IMPACT OF PLANTING PATTERNS, NITROGEN LEVELS AND WEED CONTROL TREATMENTS ON THE GROWTH AND YIELD OF UNPUDDLED TRANSPLANTED RICE (*Oryza sativa* L.)

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Agronomy

By

Sasi Chandra Gummadi

Registration Number: 12209841

Supervised by:

Dr. Ujagar Singh Walia (22567)

Department of Agronomy (Professor)

School of Agriculture, Lovely Professional University

LOVELY PROFESSIONAL UNIVERSITY, PUNJAB

2025

DECLARATION

I, hereby declared that the presented work in the thesis entitled **"Impact of planting patterns, nitrogen levels and weed control treatments on the growth and yield of unpuddled transplanted rice (*Oryza sativa* L.)"** in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of Dr. Ujagar Singh Walia, working as Professor, in Department of Agronomy, School of Agriculture, Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

(Signature of Scholar)

Name of the scholar: Sasi Chandra Gummadi

Registration No.: 12009841

Department/school: Agronomy/Agriculture

Lovely Professional University,

Punjab, India

CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled **"Impact of planting patterns, nitrogen levels and weed control treatments on the growth and yield of unpuddled transplanted rice (*Oryza sativa* L.)"** submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** Agronomy, School of Agriculture is a research work carried out by Sasi Chandra Gummadi (12209841) is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

(Signature of Supervisor)

Name of supervisor: Dr. Ujagar Singh Walia

Designation: Professor

Department/school: Agronomy/Agriculture

University: Lovely Professional University

CERTIFICATE

This is to certify that the research work reported in the Ph. D. thesis entitled "**Impact of planting patterns, nitrogen levels and weed control treatments on the growth and yield of unpuddled transplanted rice (*Oryza sativa* L.)**" submitted in the fulfilment of the requirement for the award of degree of **Doctor of Philosophy (Ph. D) Agronomy,** Department of Agronomy, School of Agriculture, LPU, Phagwara. The research project carried out by **Sasi Chandra Gummadi (12209841),** is bonafide record of his original work carried out under my supervision and has been approved by the research advisory committee after viva-voce in collaboration with external examiner.

Dr. Ujagar Singh Walia
Professor, Department of Agronomy,
School of Agriculture, LPU, Phagwara
(Major Advisor)

Dr. Surender Kumar Sharma
Senior Scientist (Agronomy)
CCS HAU, Hisar
(External Examiner)

Dr. Sandeep Menon
HOD, Department of Agronomy,
School of Agriculture, LPU, Phagwara

Dr. Pardeep Kumar Chhuneja
Dean, School of Agriculture, LPU,
Phagwara

Abstract

A field based research study was carried out for two consecutive years at Lovely Professional University, Punjab during the *kharif* seasons of 2023 and 2024 to assess the impact of different planting patterns, nitrogen levels and weed control methods on weed dynamics, growth and yield of unpuddled transplanted rice. The research was composed of two experiments, each laid out in Split-Plot Design with four replications. In both experiments, there were four main plots and four sub plots. Experiment-I comprised of four planting patterns *viz.* M_1-two rows/ridge, M_2-two rows/ridge + one in furrow, M_3-flat (unpuddled), M_4-flat (puddled) in main plots and four weed control treatments, *viz.* T_1-pendimethalin 0.75 kg/ha as pre-em. *fb* bispyribac 10 SC 25 g/ha as post-em., T_2-pendimethalin 0.75 kg/ha as pre-em. *fb* penoxsulam 240 SC 24 g/ha as post-em., T_3-pendimethalin 0.75 kg/ha as pre-em. *fb* fenoxaprop 6.7 EC 67 g/ha, post-em. and T_4- unweeded (control) in sub-plots. The research findings of Experiment-I during both the years indicated that transplanting two rows/ridge + one in furrow recorded significantly higher growth attributes, yield components (number of panicles/m^2, total number of grains/panicle, number of filled grains/panicle) and nitrogen uptake (grain + straw) while reducing weed density and biomass of grassy and broadleaf weeds compared to alternative planting patterns. Meanwhile, yields obtained from flat unpuddled and flat puddled transplanting methods were statistically at par with each other, whereas significantly more weed density and biomass of grassy and broadleaf weeds was observed in flat unpuddled. Two rows/ridge, two rows/ridge + one in furrow, flat unpuddled increased the paddy yield by 7.4%, 13.0%, 1.7% over flat puddled respectively during both the years. Among weed control treatments, sequential application of pendimethalin as pre-emergence *fb* bispyribac sodium as post-emergence significantly increased growth characteristics, yield attributes and nitrogen uptake (grain + straw) and effectively controlled weeds, including grasses, sedges, and broadleaved weeds, outperforming other weed control treatments. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence, pendimethalin pre-emergence *fb* penoxsulam post-emergence, pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence increased the paddy yield by 138.2%, 125.8%, 112.6% over unweeded (control) respectively during both the years.

Experiment-II comprised of four planting patterns *viz.* M_1-two rows/ridge, M_2-two rows/ridge + one in furrow, M_3-flat (unpuddled), M_4-flat (puddled) in main plots and four nitrogen levels N_1- 0 kg N/ha (control), N_2- 80 kg N/ha, N_3- 120 kg N/ha, N_4- 160 kg N/ha. The outcomes of Experiment-II during both the years revealed that adopting the planting pattern of two rows/ridge + one in furrow recorded significantly higher growth and yield attributes *viz.*, number of panicles/m^2, total number of grains/panicle, number of filled grains/panicle and nitrogen uptake (grains + straw) as compared to standard practice of flat puddled. Planting patterns of two rows/ridge, two rows/ridge + one in furrow and flat unpuddled increased the paddy yield by 8.4%, 13.2% and 1.0% respectively as compared to standard practice of flat puddled during both the years. Among the nitrogen levels, application of 160 kg N/ha significantly enhanced the growth parameters, yield components, nitrogen content of grains, nitrogen uptake (grains + straw) as compared to lower nitrogen levels. Application of 80 kg N/ha, 120 kg N/ha and 160 kg N/ha increased the paddy yield by 105%, 174.3% and 187.5% respectively in comparison to 0 kg N/ha (control) during both the years. Thus, from the above findings, it can be inferred that adopting the planting method of two rows/ridge + one in furrow combined with effective weed management specifically, sequential application of pendimethalin as pre-emergence *fb* bispyribac sodium post-emergence and applying adequate nitrogen dose of 160 kg N/ha seems to be the most effective practice for unpuddled rice cultivation in prevailing conditions of Punjab. However, this approach should be validated through multi-location trials to ensure its effectiveness and practicality before recommending it to farmers.

Key words: Unpuddled transplanted rice, planting patterns, nitrogen levels, weed control treatments, paddy yield

Acknowledgement

*It is with profound joy and humility that I take this opportunity to express my deepest reverence, heartfelt gratitude, and sincerest regards to my esteemed major advisor, **Dr. Ujagar Singh Walia**, Professor in the Department of Agronomy, Faculty of Agriculture, Lovely Professional University, Punjab. His invaluable guidance, creative inspiration, enthusiastic encouragement, innovative suggestions, and earnest efforts have been instrumental throughout the entire course of this investigation and the preparation of this manuscript.*

*I am deeply indebted to my father, **Gummadi Appaiah**, for his unwavering belief in my abilities and his silent sacrifices that have enabled me to pursue my dreams. My mother, **Gummadi Satya Gnana Kumari**, has been a beacon of hope and strength, providing moral support and encouragement whenever I needed it. I am also grateful to my younger brother, **Chiradeep Sai Chandra**, for his companionship and enthusiasm, which have made this journey more enjoyable and fulfilling.*

*I would like to acknowledge the invaluable support of **Ramandeep Singh** who was with me through thick and thin. His encouragement and presence were crucial during my lowest phases, helping me stay committed to my research. I also extend my gratitude to my friends **Ayush, Pavan, Mikhil, Amol** and **Manisha** whose collective support and encouragement were vital to my success. Their friendship provided a stimulating environment that fostered growth and learning. I appreciate the discussions, the laughter, and the memories we shared, which often served as a much-needed respite from the academic pressures.*

I would like to express my profound gratitude to the Department of Agronomy at Lovely Professional University, Punjab, for the invaluable support and cooperation I received throughout my research. The teachers provided essential academic guidance, the field staff ensured the success of our field experiments, the laboratory staff offered critical technical support. Their collective efforts have not only facilitated the smooth execution of my research but also provided a stimulating academic environment that greatly enriched my learning experience.

Place: LPU, Phagwara **(Sasi Chandra Gummadi)**

Date: **(Reg No: 12209841)**

Table of contents

List of Tables

List of Figures

LIST OF ABBREVIATIONS

%	Per cent
@	at the rate of
^{0}C	Degree centigrade
a.i.	Active ingredient
ANOVA	Analysis of variance
cm	Centimetre
C.D.	Critical difference
C.V	Coefficienct of variation
DAS	Days after sowing
DAT	Days after transplanting
df	Degrees of freedom
DM	Dry matter
dS/m	Deci siemen per meter
E	East
EC	Electrical conductivity
et al.	and others
fb	followed by
Fig.	Figure
g/m^2	Grams per square meter
Hr	Hour
ha	Hectare
HI	Harvest index
HW	Hand weeding
i.e.	that is
K	Potassium

kg	Kilogram
Kg/ha	Kilogram per hectare
LAI	Leaf area index
LCC	Leaf colour chart
LSD (p=0.05)	Least Significant Difference at 5% level of significance
Max.	Maximum
Min.	Minimum
MOP	Muriate of potash
m	Metre
M	Million
m^2	Metre square
mg	Milligram
mt	Million tonnes
N	Nitrogen
No.	Number
NA	Not analysed
NS	Non-significant
OC	Organic carbon
P	Phosphorous
PE	Pre-emergence
PoE	Post-emergence
q/ha	Quintal per hectare
RH	Relative humidity
SSP	Single super phosphate

SEm ±	Standard Error of mean
t/ha	Tonnes per hectare
T max.	Maximum temperature
T min.	Minimum temperature
viz.,	Namely
WCE	Weed Control Efficiency

INTRODUCTION

Rice (*Oryza sativa*) stands as a globally important cereal crop that acts as a staple food for over half of humanity. Predominantly grown in tropical and subtropical regions, it is cultivated extensively, especially in Asia, which contributes 90% to its overall production and consumption, making it integral to food security and livelihood support. Worldwide, rice cultivation covers about 167.6 million hectares with a total production of 527.6 million metric tonnes (USDA, 2024). Rice plays a vital role in global nutrition; it contains 6-7% of protein in white rice and 7-9% in brown rice due to the retention of the bran layer during processing (Nirmagustina *et al.* 2023). The protein quality in rice is high due to increased lysine content when compared to other cereals. Carbohydrates, particularly starch, make up 75–80% of rice dry matter. Fat content is low (2-2.5%) and mostly found in the bran layer, whereas the ash content ranges from 5-9%. Rice serves about 35–80% of the calorie intake globally, providing approximately 130 calories per 100 grams of cooked white rice (FAO,www.fao.org). India ranks as the world's second largest producer of rice, following China, and contributes about 26% to overall rice production, with an estimated production of 137.8 million metric tonnes of rice from approximately 48 million hectares of cultivated area with an average yield of 43.2 q/ha (USDA, 2024).

In Punjab, rice occupies an area of 31.68 lakh hectares, achieving a total paddy production of 205.24 lakh tonnes (137.5 lakh tonnes of rice) with an average productivity of 64.79 quintals per hectare, emphasising its contribution to India's food security and economic stability (Anonymous, 2024). In this region, rice is one of the most important crop that has been traditionally cultivated by manually transplanting seedlings into puddled soil. The practice of puddling or wet tillage involves cultivation of soil in standing water, creating a soft and impervious soil layer. It is a time consuming and water intensive practice. With the growth of human population at an unprecedented rate, water resources are being depleted rapidly. Asian rice farmers may soon face severe irrigation challenges in the nearby future. Puddling has several advantages in rice cultivation, such as suppression of competitive weeds, restricted oxygen diffusion that limits germination of seeds of rice specific weeds, better establishment of seedlings, assured anaerobic conditions with neutral soil pH and increased nutrient availability (Bhatt and Kukal, 2015). Despite these benefits, puddling negatively impacts soil physical properties by breaking down soil aggregates and macro pores, resulting in poor soil structure, compaction and reduced permeability due to the formation of hard plough pan in the sub surface layer (Gathala *et al.* 2011b). These adverse effects are particularly harmful to succeeding rotational crops like wheat or lentils. Over time, long term puddling increases bulk density and penetration resistance while reducing hydraulic conductivity, macro porosity and water-stable aggregates (Hobbs *et al*.,2002). Direct seeded rice has emerged as a potential alternative to traditional puddled transplanted rice, by addressing challenges like water wastage and soil degradation (Ladha *et al.* 2009b). While DSR improves the yield potential of succeeding crops, it does not consistently provide a yield benefit for rice itself compared to PTR and often results in yield penalty (Chakraborthy *et al.* 2017). Moreover, DSR faces several issues including heavy weed infestations, increases the risk of weedy rice evolution, increased soil borne pathogens like nematodes, nutrient imbalances such as Zinc and Iron deficiencies, poor crop establishment, lodging and susceptibility to diseases like blast and brown leaf spot (Singh *et al.* 2011). Although DSR reduces methane emissions by creating aerobic conditions, it also increases nitrous oxide emissions, raising environmental concerns (Hou *et al*.,2000). These challenges highlight the need for sustainable alternatives in crop establishment methods. Unpuddled transplanted rice stands out as an effective approach capable of overcoming these challenges while maintaining productivity and environmental sustainability. With unpuddled transplanted rice, farmers can avoid the labour intensive process of puddling, reduce water consumption and conserve the soil properties. It offers a sustainable approach that boosts energy efficiency and profitability, ensuring stable yields (Gathala *et al.* 2020b).

Rice is sensitive to weed competition during its early stages of growth, making weed control as a key factor in achieving higher yields. In unpuddled rice cultivation, the absence of puddling creates favourable soil conditions for the simultaneous germination of paddy and non-paddy weeds, including those suited to both aerobic and anaerobic environments. Since rice has higher water requirements than other *kharif* crops, traditional paddy weeds appear in this crop. Some important weeds of puddled rice cultivation include *Echinochloa colonum, E. crus-galli, Cyperus difformis, Cyperus iria, Leptochloa chinesis, Caesulia axillaris, Sphenoclea zeylanica, Eclipta alba, Fimbristylis spp, Ammania baccifera, Paspalum distichum* etc. However, in unpuddled transplanted or direct seeded rice, apart from weeds of puddled rice many more seasonal weeds such as *Eleusine indica, Digitaria sanguinalis, Eleusine aegyptiacum, Eragrostis spp, Digeria avrensis, Trianthema protulacastrum, Commelina benghalensis, Alternanthera sessilis, Cynodon dactylon, Panicum repens* etc. may also appear.

Average yield losses due to weeds range between 40-60%, but under severe infestations losses may ascend up to 94-96% (Chauhan and Johnson, 2011). According to Mukherjee *et al.* (2008) transplanted rice faced yield losses as high as 57-61% when weeds were left uncontrolled throughout the crop's growth cycle compared to weed-free conditions. However, implementing weed control measures during the critical period from 20 to 40 DAT drastically reduced competition, limiting yield losses to just 2-4%. Conversely, failing to manage weeds during this critical phase resulted in substantial yield reductions of 31-38%, highlighting the importance of timely weed management. Therefore, adopting proper weed control measures are necessary to maintain productivity in unpuddled rice cultivation.

Planting patterns in rice significantly influence both weed suppression and crop performance, making them a critical factor in achieving high productivity. To improve crop yield as well as to limit the yield losses due to weeds, new planting methods must be adopted to maintain weed populations below economic threshold level. Altering planting patterns in rice cultivation can enhance the crop's competitive ability by optimizing their access to essential resources like light, space and nutrients, ultimately improving yield potential (Mahajan and Chauhan, 2011). Transplanting of rice can be done using various methods, including traditional flat irrigated lands, ridges and furrow-beds. Ridge or bed planting of rice is a sustainable and efficient alternative to conventional flat planting methods, offering various advantages. By applying irrigation in furrows, this method reduces water consumption by 16-43% compared to puddled transplanted rice, by minimizing evaporation and seepage losses (Hussian *et al.* 2019). It also promotes better root development and soil aeration, improving nutrient uptake and crop establishment, boosting grain yields upto 15% (Yuan-Zhi, 2015). Ridge planting also reduces lodging risks due to stronger roots and provide flexibility in nutrient application (Ejaz *et al.* 2023). Additionally, it optimizes seed usage without compromising yield and suppress weed growth by creating less favourable conditions for weeds. Economically ridge planting cuts irrigation costs by 25-35% while reducing labour needs, making it a viable solution for sustainable rice production in regions with limited water availability (Hussain *et al.* 2019).

Hand weeding has been a traditional method for controlling weeds in rice cultivation, however, limited availability of labour during peak periods and rising labour costs and have made this method less feasible over time. Herbicides serve as an efficient alternative to manual weeding by reducing labour costs while providing effective weed control. Managing diverse weed flora of unpuddled rice systems through sole application of either pre- or post-emergent herbicide is a challenging task and carries risk of developing herbicide resistant weeds with prolonged usage (Kim, 1996). To address this concern, applying multiple herbicides with different active ingredients is suggested for achieving broad spectrum control. The use of pre-emergence herbicides like pendimethalin for weed control is quite tricky. These herbicides must be applied within a narrow time frame, typically in first two days after transplanting and require adequate moisture levels to work. However, farmers often miss this critical timing due to unpredictable rainfall or other reasons, reducing their effectiveness. The availability of new herbicides with diverse chemical formulations has become increasingly important to address challenges such as herbicide residue build up, shifts in weed populations and the emergence of herbicide resistance weeds (Saha *et al.* 2006). Post emergence herbicides such as bispyribac-sodium, penoxsulam, and fenoxaprop are commonly used by farmers for weed management in rice. However, research surveys indicate that managing the diverse and complex weed flora with a single post emergence herbicide remains a major challenge (Mahajan and Chauhan, 2009). Herbicide combinations, applied either as tank mixtures or in a sequential manner, have been found to deliver better weed control than single herbicide applications (Mahajan and Timsina, 2011). The current focus in weed management has shifted towards using low dose, high efficacy herbicides that not only enhance weed control but also reduce chemical input volumes, making them both cost-effective and environment friendly. Although chemical control initially disrupts microbial communities, studies reveal that microbial density and enzymatic activity improve as crop grows, particularly in unpuddled conditions (Pattanayak *et al.* 2022). Additionally, reduced-tillage practices often promote small-seeded weeds, which could also be observed in unpuddled transplanted rice (Chauhan, 2012).

Nitrogen serves as one of the most vital nutrients for rice cultivation by directly influencing the growth dynamics and yield outcomes. It stimulates rapid vegetative development while promoting tillering, boosting spikelet formation, improving leaf area development and ensuring effective grain filling (Qiao *et al.* 2011). As a fundamental component of proteins, enzymes and chlorophyll, nitrogen is integral to almost all plant structures. Nitrogen is universally deficient in most agricultural soils, often acting as key limiting factor for rice yields. Fertilizers have become essential tools for arable farming, helping farmers to optimize the productivity on limited land with short cultivation cycles. The global consumption of nitrogen fertilizers has drastically increased, with Asia experiencing a sharp rise in their usage after the green revolution of the 1960s (Dobermann and Cassman, 2004). Although cereals demand high nitrogen inputs for optimal growth and yield, this dependency leads to high costs and environmental risks. Excessive nitrogen application results in, losses through leaching into ground water, causing contamination, runoff into water bodies leading to eutrophication, and nitrous oxide emissions contributing to global warming (Chandna *et al.* 2011). Additionally, ammonia volatilization releases nitrogen into atmosphere disrupting ecosystems. It is estimated that around 50% of applied nitrogen is lost through these processes, reducing both efficiency of applied nitrogen and sustainability (Cassman *et al.* 2002).

In South Asia, the limited nitrogen-supplying capacity of the soils is due to low organic matter content. To overcome this issue farmers, rely on higher applications of mineral nitrogen fertilizers. However, nitrogen use efficiency in transplanted rice is low, with only 30-40% of applied urea being utilized by the plants (Choudhury and Khanif, 2004). Puddling operations lead to rapid nitrate loss when aerobic soils are flooded, with up to 54% of urea being lost though volatilization and denitrification losses ranging from 10-56%. The nitrogen runoff from puddled soils can amount to as much as 27 kg N/ha per year (Xing and Zhu, 2000). Effective nitrogen management is crucial for maximising the crop’s response to fertilizers and improve rice productivity. By scheduling nitrogen applications in order to meet the requirements of crop plants, it is necessary to improve the nitrogen utilization efficiency in the rice production system. Adopting conservation agriculture practices in unpuddled transplanted rice systems can enhance NUE as they include minimal soil disturbance and diversified cropping systems.

Considering the above-mentioned opportunities and challenges, the research study entitled "**Impact of planting patterns, nitrogen levels and weed control treatments on the growth and yield of unpuddled transplanted rice (*Oryza sativa* L.)**" has been planned and executed with the following objectives:

Objectives:

1) To evaluate the influence of planting patterns and various weed control treatments on yield of transplanted rice and growth of weeds.
2) To study the impact of planting patterns and nitrogen levels on the growth of crop and weeds.
3) To study the interactive effects of planting patterns with weed control treatments as well as with nitrogen levels on growth of rice and weeds.
4) To assess the quality and nitrogen uptake of rice and weeds under different nitrogen levels and planting patterns.

REVIEW OF LITERATURE

In this chapter, an extensive review of the relevant study was undertaken to create a robust framework for understanding the research problem. The reviewed literature has been evaluated to highlight key insights and establish a basis for analysing the effect of various treatments.

The review of literature has been presented systematically under the following sub-headings.

2.1 Weed flora of rice

2.2 Losses due to weeds in rice crop

2.3 Effect of weed control treatments on weed dynamics and yield of rice

2.4 Impact of planting patterns on growth of weeds and yield of rice

2.5 Influence of nitrogen levels on growth attributes and yield of rice.

2.6 Influence of nitrogen levels on nutrient uptake

2.7 Quality parameters of rice as influenced by various treatments.

2.1 Weed flora of rice

Ameena (2024) conducted an experiment at IFS research station, Thiruvananthapuram and revealed a diverse weed flora in the field such as *Leptochloa chinensis*, *Echinochloa colona*, *Isachne miliacea*, *Sphenoclea zeylanica*, *Bergia capensis*, *Monochoria vaginalis*, *Limnocharis flava*, *Ludwigia perennis*, *Alternanthera philoxeroides*, *Lindernia sp*., *Cyperus iria*, *Cyperus difformis*, *Fimbristylis miliacea*, and *Marsilia quadrifolia*. Grassy weeds were the most prevalent, while broadleaf weeds and sedges were comparatively less abundant.

In a study conducted by Anil *et al.* (2024) at PJTSAU, Telangana, it was reported that weed flora of the direct seeded rice comprised of grassy weeds including, *Cynodon dactylon*, *Echinochloa colona*, *Echinochloa crus-galli*, *Echinochloa glabrescens*, and *Paspalum distichum*. Among the sedges, species like *Cyperus rotundus*, *Fimbristylis dichotoma*, and *Scirpus juncoides* were dominant. Broad-leaved weeds recorded in the study included *Aeschynomene indica*, *Alternanthera sessilis*, *Eclipta zippeliana*, *Ludwigia hyssopifolia*, *Merremia marginata*, and *Portulaca oleracea.*

Mir *et al.* (2024) carried out an experiment at SKAUST, Kashmir and identified that the experimental field was infested by three major weed groups: grassy weeds, sedges, and broadleaved weeds. The dominant grassy species included *Echinochloa crus-galli*, *Echinochloa colona*, and *Cynodon dactylon*. Broad-leaved weeds such as *Ammania baccifera*, *Marsilea quadrifolia*, *Monochoria vaginalis*, *Alisma plantago-aquatica*, and *Potamogeton distinctus* were also prevalent. Among sedges, the most prominent species were found to be *Cyperus iria*, *Cyperus difformis*, and *Fimbristylis littoralis*.

Premnath *et al.* (2024) conducted an experiment at Annamalai University, Tamil Nadu and reported that the dominant weed species in the experimental field were *Echinochloa colonum*, *Echinochloa crus-galli*, and *Leptochloa chinensis* among grasses, *Cyperus rotundus* and

Cyperus iria among sedges, and *Bergia capensis* and *Eclipta alba* among broad-leaved weeds.

Sarma *et al.* (2024) conducted experiment at AAU, Jorha and observed a diverse weed community in direct-seeded rice fields. Grassy weeds like *Eleusine indica (L.)*, *Setaria pumila (Poir)*, *Panicum repens (L.)*, *Eragrostis unioloides*, *Echinochloa crus-galli*, *Cynodon dactylon (L.) Pers.*, and *Leersia hexandra Sw* were prominent alongside broadleaf species such as *Ageratum conyzoides* (L.), *Ludwigia palustris* (L.), *Phyllanthus fraternus* (L.), and *Alternanthera philoxeroides* (L.) and sedges like *Fimbristylis dichotoma*, *Cyperus iria* (L.), and *Cyperus rotundus* (L.). were also prevalent.

According to Bhattarai *et al.* (2023), an experiment conducted at Lalitpur, Nepal documented a rich diversity of weeds in rice fields, including species such as *Ammania sp.*, *Alternanthera philoxeroides*, *Caesulia axillaris*, *Cyperus iria*, and *Echinochloa crus-galli*. Other notable weeds observed were *Eleusine indica*, *Fimbristylis littoralis*, and *Rotala rotundifolia*.

Vikram Sai *et al.* (2023) carried out an investigation at Annamalai University, Tamil Nadu and identified the major weeds present at all growth stages in the experimental field were grasses *Echinochloa colona*, *Echinochloa crus-galli*, and *Leptochloa chinensis* were dominant, while sedges included *Cyperus difformis*, *Cyperus iria*, and *Cyperus rotundus*. Broadleaf species like *Eclipta alba*, *Sphenoclea zeylanica*, *Bergia capensis*, and *Marsilea quadrifolia* were also prevalent.

Based on the investigation carried out at Khowai district, Tripura, Debbarma *et al.* (2021) observed that dominant weed flora of transplanted rice comprised of *Oryza sativa* (Weedy rice) *Echinochloa crus-galli*, *Leptochloa chnensis*, *Cynodon dactylon*, *Ludwigia hyssopifolia*, *Fimbritylis milacea*, *Scirpus grossus*, *Monochoria vaginalis.*

Jehangir *et al.* (2021) identified a diverse range of predominant weed species at SKUAST, Kashmir during reaearch, including *Echinochloa colona*, *Echinochloa crus-galli*, *Setaria glauca*, *Digitaria sanguinalis*, *Ammannia baccifera*, *Rorippa amphibia*, *Potamogeton distinctus*, *Aeschynomene indica*, *Polygonum hydropiper*, *Cyperus rotundus*, *Cyperus iria*, *Cyperus difformis*, *Fimbristylis miliacea*, and *Scirpus juncoides.*

Kokilam *et al.* (2020) conducted a study at Thiruchirappalli, Tamil Nadu revealed that the weed flora in the experimental field was diverse, consisting of grasses, sedges, and broad-leaved weeds (BLWs). The dominant grass species included *Echinochloa crus-galli* (L.), *Echinochloa colona* (L.), and *Cynodon dactylon* (L.), while the prevalent sedges were *Cyperus rotundus* (L.) and *Cyperus iria* (L.). Among the broad-leaved weeds, *Eclipta alba* (L.) and *Ammania baccifera* (L.) were found to be most abundant in the direct wet-seeded rice ecosystem.

