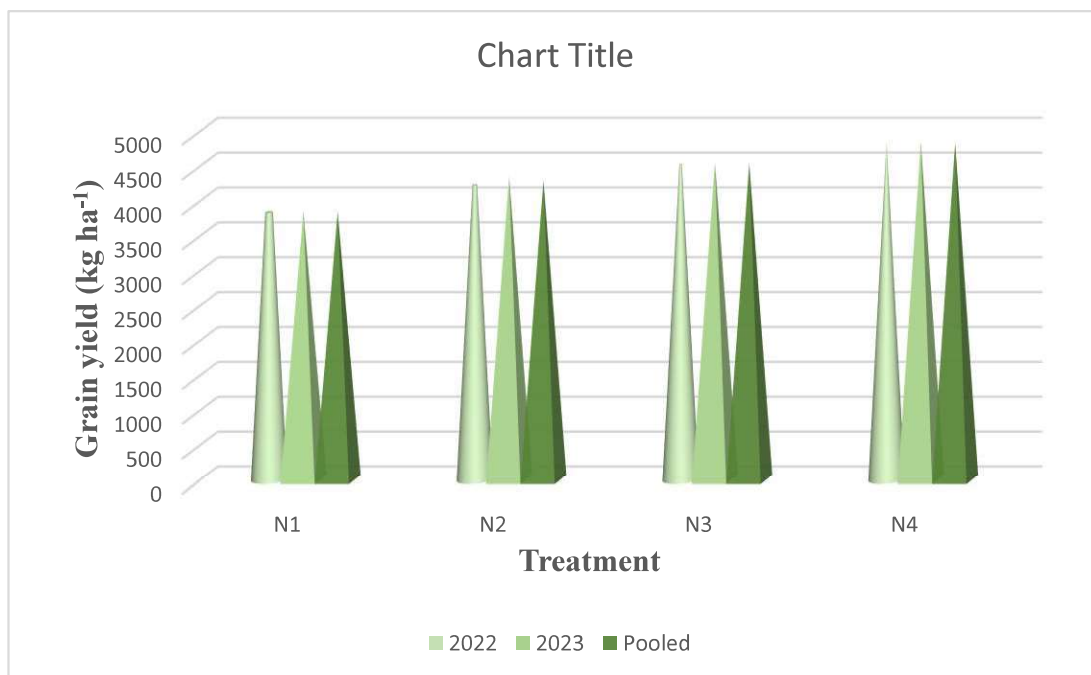


Fig. 4.7 Effect of precision nitrogen management on grain yield (kg ha⁻¹) of rice

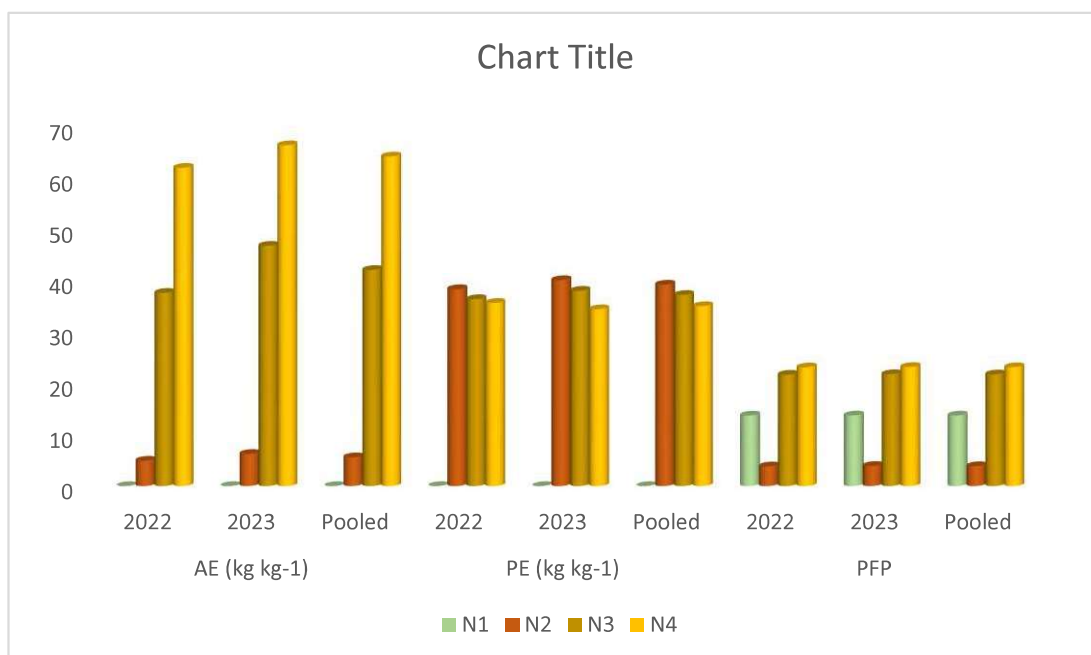


Fig. 4. 8 Effect of precision nitrogen management on AE (kg kg⁻¹), PE (kg kg⁻¹) and PFP

4.5.1 Effect of precision nitrogen management on soil properties after harvest of rice.

4.5.1.1 pH, EC and OC

The data related to pH, EC, and OC after the harvest of the rice crop as influence by precision nitrogen management is presented in the Table 4.15. Results showed that effect of precision nitrogen management on pH and EC was insignificant while precision nitrogen management showed highly significant effect on organic carbon of soil after the harvest of rice crop for both years.

A critical analysis shows that SPAD based nitrogen application was superior among the treatment and recorded the highest organic carbon (1.49 and 1.58 %) which was found to be statistically at par with LCC based N application (1.21 and 1.27 %) in both the years. The lowest organic carbon of soil was recorded from the control plot for both years.

Precision nitrogen management increase the plant growth mainly root biomass. Roots provide organic matter to the soil when they die and decompose which help in increasing soil organic carbon. As the rice field are often flooded, root exudates and decaying roots contribute heavily to below ground carbon inputs. This result is in conformity with Gawdiya *et al.* (2021) and Shukla *et al.* (2023).

4.5.1.2 Available N, P and K (kg ha⁻¹)

Data relevant to available nitrogen, phosphorus and potassium in soil after the harvest of rice as influence by precision nitrogen management is indicated in the Table 4.16

Results showed that precision nitrogen management had significant effect on available nitrogen, phosphorus and potassium of soil. SPAD based nitrogen application was found to be superior and highest available nitrogen (23.36 and 23.87kg ha⁻¹), phosphorus (23.36 and 23.87 kg ha⁻¹) and potassium (164.34 and 164.38 kg ha⁻¹) in both year of observation and found to be statistically at par with N₃ (LCC based N

application) i.e, nitrogen (256.00 and 257.13 kg ha⁻¹), phosphorus (22.07 and 22.58 kg ha⁻¹) and potassium (164.34 and 164.38 kg ha⁻¹). The lowest available N, P and K of soil was recorded from the treatment N₁ i.e. control plot for both years.

Besides higher crop uptake, significant build-up of available nitrogen under precision nitrogen management practices, could be ascribed to adequate and timely supply of nitrogen to meet the crop demand along with increased 78 microbial activity, which might have hastened the process of mineralization during the crop growth period resulting in high accumulation of N in soil. These results strongly support the findings of Swamy *et al.* (2016) and Goudra *et al.* (2021)

Application of nitrogen through SPAD based nitrogen management matches with the crop demand as it was applied in more splits(times) 3 in the form of urea which on nitrification forms hydrogen ions besides nitrate ions, thus modifies pH of the rhizosphere, due to this acidification of rhizosphere resulted in the solubilization of insoluble phosphates and release more orthophosphates in to the soil solution. Moreover, higher concentration of nitrates in the soil solution exchange for orthophosphate ions by anion exchange phenomenon. These results are match with Krishnakumar and Haefele (2013) and Goudra *et al.* (2021).

Increased of potassium might be due to increases the mineralization which lead to better root growth under SPAD based nitrogen management, which maintained parity with each other. Results were found supported with the findings of Duttarganvi *et al.* (2011) and Rao *et al.* (2016) and Goudra *et al.* (2021).

4.5.2 Effect of precision nitrogen management on nutrient content and uptake (grain and straw) of rice.

4.5.2.1a Nitrogen content (%)

Data applicable to nitrogen content in grain and straw of rice as influence by precision nitrogen management is presented in Table 4.17. Results showed that precision nitrogen management did not have significant effect on nutrient content in grain and straw of rice in both the years of observation.

4.5.2.1b Nitrogen uptake (kg ha⁻¹)

Data pertaining to nitrogen uptake by grain and straw of rice as influence by precision nitrogen management is presented in Table 4.17. The nitrogen uptake of first years was higher than that of second year.

Results indicated that precision nitrogen management had significant effect on nitrogen uptake (grain and straw) of rice in both years. The maximum nitrogen uptake was recorded from SPAD based nitrogen application (69.46 and 67.49 kg ha⁻¹ for grain and 30.48 and 28.72 kg ha⁻¹ for straw) followed by LCC based nitrogen application. The minimum nitrogen uptake by grain and straw of rice was recorded from the control.

Significant improvement in the uptake of nitrogen might be attributed to high concentration of N in grain and straw, associated with higher grain and straw yields. It might be owing to steady and adequate supply of nitrogen at the required time with better absorption of nutrients and their utilization in growth promotion which lead to translocation of photosynthates from the source to sink might have resulted in increased grain and straw yield.

The increase in nitrogen uptake by the crop might also be due to better availability of nitrogen in the soil under these treatments that showed favourable impact on higher degree of root proliferation and deep penetration which in turn absorbed higher amount of nutrients from the rhizosphere and supplied to the crop, which might have favoured higher dry matter production and lead to higher N uptake. Similar results were alleged by Duttarganvi *et al.* (2011), Pradhan *et al.* (2014), Singh *et al.* (2015) and Reena *et al.* (2017), Suresh *et al.* (2017), Goudra *et al.* (2021) and Pratap *et al.* (2024).

4.5.2.2a Phosphorus content (%)

Data related to the phosphorus content in both grain and straw as affected by the precision nitrogen management is presented in Table 4.18. Results indicated that

precision nitrogen management did not show any significant effect on phosphorus content in both grain and straw of rice for both years.

4.5.2.2b Phosphorus uptake (kg ha⁻¹)

The data pertaining to the phosphorus uptake by grain and straw of rice as affected by the precision nitrogen management is presented in Table 4.18. It is observed from the data that precision nitrogen management had significant effect on phosphorus uptake by the grain and straw of rice. SPAD based nitrogen application was superior among the treatment and recorded the maximum phosphorus uptake by grain (9.36 and 8.34 kg ha⁻¹) and straw (10.68 and 9.35 kg ha⁻¹). But phosphorus uptake by straw was found to be statistically at par with LCC based nitrogen application in first year (2022). In both year of observation, the minimum phosphorus uptake by the grain and straw of rice was recorded from the control plot.

The increase in P uptake by the crop might be due to application of adequate dose of nitrogen associated with deep penetration of roots that have enabled in absorbing higher amount of nutrients from the rhizosphere which ultimately directed to considerable increase in uptake of phosphorus from the soil. These results are in accordance with Shantappa *et al.* (2014), Das and Sahu (2015), Suresh *et al.* 2017, Goudra *et al.* 2021 and Pratap *et al.* (2024).

4.5.2.3a Potassium content (%)

Data relevant to the potassium content (%) in grain and straw of rice as affected by the precision nitrogen management is presented in the Table 4.19. It is evident from the data that precision nitrogen management had no significant effect on potassium content in grain and straw of rice for both years of observation.

4.5.2.3b Potassium uptake (kg ha⁻¹)

The data pertaining to the potassium uptake by grain and straw of rice as affected by precision nitrogen management is presented in the Table 4.19. The potassium uptake of the first year is greater than that of second year.

Results showed that precision nitrogen management had significant effect on the potassium uptake by grain and straw of rice. SPAD based nitrogen application was superior and recorded the maximum potassium uptake by grain (23.28 and 21.79 kg ha⁻¹) and straw (83.79 and 75.92 kg ha⁻¹) which was followed by LCC based nitrogen application and split application of N for both years. The minimum potassium uptake by grain and straw was recorded the control plot.

Potassium is most important cation not only with regard to its content in plant tissue but also its role in physiological and biochemical functions in imparting drought tolerance in plants. The uptake of P and K were directly proportional to the uptake of N which proved the synchronization between N supply and uptake of nutrients by the crop. These results are in conformity with Das and Sahu (2015), Suresh *et al.* (2017), Goudra *et al.* (2021) and Pratap *et al.* (2024).

4.5.3 Effect of precision nitrogen management on economics of rice

4.5.3.1 Cost of cultivation, gross return, net return and B: C

The data pertaining to cost of cultivation, gross return, net return and B: C as influenced by precision nitrogen management is presented in Table 4.20. The data of second year was greater than that of first year. It is evident from the data that highest cost of cultivation was recorded from split application of N (42.999.73 and 45709.73 ₹ ha⁻¹). Highest gross return (109642.60 and 120178.10 ₹ ha⁻¹), net return (67328.86 and 75154.34 ₹ ha⁻¹) and B: C (1.60 and 1.67) was achieved from the SPAD based N application which was followed by LCC based nitrogen management. The lowest cost of cultivation, gross return, net return and B: C ratio was recorded from the control plot.

Higher cost of cultivation was mainly due to higher cost incurred in fertilizer urea and higher labour wages. Higher gross returns, net returns and B:C compared to the other treatments due to higher rice grain and straw yield. While, lower gross returns, net returns and B:C ratio were noticed in absolute control was mainly due to reduced economic yield, attributed to lesser gross returns. The results are in accordance with Goudra *et al.* (2019), Yadav *et al.* (2023) and Borah *et al.* (2024).

Table 4.15 Effect of precision nitrogen management on available pH, EC and OC after harvest of rice.

pH				EC (ds/m)			OC (%)		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	5.23	5.25	5.24	0.72	0.75	0.75	0.71	0.83	0.77
N ₂	5.04	5.05	5.04	0.65	0.67	0.66	1.02	1.1	1.06
N ₃	5.03	5.04	5.03	0.55	0.56	0.56	1.21	1.27	1.24
N ₄	4.94	4.97	4.96	0.46	0.49	0.47	1.49	1.58	1.53
SEm±	0.365	0.367	0.258	0.131	0.143	0.097	0.12	0.14	0.09
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.41	0.48	0.28

Table 4.16. Effect of precision nitrogen management on available N, P and K (kg ha⁻¹) after harvest of rice.

Treatment	Available N (Kg ha ⁻¹)			Available P (Kg ha ⁻¹)			Available K (Kg ha ⁻¹)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	245.08	245.65	245.37	20.62	20.66	20.64	160.71	160.84	160.78
N ₂	252.33	253.8	253.07	21.28	21.15	21.22	161.56	161.81	161.68
N ₃	256.00	257.13	256.57	22.07	22.58	22.32	163.39	163.67	163.53
N ₄	258.73	259.53	259.13	23.36	23.87	23.61	164.34	164.38	164.36
SEm±	2.57	2.71	1.86	0.468	0.476	0.334	0.573	0.581	0.408
CD (P=0.05)	8.88	9.36	5.75	1.62	1.65	1.03	1.98	2.01	1.26

Where, N₁- Control,

N₂- Split application of N,

N₃- LCC based N application and

N₄- SPAD meter-based N application

Table 4.17 Effect of precision nitrogen management on nitrogen content and uptake by both grain and straw of rice

Treatment	Nitrogen content (%)						Nitrogen uptake (kg ha ⁻¹)					
	Grain			Straw			Grain			Straw		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	1.21	1.11	1.16	0.35	0.33	0.34	46.57	42.86	44.71	18.80	17.40	18.10
N ₂	1.27	1.22	1.25	0.41	0.41	0.41	55.16	53.13	54.15	22.57	22.00	22.29
N ₃	1.35	1.29	1.32	0.48	0.46	0.47	61.71	58.69	60.20	26.70	25.28	25.99
N ₄	1.44	1.40	1.42	0.54	0.51	0.53	69.46	67.49	68.48	30.48	28.72	29.60
SEm±	0.13	0.11	0.09	0.118	0.087	0.073	0.73	0.66	0.49	0.15	0.37	0.20
CD (P=0.05)	NS	NS	NS	NS	NS	NS	2.53	2.28	1.52	0.51	1.28	0.61

Table 4.18 Effect of precision nitrogen management on Phosphorus content and uptake by both grain and straw of rice

Treatment	Phosphorus content (%)						Phosphorus uptake (kg ha ⁻¹)					
	Grain			Straw			Grain			Straw		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	0.15	0.13	0.14	0.11	0.10	0.10	5.83	5.08	5.45	4.79	4.25	4.52
N ₂	0.17	0.14	0.16	0.13	0.11	0.12	7.04	6.28	6.66	7.13	5.86	6.49
N ₃	0.18	0.16	0.17	0.18	0.15	0.17	8.36	7.48	7.92	10.05	8.48	9.27
N ₄	0.19	0.17	0.18	0.19	0.17	0.18	9.36	8.34	8.85	10.68	9.35	10.02
SEm±	0.029	0.022	0.018	0.058	0.035	0.034	0.06	0.02	0.03	0.37	0.25	0.23
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.22	0.09	0.11	1.30	0.87	0.69

Where, N₁- Control, N₂- Split application of N, N₃- LCC based N application and N₄- SPAD meter-based N application

Table 4.19 Effect of precision nitrogen management on potassium content and uptake by both grain and straw of rice.

	Potassium content (%)						Potassium uptake (kg ha ⁻¹)					
	Grain			Straw			Grain			Straw		
Treatment	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	0.38	0.34	0.36	1.24	1.10	1.17	14.11	13.52	13.82	66.59	60.63	63.61
N ₂	0.43	0.36	0.40	1.36	1.22	1.29	17.72	16.26	16.99	74.03	66.35	70.19
N ₃	0.46	0.43	0.45	1.45	1.33	1.38	20.88	19.46	20.17	80.09	73.28	76.68
N ₄	0.48	0.45	0.47	1.49	1.35	1.42	23.28	21.79	22.54	83.79	75.92	79.85
SEM±	0.069	0.063	0.047	0.112	0.097	0.074	0.31	0.30	0.22	0.40	0.50	0.32
CD (P=0.05)	NS	NS	NS	NS	NS	NS	1.08	1.05	0.67	0.83	1.19	0.65

Table 4.20 Effect of precision nitrogen management on cost of cultivation, gross return, net return and B:C of rice.

Treatment	Cost of cultivation (₹ ha ⁻¹)			Gross return (₹ ha ⁻¹)			Net return (₹ ha ⁻¹)			B:C		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
N ₁	42086.09	44796.09	43441.09	89048.59	97757.47	93403.03	46962.5	52961.38	49961.94	1.12	1.18	1.15
N ₂	42999.73	45709.73	44354.73	97212.73	108863.90	103038.30	54212.99	63154.14	58683.57	1.26	1.38	1.32
N ₃	42542.63	45023.73	43783.18	103447.40	113624.30	108535.83	60904.78	68600.53	64752.65	1.43	1.52	1.46
N ₄	42313.73	45023.73	43668.73	109642.6	120178.10	114910.33	67328.86	75154.34	71241.60	1.60	1.67	1.64

Where, N₁-Control, N₂-Split application of N, N₃-LCC based N application and N₄-SPAD based N application

4.6 Performance of succeeding toria as influenced by residual effect of precision management and irrigation regimes.

The residual effect of precision nitrogen management practices and irrigation regimes on toria were studied during *rabi* season during both years of study. Each of the treatment plot of *kharif* was subdivided into three plots during *rabi* to carry the effect of three different irrigation regimes. Therefore, for *rabi* season study, the four residual treatments of nitrogen management were considered as main plot treatments and the three irrigation regimes as sub plot treatments in split plot design and the data were analysed.