Kashid *et al.* (2019) conducted an experiment at ARS, Pune and identified the predominant weed species in the experimental plots, which included monocots like *Echinochloa colona* and *Cynodon dactylon* among grasses, sedges such as *Cyperus iria* and *Cyperus difformis*, and dicots including *Eclipta alba*, *Portulaca oleracea*, *Celosia argentea*, and *Ludwigia parviflora* during the three years of study.

Kumar *et al.* (2017) reported findings from an experiment at College of Agriculture, Hyderabad where a variety of weed species were identified in rice fields. Sedges such as *Cyperus iria*, *Cyperus difformis*, and *Cyperus rotundus* were dominant, while broad-leaved weeds included species like *Eclipta alba*, *Alternanthera phyloxeroides*, *Ammannia baccifera*, *Euphorbia hirta*, *Caesulia axillaris*, *Celosia argentea*, *Commelina benghalensis*, and *Trianthema portulacastrum*. Grassy weeds like *Cynodon dactylon* and *Paspalum distichum* were also observed.

Raj and Syriac (2017) reported that major yield losses in direct seeded rice were caused by grassy weeds such as *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis*, *Oryza sativa f. spontanea*, and *Ischaemum rugosum* and sedges like *Cyperus iria*, *Cyperus difformis*, *Schoenoplectus juncoides*, and *Fimbristylis miliacea* also contributed significantly to yield reduction. Furthermore, broadleaf weeds such as *Eclipta prostrata*, *Sphenoclea zeylanica*, and *Ludwigia hyssopifolia* also significantly impacted crop productivity.

Arya and Ameena (2016) carried out research at Vellayani, Kerala and observed that broadleaved weeds were the most dominant group in the experimental field, followed by sedges and grasses, with weed composition varying significantly between dry and flooded conditions. The broad-leaved species included *Eclipta alba*, *Heliotropium indicum*, *Cleome rutidospermum*, *Commelina jacobi*, and *Ludwigia perennis*, followed by sedges such as *Fimbristylis miliacea*, *Cyperus difformis*, *Cyperus iria*, and *Cyperus compressus*, and grasses like *Isachne miliacea*, *Echinochloa stagnina*, and *Oryza sativa f. spontanea* (wild rice) throughout the crop growth period.

2.2 Losses due to weeds in rice crop

In a study conducted by Saikia *et al.* (2024) at BHU, Varanasi, it was found that in transplanted rice weeds caused a substantial yield reduction up to 28 % in the untreated weedy check plot compared to the weed-free treatment.

Kashyap *et al.* (2023) studied the impact of integrated weed management at GBPUAT, Pantnagar and observed grain yield reduction by 75.5% in direct seeded rice due to unchecked weed growth when compared to weed free treatment.

In an experiment conducted by Verma *et al.* (2023) at JNKVV, Jabalpur, Madhya Pradesh it was revealed that direct-seeded rice suffered a substantial yield reduction of 49 % when weeds were left uncontrolled, underscoring the necessity of timely and effective weed control measures.

Singh *et al.* (2023) carried out research at GBPUAT, Pantnagar and reported that yield losses in transplanted rice due to weeds were substantial, amounting to 23.4 % and 24.7 % during the two years of study, respectively.

Singh (2022) conducted experiment at ICAR-NRRI, Gerua, Assam and reported that significantly higher yield losses (20.4%) occurred during weeding at 60 DAS, followed by when weeding was done 45 DAS (15.8%) with weeding done at 30 DAS (8.8%), indicating that weed control in early growth stages is crucial to obtain ideal yields in DSR.

Based of field experiments conducted by Nazir *et al.* (2020) at SKUAST, Kashmir, the data revealed that the losses in rice yields caused by weeds were 49.9% and 42.2% during both the years of research respectively.

According to Bhuiyan *et al.* (2020), in India yield losses caused by weed infestations range from 12 to 69% in transplanted rice and 17 to 98% in direct seeded rice.

In an experiment conducted by Biswas *et al.* (2020) at Bidhan Chandra Krishi Viswavidyalaya, West Bengal, it was reported that weeds caused a significant yield reduction of 64% in the weedy check plot when compared to the manually weed-free treatment.

Fahad *et al.* (2019) observed that impact of weed infestation on rice yield is highly variable due to differences in cultivation practices across countries. Unchecked weed growth has been reported to cause yield reductions of 44% to as much as 96%, depending on the cultural methods used in rice cultivation.

A study by Gharde *et al.* (2018), based on data from 1,581 on-farm trails under the All India Coordinated Research Project on Weed Management in multiple locations across India, to assess the impact of weeds on yield losses revealed that direct-seeded rice suffered potential yield losses of 15–66% in weedy conditions, whereas transplanted rice fields recorded lower yield losses of 3–30% due to weed competition.

Rao *et al.* (2017) identified weed infestation as a key constraint in direct seeded rice, resulting in yield losses of 14-100%, which was significantly higher than losses reported in transplanted rice (7 to 80%).

Teja *et al.* (2017) conducted an experiment for two years at Institute of Agriculture VisvaBharati, Sriniketan, West Bengal and reported that yield losses in transplanted rice due to uncontrolled weeds were 33.5% and 35.1% during both the years respectively.

As per Mondal *et al.* (2017), based on the experiment conducted at BCKV, West Bengal it was revealed that agricultural production losses in India amount to 33% due to pests and out of it 12.5% due to weeds. Their study also revealed that weed density is typically higher in transplanted summer rice compared to *kharif* rice.

Singh *et al.* (2016) conducted experiment at Karnal, Haryana and reported that yield losses in rice cultivation attributed to uncontrolled weed proliferation were minimal in transplanted rice (12%), but substantial (about 85%) in dry cultivated fields, escalating to 98% in direct-seeded rice (DSR) sown without soil tillage.

Chokkar *et al.* (2014) conducted an experiment for two years at Directorate of Wheat Research (DWR), Karnal to study the effect of crop establishment methods on the yield of rice, it was reported that yield reductions due to weed infestation were significantly higher in DSR systems (91.4–99.0%) compared to transplanted rice systems, where losses ranged from only 16.0% to 41.9%.

Raj *et al.* (2013) while working at Alappuzha, Kerala, observed that yield losses in rice attributed to unchecked weed growth varied between 40.3-69.7% during the *kharif* season, and between 62.6-67.4% in the *rabi* season respectively.

In a study conducted by Singh *et al.* (2011) at Pantnagar, Uttarakhand, transplanted rice showed the lowest yield loss due to weed competition (12%), whereas dry drill seeded rice and its variant along stale seed bed exhibited greater losses of 84%. The highest yield loss of 98% was observed in zero-till dry drill seeded rice.

Based on the studies conducted at Pundibari, West Bengal, Maity and Mukherjee (2008) reported that the grain yield of dry direct-seeded rice is reduced by 96% and that of wet directseeded rice by 61% due to uncontrolled weed proliferation.

In Bangladesh, yield losses due to weed infestation varied across seasons, with highest losses recorded in aus rice (grown in early summer) at 70-80% followed by transplanted aman rice (late summer) at 30-40%, and the lowest losses observed in boro rice (winter rice) at 22-36%. (BRRI, 2006).

2.3 Effect of weed control treatments on weed dynamics and yield of rice

An experiment was conducted by Pradhan *et al.* (2023) at IGKV, Jagdalpur and it was reported that among the herbicidal treatments tested, ethoxysulfuron at 18 g/ha PoE and bispyribac sodium at 25 g/ha PoE demonstrated comparable weed control efficiency over three years of experimentation. Hand weeding twice (at 20 and 40 DAS) resulted in the highest rice grain yields (4.08, 4.86, and 4.48 t/ha), which were statistically on par with bispyribac-sodium at 25 g/ha PoE (3.65, 3.72,4.08 t/ha) and pyrazosulfuron at 25 g/ha PoE (3.27, 3.86, 3.77 t/ha) during the three years of study respectively.

Based on the experiment conducted by Kumar *et al.* (2023) at Patna, Bihar, to study the weed competitive ability of transplanted rice cultivars under various weed management practices it was revealed that applying pretilachlor @ 0.6 kg/ha PE *fb* bispyribac-sodium 30 g/ha @ PoE+ one hand weeding at 35 DAT, effectively reduced the weed density and biomass across all weed species. This treatment also achieved significantly higher grain yields of 5.11 t/ha and 6.11 t/ha over two consecutive years.

Mitra *et al.* (2022) evaluated the effect of various pre-and post-emergence herbicides at Cooch Behar, West Bengal, and found that the highest rice grain yield (4395 kg/ha) was achieved with pendimethalin @ 1.0 kg/ha followed by bispyribac 25 g/ha + pyrazosulfuron @ 20 g/ha. This treatment demonstrated a superior Weed Control Efficiency (WCE) of 78%, significantly lowering weed density by 64% and biomass by 45% compared to the untreated control.

In an experiment conducted by Choudhary and Dixit (2021) at Raipur, Chahttisgarh, it was observed that sequential application of pendimethalin @ 1.0 kg/ha *fb* bispyribac sodium @ 25 g/ha *fb* fenoxaprop @ 60 g/ha + chlorimuron + metsulfuron @ 4 g/ha provided the most effective weed control of grasses, sedges and broadleavef weeds and recorded highest weed control efficiency (89% and 85%) compared to unweeded plots during both the years of study. This treatment also recorded significantly highest rice grain yield (4.78 t/ha and 4.95 t/ha), outperforming two hand weedings at intervals of 15 and 30 DAS (4.60 t/ha and 4.73 t/ha) in the respective years.

Pooja and Saravanane (2021), while working at PJNCARI, Puducherry reported that the sequential application of pendimethalin at 1.0 kg/ha followed by bispyribac-sodium at 20 g/ha effectively reduced total weed density (113.5 plants/m^2) and weed dry weight (21.1 g/m^2), achieving a high weed control efficiency of 78.3%. This treatment also enhanced rice growth and yield attributes, including increased plant height (124.7 cm), productive tillers (378.1 tillers/m^2), panicle weight (3.58 g), and grain yield (3.73 t/ha).

Sen *et al.* (2020) conducted an experiment at IARI, New Delhi to study the weed management in direct seeded rice. The results indicated that among the herbicide treatments pendimethalin @ 1.0 kg/ha followed by penoxsulam + cyhalofop-butyl 130 g/ha produced the highest grain yield (3.92 t/ha) and harvest index (38%), showing a 378.9% improvement over unweeded control plots. Pendimethalin @ 1.0 kg/ha followed by bispyribac-sodium @ 25 g/ha (3.70 t/ha) and Brown manuring followed by Almix @ 20 g/ha (3.67 t/ha) were also effective treatments.

Nazir *et al.* (2020) carried out research at Sher-e-Kashmir University, Kashmir to examine the effect of various weed control treatments on the yield of rice. It was reported that the application of penoxsulam at 22.5 g/ha was highly effective in reducing weed dry matter across all observed stages i.e. 30, 45, 60 DAT, and harvest compared to the weedy check. Additionally, this treatment achieved superior grain yields (8.19 and 8.28 t/ha) and straw yields (10.13 and 10.44 t/ha) during both the years respectively, outperforming both untreated plots and other herbicide treatments.

Kumar *et al.* (2020), based on the experiment conducted for two years at ICAR-Research Complex for Eastern Region, Patna revealed that sequential application of pendimethalin @ 1.0 kg/ha (pre-emergence) followed by bispyribac sodium @30 g/ha (post-emergence) combined with two hand weedings at 40 and 60 DAS significantly reduced weed infestation as compared to other weed control treatments. This treatment decreased the weed density and biomass by 43 and 15%; 39 and 18%; 295 and 96% at 30, 60 and 90 DAS, respectively, while significantly increasing grain yield by 90% as compared to other treatments during both the years.

In a study conducted by Khippal *et al.* (2019) at Khaital, Haryana, they reported that the application of pendimethalin (1.0 kg/ha) followed by bispyribac sodium (25 g/ha) and pyrazosulfuron (25 g/ha) emerged as the most effective herbicide treatment, achieving superior weed control efficiency (91.81%), weed control index (87.97%), and herbicide efficiency index (23.65%). Additionally, this treatment resulted in the highest grain yield of 3794 kg/ha, straw yield of 6145 kg/ha, and a harvest index of 38.2%.

Patel *et al.* (2018), while working at NAU, Navsari, observed that maintaining a weed-free condition resulted in significantly higher weed control efficiency (73.3 %) which was statistically on par with pendimethalin @ 1.0 kg/ha *fb* bispyribac-sodium @ 0.04 kg/ha (71.2 %) and pretilachlor @ 0.75 kg/ha *fb* bispyribac-sodium @0.04 kg/ha (68.3 %). The highest grain yield (2.35 t/ha) and straw yield (4.60 t/ha) in dry-DSR were achieved under the weedfree scenario, which performed similarly to pendimethalin applied at 1.0 kg/ha *fb* bispyribacsodium at 40 g/ha.

In an experiment conducted by Kumar *et al.* (2018) at CCSHAU, Haryana, it was found that bispyribac sodium applied post-emergence at rates of 25 g/ha and 30 g/ha at 20 DAT recorded the lowest weed population (7.7 g/m^2 and 6.5 g/m^2) with high weed control efficiencies of 87.17% and 82.06%. Moreover, these treatments, resulted in grain yields (64.04 and 65.52 q/ha respectively) statistically equivalent to those obtained under weed-free conditions (66.48 q/ha).

Yadav *et al.* (2017) conducted experiment at GBPUAT, Pantnagar and found that among various weed control treatments, the pre-emergence application of pretilachlor @ 0.75 kg/ha followed by the post-emergence application of bispyribac sodium @ 20 g/ha, with no irrigation for one week after application, significantly enhanced both grain (5.73 t/ha) and straw (8.38 t/ha) yields as compared to other treatments.

A study conducted by Bhullar *et al.* (2016), at PAU, Ludhiana revealed that sequential applications of pendimethalin @ 0.75 kg/ha followed by a tank mix of fenoxaprop @ 90 g/ha with ethoxysulfuron 18 g/ha, and combined with one hand weeding, significantly enhanced rice grain yield (6.8–6.9 t/ha and 7.38–7.73 t/ha) as compared to other treatments during both the years of study. Additionally, the tank-mix combinations of fenoxaprop @ 90 g/ha with ethoxysulfuron @ 18 g/ha or bispyribac sodium @ 25 g/ha achieved the lowest weed dry matter at 45 DAS, reducing it by 84% relative to the unweeded control.

In an experiment conducted by Sreelakshmi *et al.* (2016) at Madhurai, Tamil Nadu it was reported that tank mix application of bispyribac sodium @ 25 g/ha, metsulfuron-methyl and chlorimuron-ethyl @ 4 g/ha at 25 DAT significantly reduced weed density to 4.86/m² and weed dry matter production to 7.21 kg/ha, achieving a weed control efficiency (WCE) of 92% at 60 DAT. This treatment also recorded significantly superior plant height (103.89 cm), dry matter production (4210 kg/ha), no. of productive tillers (361.43/m^2), and LAI (2.72), ultimately resulting in highest grain yield of 6.2 t/ha.

Singh *et al.* (2016) reported that the highest grain yield of 3.43 t/ha was achieved with the sequential application of pendimethalin @ 1.0 kg/ha as a pre-emergence herbicide followed by bispyribac-sodium @ 25 g/ha + azimsulfuron @ 22.5 g/ha as post-emergence herbicides. This yield was comparable to the 3.5 t/ha obtained in weed-free plots. Additionally, weed biomass was reduced by 67–86% through the sequential application of pendimethalin @ 1.0 kg/ha(PE), followed by either azimsulfuron @ 22.5 g/ha, bispyribac-sodium @ 25 g/ha (PoE), or their combination in a tank mix.

In a study carried out by Mahajan and Chauhan (2015) at PAU, Ludhiana, it was reported that the combination of azimsulfuron @ 15 g/ha, bispyribac sodium @ 18.7 g/ha, and fenoxaprop @ 50.6 g/ha as a tank mix application delivered exceptional results, by significantly reducing weed density and biomass while achieving nearly 98% weed control efficiency as compared to other treatments. This treatment resulted in the highest grain yield (7.23 t/ha, 7.86 t/ha during both the years respectively) which was on par with yields from other effective treatments like azimsulfuron @ 15 g/ha + fenoxaprop @ 50.6 g/ha (PoE) and pendimethalin @ 0.75 kg/ha (PE) followed by either bispyribac @ 25 g/ha, fenoxaprop @ 67.5 g/ha, or azimsulfuron @ 20 g/ha (PoE).

In a two-year study by Mahjan and Chauhan (2013) at PAU, Ludhiana it was found that sequential application of pendimethalin @ 0.75 kg/ha as a pre-emergence herbicide followed by azimsulfuron @ 20 g/ha as a post-emergence treatment significantly reduced weed density and biomass, performing on par with pendimethalin @ 0.75 kg/ha (PE) followed by bispyribacsodium @ 25g/ha (PoE). The highest grain yield of 4.99 t/ha was recorded with pendimethalin and bispyribac sodium applications, while untreated plots produced the lowest grain yield of 1.48 t/ha.

In a study carried out by Ramachandiran and Balasubramaniam (2012) at Madurai, Tamil Nadu, it was observed that post-emergence application of fenoxaprop @ 60 g/ha + ethoxysulfuron @ 15 g/ha at 30 DAS produced the highest grain yield of 6278 kg/ha while achieving the lowest weed dry matter and maximum weed control efficiency. This was followed by bispyribac sodium @ 25 g/ha applied solely as post-emergence at 20 DAS.

A study by Manjunatha *et al.* (2012) in Bramhavar, Karnataka, concluded that the preemergent application of bensulfuron methyl 0.6% G at 60 g/ha combined with pretilachlor 6% at 600 g/ha significantly reduced weed population (4.85 /0.25 m^2) and dry weight (2.18 g/ 0.25 m^2), performing on par with bispyribac sodium applied at 25 g/ha. In contrast, the unweeded control recorded the highest weed dry weight (4.20 /0.25 m^2). The highest grain (52.12 q/ha) and straw yields (58.58 q/ha) were achieved with the pre-emergent application of bensulfuron methyl @ 60 g/ha and pretilachlor @ 600 g/ha, which was statistically comparable to bispyribac sodium @ 25g/ha.

Yadav *et al.* (2009) found that bispyribac applied at a rate of 25 g/ha between 15 and 25 days after transplanting (DAT) showed remarkable results, increasing grain yield by 174–199% in the first year and 37–41% in the second year compared to the untreated weedy check. These findings suggest that bispyribac at this rate (25 g/ha) and timing is an effective option for managing diverse weed populations in transplanted rice.

Mahajan *et al.* (2009) conducted a study for two-years at PAU, Ludhiana and reported that penoxsulam @ 25 g/ha applied 12 days after transplanting recorded the lowest weed density, followed closely by a sequential application of pretilachlor @ 0.4 kg/ha and metsulfuron @ 15 g/ha. Penoxsulam proved highly effective in both years, reducing weed dry matter by 72.5% in 2006 and 72.8% in 2007. In 2007, the newly introduced herbicide bispyribac sodium @ 25 g/ha demonstrated superior weed control, reducing weed dry matter by 81.3% compared to the weedy check and outperforming pendimethalin + one hand weeding, pretilachlor + metsulfuron, and penoxsulam by 61.7%, 22.1%, and 31.2%, respectively.

Walia *et al.* (2008) conducted an experiment at PAU, Ludhiana and it was demonstrated that applying pendimethalin (0.75 kg/ha) as pre- emergence followed by bispyribac (25 g/ha) at 30 DAS as a post-emergence treatment was highly effective in reducing weed dry weight (2.95

q/ha). This treatment yielded the highest grain production of 5618 kg/ha, outperforming all other herbicidal treatments due to its superior control of complex weed flora.

2.4 Impact of planting patterns on growth of weeds and yield of rice

A study was conducted by Chaki *et al.* (2021) at Bangladesh Wheat and Maize Research Institute (BWMRI) across Rajshahi and Dinajpur districts, the findings reported no significant difference in yields between zero tillage unpuddled transplanted rice (4.84 t/ha) and puddled transplanted rice (4.50 t/ha). These findings underline the feasibility of zero till unpuddled transplanted rice as a sustainable alternative to conventional puddling practices.

Krishnaprabhu (2019) conducted a two-year experiment (2017–2018) at Annamalai University, Tamil Nadu to assess various planting methods and weed management in direct dry-seeded rice. The findings suggested that conventional tillage paired row (9-27-9 cm) planting method demonstrated significantly lower weed density at 60 DAS compared to conventional tillage normal spacing [row to row (R × R) -18 cm)]. At harvest, however, both treatments performed similarly over two years. In terms of yield performance, the CT paired row method recorded the highest grain and straw yields, which were statistically comparable to CT normal spacing, CT square planting, and RT paired row methods but significantly better than RT square planting across both years.

In a field experiment conducted by Yadav *et al*. (2018) during the *kharif* seasons of 2012 and 2013 at Banaras Hindu University, Varanasi, higher weed control efficiency was observed in conventional tillage with normal spacing (R x R-18 cm) (67.6 and 63.3 %) and paired row spacing (9-27-9 cm) (68.9 and 68.4%) as compared to other planting methods during both the years respectively. This resulted in increased grain yield in paired row spacing (9-27-9 cm)

(5.9 and 5.7 t/ha) which was statistically at par with conventional tillage with normal spacing (R x R-18 cm) (5.8 and 5.6 t/ha) during both the years of study.

Haque *et al*. (2016) conducted a study in Bangladesh and reported that reduced tillage techniques, such as unpuddled transplanting, can achieve rice yields on par with conventional puddling and transplanting practices. The findings further revealed that mean yield obtained from minimum tillage unpuddled transplanting, using strip tillage (4.92 q/ha) or bed planting (5.03 q/ha), performed equally well in large-scale on-farm trials and two replicated experiments. Over three consecutive years, this approach consistently produced rice yields equivalent to those of traditional puddling-based methods.

In a study conducted in China, Yuan-zhi (2015) found that ridge tillage led to a substantial improvement in rice production, with effective panicle numbers increasing by 22.12% and actual yield rising by 15.18% compared to conventional tillage.

Kumar *et al.* (2013) conducted two field experiments over three years (starting from *rabi* 2004) at Karnal, Haryana to study the effects of raised bed planting and conventional transplanting in rice-wheat cropping system on well-drained and poorly drained soils. Their findings revealed that raised bed transplanting resulted in significantly higher panicle numbers per hill (17.12, 18.53,14.69), panicle length (26.0,22.8,23.9 cm) and grain yield (47.16,49.00,53.20 q/ha) compared to conventional transplanting during the three years respectively. Additionally, rice grown on raised beds exhibited superior root characteristics i.e. increased root length (55,57,42 cm) and biomass (18.6,78,40 g) compared to those in conventional transplanting systems.

Sandhu *et al.* (2012) carried out an experiment during the *kharif* seasons of the years 2009 and 2010 respectively, at Punjab Agricultural University, Ludhiana and reported that by transplanting rice seedlings on the slopes of newly formed beds, farmers achieved a 15% reduction in irrigation water consumption, while the grain yield of bed planting (6.95 and 6.35 t/ha) was statistically on par with flat conventional puddled fields (7.21 and 6.70 t/ha).

In a study conducted by Bhuyan *et al.* (2012) at the farmer's field in Chuadanga, Bangladesh it was found that he raised bed planting method produced a rice yield of 5.83 t/ha, which was 0.93 t/ha higher than the 4.90 t/ha yield achieved with the conventional method. Additionally, weed population (123 weeds/m^2) and biomass (113 kg/ha) were significantly lower in the raised bed system compared to the conventional method, which recorded a weed population of 380 weeds/m^2 and biomass of 337 kg/ha.

An experiment by Mahajan and Chauhan (2011) at PAU, Ludhiana, revealed that under weedy conditions, rice planted in paired rows achieved higher grain yields (45.3 q/ha) compared to those planted in uniform rows (37.10 q/ha). This was attributed to lower weed biomass (131 g/m^2) and higher crop biomass accumulation (223 g/m^2) in the paired row system. The study found that weeds reduced grain yields by 18–36% more in uniform rows than in paired rows. These results suggest that the morphological adjustments associated with paired row planting enhance crop-weed competitiveness. Paired row planting could be a viable approach for improving weed management and productivity of rice cultivars under aerobic conditions.

Saharawat *et al.* (2010) carried out research at CCSHAU, Haryana and observed that grain yields from conventionally transplanted (7.28 t/ha), unpuddled transplanted (7.23 t/ha), and notill transplanted (7.16 t/ha) rice plots were comparable but significantly higher than those from wet and dry direct-seeded rice plots. The yields of wet and dry direct-seeded rice were 6–8% lower compared to the transplanted methods.

Aslam *et al.* (2008) conducted an experiment at Rice Research Institute, Lahore to evaluate the impact of various stand establishment techniques on yield and yield attributes in rice. Although the findings reported that significantly higher paddy yield (4.80 t/ha) was obtained from the treatment with double zero tillage, the study concluded that double zero tillage and bed planting are viable resource conservation technologies capable of producing high yields.

In an experiment conducted at D.I. Khan, Pakistan, Khattak *et al.* (2006) reported that among all planting techniques evaluated, transplanting on raised beds outperformed the others in terms of yield parameters, producing the highest paddy yield of 6.70 t/ha which was followed by drill sowing using a bed planter, which achieved a yield of 6.0 t/ha. These results indicate that transplanting on raised beds and drill sowing with a bed planter are the most effective methods for maximizing rice productivity and enhancing yield attributes.

Ockerby *et al.* (2001) conducted a study at University of Queensland, Australia and reported that significantly higher tiller count/m^2 (1164), grain yield (1129 kg/ha) were observed in the cultivar Ceysvoni grown on raised beds when compared to other cultivars.

2.5 Influence of nitrogen levels on growth attributes and yield of rice

In an experiment conducted by Chowdhury *et al.* (2025) at IARI, New Delhi to study the impact of nitrogen levels on yield dynamics, it was observed that grain yields of both direct seeded rice and transplanted rice improved significantly with increasing nitrogen application rates up to an optimal level of 160 kg N/ha, achieving a maximum yield of 4886 kg/ha, while the control (0 kg N/ha) produced the lowest yield of just 2455 kg/ha. However, nitrogen levels beyond 160 kg N/ha resulted in diminishing returns, with yields slightly declining to 4412 kg/ha and 4408 kg/ha at 200 kg N/ha and 240 kg N/ha, respectively.

Based on experiment conducted by Liu *et al.* (2024) at Jilin Agricultural University, China it was observed that increase in the dose of nitrogen application from 125 kg/ha to 150 kg/ha and 175 kg/ha resulted in yield improvements of 9.9% and 6.6%, respectively.