4.6.1 Residual effect of precision nitrogen management and irrigation regimes on growth parameters of toria

4.6.1.1 Plant height (cm)

The data related to plant height of toria as influenced by residue precision nitrogen management and irrigation regimes are presented in Table 4.21. It is observed from the data that residue of precision nitrogen management did not have any significant effect on plant height but irrigation regimes show highly significant effect on plant height in both years of data observation.

At 30 DAS, IW: CPE =1 was found to be superior and recorded highest plant height (21.57 and 22.52 cm) but found to be statistically at par with IW: CPE =0.8 (19.68 and 20.70 cm) in both years of observation. At 60 DAS data revealed that the highest plant height (43.75 and 43.97 cm) was recorded under IW: CPE =1 which was found to be statistically at par with IW: CPE =0.8 (42.75 and 42.87 cm). At 90 DAS, IW: CPE =1 recorded the highest plant height and found to be statistically at par with treatment I₂ i.e. IW: CPE =0.8 (98.79 and 98.95 cm). At all stages, the lowest plant height was recorded from the control i.e. IW: CPE =0 in both years observation.

Interaction effect of residue of precision nitrogen management and irrigation regimes on plant height of toria did not show any significant effect on plant height of toria in all stages of observations (30,60 and 90 DAS).

The obvious increase in plant height under treatments I₂ and I₃ might be attributed due to adequate supply of available soil moisture when required for its favourable growth process like active meristematic growth, cell division and cell elongation resulting enhanced plant height. These can be similar to results of Haque and Ali (2020), Naragund *et al.* (2023) and Saini *et al.* (2023b).

4.6.1.2 Plant population m⁻² at 20 DAS

The data relevant to the plant population m⁻² of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the table 4.22.

It is evident from the data that effect of residue of precision nitrogen management and irrigation regimes had no significant effect on plant population of toria at 20DAS in both years of data observation.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on plant population of toria at 20 DAS in both years of data observation.

4.6.1.3 Leaf area index at 30 and 60 DAS

The data relevant to the leaf area index of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.22 for both the years.

It is evident from the data that effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on leaf area index of toria at 30 and 60 DAS for both the years.

Interaction effect of residue of precision nitrogen management and irrigation regimes had no significant effect on leaf area index of toria at 30 and 60 DAS for both the years of observation.

The optimum irrigation scheduling had appreciable effect on plant shoot growth as evident in plant height accumulating higher branches and leaves which may be result of better nutrient availability and number of metabolic processes occurring in the plant which enhances plant shoot growth. Such effect of irrigation regimes on LAI was also conveyed earlier by Verma *et al.* (2018), Puppala *et al.* (2021) and Naragund *et al.* (2023).

4.6.1.4 Dry matter accumulation (g) plant⁻¹ at 15-30,30-45 and 45-60 DAS

The data applicable to the dry matter accumulation plant⁻¹ the as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.23 for both the years.

A critical analysis of data show that effect of residue of precision nitrogen management did not show any significant effect on dry matter accumulation plant⁻¹. Effect of irrigation regimes show highly significant effect on dry matter accumulation on 30-45 and 45-60 DAS but did not show significant effect on 15-30 DAS.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on dry matter accumulation of toria at 15-30, 30-45 and 45-60 DAS for both the years of observation

Significantly higher DMA was observed with proper irrigation scheduling which might be due to frequent supply and optimum amount of soil moisture as plant needed for plant root system development which in turn improves the soil water intake, nutrient uptake, translocation and metabolic processes in the plant body along with increased photosynthesis process and ultimately growth of plant. The results are coordinated with findings of Bindhani *et al.* (2020a) and Puppala *et al.* (2021).

4.6.1.5 Number of primary branches plant⁻¹ at 30 and 60 DAS

The data applicable to number of primary branches plant⁻¹ the as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.24 for both the years.

A critical analysis of data showed that effect of residue of precision nitrogen management had no significant influence on number of primary branches plant⁻¹ but effect of irrigation regimes showed highly significant effect on number of branches plant⁻¹ on 30 and 60 DAS for both of years of observation. At 30DAS, IW: CPE=1 was superior and recorded the highest number of primary branches plant⁻¹ (4.69 and 4.97) but it was found to be statistically at par with IW: CPE = 0.8 (3.65 and 3.68). At 60 DAS, the maximum number of primary branches plant⁻¹ was recorded from IW: CPE =1 which was found to be at par with IW: CPE=0.8 (4.69 and 4.81). At all stages, the minimum number of primary branches plant⁻¹ was recorded from the control plot i.e., IW: CPE= 0.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on number of primary branches plant⁻¹ of toria on 30 and 60 DAS for both the years of observation.

The increase in number of primary branches per plant is the resultant effect of better plant growth conditions. Moisture has a unique role to play for plant growth by influencing improved nutrient availability followed by higher metabolic activity and growth and ultimately with a greater number of branches. The result agreed with the finding of Yadav *et al.* (2010), Verma *et al.* (2014) and Singh *et al.* (2017) and they observed the positive effect of irrigation water towards branch formation.

4.6.1.6 Number of secondary branches plant⁻¹ at 30 and 60 DAS

The data applicable to the number of secondary branches plant⁻¹ the as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the table 4.24 for both the years.

A critical analysis of data showed that effect of residue of precision nitrogen management had no significant effect on number of secondary branches plant⁻¹ but effect of irrigation regimes showed highly significant effect on number of secondary branches plant⁻¹ on 30 and 60 DAS. At 30 DAS, maximum number of secondary branches plant⁻¹ (6.38 and 7.00) was recorded from the IW: CPE= 1 which was found to be statistically at par with IW: CPE= 0.8 (5.63 and 6.20). At 60DAS, IW: CPE=1

recorded the maximum number of secondary branches plant⁻¹ and found to be statistically at par with IW: CPE=0.8. In both years observation, the minimum number of secondary branches plant⁻¹ was recorded from the control plot at all stages.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on number of secondary branches plant⁻¹ of toria at 30 and 60 DAS for both the years of observation.

Sufficient moisture in crop root zone and uptake of various nutrients and relative increase in plant growth attributes result as a result increases number of branches. This finding was supported by Dudwal *et al.* (2013), Hossain *et al.* (2013), Ahmed *et al.* (2019) and Maurya *et al.* (2022).

4.6.17 Crop growth rate (g m⁻² day⁻¹) at 15-30,30-45 and 45-60 DAS

The data applicable to the crop growth rate as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.25 for both the years. The data of crop growth rate was decreasing order in different crop stages.

A critical analysis of data showed that effect of residue of precision nitrogen management did not have any significant effect on dry matter accumulation plant⁻¹ whereas effect of irrigation regimes showed highly significant effect on crop growth rate on 30-45 and 45-60 DAS but did not show significant effect on 15-30 DAS. At 30-45DAS, highest crop growth rate (4.05 and 4.34) was recorded from IW: CPE=1 followed by IW: CPE=0.8 (2.73 and 2.64). At 90DAS, IW: CPE=1 recorded the highest crop growth rate (3.45 and 3.46) followed by IW: CPE=0.8 (1.84 and 1.86). In all the stages, the lowest crop growth rate was recorded from the control plot i.e. IW: CPE=0 for both the years.

Increased in CGR might be due to optimum supply of soil moisture close to root zone by favourably improving the nutrient uptake and translocation, higher photosynthetic activities which ultimately associated with the plant growth and development. The results are supported by the research findings of Dadhich *et al.*

(2015), Rathore *et al.* (2017), Bindhani *et al.* (2020a), Kumar *et al.* (2020), Puppala *et al.* (2021), Maurya *et al.* (2022) and Naragund *et al.* (2023).

4.6.1.8 Relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) at 15-30,30-45 and 45-60 DAS

The data applicable to the relative growth rate as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.26 for both the years.

A critical analysis of data showed that effect of residue of precision nitrogen management did not showed any significant effect on relative growth rate but irrigation regimes showed significant effect on 15-30 DAS. At 30-45 DAS, the maximum relative growth rate (0.0281 and 0.0278) was recorded from IW: CPE=1 followed by IW: CPE=0.8. Similarly, at 45-60 DAS also maximum relative growth rate was recorded from IW: CPE=1 followed by IW: CPE=0.8. at all the stages, the minimum relative growth rate the recorded from control plot i.e. IW: CPE=0.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on relative growth rate of toria at 15- 30, 30-45 and 45-60 DAS for both the years of observation.

This might be due to increment in irrigation improved the availability of moisture and nutrients which leads to improve dry matter accumulation of plant which results into better relative growth rate. The results are in agreement with Digra *et al.* (2016), Maurya *et al.* (2022) and Saini *et al.* (2023a).

4.6.1.9 Net assimilation rate ($\text{g m}^{-2} \text{ day}^{-1}$) at 15-30,30-45 and 45-60 DAS

The data applicable to net assimilation rate as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.28 for both the years.

A critical analysis of data showed that effect of residue of precision nitrogen management had significant influenced on net assimilation rate and also effect of irrigation regimes showed highly significant effect on net assimilation 30-45 and 45-

Table 4.21 Residual effect of precision nitrogen management and irrigation regimes on plant height of toria at 30 days interval

Plant height (cm)	30 DAS			60 DAS			90 DAS		
Treatment	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
I ₁	18.14	19.14	18.64	40.57	40.83	40.70	96.77	96.86	96.82
I ₂	19.68	20.70	20.19	42.75	42.87	42.81	97.50	97.82	97.66
I ₃	21.57	22.52	22.04	43.75	43.97	43.86	98.79	98.95	98.87
SEm±	0.84	0.87	0.60	0.96	0.97	0.68	0.65	0.68	0.47
CD (P=0.05)	2.53	2.60	1.74	2.88	2.91	1.97	1.96	2.04	1.36
N ₁	18.50	19.59	19.04	42.09	42.24	42.17	97.29	97.48	97.39
N ₂	18.70	19.96	19.33	42.32	42.49	42.41	97.52	97.61	97.57
N ₃	20.52	21.46	20.99	42.43	42.54	42.49	98.00	98.07	98.04
N ₄	21.46	22.14	21.80	42.57	42.95	42.76	97.94	98.33	98.14
SEm±	1.34	1.43	0.98	1.37	1.45	1.00	1.10	1.22	0.82
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.22 Residual effect of precision nitrogen management and irrigation regimes on plant population m⁻² and leaf area index (LAI) of toria at 30 days intervals

Treatment	Plant population			LAI					
	20 DAS			30 DAS			60 DAS		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
I ₁	31.36	31.43	31.39	0.64	0.68	0.66	1.76	1.79	1.77
I ₂	32.68	32.84	32.76	0.67	0.70	0.68	1.83	1.87	1.85
I ₃	33.89	33.82	33.86	0.68	0.72	0.70	1.89	1.92	1.90
SEm±	1.10	1.11	0.78	0.02	0.03	0.02	0.08	0.14	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
N ₁	32.72	32.58	32.65	0.66	0.69	0.67	1.75	1.79	1.77
N ₂	32.47	32.56	32.52	0.66	0.69	0.68	1.81	1.84	1.83
N ₃	32.61	32.71	32.66	0.67	0.70	0.69	1.85	1.88	1.87
N ₄	32.77	32.94	32.86	0.67	0.71	0.69	1.89	1.93	1.91
SEm±	0.93	0.94	0.66	0.01	0.02	0.01	0.10	0.11	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,
I₂= IW: CPE=0.8
I₃= IW: CPE=1

N₁- Control,
N₂- RDF,
N₃- LCC based N management and
N₄- SPAD meter-based N management

Table 4.23 Residual effect of precision nitrogen management and irrigation regimes on dry matter accumulation plant⁻¹ (DMA) of toria at 15 days intervals

DMA plant ⁻¹ (g)	0-15 DAS			15-30 DAS			30-45 DAS			45-60 DAS		
Treatment	2022 -23	2023- 24	Pooled	2022- 23	2023- 24	Pooled	2022- 23	2023- 24	Pooled	2022 -23	2023- 24	Pooled
I ₁	1.37	1.57	1.24	3.27	3.31	3.29	4.42	4.45	4.43	5.25	5.27	5.26
I ₂	1.39	1.60	1.49	3.32	3.35	3.33	4.45	4.47	4.46	5.28	5.38	5.33
I ₃	1.43	1.65	2.05	3.43	3.46	3.45	5.25	5.28	5.26	6.80	6.82	6.81
SEM±	0.03	0.05	0.07	0.07	0.08	0.06	0.23	0.24	0.16	0.41	0.43	0.30
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.47	0.60	0.37	0.32	0.46	0.27
N ₁	1.38	1.59	1.49	3.32	3.35	3.33	4.68	4.71	4.69	5.73	5.75	5.74
N ₂	1.38	1.60	1.49	3.33	3.38	3.35	4.69	4.71	4.70	5.74	5.87	5.81
N ₃	1.42	1.61	1.52	3.35	3.38	3.37	4.73	4.75	4.74	5.82	5.83	5.82
N ₄	1.41	1.62	1.51	3.36	3.40	3.38	4.73	4.76	4.74	5.83	5.85	5.84
SEM±	0.04	0.05	0.03	0.03	0.06	0.03	0.20	0.20	0.14	0.15	0.18	0.12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I×N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,

N₁-Control,

I₂= IW: CPE=0.8

N₂- RDF,

I₃= IW: CPE=1

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.24 Residual effect of precision nitrogen management and irrigation regimes on primary and secondary branches of toria at 30 days intervals

Treatment	Primary branches					Secondary branches				
	30 DAS			60 DAS		30 DAS			60 DAS	
	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled	2022 -23
I ₁	2.87	2.97	2.92	3.74	3.80	3.77	4.96	5.36	5.16	9.84
I ₂	3.65	3.86	3.76	4.69	4.81	4.75	5.63	6.20	5.91	11.11
I ₃	4.69	4.97	4.83	5.56	6.14	5.85	6.38	7.00	6.69	12.40
SEm±	0.59	0.60	0.42	0.69	0.74	0.51	0.37	0.33	0.25	0.83
CD (P=0.05)	1.77	1.80	1.21	2.06	2.22	1.46	1.11	0.98	0.71	2.49
N ₁	3.38	3.59	3.48	4.43	4.39	4.57	5.35	5.52	5.43	10.43
N ₂	3.69	3.81	3.75	5.33	4.55	4.93	5.59	5.73	5.66	10.88
N ₃	3.84	4.17	4.00	5.47	4.65	4.92	5.80	5.90	5.85	11.47
N ₄	4.04	4.17	4.11	5.40	5.07	5.25	5.93	6.04	5.99	11.70
SEm±	0.44	0.43	0.31	0.30	4.39	4.57	0.35	0.36	0.25	0.73
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,

I₂= IW: CPE=0.8

I₃= IW: CPE=1

N₁- Control,

N₂- RDF,

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.25 Residual effect of precision nitrogen management and irrigation regimes on crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$) of toria at 15 days intervals

	CGR ($\text{g m}^{-2} \text{day}^{-1}$)								
	15-30 DAS			30-45 DAS			45-60 DAS		
Treatment	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled
I ₁	4.23	4.27	4.25	2.54	2.71	2.63	1.84	1.85	1.84
I ₂	4.29	4.34	4.31	2.55	2.73	2.64	1.84	1.86	1.85
I ₃	4.45	4.50	4.47	4.05	4.34	4.20	3.45	3.46	3.45
SEm±	0.06	0.07	0.04	0.40	0.42	0.29	0.45	0.46	0.32
CD (P=0.05)	NS	NS	NS	1.20	1.26	0.84	1.34	1.37	0.92
N ₁	4.30	4.35	4.33	3.03	3.25	3.14	2.32	2.36	2.34
N ₂	4.33	4.39	4.36	3.04	3.25	3.15	2.34	2.37	2.35
N ₃	4.29	4.34	4.32	3.05	3.26	3.15	2.41	2.34	2.38
N ₄	4.36	4.40	4.38	3.06	3.28	3.17	2.44	2.48	2.46
SEm±	0.06	0.05	0.04	0.19	0.24	0.16	0.23	0.25	0.17
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,

I₂= IW: CPE=0.8

I₃= IW: CPE=1

N₁- Control,

N₂- RDF,

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.26 Residual effect of precision nitrogen management and irrigation regimes on relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) of toria at 15 days intervals

		RGR ($\text{g g}^{-1} \text{ day}^{-1}$)									
		15-30 DAS			30-45 DAS			45-60 DAS			
Treatment		2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	
I ₁		0.0655	0.0479	0.0564	0.0201	0.0198	0.0199	0.0114	0.0113	0.0114	
I ₂		0.0615	0.0470	0.0547	0.0168	0.0171	0.0169	0.0142	0.0107	0.0124	
I ₃		0.0479	0.0329	0.0404	0.0281	0.0278	0.0279	0.0167	0.0166	0.0167	
SEm $\pm$		0.0047	0.0031	0.0028	0.0022	0.0022	0.0015	0.0012	0.0013	0.0008	
CD (P=0.05)		NS	NS	NS	0.0065	0.0065	0.0044	0.0036	0.0039	0.0026	
N ₁		0.0624	0.0613	0.0618	0.0228	0.0223	0.0225	0.0129	0.0128	0.0129	
N ₂		0.0579	0.0579	0.0579	0.0225	0.0222	0.0223	0.0131	0.0129	0.013	
N ₃		0.0623	0.0628	0.0626	0.0227	0.0224	0.0225	0.0134	0.0133	0.0133	
N ₄		0.0505	0.0501	0.0503	0.0188	0.0193	0.0191	0.017	0.0162	0.0166	
SEm $\pm$		0.0027	0.0032	0.0021	0.0016	0.0017	0.0012	0.0009	0.0009	0.0006	
CD (P=0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	
I $\times$ N		NS	NS	NS	NS	NS	NS	NS	NS	NS	

Where, I₁= IW: CPE=0,

I₂= IW: CPE=0.8

I₃= IW: CPE=1

N₁-Control,

N₂- RDF,

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.27 Residual effect of precision nitrogen management and irrigation regimes on net assimilation rate ($\text{g m}^{-2} \text{day}^{-1}$) of toria at 15 days intervals

	NAR (g m ⁻² day ⁻¹)									
	15-30 DAS			30-45 DAS			45-60 DAS			
Treatment	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	
I ₁	0.0043	0.0045	0.0044	0.0018	0.0017	0.0016	0.0010	0.0011	0.0010	
I ₂	0.0051	0.0053	0.0052	0.0016	0.0017	0.0016	0.0008	0.0007	0.0007	
I ₃	0.0049	0.0051	0.0050	0.0020	0.0021	0.0020	0.0011	0.0009	0.0010	
SEm±	0.00033	0.00033	0.00023	0.00008	0.00009	0.00006	0.00008	0.00008	0.00006	
CD (P=0.05)	NS	NS	NS	0.00026	0.00028	0.00018	0.0002	0.00024	0.00016	
N ₁	0.0045	0.0047	0.0046	0.0019	0.002	0.0019	0.00087	0.0009	0.00089	
N ₂	0.0046	0.0048	0.0047	0.0018	0.0018	0.0018	0.00095	0.001	0.00097	
N ₃	0.0049	0.0051	0.0049	0.0017	0.0018	0.0017	0.0010	0.0011	0.0010	
N ₄	0.005	0.0052	0.0051	0.0015	0.0016	0.0016	0.0011	0.0012	0.0011	
SEm±	0.0004	0.0004	0.00029	0.00008	0.00010	0.00006	0.00008	0.00009	0.00006	
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I×N	NS	NS	NS	NS	NS	NS	NS	NS	NS	

Where, I₁= IW: CPE=0, N₁-Control,

I₂= IW: CPE=0.8 N₂- RDF,

I₃= IW: CPE=1 N₃- LCC based N management and

N₄- SPAD meter-based N management

60 DAS but did not show significant effect on 15-30 DAS.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on net assimilation of toria at 15-30, 30-45 and 45-60 DAS for both the years of observation.

The superior vegetative and morphological parameters like plant height, dry matter accumulation, leaf area index, number of primary and secondary branches were reflected into crop indices like net assimilation rate. Similar findings were also conveyed by Sarma and Das. (2017), Ahmed *et al.* (2019), Kumar *et al.* (2020) and Muarya *et al.* (2022).