Yadav *et al.* (2023) carried out a study at ANDUAT, Ayodhya and concluded that significantly highest grain yield (57.0 q/ha) and straw yield (74.73 q/ha) were achieved with the application of 180 kg N/ha guided by the Leaf Colour Chart (LCC). In contrast, the control treatment without nitrogen resulted in the lowest grain yield (37.2 q/ha) and straw yield (50.95 q/ha).

In a study conducted by Singh *et al.* (2023) at KVK, Ferozepur it was observed that nitrogen application at 120 and 150 kg/ha produced statistically similar grain and straw yields in directseeded rice (DSR). Applying 120 kg N/ha increased rice grain yield by 52.8% and 33.9% compared to control plots without nitrogen.

Denesh *et al.* (2022) conducted an experiment at Mandya, Karnataka and reported that highest paddy grain yield (6.30 t/ha) was achieved with an application of 150% RDN, which was statistically equivalent to the yield obtained at 125% RDN (5.95 t/ha), both significantly outperforming other treatments.

Giri *et al.* (2022) carried out research at Kanchanpur, Nepal and demonstrated that applying 180 kg N/ha significantly boosted plant growth metrics such as height (74.5 cm) and number of tillers per sq m (1101.6). Yield attributes such as panicle length (25.2 cm), effective numer of tillers per sq m (577.2), test weight (22.3 g), filled grains per panicle (116.4) were also significantly enhanced, unltimately improving the grain yield (4.7 t/ha), and straw yield (10.5 t/ha) compared to lower nitrogen levels.

According to Preethika *et al.* (2022), nitrogen application at 125% RDN (187.5 kg N/ha) led to significant improvements in yield parameters such as effective tillers per square meter (270.2 and 281.5), panicle length (22.9 and 24.1 cm), panicle weight (3.23, 3.61 g), test weight (22.55, 22.67 g), and filled grains per panicle (105.8 and 116.3) over two years. These results were statistically on par with those observed under 100% RDN (150 kg N/ha). Similarly, the highest grain yield was recorded at 125% RDN (60.65 and 62.56 q/ha), which was statistically comparable to 100% RDN (56.72 and 58.57 q/ha), while the lowest grain yield was observed in control (21.25 and 22.75 q/ha) without nitrogen application across both years.

Kolo *et al.* (2021) conducted a study at University of Abeokuta, Nigeria to evaluate the effects of different nitrogen levels (0, 60, and 90 kg/ha) on rice yield and observed that applying nitrogen at 90 kg/ha, combined with effective weed control using butachlor, significantly enhanced grain yield (3.4 t/ha) as compared to other nitrogen levels.

In a study conducted by Tang *et al.* (2021) at Yangtze University, China it was observed that application of 190 kg N/ha in hybrid rice exhibited an increase in the number of effective panicles (372.03) ultimately boosting the grain yield (11.5 and 12.0 kg/ha during both the years repectively) when compared to other treatments.

Bokado *et al.* (2020) conducted an experiment at SHUATS, Prayagraj and revealed that significantly higher yield parameter including number of effective tillers (239.5), number of grains per panicle (157.6), panicle length (27.14 cm), grain yield (6.88 t/ha) and straw yield (7.63 t/ha) were observed with the application of 140 kg N/ha when compared to other treatments in direct seeded rice.

According to Dahipahle and Singh (2018), field trails at BHU, Varanasi for two years and demonstrated that nitrogen application at 180 kg/ha resulted in significantly higher panicle length (24.07, 23.98 cm), number of grains per panicle (129.94, 128.96), and panicle density per square meter (230.17, 227.06). However, these results were statistically comparable to those observed with 150 kg N/ha. Similarly, grain yield

(43.28, 42.85 q/ha) at 180 kg N/ha was also on par with the yield (43.35, 43.07 q/ha) achieved at 150 kg N/ha during both the years respectively.

Singh *et al.* (2018) conducted a study at BHU, Varanasi and revealed that nitrogen application at 160 kg/ha led to significantly better plant growth parameters such as plant height (67.4 cm), dry matter accumulation per square meter (372.6 g/m^2), and number of effective tillers per/m^2(435.8) compared to treatments with lower nitrogen levels (100, 120, and 140 kg N/ha). The highest grain yield of 5.9 t/ha was also achieved with this treatment.

In an experiment conducted by Adhikari *et al.* (2018) at Bangladesh Agricultural University, Mymensingh it was found that applying nitrogen at 80 kg/ha significantly enhanced yield parameters such as total tillers per hill (8.74), effective tillers per hill (6.18), panicle length (21.98 cm), grains per panicle (114.20), grain yield (4.00 t/ha), straw yield (5.25 t/ha), and biological yield (9.25 t/ha), outperforming all other treatments.

Patel *et al.* (2018) conducted an experiment at NAU, Gujarat and reported that increasing nitrogen levels significantly improved yield parameters, including effective tiller density (237/m^2), panicle length (25.5 cm), and number of grains per panicle (67.7) with the highest values observed at 120 kg N/ha. The application of 120 kg N/ha significantly boosted grain yield (2.0 t/ha) and straw yield (4.19 t/ha) compared to 80 kg N/ha, demonstrating the positive impact of higher nitrogen levels on direct-seeded rice.

Based on a study by Reddy *et al.* (2017) in Karnataka, it was found that applying 150 kg N/ha in three equal split doses significantly enhanced rice grain yield, achieving 40.45 q/ha and 45.48 q/ha in two consecutive years, compared to 34.80 q/ha and 41.06 q/ha with 120 kg N/ha (control). This represented an 11.8% increase in grain yield over the control treatment.

Pradhan *et al.* (2014) carried out an experiment at IGKV, Jagdalpur to investigate the performance of rice varieties under aerobic conditions with varying nitrogen levels (40, 60, 90, and 110 kg/ha) and concluded that increasing nitrogen application rate up to 90 kg/ha significantly improved panicle density/m^2(176.4), filled grains per panicle

(133.6), grain yield (4.40 t/ha) and biological yield (11.02 t/ha), when compared to other treatments.

Based on the study conducted by Meena *et al.* (2014) at Anand Agricultural University, Gujarat, significant increase in growth and yield attributes was observed with higher nitrogen levels. The treatment with 100% RDN recorded the highest total number of tillers per hill (37.49) and test weight (17.21 g), productive tillers per hill (33.54), which were statistically similar to the 75% RDN treatment. Similarly, grain yield of 100% N (35.50 q/ha) was found to be statistically at par with yield obtained from 75% RDN (33.47 q/ha). Conversely, lowest grain yield (28.72 q/ha) was obtained from control with no nitrogen.

In an experiment conducted by Gill *et al.* (2013) at PAU, Ludhiana reported the application of 125% recommended nitrogen dose (RDN) achieved significant increase in plant height (105.5 cm), dry matter accumulation (14.6 q/ha), and leaf area index (3.6). Additionally, yield attributes such as panicle length (26.7 cm), test weight (21.8 g), number of grains per panicle (142.1), as well as grain yield (3.9 t/ha) and straw yield (9.7 t/ha) were significantly improved with 125% RDN application.

In a study conducted by Kabat and Satapathy (2011) at Bhanjanagar, Odisha it was reported that increasing the nitrogen levels from 60 to 120 kg/ha led to a significant improvement in effective tillers/m^2 (261), filled grains per panicle (142), and test weight (26.98 g). The enhanced performance of these yield components under 120 kg N/ha resulted in a notable increase in hybrid rice grain yield (67.46 q/ha) and straw yield (82.46) in comparison to other levels of nitrogen.

Singh *et al.* (2007) conducted an experiment at PAU, Ludhiana and concluded that splitting a total nitrogen dose of 120 kg/ha into three equal applications at 20, 40, and 60 days after seeding significantly enhanced grain yield (5.38 t/ha) and straw yield (9.94 t/ha) when compared to other treatments, increasing the grain yield in wet-direct seeded rice by 62% compared to control without nitrogen.

Sharma *et al.* (2007) from a study conducted at Rajendra Agricultural University, Bihar reported that applying 120 kg N/ha significantly increased grain and straw yields compared to 40 kg N/ha in both years of the experiment. The grain yield improved by

26.6% with 80 kg N/ha and by 32.4% with 120 kg N/ha over the lower nitrogen application rate of 40 kg N/ha.

Zaidi and Tripathi (2007) while working at NDUAT, Uttar Pradesh observed that nitrogen application at a dose 150 kg/ha in hybrid rice significantly enhanced panicle density/m² (299), panicle weight (3.13 g), grain yield (6.30 t/ha), straw yield (9.48 t/ha) when compared to other treatments (0, 50 and 100 kg N/ha).

2.6 Influence of nitrogen levels on nutrient uptake

Gyawali *et al.* (2025) carried out research at National Rice Research Program, Dhanusha, Nepal. The results indicated that applying 150 kg N/ha resulted in the highest nitrogen uptake in rice grain (59.06 kg/ha), and it was statistically at par with grain uptake (57.09 kg/ha) of 175 kg N/ha. The lowest nitrogen uptake in rice grain was observed in the control plot (40.88 kg/ha). In rice straw, the maximum nitrogen uptake of 44.08 kg/ha was achieved with 175 kg N/ha, which was statistically equivalent to the uptake observed at 150 kg N/ha (43.08 kg/ha) and 125 kg N/ha (43.79 kg/ha).

In an experiment conducted by He *et al.* (2024) at Hunan Agricultural University, China it was reported that by applying 150 kg N/ha, there was significant increase in the nitrogen uptake and nitrogen use efficiency (54.06 %) when compared to 0 kg N/ha.

Bama *et al.* (2021) conducted an experiment at Rice Research Institute, Tamil Nadu to study the effect of various nitrogen levels on direct seeded rice and reported that nitrogen uptake in rice grain increased with higher nitrogen application rates. The application of 150 kg N/ha resulted in the highest nitrogen uptake (81.2 kg/ha), which was statistically comparable to 125 kg N/ha (75.9 kg/ha).

In a study carried out by Maurya *et al.* (2021) at BHU, Varanasi it was revealed that applying nitrogen at 160 kg N/ha resulted in significantly higher nitrogen (52.23 kg/ha) and phosphorus (11.17 kg/ha) uptake in rice grains compared to lower levels. The lowest uptakes of nitrogen

(40.34 kg/ha) and phosphorus (8.33 kg/ha) were recorded at 100 kg N/ha. However, potassium uptake in grains remained unaffected by varying nitrogen levels.

Based on the two-year study conducted by Vibhajam *et al.* (2019) demonstrated that applying nitrogen at a rate of 120 kg/ha resulted in maximum nitrogen uptake by grains (69.8 and 67.8 kg N/ha) straw (29.4 and 28.1 kg N/ha) during the years studied (2017–2018). This treatment significantly outperformed lower nitrogen levels of up to only 100, 80, or even just 60 kg N/ha.

Kaur and Mahal (2014) conducted a study on direct-seeded scented basmati rice at PAU, Ludhiana to assess the impact of varying nitrogen levels. Their findings revealed that nitrogen uptake significantly improved when the nitrogen dose was increased from 40 to 60 kg/ha, but further increasing the dose to 80 kg/ha showed no substantial improvement.

Sandhu and Mahal (2014) conducted an experiment at PAU, Ludhiana and revealed that a significant increase in nitrogen uptake (149.9 kg/ha) and phosphorus uptake by rice (43.4 kg/ha) was observed up to a nitrogen application rate of 120 kg/ha, beyond which the increase was statistically insignificant. In contrast, potassium (K) uptake remained unaffected by varying nitrogen levels.

In their experiment on nitrogen levels in Telangana, Mallareddy and Padmaja (2013) reported that applying 240 kg N/ha resulted in the highest nitrogen uptake by grain (44.8 kg/ha) and straw (27.5 kg/ha), which was significantly greater than that achieved with 120 or 180 kg N/ha. They concluded that nitrogen application improves pre-anthesis dry matter accumulation by stimulating tiller formation, increasing LAI, enhancing crop growth rate before anthesis, and improving the translocation of nutrients to grains.

Singh *et al*. (2009), while working at NDUAT, Uttar Pradesh investigated the effects of green manuring on rice productivity under different nitrogen regimes at Faizabad, U.P and observed that applying 150 kg N/ha resulted in a nitrogen uptake of 135.47 kg/ha, which was statistically similar to the uptake recorded at 75 kg N/ha.

In a study conducted by Sharma *et al*. (2007) at Rajendra Agricultural University, Bihar, it was observed that increasing nitrogen levels (40, 80, and 120 kg/ha) led to a steady rise in both dry matter accumulation and nitrogen uptake across all growth stages. The maximum nitrogen uptake by grain (38.6 kg/ha) and straw (19.8 kg/ha) was achieved with the application of 120 kg N/ha as compared to other treatments.

Singh *et al.* (2006) conducted a study at BHU, Varanasi and observed nitrogen application up to 150 kg N/ha significantly enhanced nitrogen uptake in grain (28.12 kg/ha) and straw (13.62 kg/ha). However, further increasing the rate to 180 kg N/ha did not result in a statistically significant improvement over the uptake observed at 150 kg N/ha.

2.7 Quality parameters of rice as influenced by various treatments.

Lathwal *et al.* (2024) carried out a study at CCSHAU, Haryana which demonstrated that increasing the rate of nitrogen application significantly influenced grain protein content. The maximum protein content was achieved at 150 kg N/ha (8.9%) as compared to other treatments, whereas the control plots with no nitrogen application exhibited the lowest protein levels (5.8%).

In an experiment conducted by Wang *et al.* (2024) in china, it was observed that by increasing nitrogen increasing nitrogen fertilizer application significantly enhanced rice's appearance, milling quality, and protein content. The highest values for these parameters were achieved with a nitrogen application rate of 270 kg/ha.

Lan *et al.* (2021) conducted an experiment at Sichuan Agricultural University, China and reported that the accumulation of albumin, globulin, gliadin, and glutenin in rice grains showed a steady increase during growth and development. This increase was more pronounced with higher nitrogen levels applied over time, particularly after full heading. The maximum protein content (80.32 and 81.00 mg/g) was recorded with the application of 225 kg N/ha during both the years of study, total protein content was positively correlated with nitrogen rates, ranging from 61.75 to 80.66 mg/g across both the years.

In a study conducted by Liang *et al*. (2021) Panjin city, China to investigate the impact of varying nitrogen levels (0, 160, 210, 260, 315, and 420 kg N/ha) on rice nitrogen use efficiency, grain yield, and quality, it was found that applying an optimal nitrogen rate (210–260 kg N/ha) significantly enhanced nitrogen use efficiency (42%), improved both milling and nutritional quality of rice.

An experiment was conducted by Zhou *et al.* (2018) at Shenyang Agricultural University, China. The effects of different nitrogen rates (0, 140, 180, and 220 kg/ha) on rice grain quality were examined. The results revealed that applying nitrogen at 180 kg ha^{-1} improved milling quality, enhanced grain appearance, and increased protein content significantly, with protein levels ranging from 6.2% to 8.4% and 6.5% to 9.2% respectively for both the cultivars used in the research.

Patel *et al.* (2018) reported that by applying nitrogen dose of 120 kg N/ha significantly enhanced nitrogen use efficiency (20.1%) and increased the nitrogen content in rice grains (1.38%), ultimately increasing the protein content of rice (8.62%) when compared to other treatments.

Kumawat *et al.* (2017) conducted an experiment at IARI, New Delhi and reported that grain quality parameters like milling percentage (66%), hulling percentage (71.7%), and head rice recovery (55.8%) were significantly improved by precise irrigation scheduling @ 0 kPa in saturated conditions and nitrogen application @120 kg/ha. This enhancement was attributed to higher nitrogen concentrations in the grains, which led to an increase in protein content (8.12%).

In an experiment conducted by Mishra *et al.* (2015) at Faizabad, U.P to study the effect of various nitrogen levels it was reported that the application of 225 kg N/ha resulted in significantly higher quality parameters for rice grains, including protein content (7%), hulling/milling efficiency (80.1%), kernel length (9.4 mm), and kernel length after cooking (10.9 mm).

Maqsood *et al.* (2013) conducted two-year experiments at University of Agriculture, Faisalabad, Pakistan and observed that transplanted rice exhibited higher protein content (8.11%) compared to direct-seeded rice (7.56%) during second year. However, the difference was non-significant during the first year. Nitrogen application significantly increased protein levels over both years of the experiment. The highest protein content (8.65 and 8.56%) were achieved with 100 kg N/ha, whereas the control plots without nitrogen recorded the lowest protein levels (7.12 and 7.10%), during both the years

Devi *et al.* (2012) carried out research at SVU, Andhra Pradesh and revealed that among the tested nitrogen levels, 150 kg N/ ha delivered superior grain quality attributes such as milling percentage (74.2%), head rice recovery (48.9%), kernel length (6.92 mm), amylose content (24.2%), and protein content (9.0 %). While it significantly outperformed 125 kg N/ha, its performance was on par with 175 kg N/ha.

In an experiment by Gautam *et al*. (2008) at IARI, New Delhi, the effects of varying nitrogen levels (0, 80, 160 kg/ha) on rice quality were evaluated. The results showed that the highest nitrogen application rate of 160 kg/ha led to significant improvements in head recovery (53.5 and 53%), hulling percentage (79.2 and 80%), milling percentage (66.5 and 67.7%), and protein content (7.94 and 8.00%) compared to lower nitrogen levels during both the years of study respectively.

MATERIALS AND METHODS

The current study entitled "**Impact of planting patterns, nitrogen levels and weed control treatments on the growth and yield of unpuddled transplanted rice (*Oryza sativa* L.)**" was conducted during the *kharif* seasons of 2023 and 2024 respectively. This chapter provides a comprehensive discussion on various aspects, including the location of experimental site, climatic and soil conditions, cropping history, soil properties, experimental materials used, and methodologies employed during the course of investigation.

3.1 Geographical location of experimental site:

The experiment was conducted on uniform fertility field at agriculture teaching and research farm of Lovely Professional University, located approximately 7 km from Phagwara town, falling in the central plain region agro-climatic zones of Punjab. The site lies in the fertile Indo-Gangetic Plains, known for its flat terrain and nutrient-rich alluvial soils. Geographically, the experimental area is positioned at 31^0.24' North latitude and 75^0.69' East longitude, with an elevation of 234 meters above mean sea level.

3.2 Meteorological condition:

Phagwara's climate is categorized as mild and moderate, characterized by significantly lower rainfall in winter compared to summer. The Köppen-Geiger classification places this region in the Cwa category, with an annual mean temperature of 23.2°C and receives about 816 mm of precipitation annually (climate-data.org).

Meteorological observations for *kharif* seasons of 2023 and 2024, including data on maximum and minimum temperatures, mean relative humidity and cumulative rainfall, were obtained from meteorological observatory at Lovely Professional University and are detailed in Table 3.1 and Table 3.2 respectively.

3.2.1 Temperature

Temperature is a key meteorological factor that significantly affects the germination, growth and development of plants in any agro-climatic region. The monthly mean maximum and minimum temperatures for the cropping seasons of 2023 and 2024 are summarized in Table 3.1 and Table 3.2 respectively**.** Maximum temperatures were recorded in the months of May and June during both the years.

3.2.2 Rainfall

The monthly rainfall data during both the years of study has been presented in Table 3.1 and Table 3.2. Maximum rainfall was recorded in the months of June and July during the year 2023, whereas month of august recorded peak rainfall during 2024. The month of October experienced the lowest rainfall during both the years of study.

3.2.3 Relative humidity

The percentage of relative humidity during the experimental period in both the years of study has been presented in the Table 3.1 and Table 3.2 respectively. Maximum relative humidity was observed for the months of July to October during both the years.

Table 3.1. Meteorological data during the cropping season of 2023

Month	Max. Temperature (^{0}C)	Min. temperature (^{0}C)	Max. Relative Humidity (%)	Min. Relative Humidity (%)	Rainfall (mm)
May	38.0	23.0	40.4	68.0	55.9
June	36.0	25.0	82.5	46.9	94.4
July	33.9	26.5	88.1	68.0	279.0
August	34.5	27.0	91.0	70.4	78.2
September	34.0	24.0	92.0	65.3	23.7
October	31.1	16.2	92.4	49.7	13.2

Table 3.2. Meteorological data during the cropping season of 2024

Month	Max. Temperature (^{0}C)	Min. Temperature (^{0}C)	Max. Relative Humidity (%)	Min. Relative Humidity (%)	Rainfall (mm)
May	40.2	22.3	72	26	0
June	40.3	25.7	75	37	12.1
July	35.7	27.5	90	68	8.2
August	33.9	26.5	93	74	88.4
September	34.2	25.1	94	69	15.2
October	33.9	18.4	94	53	10

3.3 Site selection and cropping history:

The productivity of the experimental field can be assessed through its past cropping history. A rectangular upland plot of uniform fertility was chosen for the experimental layout during both years i.e. 2023 and 2024 respectively. The site featured even topography, consistent soil texture, making it ideal for research. Previously, the experimental field had been under rice-wheat crop rotation system for several years.

Table 3.3 Cropping history of experimental field

Years	Crops	
	Kharif	***Rabi***
2020-21	Rice	Wheat
2021-22	Rice	Wheat
2022-23	Rice	Wheat
2023-24	Rice (Experimental crop)	Wheat
2024-25	Rice (Experimental crop)	Wheat

3.4 Initial assessment of soil properties:

Table 3.4 Physical and chemical properties of experimental field

Soil properties	Values obtained	Methodologies applied
A. Physical properties		
Soil Texture		
Sand	33.9	International Pipette method (Piper,1996)
Silt	29.8	
Clay	36.3	
Textural class	Clay loam	
B. Chemical properties		
Soil reaction (pH)	7.60 (Alkaline)	Glass electrode pH meter (Jackson, 1973)
EC (dSm^{-1})	0.18 (Normal)	Conductivity bridge (Jackson,1973)
Organic Carbon (%)	0.65 (Medium)	Walkley and Black (1934)
Available N(kg/ha)	187.5 (Low)	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P_2O_5(kg/ha)	18.3 (Medium)	Bray-1 method (Jackson,1973)
Available K_2O (kg/ha)	221.7 (Medium)	Flame photometer method (Jackson,1973)

3.5 Experimental design and field layout:

The research project comprised of two separate experiments and for each, lay out was done in Split-Plot Design with four replications, the randomization procedure was executed distinctly and independently for each replication to ensure unbiased results. There were four main plots and four sub plots in both experiments.

3.6 Technical programme of work:

3.6.1 Experiment I: Role of planting patterns and weed control treatments on yield of unpuddled transplanted rice.

Main plots (Planting patterns)

M_1- Transplanting two rows/ridge* (30 cm × 10 cm)

M_2- Transplanting two rows/ridge* + one in furrow (20 cm × 15 cm)

M_3- Flat transplanting, unpuddled (20 cm × 15 cm)

M_4- Flat transplanting, puddled (20 cm × 15 cm)

* Ridges were made at 60 cm apart and transplanting of rice seedlings were done on slopes of ridge.

Note: Plant population was kept uniform in all experimental plots.

Sub plots (Weed control treatments)

T_1- Pendimethalin 0.75 kg/ha as pre-em. *fb* bispyribac sodium 10 SC at 25 g/ha as post- em. (20-25 DAT)

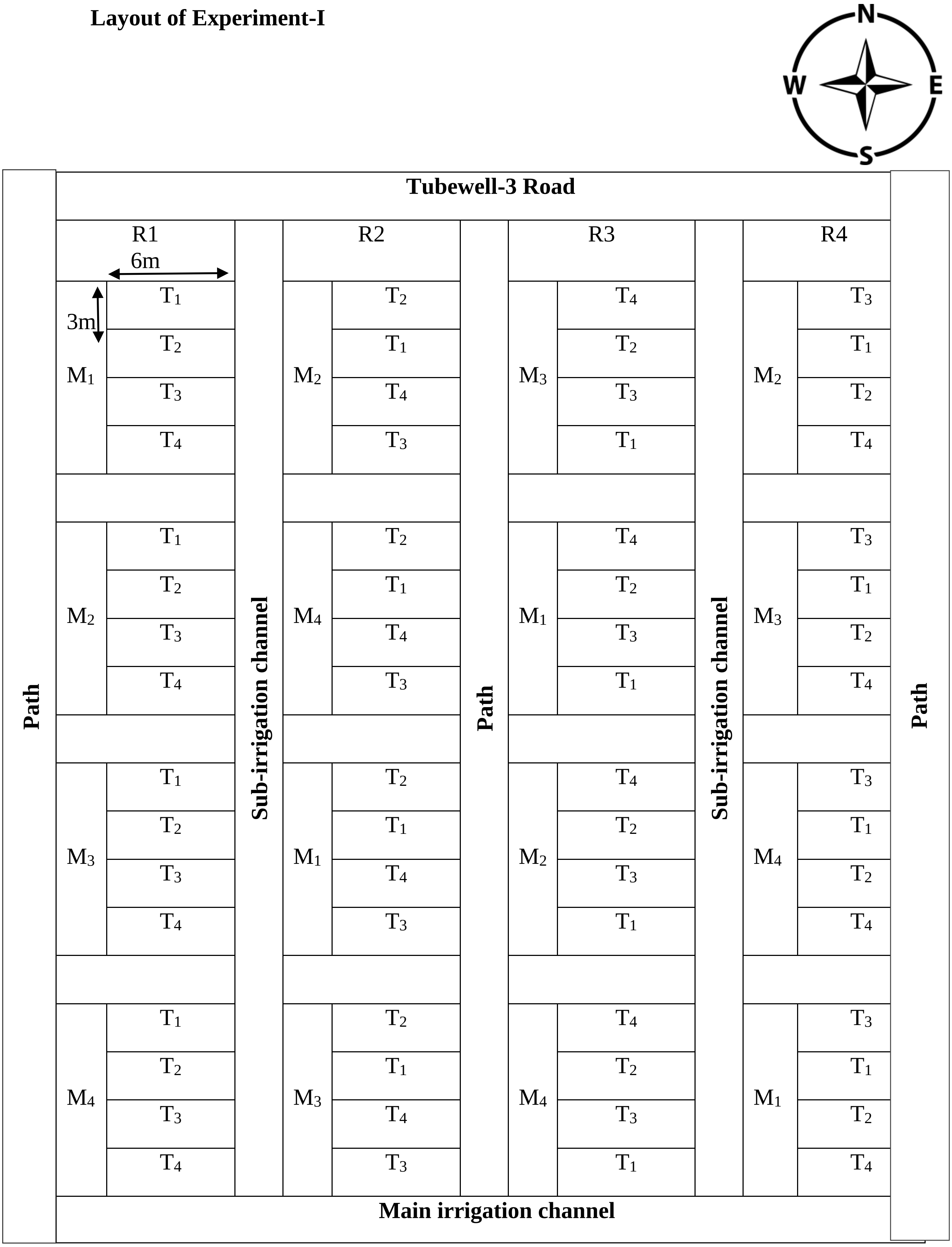
T_2- Pendimethalin 0.75 kg/ha as pre-em. *fb* penoxsulam 24 SC at 24 g/ha as post-em. (10-12 DAT)

T_3- Pendimethalin 0.75 kg/ha as pre-em. *fb* fenoxaprop-p-ethyl 6.7 EC at 67 g/ha, post-em. (20-25 DAT)

T_4- Control (Unweeded)

Note: Penidmethalin 30 EC (Stomp), Bispyribac sodium 10 SC (Nominee gold), Penoxsulam 24 SC (Granite), Fenoxaprop-p-ethyl 6.7 EC (Rice star) were used as per treatment.