4.5.2 Residual effect of precision nitrogen management and irrigation regimes on yield attributes and yield of toria

4.5.2.1 Number of siliquae plant⁻¹

The data relevant to number of siliqua plant⁻¹ as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.28 for both the years.

A critical analysis of data show that effect of residue of precision nitrogen management did not have any significant effect whereas irrigation regimes significantly enhanced on number of siliqua plant⁻¹. Maximum number of siliqua (77.55 and 77.80) was recorded from the IW: CPE=1 followed by IW: CPE=0.8 (76.41 and 76.49) and minimum number of siliquae was recorded from the IW: CPE = 0.

Interaction effect of residue of precision nitrogen management and irrigation regimes had no significant effect on number of siliqua plant⁻¹ for both the years of observation.

Increase in number of siliquae per plant of toria with proper and adequate amount of irrigation might be due to increasing rates of growth and development of the plants and also established a higher availability of nutrients which produced more

numbers of branches and cumulated in a better sink development which directed to increase in number of siliquae per plant. The findings were supported with Chaudhari *et al.* (2016), Pawar and Shelke (2016) and Jat *et al.* (2017), Kumar *et al.* (2019a) and Kumar *et al.* (2020).

4.5.2.2 Length of siliqua (cm)

The data relevant to length of siliqua as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.28 for both the years.

A critical analysis of data showed that effect of residue of precision nitrogen management had no significant effect whereas irrigation regimes showed highly significant effect on length of siliqua. The highest length of siliqua (6.44 and 6.54 cm) was recorded from IW: CPE=1 and the lowest was recorded from IW: CPE (4.59 and 4.65 cm) for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on length of siliqua for both the years of observation.

The reason may be due to increasing the irrigation frequency resulted in more nutrient uptake. This might be owing to more nutrients being available for optimum length of siliqua. Irrigation application led to a better translocation and partitioning of photosynthates from source to sink, which improved the length of siliqua. These assumptions are parallel to those of Rathore *et al.* (2014), Verma *et al.* (2014), Sarma and Das 2017 and Kumar *et al.* (2022).

4.5.2.3 Weight of siliqua

The data related to weight of siliqua as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.28 for both the years.

A critical analysis of data show that effect of residue of precision nitrogen

management did not show any significant effect whereas irrigation regimes showed highly significant effect on weight of siliqua. The maximum weight of siliqua (3.46 and 3.54 g) recorded from IW: CPE=1 and the minimum was recorded from IW: CPE (1.84 and 1.87 g) for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on weight of siliqua for both the years of observation.

The results are in accordance with Sarma and Das. (2017) and Kumar *et al.* (2019a).

4.5.2.4 Number of seed siliqua⁻¹

The data related to number of seed siliqua⁻¹ as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.28 for both the years.

A critical analysis of data indicated that effect of residue of precision nitrogen management on number of seed siliqua⁻¹ no significant effect whereas irrigation regimes showed highly significant effect on number of seed siliqua⁻¹. The maximum number of seed siliqua⁻¹ (18.78 and 18.84) recorded from IW: CPE=1 which are found to be statistically at par with IW: CPE=0.8(17.74 and 17.79) and the minimum was recorded from IW: CPE (1.84 and 1.87) for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on number of seed siliqua⁻¹ for both the years of observation.

This might be due to application of irrigation ensured the better moisture and nutrient availability with a better translocation of photosynthates from source to sink which led to a greater number of seeds per siliqua. Least number of seeds per siliqua might have been experienced due to moisture stress condition at various stages of mustard. Similar results were found by Devedee *et al.* (2019), Singh *et al.* (2019), Barick *et al.* (2020) and Barman *et al.* (2023), Kumar *et al.* (2022), Saini *et al.* (2023a).

4.5.2.5 1000 grain weight (g)

The data relevant to the test weight of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.28 for both the years.

It is evident from the data that effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on test weight of toria for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on test weight of toria at 30 and 60 DAS for both the years of observation.

4.5.2.6 Seed yield (kg ha⁻¹)

The data relevant to the harvest index of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table no. 4.29 for both the years. The seed yield of second year was slightly higher than that of first year

It is evident from the data that effect of residue of precision nitrogen management did not show any significant effect on grain yield while irrigation regimes show highly significant effect on grain yield of toria for both years. IW: CPE =1 was found to be superior among the treatment and recorded the maximum grain yield (1448.55 and 1449.96 kg ha⁻¹) but found to be statistically at par IW: CPE= 0.8 (1335.63 and 1339.33 kg ha⁻¹) in both years. The minimum grain yield was recorded from the control plot for both the years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not showed any significant effect on harvest index of toria at 30 and 60 DAS for both the years of observation.

The adequate supply of moisture favourably improved nutrient uptake and translocation which ultimately increased the yield. This increase in seed yield might

be due to maintenance of sufficient moisture in root zone during critical stages (pre flowering and siliquae formation stages) of the crop growth, resulting in higher yields and also might be attributed to the timely and adequate moisture availability, which helped in proper utilization of nutrients and also a formulation and partitioning of photosynthates to the sink. Significant improvement in seed yields might be a consequence of the increased number of siliquae plant⁻¹, number of seeds siliquae⁻¹, length of siliqua and the 1000-seed weight. Similar findings were also confirmed by Piri *et al* (2012) and Ray *et al.* (2015), Deka *et al.* (2018), Singh *et al.* (2019), Kumar *et al.* (2022) and Saini *et al.* (2023b).

4.5.2.7 Stover yield (kg ha⁻¹)

The data relevant to the harvest index of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.29 for both the years.

It is evident from the data that effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on stover yield of toria for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on stover yield for both the years of observation

4.5.2.8 Harvest index (%)

The data relevant to the harvest index of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.29 for both the years.

It is evident from the data that effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on harvest index of toria for both years.

Interaction effect of residue of precision nitrogen management and irrigation

regimes did not show any significant effect on harvest index for both the years of observation.

4.5.3 residual effect of precision nitrogen management and irrigation regimes on yield quality

4.5.3.1 Seed oil content (%)

The data relevant to seed oil content of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.30 for both the years.

It is observable from the data that effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on seed oil content in toria for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on seed oil content in toria for both the years of observation.

4.5.3.2 Oil yield (kg ha⁻¹)

The data related to oil yield of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.30 for both the years.

It is noticeable from the data that effect of residue of precision nitrogen management did not show any significant effect on oil yield while irrigation regimes showed highly significant effect on oil yield of toria for both years. IW: CPE= 1 was superior among the treatment and recorded the highest oil yield (541.11 and 542.41 kg ha⁻¹) which found to be statistically at par with IW: CPE=0.8 (491.85 and 493.73 kg ha⁻¹) in both the years. The lowest oil yield of toria was recorded from IW: CPE=0 i.e. control plot.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on oil yield of toria for both the years of observation.

The synthesis of oil in plants is a fascinating biochemical process, primarily linked to carbohydrate metabolism. During respiration, carbohydrates are broken down and provide energy, but they also serve as precursors for lipid biosynthesis. The conversion involves multiple steps, where glycerol and fatty acids essential components of fats are formed from carbohydrate intermediates.

Increased in oil yield with proper irrigation scheduling was might be due to increase in seed yield and oil content. Similar outcomes of maximum oil yield with increase in irrigation levels were conveyed by Yadav *et al.* (2010), Verma *et al.* (2014), Deka *et al.*, (2018), Bharat *et al.* (2019), Singh *et al.* (2021).

Increased on oil yield might also be owed to the fact that with the increase in amount of irrigation water improved turgidity of the cell, cell division and meristematic activity which ultimately directed to higher P and S uptake. Sulphur immensely increased the oil content of the Brassica species; therefore, oil content increased with the increasing frequency of irrigation. This outcome is configuration with the findings of Yadav *et al.* (2010), Rathore *et al.* (2019), Barman *et al.* (2023).

4.5.4 Residual effect of precision nitrogen management and irrigation regimes on water use efficiency of toria

The data pertaining to water use efficiency of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.30 for both the years and pooled also. The WUE of first year data was higher than the second year.

The data presented in the table shows that residue of precision nitrogen management did not show any significant effect on WUE of toria while different irrigation regimes show significant effect on WUE of toria for both years of experiment and in pooled also. IW: CPE=1 was superior among the treatment and recorded the

Table 4.28 Residual effect of precision nitrogen management and irrigation regimes on number of siliqua plant⁻¹, length of siliqua, weight of siliqua, number of seeds siliqua⁻¹ and 1000 grain weight of toria

Number of siliqua plant ⁻¹				Length of siliqua (cm)				Weight of siliqua (g)				Number of seeds siliqua ⁻¹			1000 grain weight (g)		
Treatment	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled		
I ₁	75.29	75.36	75.32	4.59	4.65	4.62	1.84	1.87	1.86	16.76	16.74	16.75	2.41	2.62	2.51		
I ₂	76.41	76.49	76.45	5.97	6.01	5.99	2.46	2.53	2.50	17.74	17.79	17.76	3.43	3.52	3.47		
I ₃	77.55	77.80	77.68	6.44	6.54	6.49	3.46	3.54	3.50	18.78	18.84	18.81	3.65	3.82	3.74		
SEm±	0.51	0.54	0.37	0.47	0.48	0.34	0.52	0.53	0.37	0.61	0.63	0.44	0.48	0.49	0.34		
CD (P=0.05)	1.54	1.62	1.08	1.41	1.44	0.97	1.56	1.60	1.07	1.82	1.89	1.26	NS	NS	NS		
N ₁	76.27	76.44	76.36	5.32	5.42	5.37	2.38	2.45	2.42	17.53	17.60	17.56	2.91	3.06	2.98		
N ₂	76.37	76.53	76.45	5.55	5.62	5.58	2.49	2.51	2.50	17.71	17.67	17.69	3.17	3.33	3.25		
N ₃	76.46	76.56	76.51	5.79	5.87	5.83	2.62	2.69	2.65	17.85	17.89	17.87	3.23	3.39	3.31		
N ₄	76.58	76.66	76.62	6.01	6.04	6.02	2.86	2.94	2.90	17.94	17.98	17.96	3.35	3.50	3.43		
SEm±	0.57	0.76	0.48	0.61	0.37	0.36	0.10	0.13	0.08	0.07	0.08	0.05	0.16	0.31	0.18		
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
I×N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		

Where, I₁= IW: CPE=0,

N₁- Control,

I₂= IW: CPE=0.8

N₂- RDF,

I₃= IW: CPE=1

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.29 Residual effect of precision nitrogen management and irrigation regimes on seed (kg ha⁻¹), stover yield (kg ha⁻¹) and harvest index (%).

Treatment	Seed yield (kg ha ⁻¹)			Stover yield (kg ha ⁻¹)			Harvest index (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
I ₁	924.12	929.86	926.99	1677.44	1723.31	1700.38	35.72	36.19	35.95
I ₂	1335.63	1339.03	1337.33	2341.30	2342.75	2342.03	36.35	36.37	36.36
I ₃	1448.55	1449.96	1449.26	2454.80	2456.01	2455.41	37.10	36.88	36.99
SEm±	111.28	116.09	80.40	255.31	256.10	180.81	0.70	0.73	0.51
CD (P=0.05)	333.61	348.03	231.62	NS	NS	NS	NS	NS	NS
N ₁	1222.72	1227.45	1225.09	2141.50	2143.29	2142.40	36.29	36.32	36.30
N ₂	1235.47	1238.26	1236.86	2151.20	2219.90	2185.55	36.39	36.40	36.40
N ₃	1240.93	1244.06	1242.50	2166.01	2157.16	2161.58	36.45	36.72	36.59
N ₄	1245.29	1248.70	1246.99	2172.68	2175.75	2174.21	36.44	36.46	36.45
SEm±	94.06	94.41	66.64	153.02	262.52	151.93	0.42	0.45	0.31
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
I×N	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,

I₂= IW: CPE=0.8

I₃= IW: CPE=1

N₁- Control,

N₂- RDF,

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.30 Effect of residue of precision nitrogen management and irrigation regimes on seed oil content (%), oil yield (kg ha⁻¹) and water use efficiency (kg ha⁻¹ cm)

Treatment	Oil content (%)			Oil yield (kg ha ⁻¹)			WUE (kg ha ⁻¹ cm)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
I ₁	36.45	36.58	36.51	336.80	339.14	337.97	7.82	7.72	7.77
I ₂	36.78	36.87	36.83	491.85	493.73	492.79	9.63	8.23	8.93
I ₃	37.26	37.35	37.30	541.11	542.41	541.76	11.03	9.60	10.32
SE _m ±	0.42	0.43	0.30	53.59	54.34	38.16	0.36	0.37	0.26
CD (P=0.05)	NS	NS	NS	160.68	162.91	109.93	1.09	1.11	0.75
N ₁	36.47	36.56	36.51	447.17	449.17	448.17	9.47	8.43	8.95
N ₂	36.77	36.87	36.82	454.70	456.61	455.65	9.46	8.51	8.98
N ₃	36.90	37.05	36.98	460.38	462.74	461.56	9.5	8.55	9.02
N ₄	37.19	37.25	37.22	464.09	465.19	464.64	9.54	8.58	9.06
SE _m ±	0.36	0.37	0.26	24.16	31.07	19.68	0.64	0.84	0.53
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
(I×N)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0, N₁- Control,

I₂= IW: CPE=0.8 N₂- RDF,

I₃= IW: CPE=1 N₃- LCC based N management and

N₄- SPAD meter-based N management

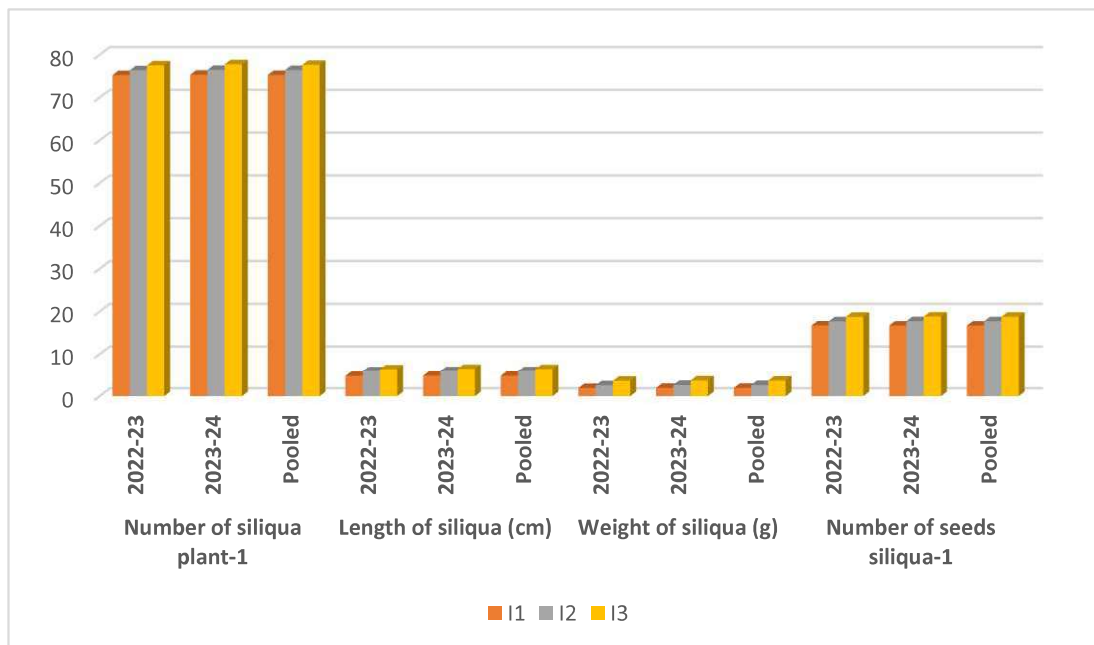


Fig 4.9 Effect of irrigation regimes on number of silique plant⁻¹, length of silique, weight of silique, number of seeds silique⁻¹

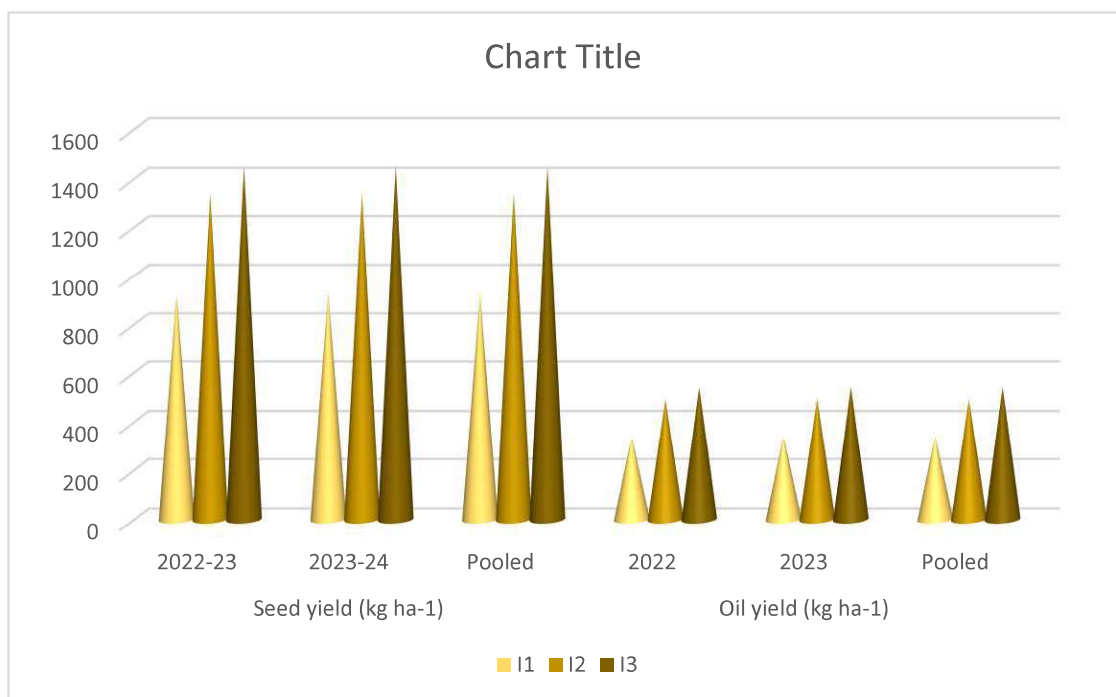


Fig 4.10 Effect of irrigation regimes on seed yield (kg ha⁻¹) and oil yield (kg ha⁻¹)

maximum water use efficiency (11.03 and 9.60 kg ha⁻¹ mm⁻¹) which was followed by IW: CPE=0.8 (9.63 and 8.23 kg ha⁻¹mm⁻¹) and the lowest water use efficiency was recorded from control plot i.e., IW: CPE=0.

It might be due to the relative availability of water during vegetative and reproductive stages of crop and its further utilization for assimilation and translocation of photosynthetes to produce higher grain yield. Lowest water use efficiency was observed in treatment no irrigation which might be due to moisture stress during various growth stages of crop. The results are in accordance with Singh *et al.* (2017), Bharat *et al.* (2019) and Konwar *et al.* (2019).

4.5.5 Effect of residue of precision nitrogen management and irrigation regimes on soil properties after harvest of toria

4.5.5.1 pH, EC (dS/m) and OC (%)

The data pertaining to pH, EC (dS/m) and OC (%) as affected by residue of precision nitrogen management and irrigation regimes after the harvest of toria is presented in Table 4.31.

Results indicated that the residue of precision nitrogen management and irrigation regimes did not show any significant effect on pH and EC of soil but showed highly significant effect on organic carbon of soil after the harvest of toria. The IW: CPE = 1 was superior treatment and recorded the highest organic carbon (1.37 and 1.39 %) which found to be statistically at par with IW: CPE =0.8 (1.35 and 1.36 %) for both the years. The lowest organic carbon was recorded from the control plot. i.e. IW: CPE=0.