Layout of Experiment-I



3.6.2 Experiment II: Influence of planting patterns and nitrogen levels on the yield of transplanted rice under unpuddled conditions

Main plots (Planting patterns)

M_1- Transplanting two rows/ridge* (30 cm × 10 cm)

M_2- Transplanting two rows/ridge* + one in furrow (20 cm × 15 cm)

M_3- Flat transplanting, unpuddled (20 cm × 15 cm)

M_4- Flat transplanting, puddled (20 cm × 15 cm)

* Ridges were made at 60 cm apart and transplanting of rice seedlings were done on slopes of ridge.

Note: Plant population was uniformly maintained in all experimental plots.

Sub plots (Nitrogen levels)

N_1- 0 kg N/ha

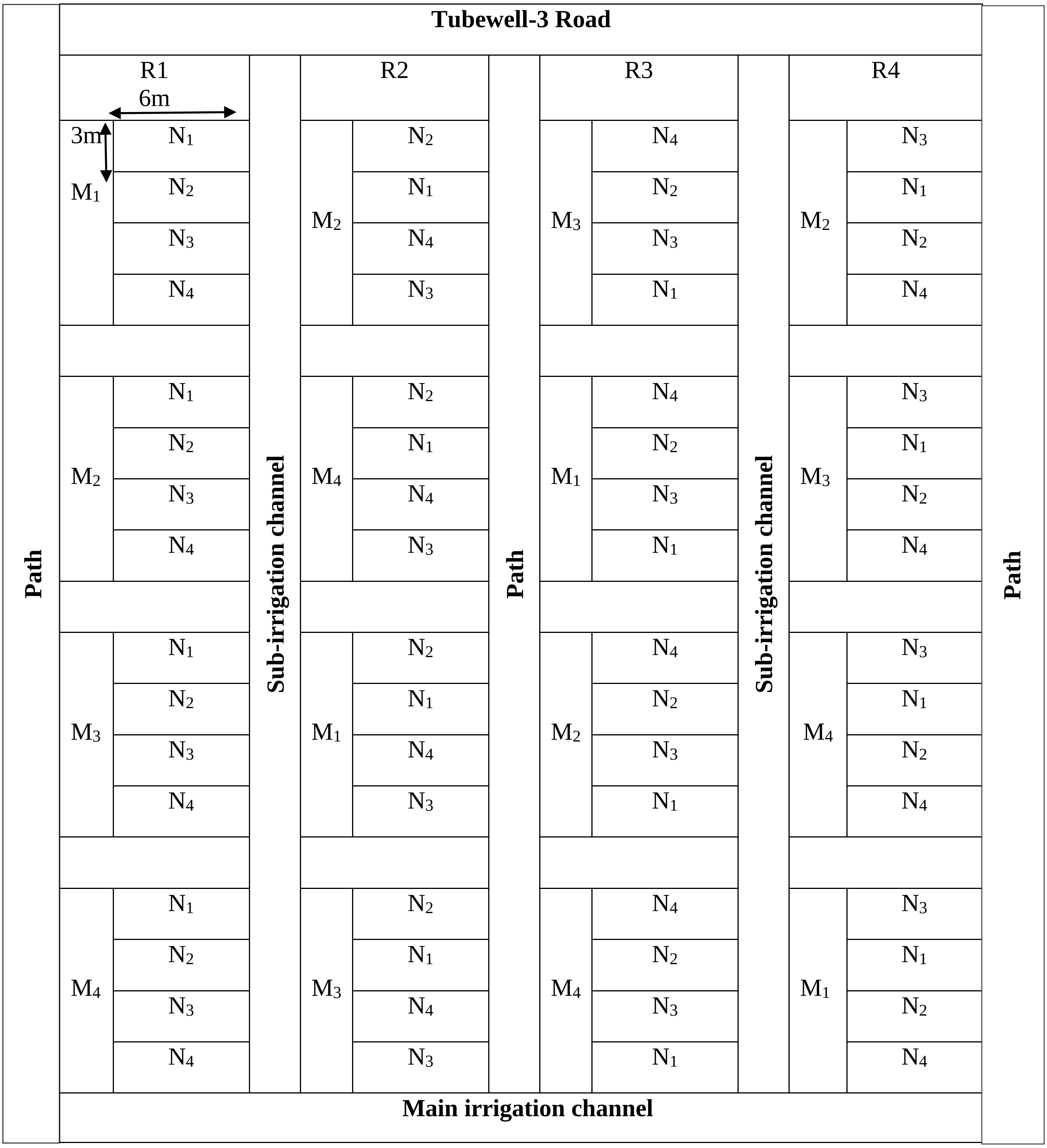
N_2- 80 kg N/ha

N_3- 120 kg N/ha

N_4- 160 kg N/ha

Note: Pre-emergence application of Stomp 30 EC (pendimethalin) 0.75 kg a.i./ha *fb* post-em. application of Nominee gold (bispyribac sodium) 25 g a.i./ha were made across all plots in the experiment uniformly.

Layout of Experiment-II



3.7 Crop variety - PR 126

PR 126, a high-yielding and early maturing rice variety that takes approximately 90-95 days to mature after transplanting was adopted during both the years. It is characterized by its long, slender translucent grains and resistance to seven of the ten bacterial blight pathotypes in Punjab region, with an average paddy yield of 74.1 q/ha.

3.8 Agronomic practices:

3.8.1 Nursery preparation

After ploughing the land twice, four plots of 5 m x 5 m each were prepared for nursey. Subsequently, 50 kg of vermicompost, 1.5 kg of single superphosphate, and 0.65 kg of zinc sulphate were broadcasted over the plots and and well mixed into the soil.

3.8.2 Seed rate and sowing

Seed rate of 25 kg/ha is recommended for rice cultivation and five kg of seed was soaked overnight and broadcasted on the well prepared nursey bed on the next day in standing water.

3.8.3 Field preparations & layout

During both the years of study, field preparation involved a systematic approach to ensure optimal soil conditions for planting. Initially, two passes were made with a disc harrow to break up large clods and loosen the soil which was followed by cultivating the soil using a cultivator to refine the tilth and further aerate the soil. Finally, levelling was done with a tractor-mounted rotavator to create an even surface for efficient water distribution across the field. The experimental layout was prepared using a tractor equipped bund-maker to prepare water channels and main plots, ensuring proper division. Subsequently, the sub plots were demarcated and prepared manually. Ridges were made 60 cm apart as per treatments. All the treatments were randomized in every replication. Puddling was carried out manually in standing water with the help of spade on the same day of transplanting in the required treatments.

3.8.4 Transplanting and spacing

In both the years, transplanting of 30-day old seedlings in the experimental plots was done, with a spacing of 20 x 15 cm in all treatments, with the exception of the treatment with two rows/ ridge (M_1), in which spacing of 30 cm × 10 cm was maintained in order to get uniform plant population across all the planting patterns.

3.8.5 Gap filling

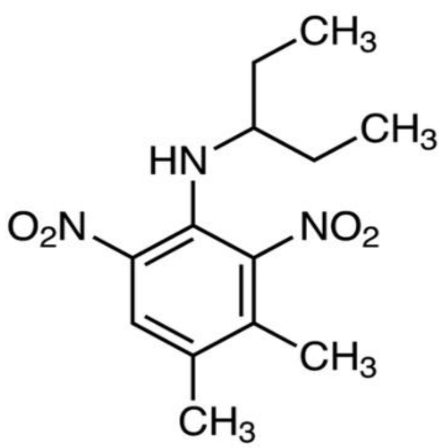
Gap filling in the required hills was carried out, 10 days after transplanting by using the surplus seedlings in the nursery bed to maintain uniform plant population in all the experimental plots.

3.8.6 Fertilizer application

To meet the nutrient requirements of nitrogen, phosphorus and zinc, fertilizers were applied in the form of urea (46% N), SSP (16% P), $ZnSO_4.H_20$ (33% Zn). The entire dose of SSP (185 kg/ha) and ZnSO4 (63 kg/ha) were applied as basal dose a day before transplanting the rice seedlings, whereas urea was split into three doses- 1/3rd of it was applied 2 DAT, 1/3rd was applied at 20 DAT during active tillering and the final dose was applied at 35 DAT. Potassium was not applied as the soil test confirmed adequate levels of potassium in the soil.

3.8.7 Herbicides used:

Pendimethalin (30% EC)



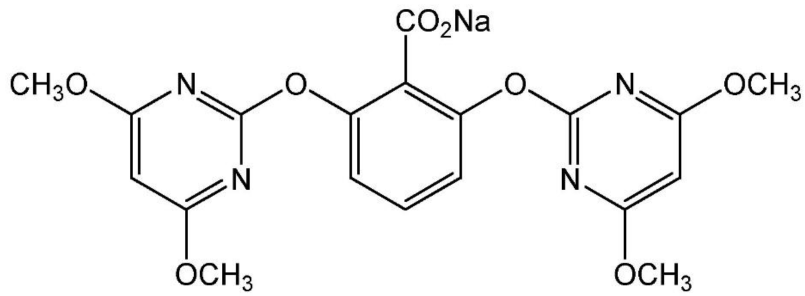
Molecular formula: $C_{13}H_{19}N_3O_4$

Chemical name: N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine

Chemical group: Dinitroaniline

Mode of action: Pendimethalin is a selective, broad-spectrum in nature, applied as pre-emergence and is extensively used in rice, other field crops and in vegetables cultivation to control annual grasses and certain broadleaf weeds. It works by targeting plant cell division and elongation processes, specifically disrupting microtubule formation during mitosis, effectively halting the growth of germinating weeds.

Bispyribac sodium (10% SC)



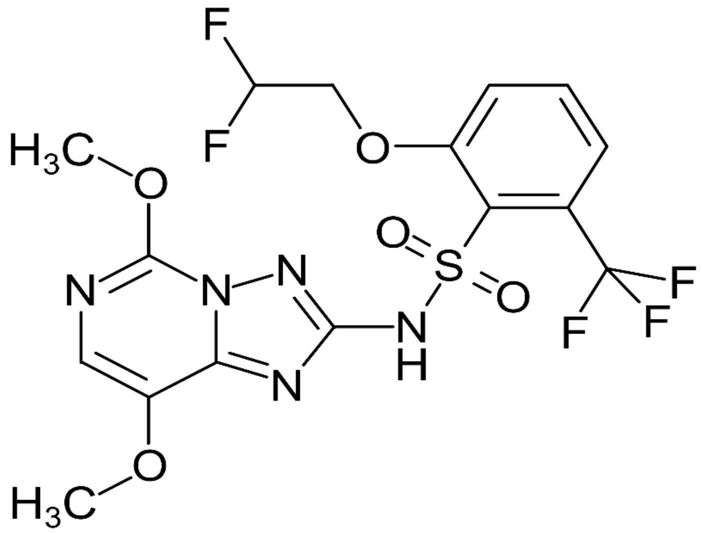
Molecular formula: $C_{19}H_{17}N_4NaO_8$

Chemical name: Sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl) oxy] benzoate

Chemical group: Pyrimidinyloxybenzoic acid

Mode of action: Bispyribac sodium is a post-emergence herbicide with selective and broad-spectrum activity, commonly used in rice cultivation It targets the acetolactate synthase (ALS) enzyme, also referred to as acetohydroxyacid synthase which is essential for producing branched-chain amino acids required for plant growth. Inhibition of this pathway interrupts protein synthesis and cell division, effectively stopping weed growth.

Penoxsulam (240 SC)



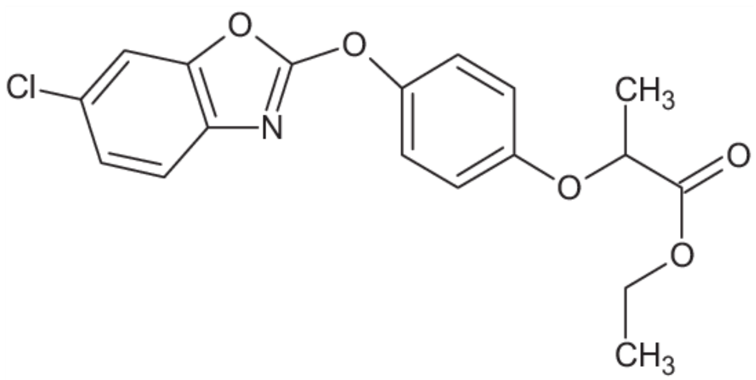
Molecular formula: $C_{16}H_{14}F_5N_5O_5S$

Chemical name: 2-(2,2-difluoroethoxy)-N-(5,8-dimethoxy- [1,2,4] triazolo[1,5-c] pyrimidin-2-yl)-6-(trifluoromethyl)benzenesulfonamide

Chemical group: Triazolopyrimidine sulfonamide

Mode of action: Penoxsulam acts as a selective, broad-spectrum herbicide that inhibits the ALS enzyme, a key component in amino acid biosynthesis. This inhibition disrupts protein formation, causes toxic build up in plant cells, and prevents cell division and growth, ultimately killing the plant.

Fenoxaprop-p-ethyl (6.7% EC)



Molecular formula: $C_{18}H_{16}ClNO_5$

Chemical name: Ethyl (R)-2-[4-[(6-chloro-2-benzoxazolyl) oxy] phenoxy] propanoate.

Chemical group: Aryloxyphenoxypropionic acid

Mode of action: Fenoxaprop-p-ethyl is a post-emergent, selective herbicide that specifically targets grassy weeds by inhibiting the Acetyl-CoA Carboxylase enzyme, a key component in fatty acid biosynthesis. This disruption prevents the production of fatty acids, which are vital for maintaining cell membrane structure and energy storage, ultimately leading to the breakdown of cellular integrity and plant death**.**

3.8.8 Application of herbicides

- **Pendimehtalin (30% EC):** Stomp 30 EC at a rate of 0.75 kg a.i/ha was applied as a pre-emergence herbicide, mixed with 150 kg of dry sand per hectare, and uniformly broadcasted into standing water, within two days after transplanting, as per treatments.
- **Bispyribac sodium (10% SC):** Nominee gold at a rate of 25 g a.i/ha was applied as post-emergence, 20 days after transplanting as per treatments through foliar spray by using water as a carrier solution at a rate of 375 lit/ ha.
- **Penoxsulam (240 SC):** Penoxsulam was applied as an early post-emergence herbicide, 10 days after transplanting at a dose of 24 g/ha as foliar spray after mixing it with 375 litres of water per hectare, when the weeds are in 2-3 leaf stage. Granite, a brand of penoxsulam was used in the experiment at the rate of 100 ml/ha.
- **Fenoxaprop-p-ethyl (6.7 EC**): Post emergence application of fenoxaprop-p-ethyl 67 g/ha was carried out 20 days after transplanting, delivered as foliar spray diluted with 375 litres of water per hectare, as per required treatments. Rice star, a branded herbicide product was applied at a dosage of 1000 ml/ha.

3.8.9 Plant protection measures:

Among the pests, rice stem borer was observed during various growth stages of crop in both the years and was successfully controlled by applying chlorantraniliprole (18.5% SC) at a rate of 150 ml/ha.

3.8.10 Harvesting and threshing:

At physiological maturity, the crop was manually harvested from centre of each plot measuring 3 m in length and 2 m breadth, covering an area of 6 m^2 during both years. Bundles were tagged and sun dried before assessing the yield parameters. After proper sun drying, each bundle was weighed, threshed plot-wise, and the yield was recorded after cleaning. Paddy yield was recorded at 14% moisture content of grains. Straw yield was derived for each treatment by subtracting the paddy yield from biological yield and expressed in quintals per hectare based on the net harvested area.

3.9 Calendar of operations (Experiment-1):

S. No	Field operation	Date of operation	
1	Nursery bed preparation	24-05-2023	26-05-2024
2	Nursery sowing	25-05-2023	27-05-2024
3	Field preparation	23-06-2023	21-06-2024
4	Preparation of Layout	26-06-2023	24-06-2024
5	Application of SSP and Zinc sulphate	27-06-2023	25-06-2024
6	Transplanting	29-06-2023	27-06-2024
7	Application of pre-emergence herbicides	01-07-2023	29-06-2024
8	Application of first split dose of N ($1/3^{rd}$)	02-07-2023	01-07-2024
9	Gap filling	09-07-2023	07-07-2024
10	Application of penoxsulam (early post-emergence herbicide)	10-07-2023	07-07-2024
11	Application of post-emergence herbicides	22-07-2023	19-07-2024
12	Application of second split dose of N ($1/3^{rd}$)	24-07-2023	20-07-2024
13	Application of third split dose of N ($1/3^{rd}$)	04-08-2023	02-08-2024
14	Application of insecticide (Coragen 18.5SC)	10-09-2023	26-08-2024
15	Harvesting	10-10-2023	05-10-2024

16	Sun drying	10-10-2023 to 12-10-2023	05-10-2024 to 08-10-2024
17	Threshing	13-10-2023	09-10-2024

3.10 Calendar of operations (Experiment-2):

S. No	Field operation	Date of operation	Date of operation
1	Nursery preparation	24-05-2023	26-05-2024
2	Nursery sowing	25-05-2023	27-05-2024
3	Field preparation	23-06-2023	21-06-2024
4	Preparation of Layout	26-06-2023	24-06-2024
5	Application of SSP and Zinc sulphate	27-06-2023	25-06-2024
6	Transplanting	30-06-2023	28-06-2024
7	Application of pre-emergence herbicide	02-07-2023	30-06-2024
8	Application of first split dose of N ($1/3^{rd}$)	03-07-2023	02-07-2024
9	Gap filling	10-07-2023	08-07-2024
10	Application of post-emergence herbicide	23-07-2023	21-07-2024
11	Application of second split dose of N ($1/3^{rd}$)	25-07-2023	22-07-2024
12	Application of third split dose of N ($1/3^{rd}$)	05-08-2023	03-08-2024
13	Application of insecticide (Coragen 18.5 SC)	11-09-2023	27-08-2024
14	Harvesting	10-10-2023	05-10-2024
15	Sun drying	10-10-2023 to 13-10-2023	05-10-2024 to 09-10-2024
16	Threshing	14-10-2023	10-10-2024

3.11 Observations recorded:

3.11.1Weed dynamics

Weed dynamics of grassy and broadleaf weeds were studied separately, with sedges included in the broadleaf weed category. Observations were taken at 30, 60 DAT and at harvest during both the years of research in Experiment-I, whereas in Experiment-II the observations were recorded at periodic intervals of 60, 90 DAT and at harvest.

3.11.1.1 Weed population/m^2:

A quadrat measuring 0.3 m x 0.3 m was used, which was randomly thrown twice in each plot, the density of grasses and broadleaved weeds + sedges in each plot was recorded individually and expressed as number of weeds per square meter. This observation was recorded 30, 60 DAT and at harvest in Experiment-I and at 60, 90 DAT and at harvest in Experiment-II.

3.11.1.2 Weed dry matter (q/ha):

Dry matter accumulation of grassy and broadleaf weeds was separately recorded alongside weed density by cutting the above-ground portions of weeds from two quadrats of 0.3 m × 0.3 m per plot at 30, 60 DAT and at harvest in Experiment-I and at 60, 90 DAT and at harvest in Experiment-II. The collected samples were sun-dried, packed in brown paper bags, and oven dried at 60^0 C to reach a constant dry weight. The final samples were weighed, and their values were converted into q/ha for final presentation.

3.11.1.3 Weed control efficiency (Experiment-1 only):

Weed control efficiency was calculated at harvest using a standard procedure and expressed as percentage, as follows.

$$\text{WCE (\%)}=\frac{WDC-WDT}{WDC} \times 100$$

Where,

WDC = Weed dry matter obtained from control plot (q/ha)

WDT = Weed dry matter obtained from treatment plot (q/ha)

3.11.2 Growth parameters of crop:

3.11.2.1 Establishment percentage:

The establishment percentage of crop was assessed at 20 DAT by counting number of transplanted plants and number of survived plants from one row per experimental unit. The collected data was then used to calculate the establishment percentage based on a defined formula.

Establishment percentage (%) = $\frac{Number\ of\ survived\ seedlings}{Number\ of\ transplanted\ seedlings} \times 100$

3.11.2.2 Plant height (cm):

Plant height (cm) was assessed by selecting five plants randomly from each plot at 30, 60 DAT and harvest. The height of each plant was measured using a measuring scale, starting from ground level to the base of the flag leaf to ensure consistency. The final plant height for each plot was expressed as the average of these five samples, recorded in centimetres.

3.11.2.3 Total number of tillers/m^2

To measure the total number of tillers per square meter, a quadrat with dimensions of 0.5 m x 0.5 m was randomly placed at two spots per plot during various periodic intervals i.e. 30,60 DAT and at harvest. The tillers of crop falling within quadrat were counted individually, and were converted to represent the tillers per square meter.

3.11.2.4 Crop dry matter(q/ha)

Random sampling using a quadrat measuring 0.5 m x 0.5 m was conducted in each experimental plot at 30,60 DAT and at harvest. The above-ground biomass of plants falling within the two quadrats per plot was cut, sun dried and stored in brown paper bags and these samples were oven dried at 60^{0}C to achieve a stable dry weight. Dry matter was recorded individually on electronic weighing balance in grams and then converted into quintals per hectare for presentation.

3.11.3 Yield attributes:

3.11.3.1 Number of panicles/m^2

At harvest, a 0.5 m x 0.5 m quadrat was randomly placed at two spots in each plot to count the number of panicles per square meter. All the panicles within the quadrat were individually counted, and the data was converted to represent number of panicles per square meter.

3.11.3.2 Panicle length (cm)

Panicle length was determined by randomly selecting five panicles from each plot at the time of harvest. The length of each panicle was recorded from its base to the tip using a measuring scale, and the average of these five readings in centimetres was used as final value to that plot.

3.11.3.3 Total number of grains/panicle

At harvest, five panicles were chosen at random from various plants in each plot. The total number of grains (filled and unfilled) of each panicle were counted individually, and the average count from these five samples was used to estimate the total number of grains per panicle for that specific plot.

3.11.3.4 Number of filled grains per panicle

After identifying and removing the unfilled, unfertile and chaffy grains from the total number of grains per panicle, the remaining count of grains represented the number of fertile (filled) grains per panicle for each plot.

3.11.3.5 Test weight (g)

A sample of seed from each plot was taken and sundried. The weight of 1000 seeds, precisely counted using a seed counter, was then measured in grams and the data was recorded.

3.11.4 Yield parameters:

3.11.4.1 Biological yield (q/ha)

After harvesting, the crop from the net area of each plot, the bundles were carefully sun dried to achieve consistent moisture levels. The dry weight of these bundles was recorded in kgs and the biological yield was expressed in quintals per hectare for each experimental plot.

3.11.4.2 Paddy yield (q/ha)

The paddy yield was determined by threshing the harvested bundles from each experimental plot, followed by sun-drying to ensure optimal moisture content. Finally, the paddy yield was recorded after cleaning the produce and expressed in quintals per hectare for presentation.

3.11.4.3 Straw yield (q/ha)

For each experimental plot, the straw yield was calculated by subtracting the paddy yield from the biological yield. The calculated straw yield was subsequently converted into quintal per hectare for standard analysis.

3.11.4.4 Harvest Index (%)

Harvest index was calculated on the basis of the following formula.

$$\text{Harvest index (\%)} = \frac{\text{Economical yield (q/ha)}}{\text{Biological yield (q/ha)}} \times 100$$

3.11.5 Soil parameters:

3.11.5.1 Soil pH and electrical conductivity:

Soil pH and electrical conductivity of the soil were recorded by preparing a 1:5 soil-water mixture with 20 g of air-dried soil and 100 ml of water stirred for 2 minutes, left to settle for 5 minutes and measured with a pH meter and an electrical conductivity meter respectively.

3.11.5.2 Soil organic carbon (%)

In Walkley and Black method (1934), 1g of soil is oxidized using potassium dichromate and sulphuric acid, with heat facilitating the reaction. Excess dichromate is back-titrated with ferrous sulphate, and a blank titration ensures accuracy. The percentage of organic carbon is calculated using a correction factor (1.3) to compensate for incomplete oxidation, as the method recovers 75-90% of total organic carbon.

3.11.5.3 Available Nitrogen (kg/ha)

The alkaline permanganate method, described by Subbaiah and Asija (1956) is a widely accepted technique for estimating available nitrogen in soil. The process involves weighing 20 g of air dried soil into a kjeldahl digestion flask, followed by the addition of 100 ml each of 0.32% $KMnO_4$ and 2.5% NaOH solutions. The flask is then connected to a distillation apparatus to release ammonia (NH_3), which is captured in 25 ml of 4% boric acid containing a mixed indicator of bromocresol green and methyl red. The absorbed ammonia is titrated with 0.02 N sulphuric acid until the solution changes colour from green to pink, marking the endpoint. A blank titration is also performed for accuracy, and the nitrogen content is calculated using a standard formula,

$$\text{Available N kg/ha} = \frac{\text{Titrant volume ml} \times \text{Normality of acid} \times 1400}{\text{Weight of soil sample (g)}}$$

3.11.5.4 Available Phosphorus (kg/ha)

In Olsen's method, soil phosphorus availability was measured by extracting it with a 0.5 M sodium bicarbonate solution at pH 8.5. The procedure starts with weighing 2.5 g of air dried soil into a 125 ml Erlenmeyer flask and adding 50 ml of $NaHCO_3$ extractant. The mixture was shaken mechanically for 30 minutes at room temperature to facilitate extraction. After shaking, the suspension was filtered. Phosphorus in the filtrate was quantified calorimetrically via the ascorbic acid, method, which forms a blue coloured phosphomolybdate complex. A blank sample was also processed for standardization, and the phosphorus content was calculated using an established formula.

$$\text{Available P kg/ha} = \frac{(a-b) \times V \times DF \times mcf}{\text{W}}$$

a: Concentration of P in the sample extract (mg/L) b: Concentration of P in the blank (mg/L)

V: Volume of extractant used (ml)

W: Weight of soil sample (g)

DF: Dilution factor

mcf: Moisture correction factor

3.11.5.5 Available Potassium (kg/ha)

Potassium content was analysed using a flame photometer, following the method described by Jackson (1973) by weighing 5 g of air dried soil into a conical flask and adding 25 ml of ammonium acetate solution (1N, pH 7.0). The sample was shaken mechanically for about half an hour and then filtered to collect the liquid extract. A standard stock solution of potassium chloride (1000 ppm) was diluted to various concentrations (e.g., 10 ppm, 20 ppm). Flame photometer was calibrated with these standards before introducing the filtrate into its atomizer. Potassium levels were recorded directly from the instrument and calculated using the following standard formula,

Available K (ppm)=K concentration from standard curve (ppm) ×dilution factor

3.11.6 Quality parameters

3.11.6.1 Nitrogen content (grains, straw and weeds)

The harvested grain, straw and weed samples per plot were oven-dried at 60^0C until their weight remained constant. The dried samples were separately made into fine powder using an electric grinder and 0.5 g of this sample was digested in concentrated H_2SO_4 along with $CuSO_4$ + K_2SO_4 + selenium powder at 420°C for three hours in a digestion unit. After dilution with distilled water to a specific volume, the solution underwent distillation with 20 ml of 40 % NaOH using a semi-micro kjeldahl apparatus. Ammonia released during distillation was captured in boric acid containing methyl red and bromocresol green solution, which is titrated against standard sulphuric acid (0.01 N), allowing nitrogen content to be calculated as percentage.