Suitable irrigation supports improved crop growth, leading to higher biomass accumulation. Residues left in the field was decomposed and contributed organic carbon to the soil. Moist soil conditions provided by irrigation favour microbial activity, which accelerates the breakdown of organic matter which leads to soil organic carbon levels.

The interaction of residue of precision nitrogen management and irrigation regimes did not show any significant effect on pH, EC and OC of soil for both years.

4.5.5.2 Available N, P and K (kg ha⁻¹)

The data relevant to available N, P and k as affected by residue of precision nitrogen management and irrigation regimes after the harvest of toria is presented in Table 4.32

Results indicated that the residue of precision nitrogen management and irrigation regimes showed significant effect available N of soil after the harvest but only the irrigation regimes showed highly significant effect on available P and K of soil after the harvest of toria. The IW: CPE = 1 was superior treatment and recorded the highest available nitrogen (262.77 and 263.15 kg ha⁻¹), phosphorus (23.53 and 23.49 kg ha⁻¹) and potassium (164.49 and 164.68 kg ha⁻¹) but for available K, it was found to be statistically at par with IW: CPE=0.8 (162.49 and 163.24 kg ha⁻¹) for both the years. The lowest organic carbon was recorded from the control plot i.e. IW: CPE=0.

With regards to residue of nitrogen management, highest available N of soil was recorded from the N₄ i.e. SPAD based nitrogen management (258.93 and 259.65 kg ha⁻¹) which was found to be statistically at par with LCC based nitrogen management.

The increased in available N with irrigation scheduling was might due to adequate amount of irrigation promotes microbial activity, which helps in the mineralization of organic nitrogen into plant-available forms (like nitrate and ammonium). Irrigation can also lead to nitrogen leaching, reducing availability in the root zone. Judicious irrigation prevents volatilization losses, helping retain nitrogen in the soil.

The available P in soil after the crop toria with irrigation scheduling was due to adequate irrigation maintains optimal soil moisture, enhancing microbial activity and organic matter decomposition, which releases phosphorus into available forms.

The increased in available K with irrigation scheduling was due to irrigation maintains soil moisture at optimal levels, preventing excessive leaching of potassium, especially in sandy soils. Maintaining proper soil aeration with moderate irrigation supports microbial processes and root growth, improving potassium retention.

The interaction of residue of precision nitrogen management and irrigation regimes did not show any significant effect on available N, P and K of soil for both years

4.5.6 Effect of residue of precision nitrogen management and irrigation regimes on nutrient (NPK) content and uptake of seed and stover

4.5.6.1a Nitrogen content (%)

The data relevant to nitrogen content (seed and stover) of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.33 for both the years. It is observable from the data that effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on nitrogen content (seed and stover) of toria for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on nitrogen content (seed and stover) in toria for both the years of observation.

4.5.6.1b Nitrogen uptake (kg ha⁻¹)

The data related to nitrogen uptake by toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented un the Table 4.33 for both years of experiment.

It is noticeable from the data that effect of residue of precision nitrogen management on nitrogen uptake was nonsignificant while irrigation regimes show highly significant effect on nitrogen uptake toria for both years. IW: CPE= 1 was superior among the treatment and recorded the highest nitrogen uptake (26.76 and 20.10 kg ha⁻¹) which was found to be statistically at par with IW: CPE=0.8 (23.34 and

17.54 kg ha⁻¹) in both the years. The lowest oil yield of toria was recorded from IW: CPE=0 i.e. control plot.

Verma *et al.* (2014), Deka *et al.* (2018), Kumar *et al.* (2019), Singh *et al.* (2019) and Saini *et al.* (2023a) conveyed significantly higher N uptake by seed and stover of toria with increase in irrigation frequency.

Interaction effect of residue of precision nitrogen management and irrigation regimes had no significant effect on oil yield of toria for both the years of observation.

4.5.6.2a Phosphorus content (%)

The data relevant to phosphorus content for both seed and stover of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.34 for both the years. It is observable from the data that effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on phosphorus content for both seed and stover in toria for both years.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on phosphorus content for both seed and stover of toria for both the years of observation.

4.5.6.2b Phosphorus uptake (kg ha⁻¹)

The data related phosphorus uptake of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in Table 4.34 for both years of experiment.

It is noticeable from the data that effect of residue of precision nitrogen management did not show any significant effect on phosphorus uptake while irrigation regimes show highly significant effect on phosphorus uptake of toria for both years. IW: CPE= 1 was superior among the treatment and recorded the maximum phosphorus

uptake by seed (6.47 and 6.18 kg ha⁻¹) and stover (4.22 and 4.11 kg ha⁻¹) which found to be statistically at par with IW: CPE=0.8 for seed (5.78 and 5.73 kg ha⁻¹) and stover (3.61 and 3.21 kg ha⁻¹) in both the years. The minimum phosphorus uptake of toria was recorded from IW: CPE=0 i.e. control plot.

Singh (2014), Singh *et al.* (2019), Deka *et al.* (2018), Kumar *et al.* (2019) and Saini *et al.* (2023a) also reported that P uptake by seed and stover suggestively increased in irrigated condition over no irrigation.

Interaction effect of residue of precision nitrogen management and irrigation regimes did not have any significant effect on phosphorus uptake of toria for both the years of observation

4.5.6.3a Potassium content (%)

The data relevant to potassium content for seed and stover of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.35 for both the years.

It is observable from the data that effect of residue of precision nitrogen management and irrigation regimes did not show any significant effect on potassium content for seed and stover of toria for both years.

Interaction effect of residue of precision nitrogen management and irrigarton regimes did not have any significant effect on potassium content for seed and stover of toria for both the years of observation.

4.5.6.3b Potassium uptake (kg ha⁻¹)

The data related to potassium uptake by both seed and stover of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the Table 4.35 for both years of experiment and in pooled also.

It is observed from the data that effect of residue of precision nitrogen management had no significant effect on potassium uptake (seed and stover) while irrigation regimes significantly affected potassium uptake (seed and stover) of toria for both years. The highest potassium uptake by seed (6.99 and 5.45 kg ha⁻¹) and stover (13.89 and 10.69 kg ha⁻¹) of toria was recorded from IW: CPE= 1 but found to be statistically at par with IW: CPE=0.8 for seed (6.2 and 4.85 kg ha⁻¹) and stover (12.99 and 9.99 kg ha⁻¹) in both the years. The lowest potassium uptake of toria was recorded from IW: CPE=0 i.e. control plot.

Similar findings were also reported by Deka *et al.* (2018), Kumar *et al.* (2019) and Saini *et al.* (2023a) that potassium uptake by both seed and stover of toria increases with proper irrigation scheduling.

Interaction effect of residue of precision nitrogen management and irrigation regimes on potassium uptake of toria was non-significant for both the years of observation

With the increased in irrigation frequency, nutrient uptake by seed and stover was higher and may be due to better availability of moisture with application of irrigation which is helpful in increasing the nutrient contents in plant. The frequent irrigation amended the uptake of less mobile nutrients such as P and K. The soluble fraction of nutrients presents in the soil solution flow to the roots as water is taken up. K is absorbed strongly by soils and only present in small quantities in the soil solution. By the process of diffusion, K moves to the root which was also helped by the presence of sufficient moisture in the root zone. This difference in nutrient uptake by toria might be described on the basis of differences in biomass (both seed and stover) brought about by different irrigational regimes.

Meena *et al.* (2023) reported that nutrient uptake by toria is mainly a function of yield and nutrients concentration in seed and stover. It may be due to nutrient uptake is interrelated with yield which lead to increase in dry matter and nutrient uptake.

It might also be due to better availability of moisture content throughout the growing period which ascribed to better nutrient uptake by Indian mustard. Because

of the increase availability of water during the growing period, soluble portion of nutrients presents in soil solution became available to plant. Singh *et al.* (2021) and Saini *et al.* (2023a) also stated that uptake of total N, P and K was increased with the increased irrigation frequency. Similar results were also stated by Verma *et al.* (2014).

The increase in nutrient uptake with proper and adequate irrigation is ascribed to enhanced nutritional environment in the rhizosphere as well as in the plant system leading to higher nutrients translocation in plant parts along with irrigation water and the nutrient uptake depends upon its content in crop plant, seed and straw yield of the crop. The increased nitrogen, phosphorus and contents in toria is due to availability of moisture in rhizosphere which solubilized the nutrients and eventually the plants exploited more nutrients from soil through their root proliferation. Under adequate soil moisture, the transpiration flow gets increased owed to full stomata opening which intends to higher content of nutrients.

4.6 Effect of residue of precision nitrogen management and irrigation regimes on economics of toria

4.6.1 Cost of cultivation, gross return, net return and B: C of toria.

The data relevant to cost of cultivation, gross return, net return and B:C of toria as influenced by effect of residue of precision nitrogen management and irrigation regimes is presented in the table 4.37 for both the year.

The highest cost of cultivation (26393 and 27403), gross return (83855.84 and 88062.62), net return (57462.84 and 60659.68) and B:C (2.18 and 2.21) obtained from I₃. The lowest cost of cultivation, gross return, net return and B:C was from I₁.

Gross return and net return were more due to higher production grain and stover yield of toria. Irrigation might be resulted in better benefit cost ratio. This might be due to fact that increment in irrigation levels increase yield. The results are conformity with the findings of Sarma and Das, (2017), Jati *et al.* (2018), Barick *et al.* (2020), Maurya *et al.* (2022) and Saini *et al.*, (2023b).

4.7 Effect of precision nitrogen management on sustainability index of rice.

The data related to sustainability index of rice influenced by precision nitrogen management is presented in Table 4.37.

The maximum sustainability index of rice was recorded highest from SPAD based nitrogen management (1.09) followed by LCC based nitrogen management (0.93), RDF (0.87) and Control (0.79). A sustainability index is more critical in precision nitrogen management because it provide a quantifiable measure of how well a farming operation is balancing crop yields with environmental and economic sustainability. This also helps the farmer make informed decision about fertilizer application, reducing waste and pollution while optimizing resource used. Thus, SPAD based nitrogen application is more sustainable than LCC based nitrogen application, split application of N and Control.

4.8 Effect of residue of precision nitrogen management and irrigation on sustainability index of toria

The data related to sustainability index of toria influenced by residual effect precision nitrogen management and irrigation regimes is presented in table 4.38.

The maximum sustainability index of toria was recoded from the combination N_4I_3 (0.998) and minimum from the combination N_1I_1 (0.623).

A sustainability index in irrigation regimes is crucial because it helps in to assess the environmental, social and economic impact of different irrigation practices, allowing for informed decision- making and the development of sustainable water management strategies. By evaluating the performance of an irrigation system across these dimensions, indices provide a comprehensive understanding of its long -term viability and its contribution to sustainable agriculture. It can also help assess the economic benefits of irrigation, including crop yields, profitability, and the overall cost of implementing and maintaining irrigation system.

4.9 System productivity of rice toria cropping system

The system productivity in terms of rice equivalent yield was calculated and the crop equivalent yield or the whole system obtained was 7477.43 kg ha⁻¹ in Table 4.39. This infers that the growing of toria in sequence with rice is profitable than growing rice alone. This may be due to toria augmenting the overall yield of the system which in turn may contribute to the increase in Benefit Cost ratio.

System productivity ensures food security by maximizing rice production which contributes to the overall economic well-being of farmers by diversifying income through oilseed cultivation and improved the soil health through beneficial rotations and nitrogen fixation. Diversifying with oilseed also helps utilize land resources more effectively and reduces the risk associated with monoculture.

Table 4.31 Residual effect of precision nitrogen management and irrigation regimes on pH, EC and OC after harvest toria

Treatment	pH			EC (ds m ⁻¹)			OC (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
I ₁	5.45	5.55	5.5	0.612	0.634	0.623	1.28	1.31	1.29
I ₂	5.25	5.35	5.29	0.601	0.591	0.596	1.35	1.36	1.36
I ₃	5.09	5.12	5.06	0.584	0.585	0.585	1.37	1.39	1.38
SEm±	0.23	0.27	0.18	0.026	0.031	0.021	0.022	0.022	0.015
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.064	0.065	0.044
N ₁	5.50	5.53	5.52	0.628	0.617	0.622	1.29	1.31	1.3
N ₂	5.33	5.37	5.35	0.61	0.602	0.606	1.34	1.35	1.35
N ₃	5.19	5.26	5.23	0.597	0.607	0.602	1.35	1.37	1.36
N ₄	5.02	5.08	5.05	0.562	0.588	0.575	1.37	1.38	1.37
SEm±	0.19	0.22	0.14	0.029	0.033	0.022	0.016	0.01	0.009
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.057	0.034	0.029
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.32 Residual effect of of precision nitrogen management and irrigation regimes on available N, P and K (kg ha⁻¹) after harvest toria

Treatment	Available N (kg ha ⁻¹)			Available P (kg ha ⁻¹)			Available K (kg ha ⁻¹)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
I ₁	248.66	249.91	249.29	20.61	20.61	20.61	160.43	160.3	160.36
I ₂	258.48	259.15	258.82	21.61	21.94	21.77	162.49	162.63	162.56
I ₃	262.77	263.15	262.96	23.53	23.49	23.51	164.49	164.68	164.59
SEm±	3.51	3.54	2.49	0.36	0.49	0.31	1.07	1.11	0.77
CD (P=0.05)	10.53	10.62	7.19	1.10	1.49	0.89	3.19	3.32	2.22
N ₁	253.89	254.73	254.32	21.67	21.75	21.71	162.15	162.35	162.25
N ₂	255.77	256.58	256.18	21.84	21.92	21.88	162.52	162.57	162.54
N ₃	257.95	258.66	258.3	22.01	22.17	22.09	162.63	162.54	162.58
N ₄	258.93	259.65	259.29	22.16	22.21	22.18	162.59	162.68	162.64
SEm±	0.89	0.98	0.66	0.2	0.24	0.16	0.79	0.73	0.54
CD (P=0.05)	3.09	3.40	2.05	NS	NS	NS	NS	NS	NS
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,

I₂= IW: CPE=0.8

I₃= IW: CPE=1

N₁- Control

N₂- Split application of N

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.33 Residual effect of of precision nitrogen management and irrigation regimes on nitrogen content (%) and uptake by seed and stover (kg ha⁻¹) of toria

Treatment	Nitrogen content (%)					Nitrogen uptake (kg ha ⁻¹)						
	Seed		Stover			Seed			Stover			Pooled
	2022 -23	2023- 24	2023- 24	2022 -23	2022 -23	2022 -23	2023-24	2022 -23	2022 -23	2023-24	2022 -23	
I ₁	1.634	1.226	1.431	0.745	0.571	0.656	11.42	13.09	12.52	9.45	10.98	
I ₂	1.745	1.307	1.526	0.769	0.591	0.681	17.54	20.44	18.26	13.64	15.95	
I ₃	1.847	1.382	1.615	0.797	0.622	0.709	20.10	23.43	19.86	14.79	17.33	
SEm±	0.083	0.102	0.066	0.0335	0.0431	0.0273	0.116	0.124	0.164	0.132	0.105	
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.479	0.356	0.493	0.395	0.304	
N ₁	1.723	1.713	1.718	0.745	0.571	0.656	21.21	21.26	16.24	16.2	16.22	
N ₂	1.731	1.723	1.727	0.758	0.785	0.772	21.51	21.32	16.72	16.38	16.55	
N ₃	1.749	1.741	1.745	0.774	0.789	0.782	21.84	21.87	17.09	16.76	16.92	
N ₄	1.764	1.757	1.761	0.799	0.804	0.802	22.07	22.11	17.47	17.38	17.42	
SEm±	0.096	0.166	0.096	0.0367	0.0318	0.0243	0.117	0.114	0.225	0.174	0.142	
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.405	0.352	0.78	0.603	0.438	
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

Where, I₁= IW: CPE=0

I₂= IW: CPE=0.8

I₃= IW: CPE=1

N₁- Control

N₂- Split application of N

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.34 Residual effect of of precision nitrogen management and irrigation regimes on phosphorus content (%) and uptake by seed and stover (kg ha⁻¹) of toria

Phosphorus content (%)						Phosphorus uptake (kg ha ⁻¹)						
Seed			Stover			Seed			Stover			
Treatment	2022 -23	2023-24	Pooled	2022 -23	2023-24	Pooled	2022 -23	2023- 24	Pooled	2022 -23	2023- 24	Pooled
I ₁	0.431	0.312	0.371	0.124	0.132	0.128	3.98	3.80	3.89	2.24	2.12	2.18
I ₂	0.436	0.321	0.378	0.136	0.154	0.145	5.83	5.73	5.78	3.61	3.21	3.41
I ₃	0.447	0.328	0.388	0.167	0.172	0.169	6.47	6.18	6.33	4.22	4.11	4.17
SEM±	0.0439	0.0475	0.0323	0.0132	0.0158	0.0103	0.65	0.66	0.46	0.61	0.66	0.45
CD (P=0.05)	NS	NS	NS	NS	NS	NS	3.98	3.80	3.89	NS	NS	NS
N ₁	0.434	0.427	0.431	0.137	0.141	0.139	5.34	5.03	5.19	3.13	3.01	3.07
N ₂	0.436	0.428	0.432	0.141	0.154	0.148	5.40	5.27	5.34	3.34	3.11	3.23
N ₃	0.438	0.427	0.433	0.143	0.156	0.150	5.46	5.33	5.39	3.45	3.13	3.29
N ₄	0.443	0.426	0.434	0.148	0.159	0.153	5.51	5.32	5.42	3.50	3.32	3.41
SEM±	0.026	0.125	0.0634	0.0154	0.0183	0.0119	0.21	0.28	0.18	0.40	0.60	0.36
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IxN	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,
I₂= IW: CPE=0.8
I₃= IW: CPE=1

N₁- Control,
N₂- Split application of N
N₃- LCC based N management and
N₄- SPAD meter-based N management

Table 4.35 Residual effect of of precision nitrogen management and irrigation regimes potassium content (%) and uptake by seed and stover (kg ha⁻¹) of toria

Treatment		Potassium content (%)					Potassium uptake (kg ha ⁻¹)				
		Seed		Stover			Seed		Stover		
		2022 -23	2023- 24	Pooled	2022 -23	2023-24	Pooled	2022 -23	2023-24	Pooled	2022 -23
I ₁		0.376	0.302	0.339	0.514	0.553	0.524	3.48	2.73	3.11	9.20
I ₂		0.464	0.362	0.413	0.549	0.562	0.555	6.21	4.85	5.53	12.66
I ₃		0.482	0.375	0.429	0.559	0.572	0.565	6.99	5.45	6.22	13.89
SEm±		0.0331	0.0398	0.0259	0.0923	0.0933	0.0656	1.07	1.10	0.77	1.48
CD (P=0.05)		NS	NS	NS	NS	NS	NS	3.21	3.29	2.21	NS
N ₁		0.418	0.419	0.419	0.513	0.533	0.523	5.22	5.26	5.24	11.41
N ₂		0.43	0.438	0.434	0.543	0.556	0.549	5.42	5.52	5.47	11.99
N ₃		0.448	0.468	0.458	0.549	0.564	0.557	5.67	5.77	5.72	12.06
N ₄		0.466	0.478	0.472	0.556	0.571	0.563	5.93	6.08	6	12.21
SEm±		0.0194	0.0436	0.0238	0.050	0.068	0.042	0.082	0.47	0.48	1.32
CD (P=0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I×N		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Where, I₁= IW: CPE=0,

I₂= IW: CPE=0.8

I₃= IW: CPE=1

N₁- Control,

N₂- Split application of N

N₃- LCC based N management and

N₄- SPAD meter-based N management

Table 4.36 Residual effect of of precision nitrogen management and irrigation regimes on cost of cultivation, gross return, net return and B:C of toria