N (%) = $\frac{0.014 \times \mathrm{N}\ (\mathrm{S}-\mathrm{B})}{\mathrm{W}} \times 100$

Where,

S = ml. of standard acid required for the titration of the plant sample

B = ml. of standard acid required for blank titration

N = normality of acid

W = weight of plant sample in gram

3.11.6.2 Chlorophyll Index

Using a SPAD meter, the chlorophyll index was estimated by selecting five random plants from each plot at 30,60 and 90 DAT. Three readings were recorded from different points of each leaf and an average SPAD value was calculated for each leaf. The final chlorophyll index for the plot was derived by calculating the mean SPAD values across all five plants.

3.11.6.3 Protein content

To determine the protein content, the nitrogen content (%) from the grains was calculated by kjeldahl method and multiplied with a conversion factor of 6.25.

3.11.7 Uptake studies:

3.11.7.1 Nitrogen uptake by paddy grains (kg/ha)

Using the formula given below, the nitrogen uptake by grains was calculated:

N uptake by paddy grains (kg/ha) = $\frac{N\ content\ (\%)\ in\ grains \times paddy\ yield\ (kg/ha)}{100}$

3.11.7.2 Nitrogen uptake by paddy straw (kg/ha)

The calculation of nitrogen uptake by paddy straw was carried out using the formula

N uptake by paddy straw (kg/ha)= $\frac{N\ content\ (\%)\ in\ straw \times straw\ yield\ (kg/ha)}{100}$

3.11.7.3 Total nitrogen uptake by crop (kg/ha)

It was calculated by adding uptake of nitrogen by paddy grains with uptake of nitrogen by straw in terms of kg/ha.

3.11.7.4 Nitrogen uptake by weeds

Nitrogen uptake by weeds was derived from the weed dry weight values obtained at the time of harvest by using the formula as mentioned below.

N uptake by weeds (kg/ha)= $\frac{N\ content\ (\%)\ in\ weeds \times weed\ dry\ weight\ (kg/ha)}{100}$

3.11.7.5 Nitrogen use efficiency (Experiment-II only)

Nitrogen use efficiency plays a key role in assessing the relationship between nitrogen application and crop productivity.

Nitrogen use efficiency is, calculated as

$$\frac{Nitrogen\ output}{Nitrogen\ input} \times 100$$

Nitrogen output = Grain yield (kg/ha) × Nitrogen content (%) of grains

Nitrogen input= Applied nitrogen (kg/ha)

Agronomic efficiency of nitrogen, is calculated as

$$\frac{Grain\ yield\ in\ nitrogen\ treated\ plot\ \ (kg/ha) - grain\ yeld\ in\ control\ (kg/ha\ )}{Applied\ nitrogen\ in\ treated\ plot} \times 100$$

Physiological efficiency of nitrogen, is given as

$$\frac{Total\ dry\ matter\ yield\ with\ N - Total\ dry\ matter\ yield\ without\ N}{N\ uptake\ with\ N - N\ uptake\ without\ N}$$

Apparent nitrogen recovery is, calculated as

$$\frac{N\ uptake\ by\ fertilized\ crop - N\ uptake\ by\ unfertilized\ crop}{Amount\ of\ nitrogen\ applied} \times 100$$

3.12 Statistical analysis:

To study the treatmental differences, analysis of variance (ANOVA) was conducted using OPSTAT software after calculating the mean values in MS excel and compared using the LSD test at a 5 % significance level. Weed density and biomass data were transformed after adding one to original values by applying square root transformation ($\sqrt{x+1}$) to reduce the variance before ANOVA.

3.13 ANOVA table:

Sources of Variation	Degrees of Freedom.	Sum of squares	Mean sum of squares	F-calculated value
Replication	r-1=3	RSS	RMS	RMS/EMS (a)
Factor A (Main plots)	m-1=3	ASS	AMS	AMS/EMS (a)
Error a	(r-1)(m-1)=9	ESS(a)	EMS (a)	
Factor B (Sub plots)	t-1=3	BSS	BMS	BMS/EMS (b)
Interaction (A × B)	(m-1)t-1)=9	ABSS	ABMS	ABMS/EMS (b)
Error b	m(r-1)(t-1)=36	ESS(b)	EMS (b)	
Total	tms-1=63	TSS		

Photo Gallery

Nursery bed preparation

Field preparation

Nursery at 25 DAS

Two rows/ridge + one in furrow- control

Two rows/ridge + one in furrow– Bispyribac sodium

Two rows/ridge + one in furrow- fenoxaprop

Two rows/ridge + one in furrow- penoxsulam

Flat unpuddled – control

Two rows/ridge- penoxsulam

Crop at 75 DAT

Two rows/ridge – 0 kg N/ha

Two rows/ridge + one in furrow- 0 kg N/ha

Two rows/ridge + one in furrow- 80 kg N/ha

Two rows/ridge – 120 kg N/ha

Two rows/ridge + one in furrow- 160 kg N/ha

Two rows/ridge – 160 kg/ha

Crop at 75 DAT

Harvesting **Threshing**

Lab analysis

RESULTS AND DISCUSSION

This chapter presents the results and discussion pertaining to current investigation entitled "**Impact of planting patterns, nitrogen levels and weed control treatments on the growth and yield of unpuddled transplanted rice (*Oryza sativa* L.).** The study evaluates various aspects, including weed dynamics, growth parameters, yield components, uptake studies and quality traits.

Experiment-I: Role of planting patterns and weed control treatments on yield of unpuddled transplanted rice.

The results of this experiment has been presented in the following subheads.

4.1 Weed dynamics:

Weed count (m^{-2}) is an important metric for assessing the degree of competition between weeds and rice plants. High weed densities can lead to substantial yield losses by reducing nutrient uptake and limiting photosynthesis. Weed count is less reliable parameter compared to dry matter accumulation as sometimes weed count is high but losses are less due to poor growth of weeds. Due to large variation in the data pertaining to weed count and dry matter of weeds, it was subjected to square root transformation after adding one to original values.

4.1.1 Count of grassy weeds (m^{-2})

Data pertaining to the periodic grassy weed count/m^2 under varying planting patterns and weed control treatments recorded at 30, 60 DAT and at harvest during 2023 and 2024 has been presented in Table 4.1.1. and depicted in Figure 4.1.1.

Perusal of data at 30 DAT during 2023 indicated that there was no significant effect of planting patterns on the grassy weed count/m^2 (Table 4.1.1). Among the weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence. significantly reduced the grassy weed count/m^2 than pendimethalin pre-emergence *fb* penoxsulam post-emergence and pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence and latter treatments were statistically at par with each other during 2023. However, unweeded (control) recorded significantly higher weed count/m^2 of grassy weeds as compared to all herbicidal treatments. These findings remained consistent during 2024 except pendimethalin pre-emergence *fb* penoxsulam was significantly better than pendimethalin *fb* fenoxaprop-p-ethyl.

During 2023, data recorded at 60 DAT revealed that planting patterns had significant effect on grassy weed count/ m^2 (Table 4.1.1). Adopting the planting pattern with two rows/ridge + one in furrow led to significant reduction of grassy weed count/m^2 as compared to other planting patterns. Flat puddled produced significantly less weed count than flat unpuddled. Meanwhile, flat unpuddled treatment recorded significantly higher grassy weed count/m^2 than two rows/ridge. Among the subplots, sequential application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence was observed to have significantly less grassy weed count/m^2 than pendimethalin pre-emergence *fb* penoxsulam post-emergence and pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl. Significantly less weed count was observed in pendimethalin pre-emergence *fb* penoxsulam as post-emergence than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl. However, unweeded (control) recorded significantly more grassy weed count/m^2 as compared to other weed control treatments. These trends remained consistent in 2024 also.

Analysis of data at harvest during 2023 and 2024 revealed that the differences in the grassy weed count/m^2 were significant among the main plots (Table 4.1.1). The planting pattern with two rows/ridge + one in furrow had significantly less grassy weed count/m^2 than all other planting patterns. However, flat unpuddled recorded significantly more grassy weed count/m^2 as compared to flat puddled. In terms of weed control treatments, pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less weed count than pendimethalin pre-emergence *fb* penoxsulam post-emergence and pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. Pre-emergence application of pendimethalin *fb* penoxsulam recorded significantly less weed count than pre-emergence pendimethalin *fb* post-emergence fenoxaprop-p-ethyl. The grassy weed count/m^2 was significantly more in unweeded (control) as compared to all other weed control treatments. These findings hold good for second year.

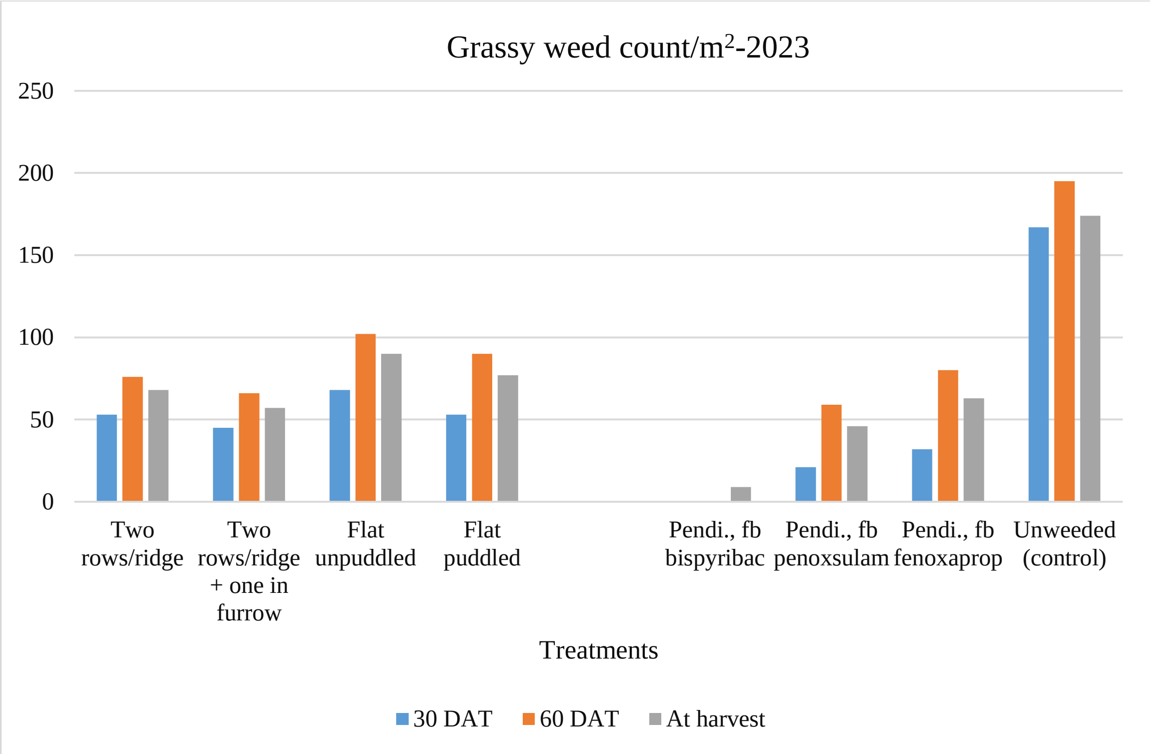
Less grassy weed count/m^{-2} in two rows/ridge + one in furrow can be attributed to dense canopy closure, which reduced light penetration and suppressed weed growth. Additionally, the proper spacing within rows in this planting pattern provided limited space for weed growth, creating a smothering effect on weeds compared to two rows/ridge, flat puddled and flat unpuddled methods. Lot of weed seeds were buried deep in the ridge method which were unable to germinate. Moreover, furrows that were kept flooded during the early crop growth stages, created unfavourable conditions for germination of annual weeds. Similar findings were reported by Mahajan and Chauhan (2011) and Hussain *et al.* (2018). Effective suppression of grassy weeds was achieved through the sequential application of pendimethalin as pre-emergence, which controlled non-paddy weeds, followed by bispyribac-sodium as post-emergence which controlled typical grassy and broadleaf weeds of transplanted paddy effectively. Similar results were reported by Kiran *et al.* (2010) and Verma *et al.* (2022).

During both the years of study, the interaction between planting patterns and weed control treatments was non-significant at all the periodic intervals during both years (Table 4.1.1).

Table 4.1.1: Influence of planting patterns and weed control treatments on periodic count of grassy weeds (m^{-2}).

Treatments	Count of grassy weeds (m^{-2})					
	30 DAT		60 DAT		At harvest	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	5.5 (53)	5.9 (53)	7.6 (76)	7.9 (84)	7.5 (68)	7.9 (74)
Two rows/ridge + one in furrow	5.1 (45)	5.8 (52)	7.0 (66)	7.4 (73)	6.7 (57)	7.4 (65)
Flat unpuddled	6.8 (68)	6.3 (61)	8.7 (102)	9.1 (109)	8.8 (90)	9.1 (96)
Flat puddled	5.9 (53)	5.8 (54)	8.2 (90)	8.5 (97)	8.0 (77)	8.5 (86)
SEm (±)	0.60	0.13	0.13	0.08	0.08	0.13
C.D.(5%)	**NS**	**NS**	**0.41**	**0.25**	**0.26**	**0.42**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	3.0 (9)	3.7 (13)
Pendi., pre-em *fb* penoxsulam	4.2 (21)	4.4 (19)	7.7 (59)	8.1 (65)	6.7 (46)	7.2 (52)
Pendi., pre-em *fb* fenoxaprop-p-ethyl	5.3 (32)	5.3 (27)	8.9 (80)	9.4 (89)	7.9 (63)	8.4 (71)
Unweeded (control)	12.8 (167)	13.2 (173)	14.0 (195)	14.4 (208)	13.2 (174)	13.6 (185)
SEm (±)	0.40	0.18	0.23	0.18	0.24	0.16
C.D. (5%)	**1.15**	**0.53**	**0.67**	**0.51**	**0.69**	**0.46**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

- Figures without parentheses are square root transformed values $\left(\sqrt{x+1}\right)$ after adding one to original values
- Figures in parentheses are original values
- Pendi. - pendimethalin



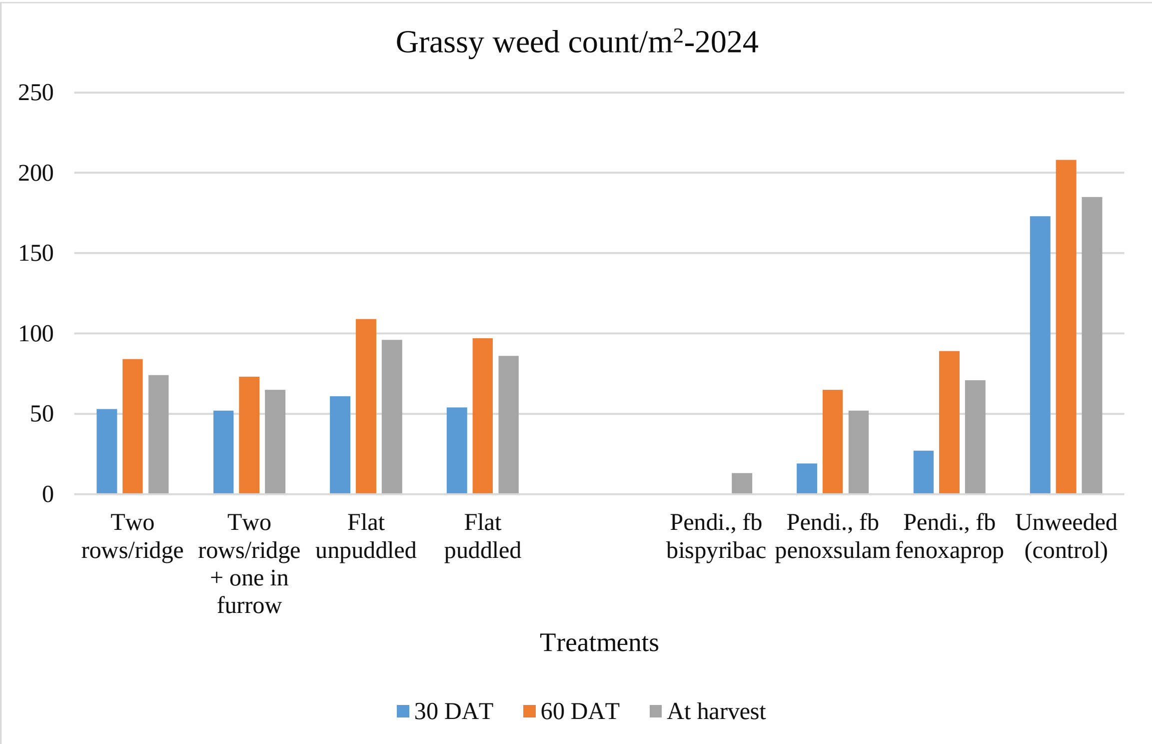


Fig 4.1.1: Effect of planting patterns and weed control treatments on periodic count of grassy weeds/m^2.

4.1.2 Count of broadleaf weeds (m^{-2}):

Data on periodic count of broadleaf weeds (m^{-2}) recorded at 30, 60 DAT and at harvest, as influenced by different planting patterns and weed control treatments during 2023 and 2024 was found to be significant and data has been presented in Table 4.1.2. and Figure 4.1.2.

At 30 DAT, during 2023 there was no significant difference in broadleaf weed count/m^{-2} among the planting patterns (Table 4.1.2). Among the sub plots, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence significantly decreased the broadleaf weed count/m^{-2} as compared to other herbicidal treatments. It was observed that application of pendimethalin pre-emergence *fb* penoxsulam post-emergence was found at par with unweeded (control). Application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence recorded significantly higher broad leaf weed count/m^{-2} when compared to other weed control treatments. During 2024, data recorded at 30 DAT showed no significant variation in broad leaf weed count/m^2 across the planting patterns. Among the weed control treatments, pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less broad leaf weed count/m^2 as compared to other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more broad leaf weed count/m^2 as compared to application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence and unweeded (control) treatments and both the latter treatments were found at par.

Perusal of data at 60 DAT during 2023 and 2024 revealed that significantly less broadleaf weed count/m^2 was observed in the planting pattern with two rows/ridge + one in furrow as compared to two rows/ridge, flat puddled and flat unpuddled methods. Meanwhile, significantly higher broadleaf weed count/m^2 was recorded in flat unpuddled treatment as compared to flat puddled method. In terms of weed control treatments, significantly less broadleaf weed count/m^2 was recorded with application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence as compared to all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly less count of broad leaf weeds as compared to unweeded (control) and pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence.

Data recorded at harvest during both years demonstrated that the differences in the broadleaf weed count/m^2 was significant among the main plots (Table 4.1.2). Planting pattern with two rows/ridge + one in furrow recorded significantly less values of broadleaf weed count/m^2 as compared to other methods. Two rows/ridge recorded significantly less count of broadleaf weeds than flat puddled and flat unpuddled method during both the years. Also, count of broadleaf weeds in flat puddled treatment was significantly less than flat unpuddled method. Among herbicidal treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less broadleaf weed count/m^2 as compared to all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more broadleaf weed count/m^2 as compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. Weed count in unweeded (control) was found to be at par with pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl. These results hold good for both years.

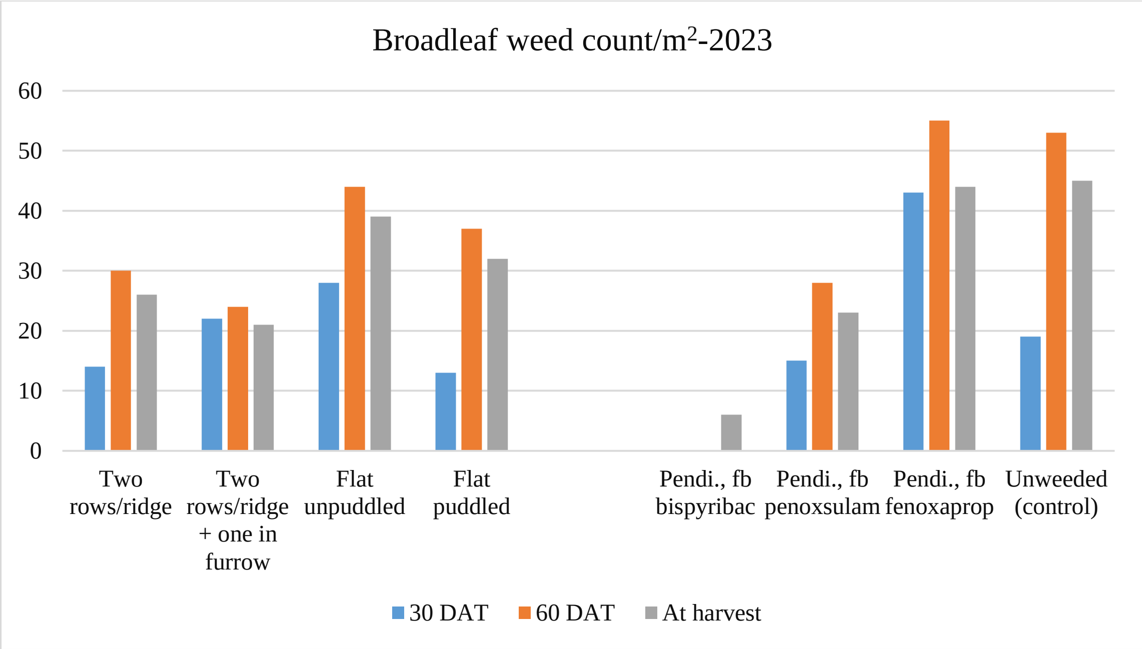
The planting pattern of two rows per ridge + one in the furrow recorded significantly less broadleaf weed count due to its ability to form a dense canopy, which minimized light penetration and hindered weed growth. Additionally, good canopy structure intensified competition in favour of the crop, effectively smothering weeds as compared to other treatments. Moreover, the weed seeds were buried deep in the ridge which showed no germination. These results align with the findings of Mahajan and Chauhan (2011) and Jat *et al.* (2005). Sequential application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence was highly effective, primarily due to broad-spectrum action against a wide variety of broadleaf weeds as compared to other herbicidal treatments. However, higher weed count in pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence can be attributed to the selective nature of fenoxaprop-p-ethyl-p-ethyl as it targets grassy weeds but provides limited control over broadleaf weeds and sedges, leaving them largely unaffected. Similar findings were reported by Mahajan and Chauhan (2015).

The interaction between planting patterns and weed control treatments on periodic broadleaf weed count/m^2 was non-significant during both the years of study (Table 4.1.2).

Table 4.1.2: Periodic count of broadleaf weeds (m^{-2}) as influenced by planting patterns and weed control treatments.

Treatments	Count of broadleaf weeds (m^{-2})					
	30 DAT		60 DAT		At harvest	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	3.4 (14)	3.7 (16)	5.0 (30)	5.6 (39)	4.9 (26)	5.6 (33)
Two rows/ridge + one in furrow	4.3 (22)	3.6 (15)	4.4 (24)	5.2 (32)	4.2 (21)	5.0 (26)
Flat unpuddled	4.9 (28)	4.1 (20)	6.0 (44)	6.4 (50)	6.0 (39)	6.6 (45)
Flat puddled	3.2 (13)	3.5 (14)	5.5 (37)	6.0 (44)	5.5 (32)	6.0 (38)
SEm (±)	0.49	0.14	0.15	0.09	0.16	0.14
C.D. (5%)	**NS**	**NS**	**0.47**	**0.28**	**0.50**	**0.46**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	2.5 (6)	3.7 (13)
Pendi., pre-em *fb* penoxsulam	3.2 (15)	3.6 (12)	5.2 (28)	6.4 (41)	4.8 (23)	5.4 (29)
Pendi., pre-em *fb* fenoxaprop-p-ethyl	7.7 (43)	5.3 (28)	7.4 (55)	7.7 (59)	6.6 (44)	7.2 (52)
Unweeded (control)	3.9 (19)	5.0 (25)	7.2 (53)	8.1 (65)	6.7 (45)	7.0 (49)
SEm (±)	0.46	0.15	0.21	0.11	0.26	0.13
C.D. (5%)	**1.33**	**0.43**	**0.60**	**0.33**	**0.74**	**0.36**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

- Figures without parentheses are square root transformed values $\left(\sqrt{x+1}\right)$ after adding one to original values
- Figures in parentheses are original values
- Pendi. - pendimethalin



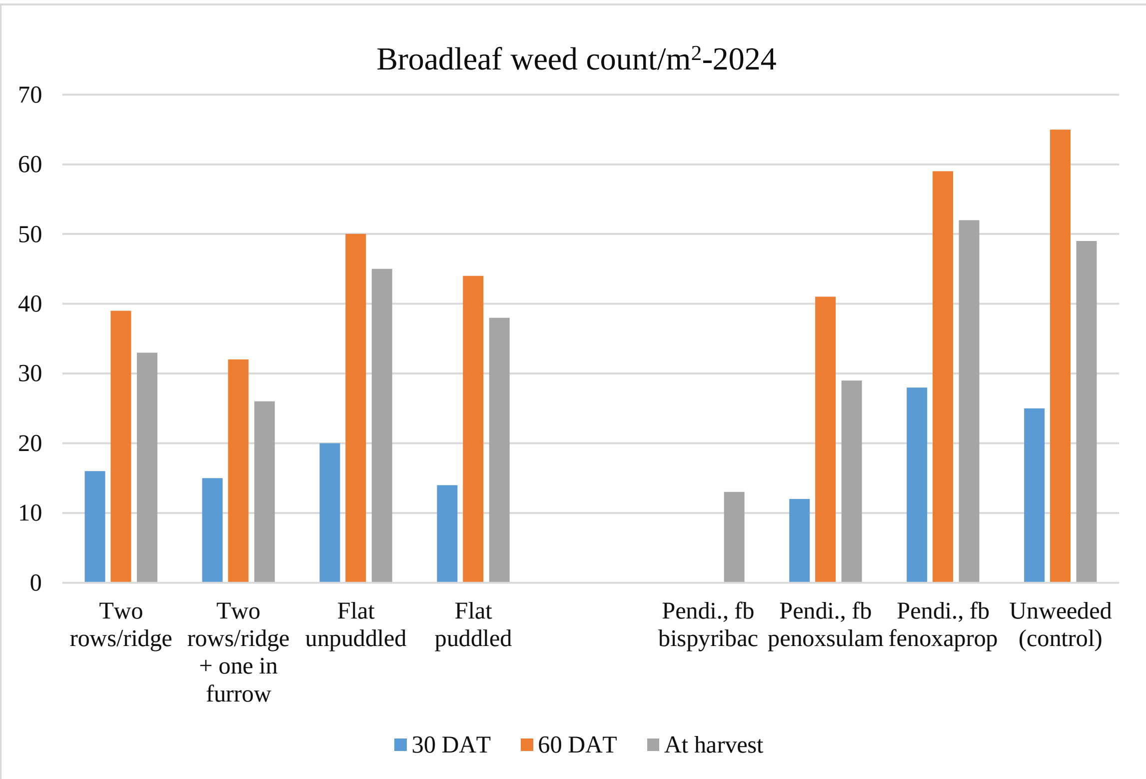


Fig 4.1.2: Effect of planting patterns and weed control treatments on periodic count of broadleaf weeds/m^2.

4.1.3 Dry matter of grassy weeds (q/ha):

Weed dry matter (q/ha) serves as a key indicator of crop weed competition as it measures the biomass of weeds competing with the crop for resources. This index is more valid as higher weed dry matter directly reduces nutrient availability, water uptake and light interception to rice plants, leading to significant yield losses. Data on the periodic weed dry matter of grassy weeds under different planting patterns and weed control treatments, recorded at 30, 60 DAT and harvest during 2023 and 2024 has been presented in Table 4.1.3 and depicted in Figure 4.1.3.

Data recorded at 30 DAT during 2023 showed that the difference in weed dry matter of grassy weeds (q/ha) was non-significant among the planting patterns (Table 4.1.3). Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less weed dry matter of grassy weeds as compared to all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly less weed dry matter of grassy weeds as compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. However, significantly higher weed dry matter of grassy weeds was recorded in unweeded (control) as compared to all other weed control treatments. Similar findings were reported in 2024 also.

Data recorded at 60 DAT during 2023 and 2024 indicated that the differences in weed dry matter (q/ha) of grassy weeds among the planting patterns was significant (4.1.3). Planting pattern with two rows/ridge + one in furrow recorded significantly less weed dry matter of grassy weeds when compared to other planting patterns. Two rows/ridge recorded significantly less dry weight of grassy weeds as compared to flat puddled and flat unpuddled methods. However, flat unpuddled was observed to have significantly higher weed dry matter of grassy weeds as compared to all other methods. Amongst the weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence significantly decreased the weed dry matter of grassy weeds as compared to all other treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly less weed dry matter of grassy weeds as compared to application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence.

Significantly higher weed dry matter of grassy weeds was recorded in unweeded (control) as compared to all other herbicidal treatments during both years.

During 2023, perusal of data at harvest showed that the difference in the weed dry matter (q/ha) of grassy weeds was significant among the planting patterns (Table 4.1.3). Two rows/ridge + one in furrow exhibited significantly less weed dry matter of grassy weeds as compared to all other planting patterns. Two rows/ridge recorded significantly less weed dry matter of grassy weeds as compared flat puddled and flat unpuddled methods. However, flat unpuddled was observed to have significantly higher weed dry matter of grassy weeds as compared to flat puddled. Among weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence, led to significant reduction in the weed dry matter of grassy weeds as compared to other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly less weed dry matter of grassy weeds than application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. However, significantly highest weed dry matter of grassy weeds was observed in unweeded (control) as compared to all herbicidal treatments. Similar results were obtained in 2024 as well.

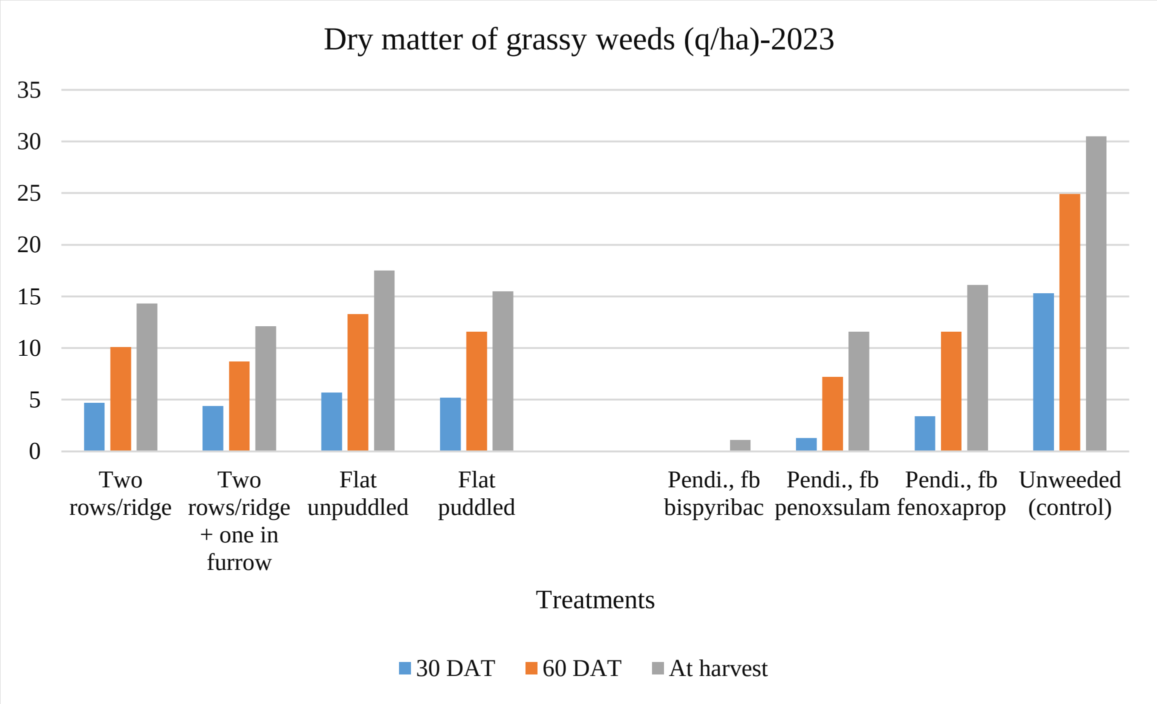
The planting pattern with two rows per ridge plus one in the furrow achieved the lowest dry matter of grassy weeds due to its early canopy closure, which restricted light availability for weeds and inhibited their growth. Furthermore, good geometry of crop favoured crop growth which smothered weeds more effectively than other treatments. Weed seeds were buried deep under the ridge planting leading to overall less weed growth. Also plant growth of rice was more in ridge sown crop due to better soil physical conditions. These findings align with Singh *et al.* (2008) and Alagbo *et al.* (2022). The wide-spectrum efficacy of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence due to its broad-spectrum nature, effectively suppressed diverse grassy weed species, significantly restricting their growth and resulting in reduced dry matter accumulation. These results corroborate with the findings reported by Ghosh *et al.* (2016) and Saravanane (2020).

The interactive effect of planting patterns and weed control treatments on dry matter of grassy weeds (q/ha) remained non-significant at all growth stages during both years (Table 4.1.3).

Table 4.1.3: Influence of planting patterns and weed control treatments on periodic dry matter of grassy weeds (q/ha).

Treatments	**Dry matter of grassy weeds (q/ha)**					
	30 DAT		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	2.1 (4.7)	2.2 (5.4)	3.0 (10.1)	3.1 (11.1)	3.6 (14.3)	3.6 (14.0)
Two rows/ridge + one in furrow	2.0 (4.4)	2.2 (5.0)	2.8 (8.7)	2.8 (8.9)	3.3 (12.1)	3.4 (12.4)
Flat unpuddled	2.3 (5.7)	2.4 (6.3)	3.4 (13.3)	3.5 (13.8)	4.0 (17.5)	4.1 (18.0)
Flat puddled	2.2 (5.2)	2.2 (5.0)	3.2 (11.6)	3.3 (12.5)	3.7 (15.5)	3.9 (16.7)
SEm (±)	0.13	0.06	0.05	0.03	0.05	0.03
C.D. (5%)	**NS**	**NS**	**0.16**	**0.11**	**0.14**	**0.10**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.4 (1.1)	1.7 (1.7)
Pendi., pre-em *fb* penoxsulam	1.5 (1.3)	1.6 (1.6)	2.8 (7.2)	2.9 (7.7)	3.5 (11.6)	3.6 (11.9)
Pendi., pre-em *fb* fenoxaprop-p-ethyl	2.1 (3.4)	2.2 (3.9)	3.5 (11.6)	3.6 (11.9)	4.1 (16.1)	4.1 (15.9)
Unweeded (control)	4.0 (15.3)	4.1 (16.3)	5.1 (24.9)	5.2 (26.7)	5.6 (30.5)	5.7 (31.5)
SEm (±)	0.10	0.06	0.07	0.06	0.06	0.04
C.D. (5%)	**0.29**	**0.16**	**0.20**	**0.17**	**0.17**	**0.13**
Interaction C.D. (5%) (A×B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

- Figures without parentheses are square root transformed values $(\sqrt{x+1})$ after adding one to original values
- Figures in parentheses are original values
- Pendi. - pendimethalin



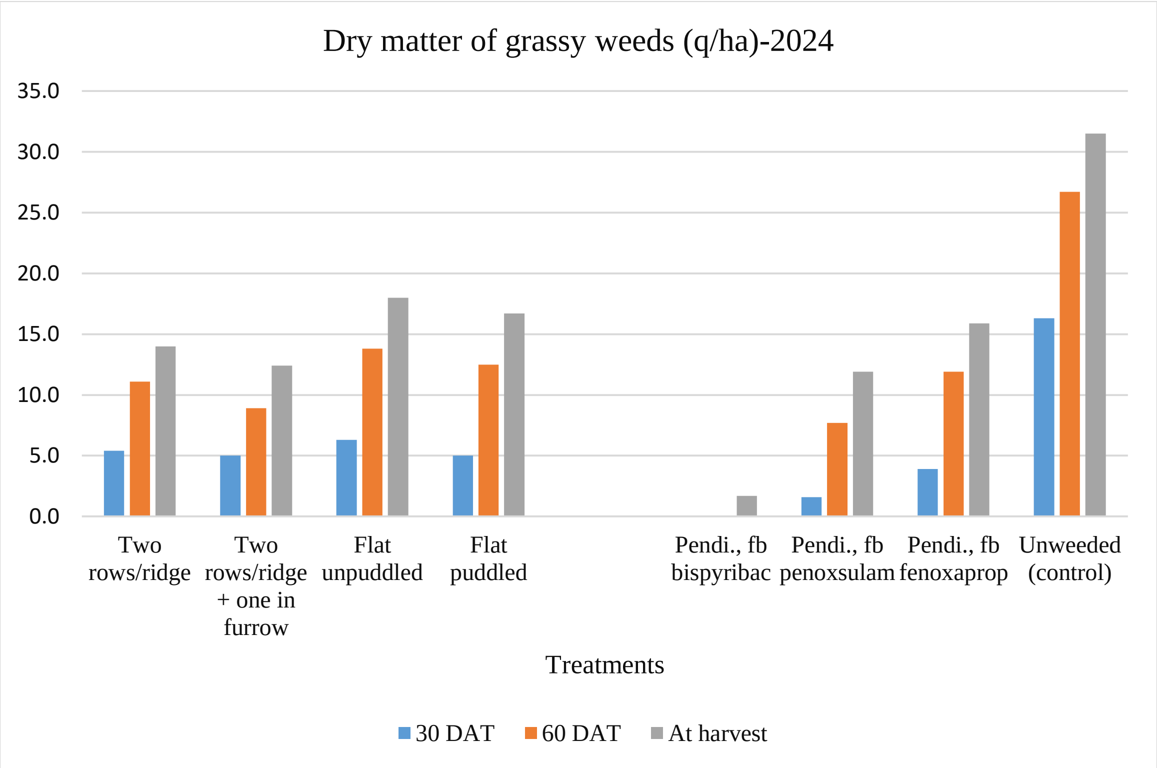


Fig 4.1.3: Effect of planting patterns and weed control treatments on periodic dry matter of grassy weeds (q/ha).

4.1.4 Dry matter of broadleaf weeds (q/ha):

Data pertaining to dry matter of broadleaf weeds (q/ha) as influenced by planting patterns and weed control treatments recorded at 30, 60 DAT and at harvest during 2023 and 2024 has been detailed in Table 4.1.4 and depicted in Figure 4.1.4.

Perusal of data at 30 DAT during 2023 indicated that planting patterns had no significant effect on dry matter of broadleaf weeds (Table 4.1.4). Among the sub plots, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significant reduction in dry matter of broadleaf weeds than all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly less dry weight of broadleaf weeds than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. Also, dry matter of broadleaf weeds was significantly less in unweeded (control) compared to pre-emergence pendimethalin *fb* fenoxaprop-p-ethyl. Similar findings were observed in 2024.

At 60 DAT, during 2023 and 2024, planting patterns were observed to have significant impact on dry matter of broadleaf weeds (Table 4.1.4). The planting pattern with two rows/ridge + one in furrow was observed to have significantly less dry matter of broadleaf weeds as compared to other methods. Two rows/ridge recorded significantly less dry matter as compared to flat puddled and flat unpuddled planting patterns. However, significantly more dry matter of broadleaf weeds was observed in flat unpuddled as compared to flat puddled method. Regarding the sub plots, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence exhibited significantly less dry matter of broadleaf weeds as compared to other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly less dry matter of broadleaf weeds as compared with pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence and unweeded (control). These findings hold good for both years.

During 2023, data recorded at harvest revealed that the difference in dry matter of broadleaf weeds was significant amongst the planting patterns (Table 4.1.4). Planting pattern with two rows/ridge + one in furrow recorded significantly less weed dry matter when compared to other planting patterns. Flat puddled treatment exhibited significantly less dry matter of broadleaf weeds when compared to flat unpuddled. Two rows/ ridge recorded significantly less dry weight of broadleaf weeds than flat puddled and flat unpuddled method. Among the weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less dry matter of broadleaf weeds than all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly less dry weight of weeds as compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl. However, significantly higher dry matter of broadleaf weeds was recorded in unweeded (control) which was statistically at par with pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence These trends remained consistent in 2024 as well.

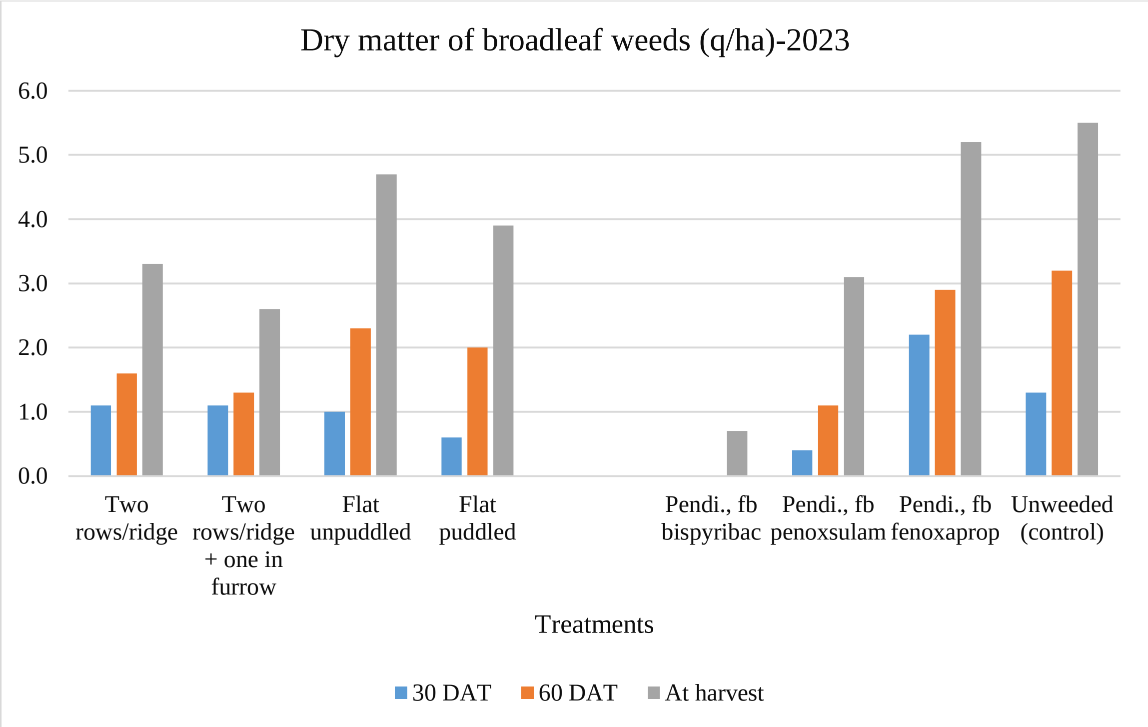
Early canopy closure in the planting pattern with two rows per ridge + one in the furrow significantly reduced grassy weed dry matter by limiting light availability for weed growth. The optimum crop geometry further strengthened crop competition, enabling rice plants to compete with weeds more effectively as compared to other planting patterns. Under ridge planting, the soil physical conditions were improved. These results align with the findings reported by Ram *et al.* (2005). Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence exhibited broad spectrum efficacy over a variety of broadleaf weeds and sedges. This treatment restricted weed growth, leading to reduced dry matter accumulation and improved weed control efficiency. Meanwhile, application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence left broadleaf weeds and sedges largely unaffected, enabling them to grow and increase overall weed biomass. Similar results were reported by Kumar *et al.* (2018) and Mahajan and Chauhan (2015).

The interactive effect of planting patterns and weed control treatments on dry matter of broadleaf weeds was non-significant at 30, 60 DAS and at harvest during 2023 and 2024 (Table 4.1.4).

Table 4.1.4: Periodic dry matter of broadleaf weeds (q/ha) as influenced by planting patterns and weed control treatments.

Treatments	Dry matter of broadleaf weeds (q/ha)					
	30 DAT		60 DAT		At harvest	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	1.4 (1.1)	1.5 (1.3)	1.6 (1.6)	1.6 (1.9)	2.0 (3.3)	2.2 (3.9)
Two rows/ridge + one in furrow	1.4 (1.1)	1.5 (1.3)	1.5 (1.3)	1.6 (1.6)	1.8 (2.6)	2.1 (3.4)
Flat unpuddled	1.4 (1.0)	1.5 (1.2)	1.8 (2.3)	1.9 (2.7)	2.3 (4.7)	2.4 (5.0)
Flat puddled	1.2 (0.6)	1.4 (1.0)	1.7 (2.0)	1.7 (2.3)	2.2 (3.9)	2.3 (4.5)
SEm (±)	0.08	0.03	0.02	0.02	0.04	0.02
C.D. (5%)	**NS**	**NS**	**0.06**	**0.07**	**0.13**	**0.07**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.3 (0.7)	1.6 (1.5)
Pendi., pre-em *fb* penoxsulam	1.2 (0.4)	1.3 (0.6)	1.4 (1.1)	1.5 (1.2)	2.0 (3.1)	2.1 (3.5)
Pendi., pre-em *fb* fenoxaprop-p-ethyl	1.8 (2.2)	1.9 (2.4)	2.0 (2.9)	2.2 (3.7)	2.5 (5.2)	2.6 (5.8)
Unweeded (control)	1.5 (1.3)	1.6 (1.7)	2.0 (3.2)	2.1 (3.6)	2.5 (5.5)	2.6 (5.9)
SEm (±)	0.08	0.03	0.04	0.03	0.04	0.02
C.D. (5%)	**0.23**	**0.08**	**0.10**	**0.09**	**0.10**	**0.05**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

- Figures without parentheses are square root transformed values $\left(\sqrt{x+1}\right)$ after adding one to original values
- Figures in parentheses are original values
- Pendi. - pendimethalin



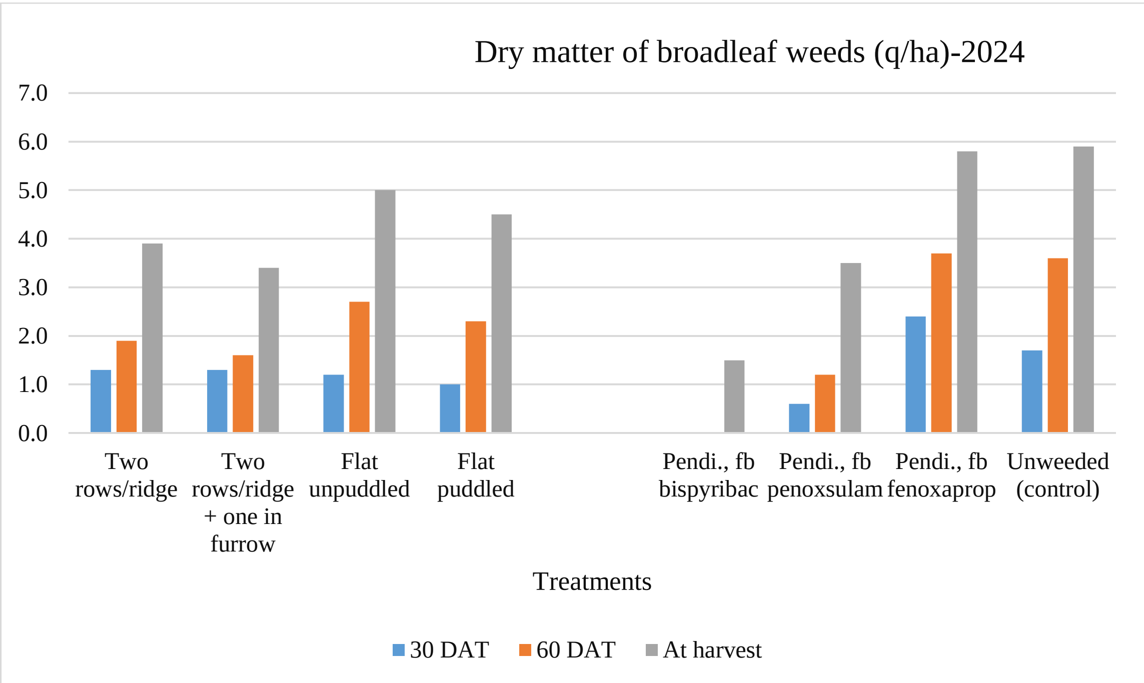


Fig 4.1.4: Effect of planting patterns and weed control treatments on periodic dry matter of broadleaf weeds (q/ha).

4.1.5 Weed control efficiency (%):

Weed control efficiency plays an important role in evaluating the efficacy of the herbicides on weed suppression. Data pertaining to weed control efficiency was worked out from final dry matter accumulation by weeds under varying planting patterns and weed control treatments during 2023 and 2024 has been summarized in Table 4.1.5.

Data on weed control efficiency (%) at harvest indicated that among main plots, maximum weed control efficiency was observed in the treatment with two rows/ridge and one in furrow (59.2 and 57.8%), this was followed by two rows/ridge (51.2 and 52.2%) and flat puddled (46.2 and 43.4%), whereas minimum weed control efficiency was recorded in flat unpuddled (38.3 and 38.6%) during both the years of study, respectively. Amongst the herbicidal treatments, highest weed control efficiency was observed with application of pendimethalin pre-emergence *fb* bispyribac post-emergence (94.8 and 91.3%) which was followed by pendimethalin pre-emergence *fb* penoxsulam post-emergence (59.2 and 58.9%), respectively. Lowest weed control efficiency was recorded with the application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence (40.8 and 41.8%) during both the years of study, respectively.

Table 4.1.5: Influence of planting patterns and weed control treatments on weed control efficiency (%).

Treatments	Weed control efficiency (%)	
Main plots (Planting patterns)	**2023**	**2024**
Two rows/ridge	51.2	52.2
Two rows/ridge + one in furrow	59.2	57.8
Flat unpuddled	38.3	38.6
Flat puddled	46.2	43.4
Sub-plots (Weed control treatments)		
Pendi., pre-em *fb* bispyribac sodium	94.8	91.3
Pendi., pre-em *fb* penoxsulam	59.2	58.9
Pendi., pre-em *fb* fenoxaprop-p-ethyl	40.8	41.8
Unweeded (control)	-	-

- Weed control efficiency was calculated from the original values of weed dry matter

4.2 Plant growth parameters:

4.2.1 Establishment percentage:

Establishment percentage of rice is a key factor in assessing the population of crop per unit area as it reflects the success of seedling survival and uniformity across the field. Data regarding the establishment percentage of rice under various planting patterns and weed control methods was detailed in Table 4.2.1. Perusal of data at 20 DAT during 2023 indicated that there was no significant impact of planting patterns on the establishment percentage of rice. Similarly weed control treatments showed no significant differences in establishment percentage. These observations were consistent in 2024 also.

The interactive effect of planting patterns and weed control treatments on establishment percentage of rice was non-significant during both the years of study (Table 4.2.1).

Table 4.2.1: Influence of planting patterns and weed control treatments on establishment percentage of rice.

Treatments	Establishment percentage (20 DAT)	
Main plots (Planting patterns)	**2023**	**2024**
Two rows/ridge	88.1	90.0
Two rows/ridge + one in furrow	92.8	94.2
Flat unpuddled	86.0	90.8
Flat puddled	91.8	88.9
SEm (±)	2.04	1.44
C.D. (5%)	**NS**	**NS**
Sub-plots (Weed control treatments)		
Pendi., pre-em *fb* bispyribac sodium	91.2	90.4
Pendi., pre-em *fb* penoxsulam	90.6	91.1
Pendi., pre-em *fb* fenoxaprop-p-ethyl	90.3	93.6
Unweeded (control)	86.6	88.9
SEm (±)	1.47	1.87
C.D. (5%)	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**

4.2.2 Plant height (cm):

Plant height plays a significant role in assessing the growth performance of rice, reflecting the crop's capacity to harness nutrients and water effectively. This trait is closely linked to yield attributes, making it a critical factor in productivity. Data pertaining to plant height (cm) of rice at different growth phases, as effected by various planting patterns and weed control treatments during 2023 and 2024 are presented in Table 4.2.2 and graphically depicted in Figure 4.2.1.

Perusal of data at 30 DAT during the years 2023 and 2024 revealed that there was no significant impact of planting patterns on the plant height (cm) of rice (Table 4.2.2). Amongst the weed control treatments, plant height recorded 30 DAT during 2023 in pendimethalin as pre-emergence *fb* bispyribac sodium as post-emergence was statistically at par with pendimethalin pre-emergence *fb* penoxsulam post-emergence and pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence and all these herbicidal treatments were found to be significantly superior to unweeded (control) during both the years.

The differences in plant height recorded at 60 DAT during both the years was not influenced by planting patterns (Table 4.2.2). Plant height (cm) during 2023 was significantly higher in pendimethalin pre-emergence *fb* bispyribac sodium post-emergence as compared to other herbicidal treatments. Plant height in pendimethalin pre-emergence *fb* penoxsulam post-emergence was significantly more than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl. Significantly lower plant height was recorded in unweeded (control) as compared to all other weed control treatments. Similar findings were noticed in 2024.