Treatment	Cost of cultivation			Gross return			Net return			B: C		
	2022-23	2023-24	Poole d	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Poole d
I ₁	25343	26683	26013	53719.66	56845.55	55282.61	28376.66	30162.55	29269.61	1.11	1.13	1.12
I ₂	26163	27043	26603	77474.39	81512.26	79493.33	51311.39	54469.26	52890.33	1.96	2.01	1.98
I ₃	26393	27403	26898	83855.84	88062.68	85959.26	57462.84	60659.68	59061.26	2.18	2.21	2.20

Where, I₁= IW: CPE=0,

I₂= IW: CPE=0.8

I₃= IW: CPE=1

Table 4.37 Sustainability index of rice

Treatment	2022	2023	S.D	Average yield	Y _{max}	SI
N ₁	3838.33	3844.67	4.48	3841.50	4830	0.79
N ₂	4231.67	4343.00	78.73	4287.33		0.87
N ₃	4526.67	4550.00	16.50	4538.33		0.93
N ₄	4823.33	4838.33	10.61	4830.83		1.09

Where, N₁- Control, N₂- Split application of N, N₃- LCC based N application, N₄- SPAD meter-based N application

Table 4.38 Sustainability index of toria

Treatment	2022	2023	S.D	Average yield	Y _{max}	SI
N ₁ I ₁	910.367	914.73	3.08	912.55	1459.07	0.623
N ₁ I ₂	1321.63	1329.63	5.66	1325.63		0.904
N ₁ I ₃	1436.17	1438.00	1.29	1437.09		0.98
N ₂ I ₁	922.69	928.54	4.14	925.61		0.631
N ₂ I ₂	1338.02	1339.07	0.75	1338.54		0.916
N ₂ I ₃	1445.69	1447.17	1.05	1446.43		0.990
N ₃ I ₁	928.14	932.92	3.39	930.53		0.635
N ₃ I ₂	1340.03	1343.67	2.57	1341.85		0.917
N ₃ I ₃	1454.63	1456.60	1.39	1455.62		0.996
N ₄ I ₁	935.31	943.26	5.62	939.28		0.639
N ₄ I ₂	1342.84	1343.77	0.65	1343.30		0.920
N ₄ I ₃	1457.72	1459.07	0.95	1458.39		0.998
Average	1236.10			1237.90		

Table 4.39 Sysytem productivity of rice toria cropping system (mean of 2 years)

Mean Crop yield (kg ha ⁻¹)	Rice equivalent Yield (kg ha ⁻¹)		System Productivity (kg ha ⁻¹)
Kharif (Rice)	Rabi (Toria)	Rabi (REY)	7477.43
4375	1237	3252.28	



Plate 1: General view of experimental field (Rice)



Transplanting of seedling



Tillering stage



Booting stage



Flowering stage



Grain filling stage



Maturity stage

Plate 2: Different stages of the crop (Rice)

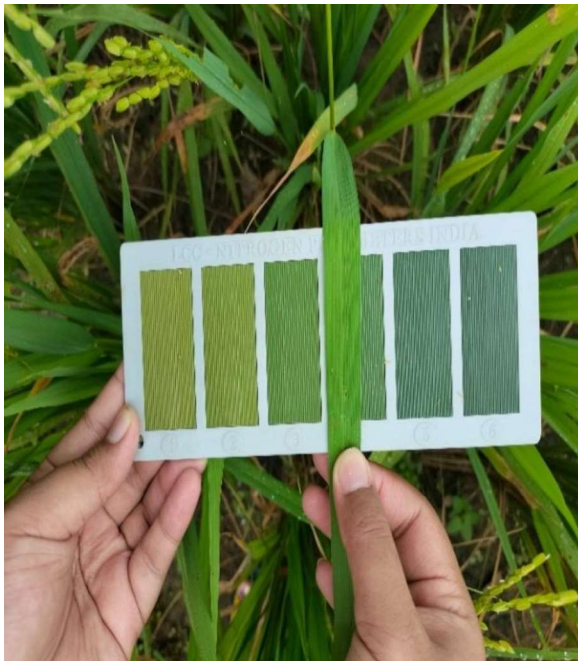
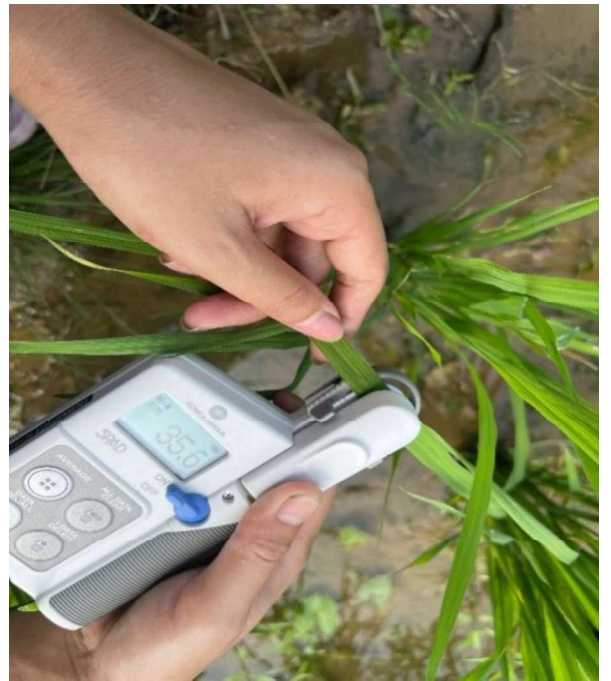


Plate 3: Observation of SPAD and LCC

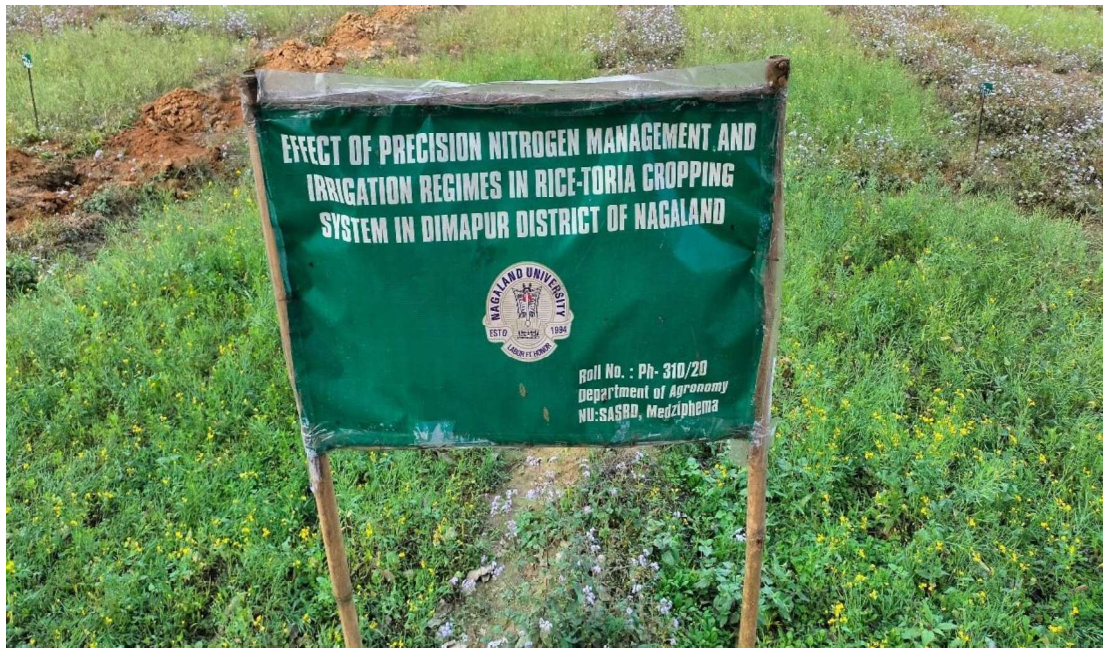


Plate 4: General view of the experimental field (Toria) var. TS-67



Sowing of seed



Emergence of crop



Flowering stage



Pod filling



Maturity

Plate 5: Different stages of crop (Torja)



Plate 6: Laboratory analysis

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A field experiment entitled “Effect of precision nitrogen management and irrigation regimes in rice - toria cropping system in Dimapur district of Nagaland” was conducted at ICAR Research Farm, Jharnapani, Nagaland Centre during *kharif* and *rabi* season of 2022-23 and 2023-24. The experiment was laid out in Randomized block design (RBD) and replicated thrice in *kharif* season of 2022-23 and 2023-24. The experiment consisting of four precision nitrogen management treatment viz., N₁- Control, N₂- Split application of N (3 Split), N₃- Leaf Colour Chart (LCC) based N application and N₄- SPAD (Chlorophyll Meter) based N application was carried out.

While in *rabi* season, the experiment was laid out in the split plot design (SPD) and replicated thrice. The main plot treatment consisted of four residual precision nitrogen management and each *kharif* plot was sub divided into three plots to accommodate three irrigation regimes viz., I₁- IW: CPE= 0, I₂- IW: CPE= 0.8 and I₃- IW: CPE= 1) in toria crop and treated as sub plot.

The initial analysis of available NPK in soil and after the harvest of the *kharif* rice and *rabi* toria were also recorded. The weather during the crop growth period was pleasant.

Observations were recorded on growth parameters viz., plant height, plant population, DMA, number of tillers m⁻², CGR, RGR, NAR, leaf area index and relative water content, phenological parameters, yield attributes, yield of rice, nutrient uptake by grain and straw, nutrient availability in soil, economics for both the crops, oil quality of toria sustainability index and system productivity. The silent features of the results obtained from the experiment are summarized below;

The growth parameters of rice like plant height, DMA plant⁻¹, number of tillers m⁻², leaf area index, relative water content was found to be highest with SPAD based N application (N₄) and was found to be at par with LCC based N application (N₃) except the plant height. The other growth parameters like CGR, RGR and NAR was also found to be highest with SPAD based N application(N₄) followed by treatment

N₃. The lowest crop growth parameters were recorded from N₁ (control) during two years of experiment and pooled data also.

The phenological parameters like days to flowering and days to maturity of rice did not show any significant variation with different nitrogen management.

The yield attributes like number of panicles m⁻², panicle length, weight of the panicle and number of filled grain panicle⁻¹ was found to be significantly influenced with different nitrogen management and highest were recorded from SPAD based N application while number of unfilled grain panicle⁻¹ and test weight was not significantly influenced. The lowest yield attributes parameters of rice were recorded from N₁ (control) during two years of experiment and pooled data also.

The grain yield of rice exhibited significant differences due to different nitrogen management. Among all the treatments, the maximum grain yield was recorded with SPAD based N application (N₄) which was followed by LCC based N application during first year, second year of study and in pooled data also. The lowest grain yield was recorded from control plot.

The straw yield and harvest index were not significantly influenced by different nitrogen management.

The efficiency parameters viz., agronomic efficiency, phenological efficiency and partial factor productivity were significantly influenced with different nitrogen management. The maximum efficiency parameters were recorded from SPAD based N application (N₄) followed by LCC based N application (N₃) and minimum was recorded from control plot (N₁).

Nitrogen, phosphorus and potassium content in the grain and straw of rice did not show any significant differences while the uptake of respective nutrient were significantly influenced by different nitrogen application. Uptake of nutrient (NPK) in grain and straw were increased with the increased fertility level. The treatment N₄ (SPAD based N application) recorded the highest uptake of NPK and followed by

treatment N₃. Relatively, the lowest uptake of NPK was recorded from no nitrogen plot (N₁).

Similarly, post harvest soil status of nutrient (NPK) after rice was significantly influenced due to different nitrogen application imposed in rice. Significantly, highest nitrogen and potassium in soil were recorded from SPAD based N application (N₄) followed by LCC based N application (N₃). Similarly highest available phosphorus in soil was recorded in treatment N₄ (SPAD based N application) which was found to be at par with treatment N₃(LCC based N application). The lowest available NPK was recorded with treatment N₁(control).

Among the treatment, gross return and net return increased with different nitrogen application. The highest gross return, net return and B:C was recorded from the treatment N₄ (SPAD based N application) followed by N₃(LCC based N application). The lowest gross return, net return and B:C was recorded with treatment N₁(control).

In *rabi* season, residue of precision nitrogen management did not show any significant effect but irrigation regimes showed highly significant effect on growth parameters, yield attributes, yield, quality, nutrient availability, nutrient uptake and economic of toria.

Growth parameters like plant height, dry matter accumulation, number of primary branches and secondary branches plant⁻¹ were found to be significantly different with different irrigation regimes. The highest plant height, dry matter accumulation, number of primary branches and secondary branches plant⁻¹ were recorded from the treatment I₃ (IW: CPE=1) and found to be statistically at par with treatment I₂ (IW: CPE=0.8) except DMA for both years of experiment and pooled data also. The lowest was recorded from the control plot.

Other growth parameters like CGR, RGR and NAR were found to be significant at 30-45 and 45-60 DAS. The highest CGR, RGR and NAR was recorded from I₃ (IW: CPE=1) followed by I₂ (IW: CPE=0.8) for first year, second year and pooled data.

Yield attributes like number of siliquae, length of siliqua, weight of siliqua and number of seed were significantly influenced with different irrigation regimes. The treatment I₃ i.e. IW: CPE =1 recorded the highest yield attributes followed by treatment I₂ i.e. IW: CPE=0.8 for both years of experiment and in pooled also.

Among all the treatment tested, significantly higher grain yield was recorded from the treatment I₃ i.e. IW: CPE =1 followed by I₂ i.e. IW: CPE=0.8 for both years of experiment and in pooled also. The straw yield and harvest index were not found significantly influenced by irrigation regimes.

Similarly, oil content was not significantly influenced by different irrigation regimes. But oil yield was significantly influenced by different irrigation regimes. The highest oil yield was recorded with irrigation regimes of IW: CPE =1(I₃) and found to be at par with I₂ (IW: CPE=0.8). The lowest oil yield was recorded from control plot for first year, second year of experiment and in pooled also.

The WUE was found to be significantly influenced with different irrigation regimes. The maximum WUE was also recorded from the treatment I₃ i.e. IW: CPE =1 followed by I₂ i.e. IW: CPE=0.8 for both years of experiment and in pooled also.

The nutrient (NPK) content was not significantly influenced by different irrigation regimes while the uptake of NPK by seed and stover of toria was significantly influenced by different irrigation regimes. The highest uptake of NPK by seed and stover of toria was recorded from the treatment I₃ (IW: CPE=1) followed by I₂ for both years and in pooled also. The lowest uptake was recorded from I₁ (control).

With respect to post harvest soil available nitrogen, phosphorus and potassium was significantly influenced by different irrigation regimes. The highest available NPK in soil was recorded with treatment I₃ (IW: CPE=1) followed by I₂ (IW: CPE=0.8) for both years and in pooled also. The lowest uptake was recorded from I₁ (control).

Significantly gross return, net return and B:C ratio were obtained with IW: CPE=1(I₃) followed by IW: CPE=0.8 (I₂). Lowest was obtained from control plot.

The system productivity was calculated for the whole system in terms of REY for the mean two years.

CONCLUSION

On the basis of preceding summary, following conclusion can made:

□ Significant increase in growth, yield attributes, yield, agronomic efficiency, physiological efficiency and partial factor productivity, nutrient availability, nutrient uptake and economics of rice was recorded with SPAD based N application over the rest of the treatments.

SPAD based nitrogen management(N_4) help us to reduce nitrogen fertilizer from 80 kg N ha⁻¹ (RDF) to 45-50 kg N ha⁻¹, resulting in a nitrogen saving of approximately 37.5-43.75% while maintaining crop productivity.

□ In case of irrigation regimes, IW:CPE=1 is required for higher growth, yield attributes, yield, quality, nutrient availability, nutrient uptake and economics of succeeding crop toria.

From the present investigation it can be concluded that SPAD based N application and IW: CPE=1 proved to be most promising, feasible and economically viable nitrogen management and irrigation practice for higher yield in (kharif) rice- (rabi) toria cropping system for Dimapur district of Nagaland.

FUTURE ASPECT OF MY RESEARCH

Further studies of this research works would emphasize integration of advanced technology, climate resilience resource use efficiency, environment sustainability and economic feasibility. such approaches will contribute to improve profitability and sustainable agriculture development while conserving water and nutrient resources.

APPENDICES

APPENDIX I

Cost of cultivation per ha for rice (both years) under precision nitrogen management for control treatment

Sl. No.	Particulars	Mandays/quantity		Rate		Total (₹)	
		2022	2023	2022	2023	2022	2023
1	Field preparation						
	a. Tractor	2	2	800/hr	900/hr	1600	1800
	b. Power tiller	1	1	800/hr	900/hr	800	900
	c. Manual	8	9	400	400	3200	3600
2	Application of fertilizers and puddling	10	10	400	400	4000	4000
3	Cost of fertilizer						
	a. Urea	0	0	7	7	0	0
	b. SSP	250 kg/ha	250 kg/ha	8.4	8.4	2100	2100
	c. Mop	66.67 kg/ha	66.67kg/ha	19.6	19.6	1306.7	1306.732
4	Uprooting and transplanting of seedling	15	16	400	400	6000	6400
5	Interculture operation	10	10	400	400	4000	4000
6	Harvesting, threshing and winnowing	35	36	400	400	14000	14400
7	Seed	35kg/ha	35kg/ha	15/kg	15/kg	525	525
8	Miscellaneous					1500	1500
	TOTAL (₹)					39031.73	40531.73

**Cost of cultivation per ha for rice (both years) under precision nitrogen
management for Split application of N**

Sl. No.	Particulars	Mandays/quantity		Rate		Total (₹)	
		2022	2023	2022	2023	2022	2023
1	Field preparation						
	a. Tractor	2	2	800/hr	900/hr	1600	1800
	b. Power tiller	1	1	800/hr	900/hr	800	900
	c. Manual	8	9	400	400	3200	3600
2	Application of fertilizers and puddling	10	10	400	400	4000	4000
3	Cost of fertilizer						
	a. Urea	174 kg/ha	174 kg/ha	7	7	1218	1218
	b. SSP	250 kg/ha	250 kg/ha	8.4	8.4	2100	2100
	c. Mop	66.67 kg/ha	66.67kg/ha	19.6	19.6	1306.73	1306.73
4	Uprooting and transplanting of seedling	15	16	400	400	6000	6400
5	Interculture operation	10	10	400	400	4000	4000
6	Harvesting, threshing and winnowing	35	36	400	400	14000	14400
7	Seed	35kg/ha	35kg/ha	15/kg	15/kg	525	525
8	Miscellaneous					1500	1500
	TOTAL (₹)					40249.73	41749.73

Cost of cultivation per ha for rice (both years) under precision nitrogen management for LCC based N application

Sl. No.	Particulars	Mandays/quantity		Rate		Total (₹)	
		2022	2023	2022	2023	2022	2023
1	Field preparation						
	a. Tractor	2	2	800/hr	900/hr	1600	1800
	b. Power tiller	1	1	800/hr	900/hr	800	900
	c. Manual	8	9	400	400	3200	3600
2	Application of fertilizers and puddling	10	10	400	400	4000	4000
3	Cost of fertilizer						
	a. Urea	108.7 kg/ha	108.7 kg/ha	7	7	760.9	760.9
	b. SSP	250 kg/ha	250 kg/ha	8.4	8.4	2100	2100
	c. Mop	66.67 kg/ha	66.67kg/ha	19.6	19.6	1306.73	1306.73
4	Uprooting and transplanting of seedling	15	16	400	400	6000	6400
5	Interculture operation	10	10	400	400	4000	4000
6	Harvesting, threshing and winnowing	35	36	400	400	14000	14400
7	Seed	35kg/ha	35kg/ha	15/kg	15/kg	525	525
8	Miscellaneous					1500	1500
	TOTAL (₹)					39792.63	41063.73

Cost of cultivation per ha for rice (both years) under precision nitrogen management for SPAD based N application