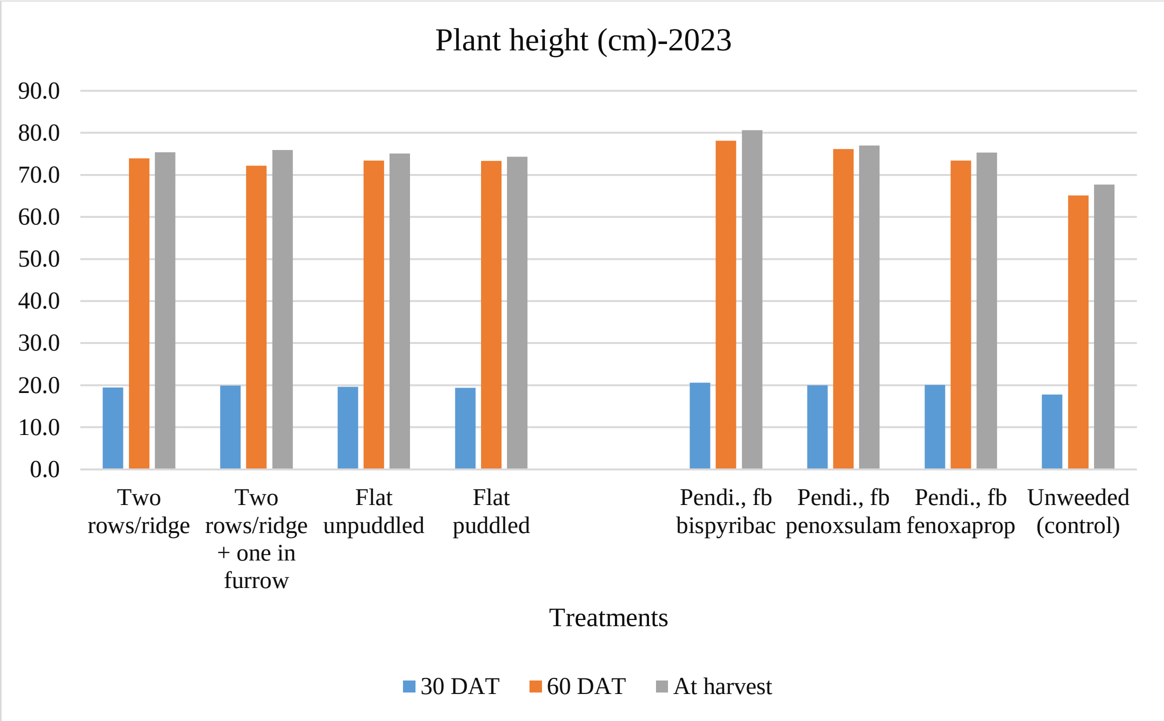
At harvest, planting patterns did not have any significant effect on the plant height of rice (Table 4.2.2). Among weed control treatments, significantly higher plant height (cm) at harvest was achieved in pendimethalin pre-emergence *fb* bispyribac sodium post-emergence than all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly lower plant height as compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. Meanwhile, significantly less plant height was observed in unweeded (control) as compared to other weed control treatments. These findings hold good during both the years of study.

The plant height (cm) in main plot treatments was non-significant which may be due to negligible effect of planting patterns on the plant growth. Sequential application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence increased crop plant height significantly which may be due to effective control of typical grassy and broadleaf weeds with bispyribac sodium due to its wide spectrum. So, more nutrients were available for use by crop in the treatment where bispyribac sodium has been sprayed after pre-emergence application of pendimethalin. The findings are in congruity with Hashim *et al.* (2022).

The interaction between planting patterns and weed control treatments at all periodic intervals showed non-significant effect on periodic plant height during both years of the study (Table 4.2.2).

Table 4.2.2: Impact of planting patterns and weed control treatments on periodic plant height (cm) of rice.

Treatments	**Plant height (cm)**					
	30 DAT		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	19.5	20.4	73.9	71.6	75.4	73.8
Two rows/ridge + one in furrow	19.9	20.6	72.2	72.7	75.9	74.2
Flat unpuddled	19.6	20.3	73.4	72.8	75.1	74.3
Flat puddled	19.4	20.6	73.3	72.2	74.3	74.4
SEm (±)	0.28	0.41	0.44	0.39	0.47	0.51
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	20.6	21.1	78.1	78.4	80.6	80.7
Pendi., pre-em *fb* penoxsulam	20.0	21.4	76.1	74.8	77.0	76.0
Pendi., pre-em *fb* fenoxapropp-ethyl	20.1	21.2	73.4	72.3	75.3	74.0
Unweeded (control)	17.8	18.3	65.1	63.8	67.7	66.0
SEm (±)	0.29	0.35	0.69	0.41	0.53	0.50
C.D. (5%)	**0.83**	**1.00**	**1.97**	**1.17**	**1.52**	**1.44**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



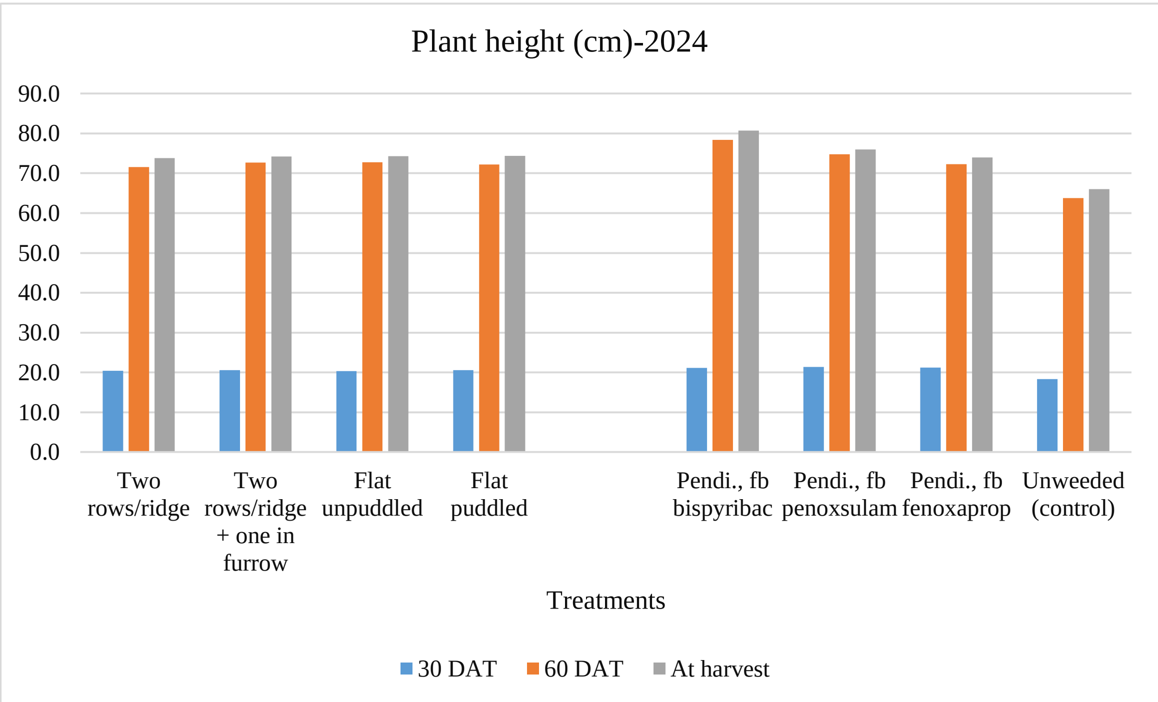


Fig 4.2.1: Effect of planting patterns and weed control treatments on periodic plant height (cm) of rice.

4.2.3 Total number of tillers/m^2:

Total number of tillers per unit area is a crucial growth parameter as it directly correlates with the productive capacity of the plants. It helps to assess the crop's ability to produce panicles, which significantly impact grain yield and overall productivity. Data regarding the periodic count of total number of tillers/m^2 as effected by various planting patterns and weed control treatments during 2023 and 2024 has been compiled in Table 4.2.3 and depicted graphically in Figure 4.2.2.

During 2023, planting patterns did not significantly influence the total number of tiller/m^2 at 30 DAT (Table 4.2.3). Among the weed control treatments, the total number of tillers/m^2 of rice in pendimethalin pre-emergence *fb* bispyribac sodium post-emergence were statistically at par with pendimethalin pre-emergence *fb* penoxsulam post-emergence and pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. Total number of tillers/m^2 in unweeded (control) were significantly less than all herbicidal treatments. These trends remained consistent in 2024.

Perusal of data at 60 DAT during 2023 revealed that the planting pattern with two rows/ridge + one in furrow significantly enhanced the total number of tillers/m^2 than all other planting patterns. Flat unpuddled and flat puddled were statistically at par with each other and these planting patterns produced significantly less total number of tillers/m^2 than both the ridge planting methods i.e two rows/ridge and two rows/ridge + one in furrow. Among the sub-plots, the application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence significantly improved the count of total number of tillers/m^2 as compared to all other treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence produced significantly more total tillers than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl. Conversely, unweeded (control) recorded substantially less count of total number of tillers/m^2 than all other treatments. Similar results were obtained in 2024 as well.

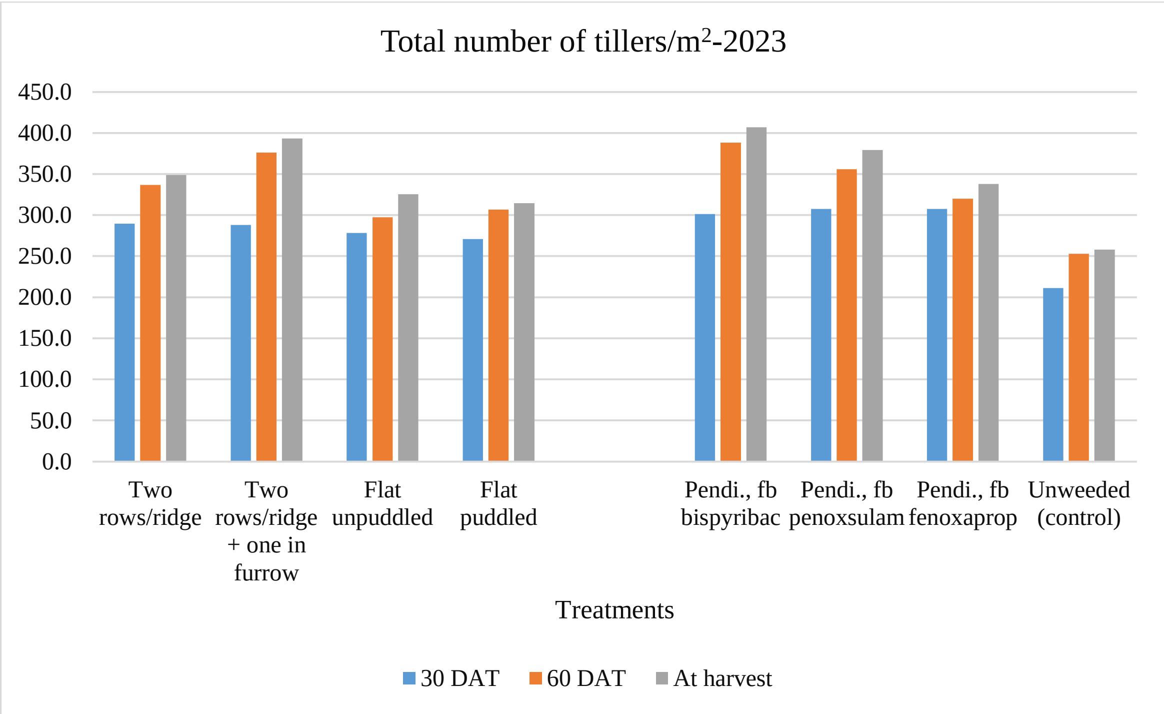
The data collected at harvest during 2023 and 2024 (Table 4.2.3) revealed that significantly increased count in total number of tillers/m^2 was observed in the planting pattern consisting of two rows/ridge + one in furrow than other planting patterns. In contrast, flat puddled and flat unpuddled treatments recorded significantly less count of total number of tillers/m^2 than two rows/ ridge, while both flat sown methods remained statistically at par with each other. The treatment with application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded higher count of total number of tillers/m^2 and was significantly superior over other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence produced significantly less count of total number of tillers/m^2 than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. Significantly less count of total number of tillers/m^2 were recorded in unweeded (control) than all other weed control treatments.

Higher production of total number of tillers/m^2 in two rows/ridge + one in furrow may be attributed to increased surface area, better physical soil conditions and better geometry of crop. This method promotes deeper root penetration, resulting in improved nutrient and moisture uptake, leading to better tiller growth compared to flat transplanting. Similar findings were reported by Baurai *et al.* (2020) and Reuben *et al.* (2016). Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence effectively minimized crop-weed competition during the critical growth phase of rice (the initial 6 weeks of transplanting). By keeping weed populations below the threshold level, this approach allowed the rice crop to efficiently utilize available nutrients, water, space and sunlight, resulting in enhanced growth and a higher number of tillers. Similar results were reported by Ahmed *et al.* (2021) and Mukherjee *et al.* (2008).

Both years of the study revealed that the interaction between planting patterns and weed control treatments did not have a significant impact on periodic count of total number of tillers/m^2 of rice crop (Table 4.2.3).

Table 4.2.3: Periodic count of total number of tillers/m^2 of rice as influenced by planting patterns and weed control treatments.

Treatments	**Total number of tillers/m^2**					
	30 DAT		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	289.7	293.3	336.9	333.1	348.8	340.1
Two rows/ridge + one in furrow	288.1	277.8	376.3	376.6	393.4	384.7
Flat unpuddled	278.4	289.4	297.2	298.8	325.3	309.4
Flat puddled	270.9	276.9	306.6	292.5	314.4	305.6
SEm (±)	6.7	5.15	5.7	4.39	5.45	6.69
C.D. (5%)	**NS**	**NS**	**18.20**	**14.03**	**17.70**	**21.39**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	301.1	313.0	388.3	389.0	407.1	405.2
Pendi., pre-em *fb* penoxsulam	307.3	305.6	355.9	348.3	379.1	362.0
Pendi., pre-em *fb* fenoxaprop-p-ethyl	307.6	300.2	320.0	313.9	337.9	323.5
Unweeded (control)	211.2	218.7	252.8	249.7	257.8	249.2
SEm (±)	5.1	5.67	9.5	4.83	7.81	6.59
C.D. (5%)	**14.70**	**16.27**	**27.30**	**13.87**	**22.48**	**18.91**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



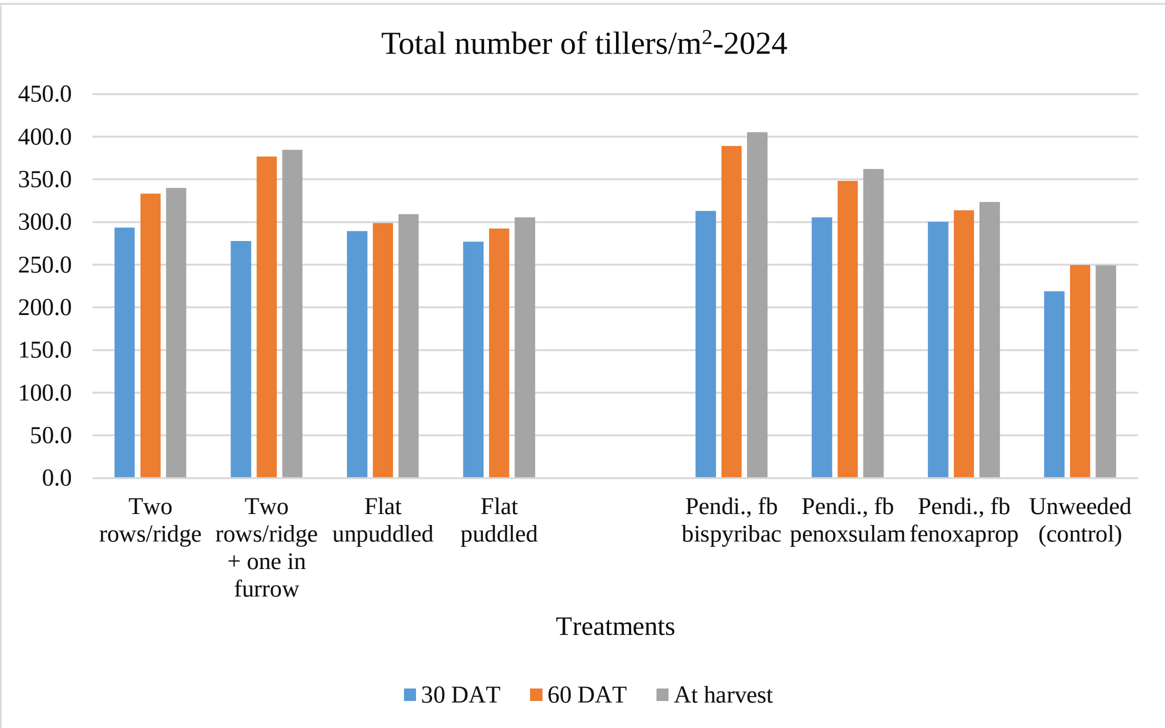


Fig 4.2.2: Effect of planting patterns and weed control treatments on periodic count of total number of tiller/m^2.

4.2.4 Crop dry matter accumulation (q/ha):

Accumulation of dry matter by crop is essential for analysing the plant's growth pattern and biomass production. It helps to evaluate the efficiency of resource utilization, such as water, nutrients and light and is also a key determinant of yield potential. The periodic data of crop dry matter accumulation, influenced by different planting patterns and weed control treatments during the years 2023 and 2024, has been summarized in Table 4.2.4 and depicted in Figure 4.2.3.

At 30 DAT, the differences in the dry matter accumulation (q/ha) among the planting patterns was found non-significant during 2023 (Table 4.2.4). On the other hand, weed control treatments comprising pendimethalin pre-emergence *fb* bispyribac sodium post-emergence, pendimethalin pre-emergence *fb* penoxsulam post-emergence, pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence resulted in statistically similar crop dry matter accumulation values. Contrarily, unweeded (control) exhibited significantly less dry matter accumulation as compared to all other herbicidal treatments. These findings were replicated during the year 2024, showing similar outcomes.

Data recorded at 60 DAT during 2023 and 2024 indicated that the planting pattern consisting of two rows/ridge + one in furrow significantly increased crop dry matter (q/ha) as compared to all other planting patterns (Table 4.2.4). The flat unpuddled and flat puddled methods remaining statistically at par with each other with respect to crop dry matter accumulation. The crop dry matter accumulation in two rows/ ridge was significantly more than flat puddled and flat unpuddled planting methods. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence significantly increased the dry matter accumulation by crop as compared to other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more crop dry matter compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. The unweeded (control) recorded significantly less crop dry matter accumulation as compared to all herbicidal treatments.

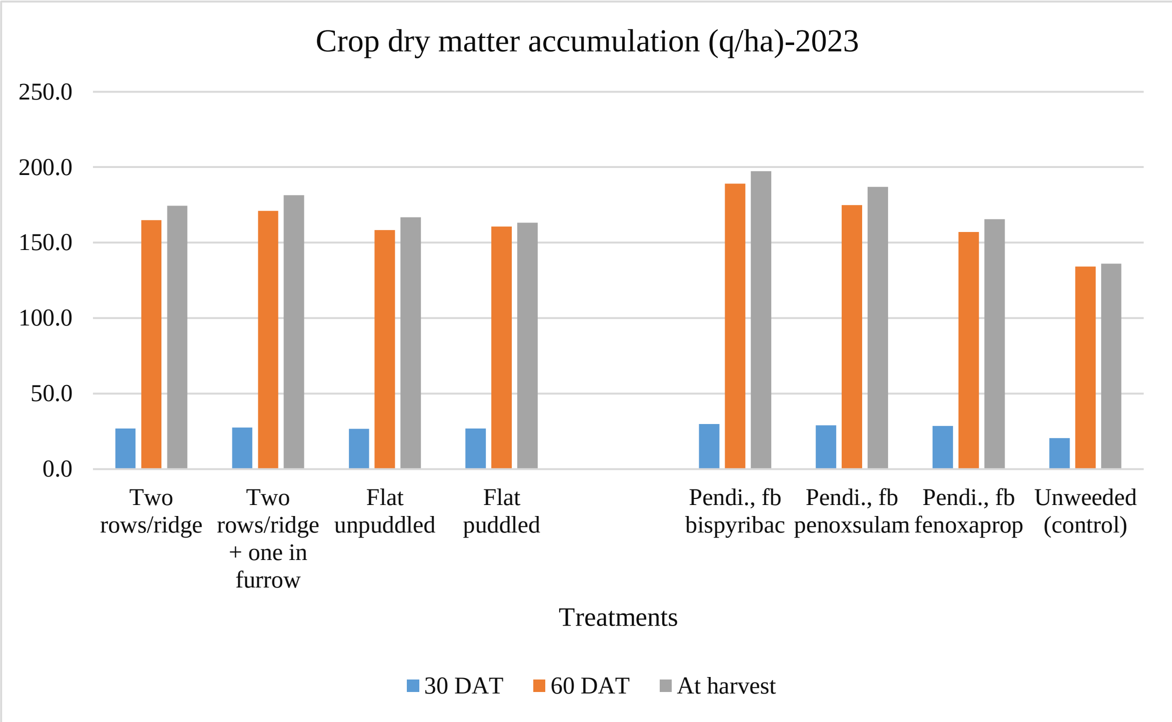
Perusal of data at harvest during 2023 showed that planting pattern involving two rows per ridge plus one in the furrow produced significantly higher crop dry matter as compared to other planting patterns (Table 4.2.4). Conversely, flat unpuddled and flat puddled methods were statistically at par with each other and recorded significantly lower crop dry matter as compared to two rows/ridge planting pattern. Amongst the sub plots, sequential application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly more crop dry matter when compared to other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence produced significantly higher crop dry matter as compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. Unweeded (control) recorded significantly less crop dry matter (q/ha) as compared to all herbicidal treatments. The findings remained consistent during the year 2024 as well.

Planting pattern involving two rows/ridge + one in furrow improves soil aeration and enhances soil structure, providing an ideal environment for root development. The deeper root penetration enabled the plants to access nutrients and water more efficiently, increasing the overall growth of crop, ultimately resulting in greater dry matter accumulation. Baurai *et al.* (2020) and Hussain *et al.* (2019) reported similar findings. Sequential application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence due to their wide spectrum nature, reduced weed pressure and hence reduced competition for resources such as water and nutrients with the crop. This may have facilitated better crop growth, reflected in increased plant height and tiller production, ultimately leading to higher dry matter accumulation. Similar results were reported by Pavithra *et al.* (2021).

Across both years, the interactive effect of planting patterns and weed control treatments on periodic crop dry matter (q/ha) was found to be non-significant (Table 4.2.4).

Table 4.2.4: Periodic dry matter accumulation (q/ha) of rice as influenced by planting patterns and weed control treatments.

Treatments	**Dry matter accumulation (q/ha)**					
	30 DAT		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	26.8	26.6	165.0	163.8	174.5	173.9
Two rows/ridge + one in furrow	27.6	26.5	171.0	168.5	181.4	180.6
Flat unpuddled	26.7	27.0	158.3	156.5	166.8	167.2
Flat puddled	26.8	27.1	160.7	158.7	163.2	164.0
Sm (±)	0.53	0.19	0.88	0.82	1.39	1.77
C.D. (5%)	**NS**	**NS**	**2.84**	**2.63**	**4.51**	**5.67**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	29.8	29.1	189.0	187.3	197.3	198.8
Pendi., pre-em *fb* penoxsulam	29.0	28.9	174.9	173.2	187.0	186.5
Pendi., pre-em *fb* fenoxaprop-p-ethyl	28.6	28.9	157.0	155.4	165.6	164.5
Unweeded (control)	20.5	20.4	134.1	131.6	136.1	135.8
SEm (±)	0.49	0.32	1.15	0.92	2.20	1.71
C.D. (5%)	**1.42**	**0.91**	**3.32**	**2.64**	**6.33**	**4.90**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



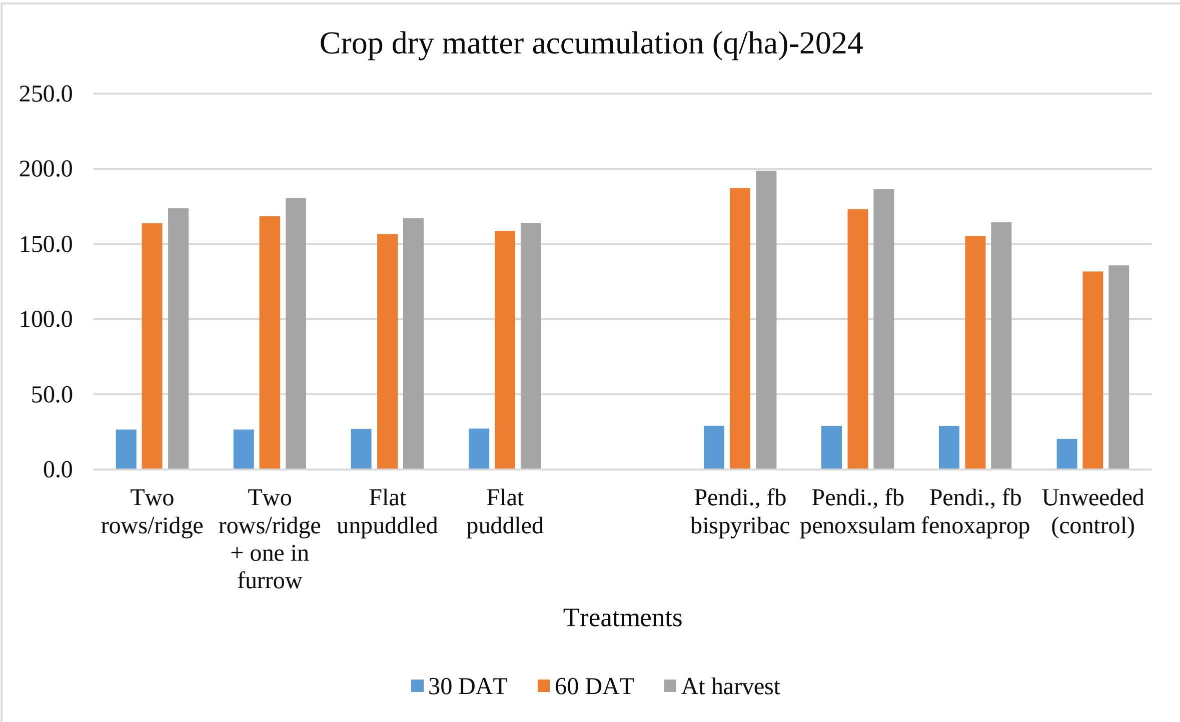


Fig 4.2.3: Effect of planting patterns and weed control treatments on periodic dry matter accumulation (q/ha) of rice.

4.2.5 Chlorophyll index:

Chlorophyll index helps in monitoring the plant's ability to absorb sunlight for photosynthesis, which is closely linked to nitrogen efficiency and yield potential. Data pertaining to periodic chlorophyll index of rice at 30, 60 DAT and harvest, under varying planting patterns and weed control treatments during 2023 and 2024 has been summarized in Table 4.2.5.

At 30 DAT, during 2023, there was non-significant influence of planting patterns on chlorophyll index of rice (Table 4.2.5). Among the sub plots, all the herbicidal treatments *viz.,* pendimethalin pre-emergence *fb* bispyribac sodium post-emergence, pendimethalin pre-emergence *fb* penoxsulam post-emergence, pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence were at par among each other and all these treatments were found to produce significantly higher chlorophyll index than unweeded (control). Similar trend in the observations was noticed in 2024.

Perusal of data at 60 DAT during 2023 and 2024 indicated that the differences in chlorophyll index among the planting patterns were non-significant (Table 4.2.5). Among the weed control treatments, chlorophyll index of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence, pendimethalin pre-emergence *fb* bispyribac sodium post-emergence and pendimethalin pre-emergence *fb* penoxsulam post-emergence was significantly more than unweeded (control) and all the herbicidal treatments were found at par with each other.

Data recorded at harvest during 2023 revealed that there was no significant impact of planting patterns on chlorophyll index of rice (Table 4.2.5). Likewise, the differences in chlorophyll index among the weed control treatments were observed to be non-significant. These findings remained consistent in 2024 as well.