Sl. No.	Particulars	Mandays/quantity		Rate		Total (₹)	
		2022	2023	2022	2023	2022	2023
1	Field preparation						
	a. Tractor	2	2	800/hr	900/hr	1600	1800
	b. Power tiller	1	1	800/hr	900/hr	800	900
	c. Manual	8	9	400	400	3200	3600
2	Application of fertilizers and puddling	10	10	400	400	4000	4000
3	Cost of fertilizer						
	a. Urea	76 kg/ha	76 kg/ha	7	7	532	532
	b. SSP	250 kg/ha	250 kg/ha	8.4	8.4	2100	2100
	c. Mop	66.67 kg/ha	66.67kg/ha	19.6	19.6	1306.73	1306.73
4	Uprooting and transplanting of seedling	15	16	400	400	6000	6400
5	Interculture operation	10	10	400	400	4000	4000
6	Harvesting, threshing and winnowing	35	36	400	400	14000	14400
7	Seed	35kg/ha	35kg/ha	15/kg	15/kg	525	525
8	Miscellaneous					1500	1500
	TOTAL (₹)					39563.73	41063.73

Cost of cultivation per ha for toria (both years) under irrigation for control treatment

Sl. No.	Particulars	Mandays/quantity		Rate		Total (₹)	
		2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
1	Field preparation						
	a. Power tiller	1	1	800/hr	900/hr	800	900
	. Manual	8	9	400	400	3200	3200
2	Application of fertilizers	5	10	400	400	2000	2000
3	Cost of fertilizer						
	a. Urea	109 kg/ha	109 kg/ha	7	7	763	763
	b. SSP	375 kg/ha	375 kg/ha	8.4	8.4	3150	3150
	c. Mop	50 kg/ha	50 kg/ha	19.6	19.6	980	980
4	Line sowing	10	10	400	400	4000	4000
5	Interculture operation	10	10	400	400	4000	4800
6	Harvesting, threshing and winnowing	13	13	400	400	5200	5200
7	Seed	5kg/ha	5kg/ha	90/kg	90/kg	450	450
8	Miscellaneous					1000	1000
	TOTAL (₹)					25543	25643

Cost of cultivation per ha for toria (both years) under irrigation for IW: CPE=0.8

Sl. No.	Particulars	Mandays/quantity		Rate		Total (₹)	
		2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
1	Field preparation						
	a. Power tiller	1	1	800/hr	900/hr	800	900
	. Manual	8	9	400	400	3200	3200
2	Application of fertilizers	5	10	400	400	2000	2000
3	Cost of fertilizer						
	a. Urea	109 kg/ha	109 kg/ha	7	7	763	763
	b. SSP	375 kg/ha	375 kg/ha	8.4	8.4	3150	3150
	c. Mop	50 kg/ha	50 kg/ha	19.6	19.6	980	980
4	Line sowing	10	10	400	400	4000	4000
5	Interculture operation	12	11	400	400	4800	4400
6	Harvesting, threshing and winnowing	13	13	400	400	5200	5200
7	Seed	5kg/ha	5kg/ha	90/kg	90/kg	450	450
8	Miscellaneous					1000	1000
	TOTAL (₹)					26343	26043

Cost of cultivation per ha for toria (both years) under irrigation for IW: CPE=0.1

Sl. No.	Particulars	Mandays/quantity		Rate		Total (₹)	
		2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
1	Field preparation						
	a. Power tiller	1	1	800/hr	900/hr	800	900
	. Manual	8	9	400	400	3200	3200
2	Application of fertilizers	5	10	400	400	2000	2000
3	Cost of fertilizer						
	a. Urea	109 kg/ha	109 kg/ha	7	7	763	763
	b. SSP	375 kg/ha	375 kg/ha	8.4	8.4	3150	3150
	c. Mop	50 kg/ha	50 kg/ha	19.6	19.6	980	980
4	Line sowing	10	10	400	400	4000	4000
5	Interculture operation	13	12	400	400	5200	4800
6	Harvesting, threshing and winnowing	13	13	400	400	5200	5200
7	Seed	5kg/ha	5kg/ha	90/kg	90/kg	450	450
8	Miscellaneous					1000	1000
	TOTAL (₹)					26743	23443

REFERENCES

REFERENCES

- Ali, A. M., Darvishzadeh, R., Skidmore, A. K., & Van Duren, I. 2017a. Specific leaf area estimation from leaf and canopy reflectance through optimization and validation of vegetation indices. *Agricultural and Forest Meteorology*. **236**:162–174.
- Ali, A. M., Thind, H. S., Varinderpal, S. and Bijay, S. 2015a. A framework for refining nitrogen management in dry direct-seeded rice using green seeker optical sensor. *Computers and Electronics in Agriculture*. **110**(2):114-120.
- Ali, S.A., Elamathi, S., Suryendra, S., Debbarma, V and Ghosh, G. 2017b. Leaf colour chart for proficient nitrogen management in transplanted rice (*Oryza sativa* L.) in Eastern Uttar Pradesh, India. *International Journal of Current Microbiology and Applied Science*. **6**(11): 5367-5372.
- Anonymous, 2023a. Agricultural Statistics at a Glance. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. Pp:52-99.
- Anonymous, 2023b. Nagaland Statistical Handbook, 2020. Directorate of Economics and Statistics, Nagaland Kohima. Pp:19-31.
- AOAC.1975. Official methods of analysis.12th edn. Association of Analytical Chemists. P.O. Box. 546, Benjamin Franklin Station, Washington, D.C. 20044.
- Attri, M., Sharma. N., and Sharma, B.C. 2022. Effect of Foliar Application of Nano Urea on Productivity and Profitability of Fine Rice under Irrigated Subtropics of Jammu Region. *Indian Journal of Ecology*. **49**(5): 1935-1938.
- Barad, B.B., Mathukia, R.K., Der, H.N and Bodar, K.H. 2018. Real time nitrogen fertilization using precision tools for enhancing productivity of wheat (*Triticum aestivum*). *International Journal of Pure and Applied Bioscience*. **6**(2): 434- 440.
- Baraki, B., Kassie, M., Kibrom, A. and Assefa, G. 2016. Time of nitrogen application affects rice grain yield and yield components in the Central Highlands of Ethiopia. *Journal of Agricultural Science*. **8**(10): 161-172.
- Baral, B. R., Pande, K. R., Gaihre, Y. K., Baral, K. R., Sah, S. K., Thapa, Y. B. and Singh, U. 2021. Real-time nitrogen management using decision support-tools increases nitrogen use efficiency of rice. *Nutr Cycl Agroecosyst* ://doi.org/10.1007/ s10705-021-10129-6.
- Barick, B. B., Patra, B. C. and Bandyopadhyay, P. 2020. Performance of rapeseed (*Brassica campestris* L.) under varied irrigation and sowing methods. *Journal of Crop and Weed*. **16**(2): 269-273.

- Barman, A., Singh, V. K., Rathore, S. S., Babu, S. and Saha, P. 2023. Nutrient uptake, quality and fertilizer productivity of Indian mustard (*Brassica juncea* L.) as influenced by deficit drip irrigation scheduling under fruit plantation. *Bangladesh Journal of Botany*. **52**(3): 821-827.
- Barman, A., Singh, V. K., Rathore, S. S., Babu, S. and Sharma, V. K. 2020. Deficit irrigation management and Agri Horti system compatibility using drip for enhancing water use efficiency and profitability in Indian mustard (*Brassica juncea*). *Indian Journal of Agronomy*. **66**(3):378-381.
- Bejbaruah, R., Sharma, R. C. and Banik, P. 2013. Split application of vermicompost to rice (*Oryza sativa* L.): Its effect on productivity, yield components, and N dynamics. *Organic Agriculture*. **3**(20):123-128.
- Bharat, R., Kumar, J., Rai, S. K. and Gupta, R. 2019. Effect of hydrogel and irrigation scheduling on water use efficiency and productivity of Indian mustard (*Brassica juncea* L.) in Jammu region. *Journal of Oilseed Brassica*, **10** (2): 63-66.
- Bhat, T. A., Kotru, R., Verma, A., Ganai, M. A., Dar, L. L. A. and Teli, N. A. 2017. Leaf Colour Chart based N management for yield, nutrient uptake and yield of rice genotypes. *International Journal of Current Microbiology and Applied Sciences*. **6**(9): 3531-3538.
- Bhatt, M. K., Labanya, R., Joshi, H. C., Pareek, N., Chandra, R. and Raverkar, K. P. 2017. Long term effects of inorganic fertilizers and FYM on soil chemical properties and yield of wheat under rice - wheat cropping system. *ENVIS Bulletin Himalayan Ecology*. **25**:28-35.
- Bhatt, P. and Kushwaha, H. S. 2019. Water use efficiency and nutrient uptake of yellow mustard (*Brassica juncea* L.) as influenced by different irrigation schedules through non weighing lysimeters associated with varying water table conditions. *International Journal of Chemical Studies*. **7**(4): 2417-2421.
- Bhattarai, K., Pandey, K. R., Marahatta, S., Dhakal, M., Bhusal, N. R. and Thapa, R. 2024. Precision Nitrogen Management in Spring Rice (*Oryza sativa* L.) using Decision Support Tools in Chitwan, Nepal. *Turkish Journal of Agriculture - Food Science and Technology*. **12**(6): 955-965.
- Bhavana, B., Laxminarayana, P., Latha, A. M. and Anjaiah, T. 2020. Need based nitrogen management using leaf colour chart for short duration transplanted rice: Effect on nitrogen use efficiency. *Journal of Pharmacognosy and Phytochemistry*. **9**(3): 1704-1709.
- Bhukhar, O. S., Shivran, A. C., Dudwal, B. L., Kumawat, P., Kuldeep, S., Douthaniya, R. K. and Kumawat, S. K. 2022. Productivity and Profitability of Indian Mustard (*Brassica juncea* L.) influenced by Drip Irrigation and Micronutrient Application Methods. *Indian Journal of Ecology*. **49**(1): 99-103.

- Billa, S.K., Murthy, K.R., Ramana, A.V. and Jagannadham, J. 2020. The potential of green seeker in nitrogen management of transplanted rice crop under North Coastal environment of Andhra Pradesh, India. *International Journal of Agricultural Statistical Sciences*. **16**(1): 1925-1929.
- Bindhani, D., Goswami, B. S. and Nayak, S. 2020. Growth and yield of hybrid mustard as influenced by irrigation scheduling and nitrogen management. *International Journal of Chemical Studies*. **8**(4): 246-250.
- Bindhani, D., Goswami, S. B., Kumar, A., Bhupenchandra, I., Gudade, B. A., Talukdar, D., Verma, G., Bora, S. S., Devi, E. L., Chongtham, S. K., Devi, S. H., Sinyorita, S., Olivia, L. C. and Shettigar, N. 2020. Yield, Quality, Nitrogen Use efficiency (NUE) and Water Use efficiency (WUE) of Indian mustard (*Brassica juncea* L.) as Influenced by Irrigation and Nitrogen Levels. *International Research Journal of Pure & Applied Chemistry*. **21**(24): 265-27.
- Black, C. A. 1965. Methods of soil analysis Part 2. American Soc. Agron., Madison Wisconsin, U.S.A. pp. 1372-1376.
- Blackman, V. H. 1919. The compound interest law and plant growth. *Annals of Botany*. **33**:353-360.
- Bo, W., Genyou, Z., Shiyang, G., Xiaohui, Li., Jiaqi, Y., and A., Hu. 2020. Improving Nitrogen Use Efficiency in Rice for Sustainable Agriculture: Strategies and Future Perspectives. *Reproductive and developmental Biology*. **12**(10):1653-1653.
- Borah, K. S., Pathak, K., Saikia, M., Medhi, K. B., Goawami, J., Konwar, M. J. and Bora, S. S. (2024). Precision nitrogen management in wet direct seeded Sali rice through green seeker, leaf colour chart and nano nitrogen. *International Journal of Research in Agronomy*. **7** (2): 233-237.
- Budhathoki, P., Shrestha, J. and Ghimire, B. 2018. Effect of nutrient expert tool on yield and yield attributes of rice (*Oryza sativa* L.) in Sundarbazar, Lamjung, Nepal. *International Journal of Applied Sciences and Biotechnology*. **6**(4): 462-466.
- Bray, R.H. and Kurtz, L.T. 1945. Determination of Total, Organic, and Available Forms of Phosphorus in Soils. *Soil Science* **59**: 39-45. <https://doi.org/10.1097/00010694-194501000 00006>.
- Chapman, H. D. and Parker, M. L. 1961. Methods of analysis for soils, plants and water California. Div. Agric. Sci., Univ. California. pp. 169-170.
- Chaudhari, D. M., Sadhu, A. C. and Patel, H. K. 2016. Role of irrigation scheduling and weed management on growth, yield attributes and yield of Indian mustard (*Brassica juncea* L.). *Research in Environment and Life Sciences*. **9**(3):731-733.

- Chaudhary, M. M., Chaudhari, H. L., Patel, J. A., Patel, C. K., & Patel, H. K. 2019. Precision nitrogen management in cereal crops. *International Journal of Agricultural Sciences*. **11**(8), 8317–8321.
- Choudhary, D., Singh, R., Dagar, C.S., Kumar, A., Rajeev and Pattam, K. 2018. Response of Indian mustard to different sowing environments and varieties in semi-arid of Haryana. *International Journal of Chemical Studies*. **6**(2): 1452-1457.
- Dadhich, R. K., Meena, R. S., Reager, M. L. and Kansotia, B. C. 2015. Response of bio-regulators to yield and quality of Indian mustard (*Brassica juncea* L. Czernj. and Cosson) under different irrigation environments. *Journal of Applied and Natural Sciences*. **7**(1):52-57.
- Das, A., Layek, J., Ramkrushna, G. I., Patel, D. P., Choudhury, B. U. and Krishnappa, R. 2018. Modified system of rice intensification for higher crop and water productivity in Meghalaya, India: opportunities for improving livelihoods for resource-poor farmers. *Paddy and Water Environment*. **16**: 23-34.
- Das, A., Singh, A. and Choudhary, A. K. 2015. Enhancing productivity and profitability through site-specific nutrient management in transplanted rice in eastern Uttar Pradesh, India. *Archives of Agronomy and Soil Science*. **61**(6): 819-832.
- Das, I. and Sahu, N.C. 2015. Nitrogen management by using leaf colour chart in kharif rice in alluvial soils of West Bengal. *Journal of Krishi Vigyan*. **3**(2): 69-72.
- Das, J., Pathak, K., Das, S., Dey, J. K. and Debnath, A. 2021. Response of late sown rapeseed varieties for physiological traits under different levels of irrigation. *The Pharma Innovation Journal*. **10**(2): 639-642.
- Das, J., Sarma, A. and Das, A. 2019. Response of irrigation levels on productivity and moisture extraction pattern of late sown rapeseed (*Brassica campestris* var. toria) varieties under Assam condition. *Indian Journal of Hill Farming*. **32**(1): 79-83.
- De, B. and Sinha, A. C. 2011. Integrated nutrient management to rapeseed: An integrated approach for enhancing the growth and yield of rapeseed (*Brassica campestris* var. yellow sarson). *Lambert Academic Publishing house*. Pp.1-6.
- Deepthi, K.Y. 2015. Evaluation of water and nitrogen productivity for maize preceeded by green gram under drip irrigation. Ph. D Thesis. Acharya N. G. Ranga Agricultural University, Hyderabad, India.
- Deka, P., Pathak, K., Begum, M., Sarma, A. and Dutta, P. K. 2018. Seed yield and nutrient uptake in late sown toria (*Brassica campestris* var. toria) as influenced by different irrigation and fertilizer levels. *Agricultural Science Digest*. **38** (2): 127-130.

- Devedee, A. K., Singh, R. K., Meena, R. N. and Choudhary, K. 2019. Effect of moisture conservation on growth and yield of linseed under varying fertility levels. *Journal of Crop and Weed*. **15**(1):198-200.
- Digra, A., Giri, U. and Bandyopadhyay, P. 2016. Performance of rapeseed (*Brassica campestris* L. Prain) towards irrigation and mulch in new alluvial zone of West Bengal. *Journal of Crop and Weed*. **12**(3):20-22.
- Dinesh, D., Baskar, A and Rajan, K. 2017. Effect of cultivation methods and nitrogen management strategies on growth and yield of rice (*Oryza sativa* L.) grown in coastal alluvial soils of Southern India. *International Journal of Current Microbiology and Applied Sciences*. **6**(3): 2176-2187.
- Donald, C.M.1962. In search of yield. *Journal of the Australian Institute of Agricultural Science*. **28**: 171-178.
- Dudwal, B. L., Yadav, S. K., Rakesh, K., Meena, R. L. and Hassim, M. 2013. Performance and production potential of Mustard (*Brassica juncea* L.) to different levels of irrigation in the central plain zone of Uttar Pradesh, India. *Agricultural Science Digest*. **33**(1): 33-37.
- Duttarganvi, S., Channabasavanna, A. S., Halepyati, A. S., Nagalikar, V. P., Satyanarayana, R and Vasudevan, S. N. 2011. Economic adoptability of leaf colour chart and chlorophyll meter in nitrogen management in lowland rice (*Oryza sativa* L.). *Karnataka Journal of Agricultural Sciences*. **24**(4): 531-532.
- Duttarganvi, S., Channabasavanna, A. S., Rao, S and Halepyati, A. S. 2014. Effect of LCC and SPAD based nitrogen management on growth and yield of lowland rice (*Oryza sativa* L.). *International Quarterly Journal of Life Science*. **9** (2):663-665.
- Gawdiya, S., Kumar, M., Naresh, R, K., Kumar, R., Kumar, S., Meena, S., Saini, R. and Prajapat, M. 2021. Winter wheat response in precision nitrogen management and conservation tillage practices under irrigated condition of western India: Effect on soil nutrient availability, physicochemical properties and nutrient use efficiency. *The Pharma Innovation Journal*. **10**(12): 2944-2949.
- Ghosh, M., Dillip, K. S., Madan, K. J. and Virendra, K. T. 2013. Precision nitrogen management using chlorophyll meter for improving growth, productivity and N use efficiency of rice in Subtropical climate. *Journal of Agricultural Sciences*. **5**(2):253-266.
- Ghosh, M., Swain, D. K., Jha, M. K., Tewari, V. K. and Bohra, A. 2017. Optimizing chlorophyll meter (SPAD) reading to allow efficient nitrogen use in rice and wheat under rice-wheat cropping system in eastern India. *Plant Production Science*. DOI: 10.1080/1343943X.2020.1717970.

- Gill, G. S. and Singh, K. 2013. Effect of Nitrogen and phosphorus on direct seeded rice under sodic soil. *Oryza- International Journal of Rice*. **50**(2): 103-108.
- GOI (Government of India). 2020. Agricultural Statistics at a Glance. Agricultural Statistics Division, Department of Agriculture and Cooperation and Farmers Welfare, Ministry of Agriculture, Government of India, New Delhi.
- Gomez, A. K. and Gomez, A. A. 1984. Statistical procedure for agricultural research. An International Rice Research Institute Book. A Wiley- Inter Science Publication. John Wiley and Sons. Singapore.
- Goudra, S., Mudalagiriappa, Hanumanthappa, D. C. and Prakasha G. 2021. Influence of optical sensor-based precision nitrogen management on yield, nutrient uptake and available nutrient status of aerobic rice (*Oryza sativa* L.). *The Pharma Innovation Journal*. **10**(12): 3097-3101.
- Goudra, S., Mudalagiriappa, Hanumanthappa, D.C., Murthy, K.N.K., Basavaraja, P. K. and Kumar, M. K. P. 2019. Influence of precision nitrogen management through crop sensors on growth and yield of aerobic rice (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry*. **8** (6): 2409-2413.
- Gupta, R. K., Varinderpal, S., Yadvinder, S., Bijay, S., Thind, H. S. and Ajay, K. 2011. Need based fertilizer nitrogen management using leaf colour chart in hybrid rice (*Oryza sativa* L.). *Indian Journal of Agricultural Sciences*. **81**(12):1153-1157.
- Gupta, S. and Tomar, S.S. 2015. Impact Analysis of FrontLine Demonstrations on Mustard in Tribal Area of M.P. *Progressive Research – An International Journal*. **10** (1): 493-495.
- Gurupadappa. 2018. Nitrogen management through decision support tools in direct seeded rice (*Oryza sativa* L.) under Tungabhadra Project Command Area. M. Sc Thesis. University of Agricultural Sciences, Raichur.
- Haider, I. K. 2018. Appraisal of biofertilizers in rice: To supplement inorganic chemical fertilizer. *Rice Science*. **25**:357-362.
- Hanway, J. J. and Heidel, H. 1952. Soil analysis methods as used in Iowa state college of soil testing laboratory. *Iowa Agriculture*. **57**:1-31.
- Haque, M. A. and Ali, M. M. 2020. Integrated effects of vermicompost with chemical fertilizers on the yield of mustard. *Progressive Agriculture*. **31**(2): 81–88
- Haque, M. A. and Haque, M. M. 2016. Growth, yield and nitrogen use efficiency of new rice variety under variable nitrogen rates. *Journal of Plant Sciences*. **7**(3):612-622.
- Haque, M. A., Singh, R., Kumar, A., Kumar, S., Singh, A. K. and Singh, K. K. 2018. Site-specific nutrient management in wheat using nutrient expert and green

- seeker in Eastern India. *Journal of the Indian Society of Soil Science*. **66**(2): 180-187.
- Harish, M. N., Choudhary, A. K., Singh, Y., Pooniya, V., Das, A., Varatharajan, T. and Babu, S. 2018. Effect of promising rice (*Oryza sativa* L.) varieties and nutrient management practices on growth, development and crop productivity in eastern Himalayas. *Annals of Agricultural Research*. **38**(4):375-385.
- Hemalatha, K. and Singh, Y. 2018. Effect of leaf colour chart based nitrogen and weed management on direct seeded rice. *Journal of Pharmacognosy and Phytochemistry*. **7**(4): 1244-1247.
- Hossain, M. B., Alam, M. S. and Ripon, M. A. 2013. Effect of irrigation and sowing method on yield and yield attributes of mustard. *Rajshahi University Journal of Life and Earth and Agricultural Sciences*. **41**: 65-70.
- Houshmandfar, A. and Kimaro, A. 2011. Callibrating the leaf colour chart for rice nitrogen management in northern Iran. *African Journal of Agricultural Research*. **6**: 2627-2633.
- Huang, J., He, F., Cui, K., Buresh, R.J., Xu, B., Gong, W. and Peng, S. 2008. Determination of optimal nitrogen rate for rice varieties using a chlorophyll meter. *Field Crops Research*. **105**:70–80.
- Jackson, M. L. 1973. Soil chemical analysis, Prentice Hall of India Pvt. Ltd. New Delhi, pp. 498-499.
- Jahan, M. A., Rashid, M. H. U., Akter, M. B. and Ahmed, F. 2018. Effect of nitrogen and potassium fertilization on the yield and nitrogen use efficiency of winter rice (*Oryza sativa* L.). *Bangladesh Journal of Agricultural Research*. **43**(2): 291-303.
- Jahan, N.A., Yeasmin, S., Anwar, M.P., Islam, M.A., Rahman, H and Islam, A.M. 2018. Efficacy and economics of different need-based nitrogen management approaches in winter rice. *American Journal of Plant Sciences*. **2**(9): 2601-2611.
- Jain, V. K. 2016. Fundamentals of Plant Physiology. S. Chand Publishers, India pp 1-723.
- Jat S, Nath T, Kumar D, Kashiwar S. 2017. Response of sulphur nutrition and mulching on Indian mustard (*Brassica napus* L.). **19**(6):9-11.
- Jati, A. L., Rathore, B. S., Desai, A. G. and Shah, S. 2018. Production potential, water productivity and economic feasibility of Indian mustard (*Brassica juncea*) under deficit and adequate irrigation scheduling with hydrogel. *Indian Journal of Agricultural Sciences*. **88**(2): 212–215.
- Jat, R. S., Singh, V. V., Sharma, P. and Rai, P. K. 2019. Oilseed brassica in India: Demand, supply, policy perspective and future potential.

- Karthik, R., Ghosh, M., Chowdhury, A. R. and Dhaker, D. L. 2023. Impact of SPAD chlorophyll meter-based nitrogen management strategy on N uptake and soil properties in direct seeded rice. *ORYZA- An International Journal on Rice*. **60**(3): 457-463.
- Konwar, K., Bharadwaj, A. S. K and Boruah, P. 2019. Productivity and profitability of rapeseed (*Brassica rapa* var. dichotoma) under system of rapeseed intensification. *Journal of Oilseed Brassica*. **10** (2): 106-111.
- Krishna, A., Singh, Y., Singh, R. and Singh, G. 2017. Site-specific nutrient management for optimizing wheat productivity in Indo-Gangetic plains of India. *Nutrient Cycling in Agroecosystems*. **107**(3): 299-312.
- Krishnakumar, S. and Haefele, S. 2013. Integrated nutrient management and LCC based nitrogen management on soil fertility and yield of rice (*Oryza sativa* L.). *Scientific Research and Essays*. **8**(41): 2059-2067.
- Kumar, A., Bindhani, D., Goswami, S. B., Verma, G. and Behera, P. 2020. Growth, Yield attributes and Yield of Indian Mustard [*Brassica juncea* (L.) Czern & Coss] as Influenced by Irrigation and Nitrogen Levels. *International Journal of Current Microbiology and Applied Sciences*. **9**(7): 1735-1746.
- Kumar, A., Mishra, S. N., Kumar, S. and Kumar, A. 2014. Effect of Vermicompost and Inorganic Fertilizers on Yield and Yield Attributes of Rice (*Oryza sativa* L.) in Bihar. *Journal of Applied and Natural Science*. **6**(1): 122-127.
- Kumar, B. S., Das, J. C. and Sarma, A. 2019. Effect of irrigation and nutrient management on growth, yield and nutrient uptake of Indian mustard (*Brassica juncea*). *Green Farming*. **4**: 419-423.
- Kumar, S., Bhagat, R. M. and Singh, R. 2017. Response of Rice (*Oryza sativa* L.) to NPK fertilization and organic sources of nutrients in sandy loam soils of Jammu. *Journal of Soil and Water Conservation*. **16**(2): 116-120.
- Kumar, Y. S. S., Basha, S. J., Rao, E. N., Babu, D. V. and Vardhan, K. M. V. 2021. Effect of plant Sensor based real time Nitrogen management on growth, yield and economics of rice (*Oryza sativa* L.) crop. *Annals of Plant and Soil Research*. **23** (4):415-418.
- Kumar, Y., Niwas, R. and Dipak. 2022. Effect of irrigation and sowing time on growth and yield of Indian mustard (*Brassica juncea* L.) in central plain zone of UP. *The Pharma Innovation Journal*. **11**(7): 2143-2146.
- Kunapara, A.N., Subhaiah, R., Prajapati, G. V. and Makwana, J. J. 2016. Influence of drip irrigation regimes and lateral spacing on cumin productivity. *Current world Environment*. **11**(1): 333-337.

- Kutikuppala, S. and Singh, Y. 2018. Effect of leaf colour chart based nitrogen and weed management on yield and economics of direct seeded rice. *International Journal of Chemical Studies*. **6**(4): 2428-2432.
- Latha, M., Prasad, P. R., Prasad, P. R. K., Lakshmipathy, R. and Srinivasarao, V. 2019. Effect of integrated nitrogen management on rice and rice fallow rabi crops. *International Journal of current Microbiology and Applied Sciences*. **8**(1):271-280.
- Lee, D. K., Han, K. H., Jung, S. Y., Park, Y. H. and Choi, S. W. 2010. Growth and yield responses of rice (*Oryza sativa* L.) cultivars to top-dressing with nitrogen. *Korean Journal of Crop Science*. **55**(3): 221-225.
- Li, P., Lu, J., Hou, W., Pan, Y., Wang, Y., Khan, M. R., Ren, T., Cong, R. and Li, X. 2017. Reducing nitrogen losses through ammonia volatilization and surface runoff to improve apparent nitrogen recovery of double cropping of late rice using controlled release urea. *Environmental Science and Pollution Research International*. **24**(12), 11722–11733.
- Liu, K., Li, Y., Hu, H., Zhou, L., Xiao, X. and Yu, P. 2015. Estimating rice yield based on normalized difference vegetation index at heading stage of different nitrogen application rates in South East of China. *Journal of Agricultural and Environmental Sciences*. **2**(13):1-8.
- Liu, L.J., Chen, T.T, Wang, Z.Q, Zhang, H., Yang, J.C. and Zhang, J.H. 2013. Combination of site-specific nitrogen management and alternate wetting and drying irrigation increases grain yield and nitrogen and water use efficiency in super rice. *Field Crops Research*. **154**: 226-235.
- Lone, A. A., Wani, A. M., Sofi, J. A., Wani, S. H., Mir, R. R. and Padder, B. A. 2017. Response of rice (*Oryza sativa* L.) to real time nitrogen management using leaf colour chart and conventional methods. *International Journal of Chemical Studies*. **5**(6): 1948-1952.
- Mahapatra, I. C., Rao, K. S., Panda, B. B. and Shivay, Y. S. 2012. Agronomic research on rice (*Oryza sativa*) in India. *Indian Journal of Agronomy*. **57**(3):9-31.
- Malviya, P., Suraywanshi, V. S. and Upadhyaya, V. B. 2018. Studies on Effect of Various Proportions of Vermicompost and Fertilizers on Physiological Parameters, Growth, Yield and Yield Components of Scented Rice. *International Journal of Current Microbiology and Applied Science*. **7**(11):1587-1593.
- Mannade, A., Patil, P. R. and Chandrakar, B. R. 2017. Effect of site-specific nutrient management on yield attribute of rice variety under rainfed condition of Chhattisgarh. *Journal of Pharmacognosy and Phytochemistry*. **6**(6):1436-143.

- Mannade, A.K., Tedia, A.K., Tomar, G.S and Kumar, R. 2017. Evaluate the effect of SSNNM on yield and yield attributing parameters of rice in vertisol. *International Journal of Chemical studies*. **5**(4): 2082-2085.
- Mathukia, R. K., Puja, R. and Dadhania, N. M. 2014. Climate change adaptation: real time nitrogen management in maize (*Zea mays* L.) using leaf colour chart. *Current World Environment*. **9**(3):1028-1033.
- Maurya, S. K., Kalhapure, A., Singh, N., Kumar, A., Yadav, P., Kumar, M. and Maurya, B. K. 2022. Growth and Yield Response of different Indian Mustard [*Brassica juncea* (L.)] varieties to Irrigation Scheduling. *Biological Forum-An International Journal*. **14**(3): 434-439.
- Meena, S., Shivran, A. C., Dhaker, D. L., Karthik, R. and Meena, B. R. 2023. Effect of Irrigation Scheduling and Thiourea on Nutrient Concentration, Uptake and Water Use Efficiency of Mustard. *Environment and Ecology*. **42**(3): 1212-1218.
- Mohanta, S., Singh, M., Singh, A. K. and Singh, Y. V. 2021. Effect of site-specific nutrient management on growth, yield, and economics of rice (*Oryza sativa* L.) in eastern Uttar Pradesh, India. *Journal of Plant Nutrition*. **44**(3):502-514.
- Mohanty, S. K., Singh, A. K., Jat, S. L., Parihar, C. M., Pooniya, V. and Sharma S. 2015. Precision nitrogen management practices influence growth and yield of wheat (*Triticum aestivum*) under conservation agriculture. *Indian Journal of Agronomy*. **60**(4):617-621.
- Mohapatro, S. and Shankar. T. 2022. Impact of precision nitrogen management on growth and productivity of rabi maize. *Indian Journal of Natural Sciences*. **13**(72): 44530- 44534.
- Naik, M.R., Hemalatha, S., Reddy, A.P.K., Naga, K.V. and Umamahesh, M.V. 2019. Calibrating leaf colour chart for nitrogen management in rabi maize (*Zea mays* L.) under varied plant density. *Journal of Pharmacognosy and Phytochemistry*. **8**(3): 4360-4364
- Nandan, N., Roy, D. K., Kumar, S. and Kumar, A. 2020. Effect of Nitrogen on Growth, Yield and Nutrient Uptake of Rice under Aerobic Condition. *International Journal of Current Microbiology and Applied Sciences*. **9**(2): 2025-2035.
- Naragundi, R., Patel, R. A., Singh, Y. V., Kadam A, P and Praveen, B, R. 2023. Effect of irrigation scheduling and nitrogen management on growth and development of Indian mustard (*Brassica juncea*). *Indian Journal of Agricultural Sciences*. **93** (11): 1231–1237.
- Nayak, R., Satapathy, M., Rath, B., Panda, R. K., Paikaray, R. K. and Jena, S. 2023. Effect of site-specific nitrogen management on growth, yield attributes and yield

- of kharif rice (*Oryza sativa* L.) in rice-groundnut cropping system in Odisha. *The Pharma Innovation Journal*. **12**(2): 2063-2067.
- Niwas, R., Singh, B. N., Verma, V. K., Kumar, V., Kumar, K., Singh, D. P. and Singh, D. 2020. Effect of Irrigation Management (IW/CPE Ratio & Critical Growth Stages) on Yield and Quality of Wheat (*Triticum aestivum* L.). *International Journal of Current Microbiology and Applied Sciences*. **11**: 1349-1354.
- Pateel, V. L., Veeresh, H., Narayana, K. R., Gaddi, A. K. and Basavanneppa, M. A. 2017. Use of chlorophyll meter and optical sensors for nitrogen management in direct seeded rice. *Journal of Farm Sciences*. **30**(3):365-369.
- Patil, V. B., Desai, B. K. and Jagadish. 2018. Effect of nitrogen management through LCC and SPAD meter on growth and yield in direct seeded rice (*Oryza sativa* L.). *International Journal of Chemical Studies*. **6**(4): 1074-1078.
- Pawar, S. K. and Shelke, D. K. 2016. Studies on application of various irrigation schedules and nutrients on main quality parameters in mustard (*Brassica juncea* L.). *Advances in Life Sciences*. **5**(18):7784-7785.
- Piper, C. S. 1966. Soil and Plant analysis. Academic Press. pp 47-77.
- Piri, I., Nik, M.M., Tavassoli, A., Rastegaripour, F. and Babaeian, M. 2011. Effect of irrigation frequency and application levels of sulphur fertilizer on water-use efficiency and yield of Indian mustard (*Brassica juncea*). *African Journal of Biotechnology*. **10**(55): 1,1459–1,1467.
- Piri, P. 2012. Study of yield and yield components of black mustard (*Brassica nigra*) in condition of sulphur application and water stress. *Annals of Biological Research*. **3**(5): 2074-2077.
- Prabhudev, D. S., Sheshadri, T. N., Basavaraja, P. K., Timmegouda, M. N. and Mallikarjuna, G. B. 2017. Precision management practices-a much-needed set of agro techniques to improve rice productivity and cutback the resources in aerobic rice condition under drip irrigation. *International Journal of Current Microbiology and Application Sciences*. **6**(8):2800-2810.
- Pradhan, A., Thakur, A. and Sonboir, H. L. 2014. Response of rice (*Oryza sativa*) varieties to different levels of nitrogen under rainfed aerobic ecosystem. *Indian Journal of Agronomy*. **59**(1): 76-79.
- Prakash, O., Singh, N. A. and Pandey, N. K. 2014. Response of rice (*Oryza sativa*) varieties to different levels of nitrogen under rainfed upland condition of Mizoram. *Advance Research Journal of Crop*. **5**(2): 194-196.
- Pramanik, K., & Bera, B. 2013. Effect of nitrogen levels on growth and yield of summer sesame (*Sesamum indicum* L.) under red and lateritic soils of West Bengal. *International Journal of Agriculture, Environment and Biotechnology*. **6**(1): 39-44.

- Pratap, V., Dass, A., Dhari, S., Kumari, K. and Sudhishri, S. 2024. Precision nitrogen, irrigation and cultivation regimes for enhanced yield, and nutrient accumulation in direct-seeded basmati rice (*Oryza sativa* L.). *Indian Journal of Agricultural Sciences*. **94** (6): 571–576.
- Premalatha, B. R. 2017. Use of leaf colour chart for nitrogen management as a tool in bridging the yield gap in rainfed rice (*Oryza sativa* L.) production. *Advance Research Journal of Crop Improvement*. **8**(1): 36-44.
- Premalatha, P. 2017. Effect of nitrogen application through leaf colour chart on dry matter accumulation in rice (*Oryza sativa* L.). *International Journal of Pure and Applied Bioscience*. **5**(1): 129-135.
- Puppala, S., Akula, D. K. and Jaya, T. S. 2021. Variation in dry matter accumulation and growth indices of mustard as influenced by irrigation regimes and fertilizer levels. *Pharma Innovation Journal*. **10**(7): 838–41.
- Qureshi, A. S., Singh, A. K., Kumar, A., Kumar, U. and Kumar, S. 2016. Leaf colour chart-based nitrogen management for maize in India. *Nutrient Cycling in Agroecosystems*. **105**(3): 265-275.
- Rafiei, S., Delkhush, B., Red, A. H. S. and Zandi, P. 2011. Effect of sowing dates and irrigation on Agronomic traits of Indian mustard in semi-arid area of Takestan. *Journal of American Sciences*. **7**(10) 721-728.
- Rajesh, K., Thatikunta, R., Naik, D. S. and Arunakumari, J. 2017. Effect of Different Nitrogen Levels on Morpho Physiological and Yield Parameters in Rice (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Sciences*. **6**(8): 2227-2240.
- Rana, K., Parihar, M., Singh, J. P. and Singh, R. K. 2020. Effect of sulfur fertilization, varieties and irrigation scheduling on growth, yield, and heat utilization efficiency of Indian mustard (*Brassica juncea* L.). *Communication in Soil Science and Plant Analysis*. **51**(2):265–275.
- Rao, G. B. S., Baradhan, G., Sureshkumar, S. M., Immanuel, R. R. and Ramesh, S. 2019. Influence of integrated nutrient management practices on growth and yield of Rice-Green gram cropping system. *Plant Archives*. **19**: 441-443.
- Rao, V. P., Subbaiah, G. and Veeraraghavaiah, R. 2016. Productivity and nutrient uptake of rice fallow maize (*Zea mays* L.) as influenced by plant density and fertilizer under no till conditions. *International Journal of Current Microbiology and Applied Sciences*. **5**(6): 826-836.
- Rathore, S. S., Shekhawat, K. and Kandpal, B. K. 2014. Micro-Irrigation and Fertigation Improves Gas Exchange, Productivity Traits and Economics of Indian Mustard (*Brassica juncea* L. Czernj and Cosson) under Semi-Arid Condition. *Australian Journal of Crop Science*. **8**(4): 582-595.

- Rathore, S. S., Shekhawat, K., Babu, S. and Singh, V. K. 2020. Mitigating moisture stress in Brassica juncea through deficit irrigation scheduling and hydrogel in ustocherpts soils of semi-arid India. *Heliyon*. **6**: 1-10.
- Rathore, S. S., Shekhawat, K., Dass, A., Premi, O. P., Rathore, B. S. and Singh, V. K. 2019. Deficit irrigation scheduling and superabsorbent polymer hydrogel enhance seed yield, water productivity and economics of Indian mustard under semiarid ecologies. *Irrigation and Drainage*. **68**: 531-541.
- Rathore, S. S., Shekhawat, K., Kandpal, B. K and Premi, O. P. 2017. Improvement of physiological and productivity traits of Indian mustard (*Brassica juncea* L.) through micro irrigation and fertigation under hot semi-arid eco-region. *Indian Journal of Agricultural Sciences*. **87**(9):1257-1262.
- Ray, K., Sengupta, K., Pal, A. K. and Banerjee, H. 2015. Effects of sulphur fertilization on yield, S uptake and quality of Indian mustard under varied irrigation regimes. *Plant Soil & Environment*. **61**(1): 6–10.
- Reena, V. C., Dhyani, S. C. and Himansu, S. G. 2017. Growth, yield and nitrogen use efficiency in wheat as influenced by leaf colour chart and chlorophyll meter-based nitrogen management. *International Journal of Current Microbiology and Applied Sciences*. **6**(12):1696 1704.
- Roy, K.C., Rahman, M.M., Rahman, K.A.M.M., Miah, M.A.M., Hossain, A. and Zaman, M.A.U. 2017. Effects of irrigation and sulphur application on growth, yield and oil content of rapeseed (*Brassica napus*). *Eco-Friendly Agriculture Journal* 10(3): 30-34.
- Sadhukhan, R., Kumar, D., Sen, S., Sepat, S., Ghosh, A., Shivay, Y. S., Meena, M. C., Anand, A., Kumar, R., Sharma, L. D., Patra, K., Pratap, V., Alsuhaibani, A. M., Gaber, A. and Hossain, A. 2023. Precision nutrient management in zero-till direct-seeded rice influences the productivity, profitability, nutrient, and water use efficiency as well as the environmental footprint in the Indo Gangetic plain of India. *Agriculture*. **13**(4): 784.
- Saini, A. K., Saini, L. H., Chaudhary, Vaghela, P. J. and Chaudhary, M. M. 2023a. Assessment of growth and yield attributes of mustard under irrigation, nitrogen and mulch levels. *The Pharma Innovation Journal*. 12(3): 3401-3407.
- Saini, A. K., Saini, L. H., Nand, B., Vaghela, P. J. and Malve, S. H. 2023b. Response of mustard to levels of irrigation and nitrogen with and without mulch. *The Pharma Innovation Journal*. **12**(3): 3395-3400.
- Sairam RK, Hari Ramulu D, Govindarajulu MB and Dhandapani A. 2020. Effect of integrated nutrient management on soil fertility, nutrient uptake and yield of rice (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Sciences*. **9**(3):2456-2463.

- Sarma, A. and Das, J. C. 2017. Irrigation and fertilizer effect on productivity, quality, water use and economics of Yellow Sarson (*Brassica rapa* L. var trilocularis.). *Journal of Oilseed Brassica*. **8**(1): 72-79.
- Satpute, S.B., Das, T.K., Surje, D.T and Maity, S.K. 2015. Nitrogen management using Leaf Color Chart (LCC) and nitrogen level in kharif rice. *Indian Journal of Applied Research*. **5**(2): 818-820.
- Sen, T. K., Kundu, S. and Ghosh, A. B. 2011. Leaf colour chart-based N management for rice in West Bengal. *Journal of Plant Nutrition*. **34**(9):1297-1314.
- Seth, M., Thakur, D. R., Manuja, S., Singh, S. and Sharma, A. 2019. Effect of site specific nutrient management on growth indices in wheat in rice-wheat cropping system. *Journal of Pharmacognosy and Photochemistry*. 162-165.
- Shankar, T., Banerjee, M., Malik, G. C. and Dutta, S. 2020. Effect of nutrient management on growth, productivity and economics in rice based cropping system in lateritic soil of West Bengal. *International Journal of Chemical Studies*. **8**(2):2694-2698.
- Shantappa, D., Channabasavanna, A.S., Rao, S. and Halepyati, A.S. 2014. Effect of LCC and SPAD based nitrogen management on growth and yield of lowland rice (*Oryza sativa* L.). *The Bioscan*. **9** (2): 663-665.
- Sharma, P. 2011. Nitrogen management in rice using chlorophyll meter and Green Seeker optical sensor. M.Sc. (Agri.) Thesis, Punjab Agricultural University Ludhiana.
- Sheeraz, A.W., Sameera, Q., Mohammad, A. B., Aijaz, A. S., Tariq, A. B. and Sharbat, H. 2017. Effect of varying sowing dates and nitrogen levels on growth and physiology of scented rice. *Oryza*. **54**(1): 97-106.
- Shivashankar K, Potdar, M. P., Biradar, D. P., Math, K. K. and Balol, G. 2023. Effect of sensor-based precision nitrogen management through SPAD and green seeker on dry matter accumulation and growth indices of maize. *The Pharma Innovation Journal*. **12**(2): 3555-3559.
- Shivashankar, G., Naik, R. K. and Ramakrishna, Y. S. 2022. Influence of nitrogen levels on maize (*Zea mays* L.) growth, dry matter accumulation, and growth indices under irrigated conditions. *Journal of Plant Nutrition*. **45**(6): 1372-1386.
- Shivran, H., Kumar, S., Tomar, R. and Chauhan, G. V. 2018. Effect of irrigation schedules on productivity and water use efficiency in Indian mustard (*Brassica juncea* L.). *International Journal of Chemical Studies*. **6**(4): 15-17.
- Shrestha, S., Amgain, L. P., Subedi, R., Shrestha, P. and Shahi, S. 2018. Productivity and profitability analysis of old aged hybrid rice seedling using Nutrient-Rice

Expert and other precision nutrient management practices at Lamjung, Nepal. *International Journal of Applied Sciences and Biotechnology*. **6**(3): 232–237.

- Shukla, A., Kumar, M., Dhama, V., Kumar, S., Yadav, R. B., Singh, A., Verma, S. and Akanksha Shukla, A. 2023. Effect of conservation tillage and precision nitrogen management techniques on soil health and soil available N, P and K in wheat in rice-wheat cropping system. *The Pharma Innovation Journal*. **12**(7): 2952-2956.
- Singh AK, Bhatt RK, Sharma RK and Jat RA. 2017a. Precision nitrogen management in wheat: *An Indian perspective, Nutrient Cycling in Agroecosystems*. **108**(1): 23-40.
- Singh, B., Nayak, A. K., Upadhyay, A. K., Kumar, R. and Kumar, A. 2018. Comparative evaluation of nutrient management practices on soil quality and crop productivity under rice-wheat cropping system in Eastern Uttar Pradesh. *Journal of Soil Science and Plant Nutrition*. **18**(3):699-709.
- Singh, B., Singh, V., Singh, Y., Kumar, A., Singh, J., Vashistha, M., Thind, H. S. and Gupta, R. K. 2016. Fertilizer nitrogen management in irrigated transplanted rice using dynamic threshold greenness of leaves. *Agricultural Research*. **5**(2): 174–81.
- Singh, B., Varinderpal S., Jaspreet P., Sharma, R.K., Jat, M.L., Yadvinder S., Thind, H.S., Gupta, R.K., Chaudhary, O.P., Chandna, P., Khurana, H.S., Ajay k., Jagmohan S., Uppal, H.S., Uppal, R.K., Monika, V and Raj G. 2015. Site specific fertilizer nitrogen management in irrigated transplanted rice (*Oryza sativa*) using an optical sensor. *Precision Agriculture*. **16**(2): 455–475.
- Singh, S, P., B.S. Mahapatra, B. S. and Yadav, V. R. 2019a. Effect of Irrigation Management and Water Conservation Practices on Growth and Yields in Yellow Sarson (*Brassica rapa* L.) in Uttarakhand Region. *International Journal of Current Microbiology and Applied Sciences*. **8**(2): 151-155.
- Singh, S, P., B.S. Mahapatra, Pande, P. and Chandra, S. 2019b. Influence of different irrigation levels, planting methods and mulching on yield, water-use efficiency and nutrient uptake in yellow sarson (*Brassica rapa*). *Indian Journal of Agronomy*. **64** (1): 123-128.
- Singh, S, P., Mahapatra, B, S., Pramanick, B. and Yadav, V, R. 2021a. Effect of irrigation levels, planting methods and mulching on nutrient uptake, yield, quality, water and fertilizer productivity of field mustard (*Brassica rapa* L.) under sandy loam soil. *Agricultural Water Management*. **224**: 1-8.
- Singh, S. M. 2014. Enhancing water use efficiency of Indian mustard (*Brassica juncea* L.) under deficit and adequate irrigation scheduling with hydrogel. Ph.D. Thesis, G.B.P.U.A.T, Pantnagar, Uttarakhand, India.

- Singh, S. M., Shukla, A., Chaudhary, S., Semwal, M, P., Bhushan, C., Negi, M. S. and Mahapatra, B. S. 2017b. Enhancing water-use efficiency of Indian mustard (*Brassica juncea*) under deficit and adequate irrigation scheduling with hydrogel. *International Journal of Basic and Applied Agricultural Research*. **15**(1,2):1-4.
- Singh, S. P., Mahapatra, B. S. and Yadav, V. R. 2019c. Effect of irrigation management and water conservation practices on growth and yields in Yellow Sarson (*Brassica rapa* L.) in Uttarakhand Region. *International Journal of Current Microbiology and Applied Sciences*. **6**(2).
- Singh, S. P., Mahapatra, B. S., Pramanick, B. and Yadav, V. R. 2021b. Effect of irrigation levels, planting methods and mulching on nutrient uptake, yield, quality, water and fertilizer productivity of field mustard (*Brassica rapa* L.) under sandy loam soil. *Agricultural Water Management*. **244**: 106539-1-13.
- Singh, S., Kumar, D., Bhawana and Sharma, G. L. (2022). Response of Select Mustard (*Brassica juncea* L.) Varieties to varying Irrigation Schedules based on IW/CPE Ratio. *Biological Forum– An International Journal*. **14**(3): 1540-1545.
- Singh, V. 2019. Effect of site-specific nutrient management on yield and nutrient uptake in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. *Annals of Plant and Soil Research*. **21**(2):135-140.
- Singh, Y. K., Singh, B.V., Katiyar, D., Saikanth, D., Kumar, K., Singh, O., Verma, S. and Kumar, P. 2023. Efficacy of nano fertilizers on yield, attributes and economics of wheat. *International Journal of Environment and Climate Change* **13**(7): 291-297.
- Singh, V., Singh, Y., Singh, B., Thind, H. S., Kumar, A. and Vashistha, M. 2011. Calibrating the leaf colour chart for need based fertilizer nitrogen management in different maize (*Zea mays* L.) genotypes. *Field Crops Research*. **120**: 276-282.
- Sivaram, H., Kumar, S., Tomar, S and Chauhan G.V. 2018. Effect of irrigation scheduling on productivity and water use efficiency in Indian mustard (*Brassica juncea* L.). *International journal of chemical studies*. **6**(4): 15-17.
- Sow, S., Singh, G., Ghosh, M., Dutta, S. K., Mandal, N., Kumar, S. and Ranjan, S. 2023 Nitrogen-management strategy through leaf-colour chart and SPAD meter for optimizing the productivity in irrigated wheat (*Triticum aestivum*). *Indian Journal of Agronomy*. **68** (2): 219-222.
- Sowmya, D., Hemalatha, S., Vineetha, U. and Prasanthi, A. 2023. Growth and yield attainment of Rabi rice (*Oryza sativa* L.) under precision nitrogen management practice. *The Pharma Innovation Journal*. **12**(3): 310-312.

- Sridhar, K., Srinivas, A., Kumar, K. A., Ramprakash, T. and Rao, P. R. 2019. Physiological Growth Parameters of Rabi Rice (*Oryza sativa* L.) under Alternate Wetting and Drying Irrigation with Varied Nitrogen Levels. *International Journal of Current Microbiology and Applied Sciences*. **8**(1): 1-15.
- Subbiah, B.V and Asija, G.L. 1956. A rapid procedure of estimation of available nitrogen in soils. *Current science*. **5**(2): 477-480.
- Sunawan, Y., Aswidinnoor, H. and Hartatik, W. 2018. Effect of nitrogen fertilizer rates on growth and yield of rice variety Ciherang. *Earth and Environmental Science*. **202**(1): 012028.
- Suresh, M., Balaguravaiah, D. and Jayasree, G. 2017a. Calibrating the LCC and SPAD based nitrogen management on leaf N content and yield in rice. *International Journal of Pure & Applied Bioscience*. **5**(4):1382-1386.
- Suresh, M., Balaguravaiah, D. and Jayasree, G. 2017b. Effect of site- specific nitrogen management on yield, nitrogen use efficiency and nutrient uptake in rice (*Oryza sativa* L.) *Indian Journal of Pure and Applied Biosciences*. **5**(4):1813-1820.
- Suresh, M., Balaguravaiah, D., Jayasree, G and Kumar, B. N. 2015. Integrated approaches through leaf colour chart and SPAD based N management on yield, N concentration in leaf and nutrients uptake in rice (*Oryza sativa* L.). *Research Journal of Agricultural Sciences*. **6**(3): 680-683.
- Swamy, M., Umesh, M. R., Ananda, N., Shanwad, U. K., Amaregouda, A. and Manjunath, N. 2016. Precision nitrogen management for rabi sweet corn (*Zea mays saccharata* L.) through decision support tools. *Journal of Farm Sciences*. **29**(1): 14-18.
- Syeda, R. S., Amjed, A., Ashfaq, A., Muhammad, M., Zia, U. I. and Haq, M. 2014. Normalized difference vegetation index as a tool for wheat yield estimation. *Science World Journal*. **8**(2):1-9.
- Tabar, Y.S. 2012. Effect of nitrogen and phosphorus fertilizer on growth and yield rice (*Oryza sativa* L). *International Journal of Agronomy and Plant Production*. **3**: 579-584.
- Tewatia, R. K. and Chanda, T. K. 2017. Trends in Fertilizer Nitrogen Production and Consumption in India. *The Indian Nitrogen Assessment*. 45-56.
- Thakur, A., Gangmei, T, P., Kumar, A. and Manuja, M. 2022. Effect of irrigation levels on growth and yield of different Brassica species under natural and conventional farming. *Himachal Journal of Agricultural Research*. **48**(2): 280-284.

- Thakur NS. 2013. Effect of irrigation levels and row spacings on growth, development and yield of Indian mustard [*B. juncea* (L.) Czern & Coss.]. M.Sc. (Agri) Thesis submitted to the Department of Agronomy, JNKVV, Jabalpur, Madhya Pradesh.
- The, S. V., Snyder, R. and Tegeder, M. 2021. Targeting Nitrogen Metabolism and Transport Processes to Improve Plant Nitrogen Use Efficiency. *Frontiers in plant science*. **11**: 628366.
- Thirunavukkarasu, M. and Vinoth, R. 2013. Influence of vermicompost application along with nitrogen on growth, nutrients uptake, yield attributes and economics of rice (*Oryza sativa* L.). *International Journal of Agriculture, Environment & Biotechnology*. **6**(4): 599-604.
- Trivedi, S. K., Pachauri, R. K. and Singh, N. 2014. Response of mustard (*Brassica juncea* L.) to moisture regimes and levels of nitrogen, phosphorus, potash and zinc. *Applied Biological Research*. **16** (2):143-149.
- Upadhyay, P. K., Sen, A., Prasad, S. K., Singh, Y., Srivastava, J. P., Singh, S. P. and Singh, R. K. 2018. Effect of panchgavya and recommended dose of fertilizer on growth nutrient content and productivity of transplanted rice (*Oryza Sativa* L.) under middle Gangetic Plain of India. *Indian Journal of Agricultural Sciences*. **88**(6): 931-936.
- Veer, S., Bhatnagar, A. and Singh, A.P. 2016. Evaluation of leaf-colour chart for need-based nitrogen management in maize (*Zea mays*) grown under irrigated condition of Mollisols. *Indian Journal of Agronomy*. **61**(1): 47-52.
- Velmurugan, A., Subramani, T., Narayanasamy, B., Ramakrishna, Kumar, M. and T.P., Swarnam. 2021. The effect of foliar application of nano urea (liquid) on rice (*Oryza sativa* L). *Journal of the Andaman Science Association*. **26**(2): 76-81.
- Verma, H. K., Singh, M. M., Singh, M. K. and Kumar, S. 2014. Response of Indian mustard (*Brassica juncea* L.) varieties to irrigation for better growth, yield and quality of mustard crop. *International Journal of Agricultural Sciences*. **10**(1): 426-429.
- Verma, O. P., Singh, S., Pradhan, S., Kar, G. and Rautaray, S. K. 2018. Irrigation, nitrogen and sulphur fertilization response on productivity, water use efficiency and quality of Ethiopian mustard (*Brassica carinata*) in a semi-arid environment. *Journal of Applied and Natural Science*. **10**(2): 593-600.
- Walkley, A and Black, C.A. 1934. An examination of determining soil organic carbon and proposed modification of the chromic acid titration method. *Soil Science*. **37**(2): 29-34.
- Wang, Y., Li, C., Li, Y., Zhu, L., Liu, S., Yan, L., Feng, G. and Gao, Q. 2020. Agronomic and environmental benefits of nutrient expert on maize and rice in

Northeast China. *Environmental science and pollution research international*. **27**(22): 28053–28065.

Watson DJ. 1956. Comparative physiological studies on the growth of field crops. Variation in net assimilation rate and leaf area between species and varieties and within and between years. *Annals of Botany*, **2**:41-46.

Watson, D.J. 1952. The physiological basis of variation in yield. *Advances in Agronomy*. **6**(1): 103-109.

Williams RF. 1946. The physiology of plant growth with special reference to the concept of net assimilation rate, *Annals of Botany*. **10**: 41-72.

Xu, G., Fan, X. and Miller, A.J. 2012. Plant nitrogen assimilation and use efficiency. *Annual Review of Plant Biology*. **63**(1):153-182.

Yadav, R. K., Kumar, R., Singh, D., Yadav, A. and Singh, R. P. 2023. Study the effect of real time nitrogen management in transplanted rice of Eastern Uttar Pradesh. *The Pharma Innovation Journal*. **12**(6): 2933-2936.

Yadav, R. P., Tripathi, M. L. and Trivedi, S. K. 2010. Yield and quality of Indian mustard (*Brassica juncea*) as influenced by irrigation and nutrient level. *Indian Journal of Agronomy*. **55**(1): 56-59.

Yoseftabar, S., Fallah, A. and Daneshian, J. 2012. Effect of Split Application of Nitrogen Fertilizer on SPAD Values in Hybrid Rice (GRH1). *International Journal of Agriculture and Crop Sciences*. **4**(10): 647-651.

Yoshida, S., Shiraiwa, T., Horie, T., Tsubo, M. and Ae, N. 2010. Varietal differences in tillering ability and N uptake in rice plants and their relation to grain yield. *Soil Science and Plant Nutrition*. **56**(5): 744-752.

Zhang, W. F., Ma, L., Huang, G. Q., Wu, L., Chen, X. P. and Zhang, F. S. 2013. The development and contribution of nitrogenous fertilizer in China and challenges faced by the country. *Scientia Agricultura Sinica*. **46** (15): 3161-3171.



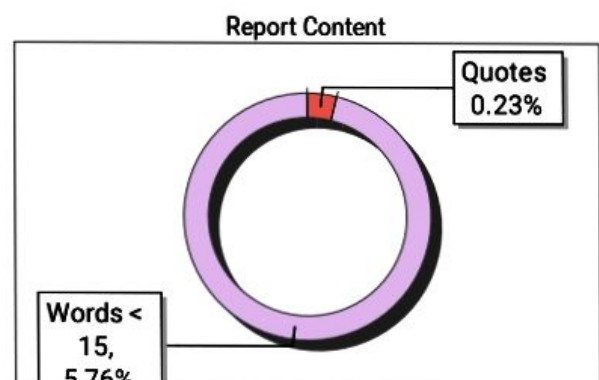
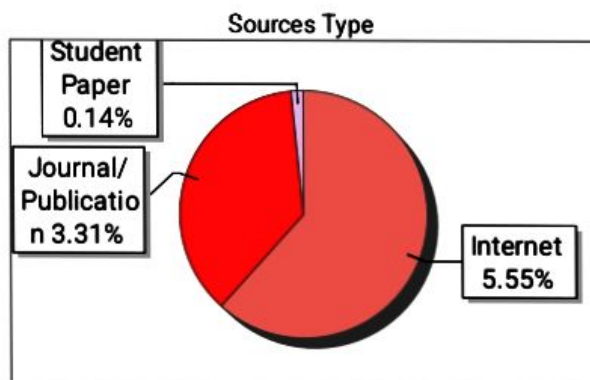
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