The lower chlorophyll index in unweeded (control) plots as compared to herbicidal treatments can be attributed to the high weed density, which induced nutrient stress in rice plants, leading to yellowing of leaves. This condition may have reduced chlorophyll synthesis caused by limited access to light and nutrients due to intense weed competition. The results are in congruity with Linu and Girija (2021).

The interactive effect of planting patterns and weed control treatments on periodic chlorophyll index of rice was non-significant during both the years of study (Table 4.2.5).

Table 4.2.5: Influence of planting patterns and weed control treatments on periodic chlorophyll index of rice.

Treatments	**Chlorophyll index**					
	30 DAT		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	43.6	43.7	47.8	47.6	25.9	25.8
Two rows/ridge + one in furrow	43.6	44.4	48.2	48.2	25.7	25.3
Flat unpuddled	43.7	43.7	48.6	48.5	26.0	25.6
Flat puddled	43.6	43.6	49.0	48.5	25.9	25.7
SEm (±)	0.42	0.26	0.54	0.27	0.31	0.15
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	43.8	44.6	50.5	49.7	25.6	25.9
Pendi., pre-em *fb* penoxsulam	45.0	44.4	49.7	49.1	26.2	25.6
Pendi., pre-em *fb* fenoxaprop-p-ethyl	44.2	45.4	49.3	49.7	25.9	25.6
Unweeded (control)	41.5	40.9	44.3	44.2	25.8	25.3
SEm (±)	0.46	0.43	0.45	0.39	0.29	0.22
C.D. (5%)	**1.32**	**1.24**	**1.29**	**1.12**	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.3 Yield components:

4.3.1 Number of panicles/m^2 and panicle length (cm):

The number of panicles/m^2 is an essential determinant of rice yield, representing the effectiveness of tillering and crop growth. Increased panicle numbers are often associated with higher yields. Panicle length influences the grain bearing capacity of the plant. Longer panicles often accommodate more grains, thereby contributing to higher productivity. Data pertaining to the number of panicles/m^2 and panicle length as influenced by various planting patterns and weed control treatments during 2023 and 2024 has been summarized in Table 4.3.1 and graphically depicted in Figure 4.3.1.

The analysis of data at harvest during 2023 revealed that there was notable effect of planting patterns on number of panicles/m^2 and significantly higher number of panicles/m^2 were observed in two rows/ridge + one in furrow as compared to all other methods (Table 4.3.1). Meanwhile flat unpuddled and flat puddled methods were statistically at par and produced significantly less number of panicles/ m^2 as compared to two rows/ ridge method. Among sub plots, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence resulted in significantly more number of panicles/m^2 than all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more panicles / m^2 as compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. The unweeded (control) treatment recorded significantly less number of panicles/m^2 as compared to all herbicidal treatments. Consistent trends in the results were observed during 2024 as well.

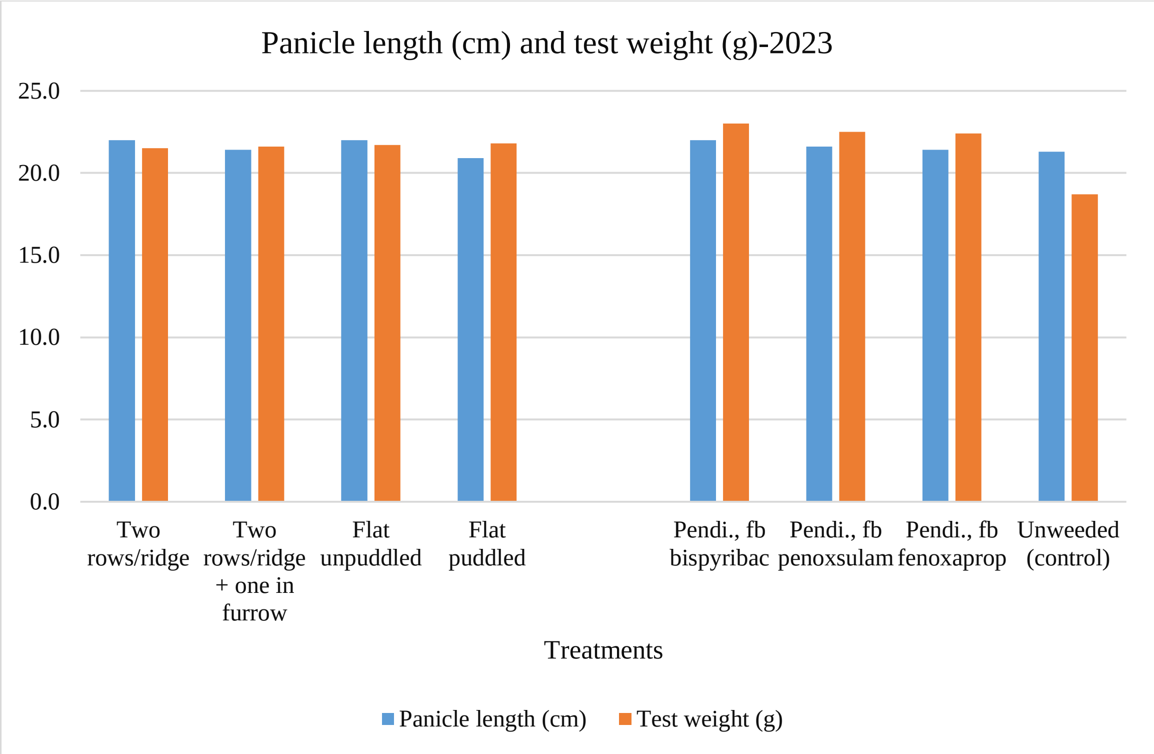
Data recorded at harvest during 2023 and 2024 indicated that there was no significant impact of planting patterns and weed control treatments on the panicle length (cm) of rice (Table 4.3.1).

Higher panicle density in two rows/ridge + one in furrow can be attributed to improved physical conditions of soil which facilitated greater concentration of roots that may have enhanced the tiller production, thereby increasing the number of panicles/m^2. There was better crop growth in the planting patterns of two rows/ridge + one in furrow due to better crop geometry which improved number of panicles/m^2. Similar findings were reported by Borrell *et al.* (1998). Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence effectively suppressed weed growth during the critical stages of crop weed competition and kept weed populations under control, enabling the rice crop plants to maximize their access to essential resources like nutrients, water, and light, which translated into improved tiller production, thereby increasing the number of panicles/m^2. The results are in conformity with Baloch *et al.* (2005) and Mahajan and Chauhan (2013).

The interactive effect of planting patterns and weed control treatments on number of panicles/m^2 and panicle length (cm) remained non-significant during both the years of study (Table 4.3.1).

Table 4.3.1: Number of panicles/m^2 and panicle length (cm) of rice as influenced by planting patterns and weed control treatments.

Treatments	Number of panicles/m^2		Panicle length (cm)	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	333.3	331.7	22.0	21.4
Two rows/ridge + one in furrow	371.6	366.6	21.4	21.8
Flat unpuddled	312.8	310.6	22.0	21.7
Flat puddled	306.9	309.1	20.9	22.1
SEm (±)	6.86	4.81	0.54	0.15
C.D. (5%)	**22.25**	**15.38**	**NS**	**NS**
Sub-plots (Weed control treatments)				
Pendi., pre-em *fb* bispyribac sodium	390.5	392.4	22.0	21.7
Pendi., pre-em *fb* penoxsulam	365.2	359.6	21.6	21.9
Pendi., pre-em *fb* fenoxaprop-p-ethyl	327.1	322.5	21.4	21.4
Unweeded (control)	241.8	243.4	21.3	22.0
SEm (±)	5.28	5.49	0.27	0.22
C.D. (5%)	**15.20**	**15.75**	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**



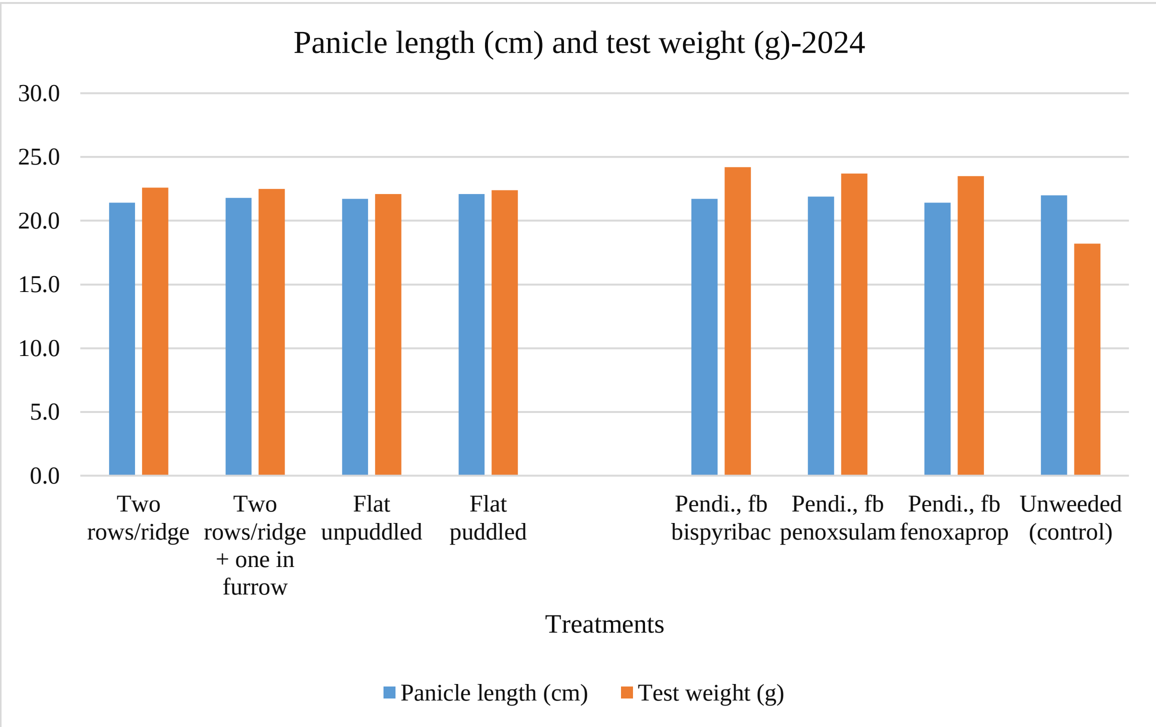


Fig 4.3.1: Effect of planting patterns and weed control treatments on number of panicle length (cm) and test weight (g).

4.3.2 Total number of grains/panicle, number of filled grains/panicle and test weight (g):

The total number of grains per panicle and filled grains per panicle are key yield-determining factors in rice. A higher grain count per panicle increases the potential yield, while the proportion of filled grains determines the efficiency of grain filling of a particular treatment and overall productivity as well as quality. Recording test weight (g) serves as an indicator of grain quality and size, directly influencing the overall yield. Data pertaining to total number of grains/panicle, number of filled grains/panicle and test weight (g) at harvest during the years 2023 and 2024 has been presented in Table 4.3.2 and depicted in Figure 4.3.2.

Data recorded at harvest during 2023 revealed that planting patterns had significant impact on the total number of grains/panicle (Table 4.3.2). Planting pattern with two rows/ridge + one in furrow significantly outperformed other planting techniques by recording significantly higher count of total number of grains/panicle. It was followed by treatment with two rows/ridge which was significantly superior to both the flat transplanting methods. However, flat puddled and flat unpuddled remained statistically at par with each other and these methods recorded significantly less count of total number of grains/ panicle as compared to two rows/ ridge. Among weed control treatments, combined application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence was observed to have maximum number of grains/panicle and was significantly superior to other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence produced significantly more number of grain/ panicle than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl, post-emergence. However, unweeded (control) recorded significantly less number of grains/panicle than all other weed control treatments. Similar trend in the observations was noticed in 2024.

The planting pattern comprising two rows/ridge + one in furrow produced significantly more number of filled grains/panicle as compared to other planting methods (Table 4.3.2). Conversely, flat unpuddled and flat puddled methods remained statistically at par with each other and produced significantly less number of filled grains per panicle as compared to two rows/ ridge. Among weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence significantly increased number of filled grains per panicle as compared to all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence produced significantly more number of filled grains/ panicle compared to application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. The unweeded (control) was observed with significantly less number of filled grains/panicle than all herbicidal treatments. These results hold good for both the years.

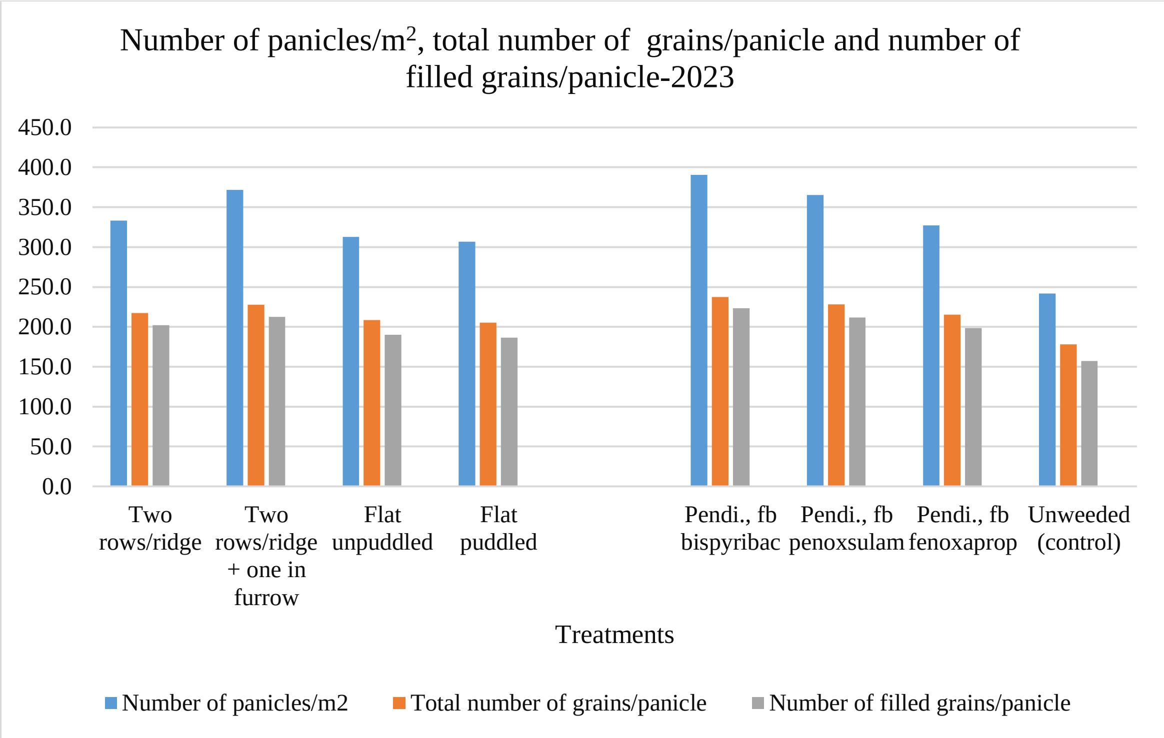
Perusal of data at harvest during 2023 indicated that there was no significant effect of planting patterns on test weight (g) of rice (Table 4.3.2). Among the sub plots, all the herbicidal treatments *viz.,* pendimethalin pre-emergence *fb* bispyribac sodium, pendimethalin pre-emergence *fb* penoxsulam, pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence remained statistically at par with each other and recorded significantly higher test weight than unweeded (control). These trends remained consistent during 2024 as well.

Improved soil physical conditions and dense root concentration in two rows/ridge + one in furrow may have supported better tiller growth, ultimately boosting the number of panicles per square meter and overall grain production as compared to flat transplanting. Similar results were reported by Borrell *et al.* (1998). Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence effectively reduced weed pressure, allowing rice plants to utilize resources more efficiently and improve photosynthetic activity. This reduction in weed biomass ensured availability of nutrients to crop up to harvest, promoting robust vegetative growth and reproductive development, which may have enhanced the production of total number of grains/ panicle, number of filled grains/panicle and test weight (g). The results are in congruity with Choudhary and Dixit (2021) and Sar *et al.* (2024).

During both the years of study, the interactive effect of planting patterns and weed control treatments had no significant impact on total number of grains/panicle, number of filled grains per panicle and test weight (g) (Table 4.3.2).

Table 4.3.2: Total number of grains/panicle, number of filled grains/panicle and test weight (g) of rice as influenced by planting patterns and weed control treatments.

Treatments	**Total number of grains/panicle**		**Number of filled grains/panicle**		**Test weight (g)**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	217.3	225.0	202.0	208.8	21.5	22.6
Two rows/ridge + one in furrow	227.7	234.8	212.7	218.9	21.6	22.5
Flat unpuddled	208.7	215.5	189.9	197.2	21.7	22.1
Flat puddled	205.5	210.6	186.3	194.4	21.8	22.4
SEm (±)	2.29	2.48	2.96	1.79	0.18	0.15
C.D. (5%)	**7.44**	**7.92**	**9.61**	**5.72**	**NS**	**NS**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	237.5	247.7	223.5	232.2	23.0	24.2
Pendi., pre-em *fb* penoxsulam	228.3	234.1	211.6	217.7	22.5	23.7
Pendi., pre-em *fb* fenoxaprop-p-ethyl	215.4	221.7	198.4	206.9	22.4	23.5
Unweeded (control)	178.1	182.4	157.3	162.5	18.7	18.2
SEm (±)	2.79	2.24	2.8	2.03	0.23	0.21
C.D. (5%)	**8.04**	**6.42**	**8.15**	**5.82**	**0.66**	**0.61**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



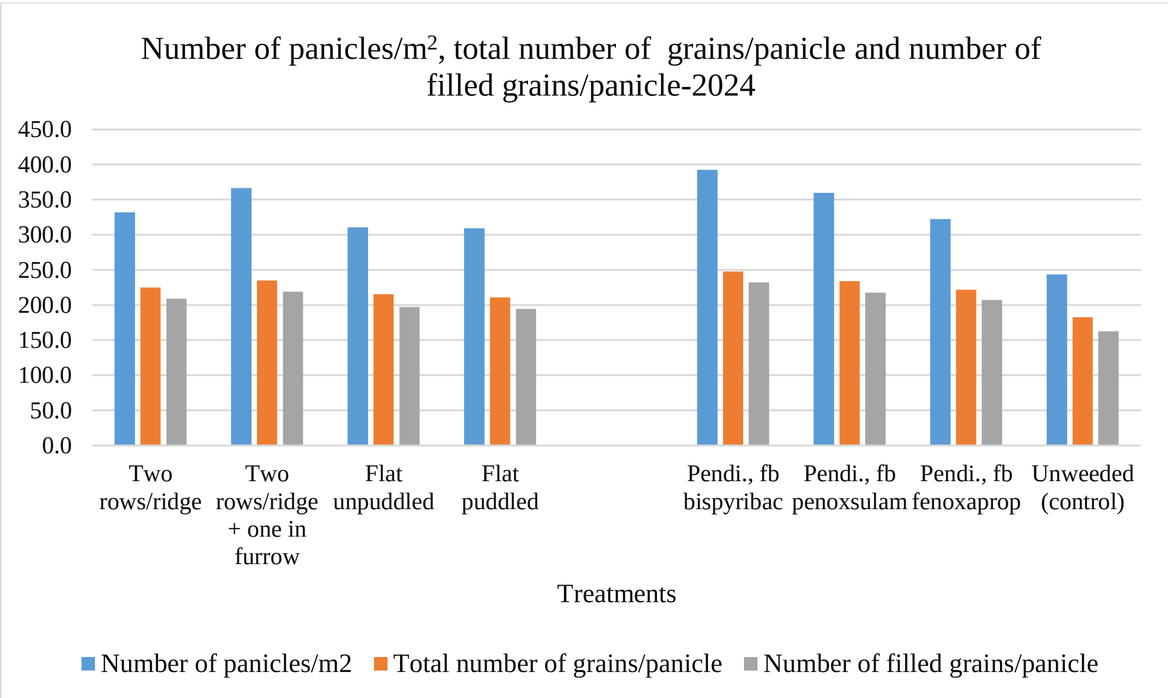


Fig 4.3.2: Effect of planting patterns and weed control treatments on number of panicles/m^2, total number of grains/panicle and number of filled grains/panicle.

4.3.3 Paddy yield (q/ha) and straw yield (q/ha):

Paddy yield and straw yield provide a comprehensive measure of crop productivity. Paddy yield directly reflects the economic output, while straw yield indicates biomass production. Data pertaining to paddy yield (q/ha) and straw yield (q/ha), as influenced by planting patterns and weed control treatments during 2023 and 2024 has been detailed in Table 4.3.3 and depicted in Figure 4.3.3.

Perusal of data during 2023 and 2024 showed that adopting the planting pattern with two rows/ridge + one in furrow recorded significantly more paddy yield when compared to other planting pattern *viz*. two rows/ridge, flat puddled and flat unpuddled (Table 4.3.3). Meanwhile, flat puddled and flat unpuddled were statistically comparable with each other and recorded significantly less paddy yield as compared to two rows/ridge. Similar findings were reported by Bhuyan *et al*. (2012). Amongst the weed control treatments, significantly more paddy yield was recorded with the application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence as compared to all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more paddy yield compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. The unweeded (control) recorded significantly less yield than all other weed control treatments. These findings hold good for both years. Similar findings were reported by Mahajan and Chauhan (2015).

Pooled data of both the years of study indicated that among the main plots, implementing the planting pattern of two rows/ridge + one in furrow significantly increased the paddy yield as compared to other planting methods (Table 4.3.3). Flat puddled and flat unpuddled recorded significantly less paddy yield than two rows/ridge and remained at par with each other. Amongst the weed control treatments, significantly higher paddy yield was obtained with the application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence when compared to other treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more paddy yield compared to pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. However, unweeded (control) recorded significantly less paddy yield as compared to other weed control treatments.

The higher paddy yield in ridge planted crop especially in two rows/ridge and one in furrow may be due to better weed control (Table 4.1.1 to 4.1.5), better crop growth attributes (Table 4.2.1 to 4.2.5) and superior yield attributes (Table 4.3.1 and 4.3.2) as compared to other planting patterns. On an average of two years, the planting pattern of two rows/ ridge and one in furrow, two rows/ ridge and flat puddled crop increased paddy yield by 13.04, 7.36 and 1.67 percent than flat unpuddled crop, respectively. Similarly, higher paddy yield in pendimethalin pre-emergence *fb* bispyribac sodium post-emergence may be due to better weed control (Table 4.1.1 to 4.1.5), better crop growth parameters (Table 4.2.1 to 4.2.5) and better yield attributes (Table 4.3.1 and 4.3.2) as compared to other weed control treatments. Pendimethalin pre-emergence *fb* post-emergence bispyribac sodium, pre-emergence pendimethalin *fb* penoxsulam post-emergence and pre-emergence pendimethalin *fb* fenoxaprop-p-ethyl post-emergence increased paddy yield by 138.15, 125.85 and 112.62 percent than unweeded (control) respectively on the basis of pooled data.

The interactive effect of planting patterns and weed control treatments on paddy yield was found to be significant during both the years of study (Table 4.3.4). Data on interactive effect of planting patterns and weed control treatments during 2023 and 2024 have been compiled in Table 4.3.4. During both years, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence to flat unpuddled crop produced statistically at par paddy yield compared to pre-emergence application of pendimethalin *fb* post-emergence application of penoxsulam to the planting pattern of two rows/ ridge crop (Table 4.3.4). Unweeded (control) crop under two rows/ridge + one in furrow produced significantly more paddy yield than two rows/ridge during 2023 under similar conditions indicating that planting pattern of two rows/ridge + one in furrow had more smothering effect on weeds but differences between these treatments during 2024 were found to be non-significant. Also, during both years, paddy yield under two rows/ ridge treated with pendimethalin pre-emergence *fb* bispyribac sodium post-emergence was found at par with two rows on ridge and one in furrow treated with pendimethalin pre-emergence *fb* penoxsalum post-emergence (Table 4.3.4).

Data collected at harvest during 2023 and 2024 indicated that the difference in straw yield (q/ha) among the planting patterns was significant (Table 4.3.3). Planting pattern with two rows/ridge + one in furrow recorded significantly higher straw yield when compared to other planting patterns, which was followed by two rows/ridge. Meanwhile, flat puddled and flat unpuddled treatments were at par and recorded significantly less straw yield when compared to both ridge-based planting patterns. Straw yield in two rows/ridge planting pattern was found significantly more than flat puddled and flat unpuddled methods. Among the weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly higher straw yield as compared to other weed control treatments. Also, pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more straw yield than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. However, unweeded (control) recorded significantly less straw yield as compared to all other weed control treatments. Similar findings were reported during 2024 as well.

The planting pattern of two rows per ridge + one in the furrow achieved the highest paddy and straw yield likely due to its ability to promote early canopy closure, which effectively restricted light availability for weeds and inhibited their growth. In weed-free environments, due to availability of more space rice plants were allowed to grow toward areas with abundant resources like sunlight and nutrients while reducing intra-crop competition between rows. As a result, resources such as nutrients and water were predominantly utilized by rice plants rather than weeds. Additionally, improved soil physical conditions and better soil aeration created a favourable environment for root development and nutrient uptake, leading to higher tiller production, which directly contributed to enhanced straw yield. There was good formation of crop geometry in planting pattern of two rows/ridge + one in furrow which resulted in better paddy and straw yield. The results are in congruity with Bhuyan *et al.* (2012) and Hobbs and Gupta (2003). The sequential application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence ensured effective weed control throughout the critical stages of rice growth. This complementary action may have significantly reduced weed density and biomass, allowing rice plants to grow without competition for nutrients, water, and light. Similar findings were reported by Mahajan and Chauhan (2015) and Walia *et al.* (2008).

Across both the years, the interactive effect of planting patterns and weed control treatments on straw yield was observed to be non-significant (Table 4.3.3).

Table 4.3.3: Paddy yield (q/ha) and straw yield (q/ha) as influenced by planting patterns and weed control treatments.

Treatments	**Paddy yield (q/ha)**			**Straw yield (q/ha)**	
Main plots (Planting patterns)	**2023**	**2024**	**Pooled**	**2023**	**2024**
Two rows/ridge	63.6	64.7	64.2	89.7	90.8
Two rows/ridge + one in furrow	67.6	67.5	67.6	94.9	96.2
Flat unpuddled	60.2	61.4	60.8	84.5	87.3
Flat puddled	58.9	60.6	59.8	81.4	85.6
SEm (±)	0.60	0.42	0.51	1.12	0.97
C.D. (5%)	**1.92**	**1.34**	**1.63**	**3.59**	**3.12**
Sub-plots (Weed control treatments)					
Pendi., pre-em *fb* bispyribac sodium	77.9	76.9	77.4	107.3	107.1
Pendi., pre-em *fb* penoxsulam	72.7	74.1	73.4	100.3	102.5
Pendi., pre-em *fb* fenoxaprop-p-ethyl	68.3	69.8	69.1	92.7	95.2
Unweeded (control)	31.5	33.4	32.5	50.3	55.0
SEm (±)	0.71	0.61	0.66	1.27	1.23
C.D. (5%)	**2.04**	**1.74**	**1.89**	**3.64**	**3.51**
Interaction C.D. (5%) (A × B)	**4.21**	**3.47**	**NS**	**NS**	**NS**

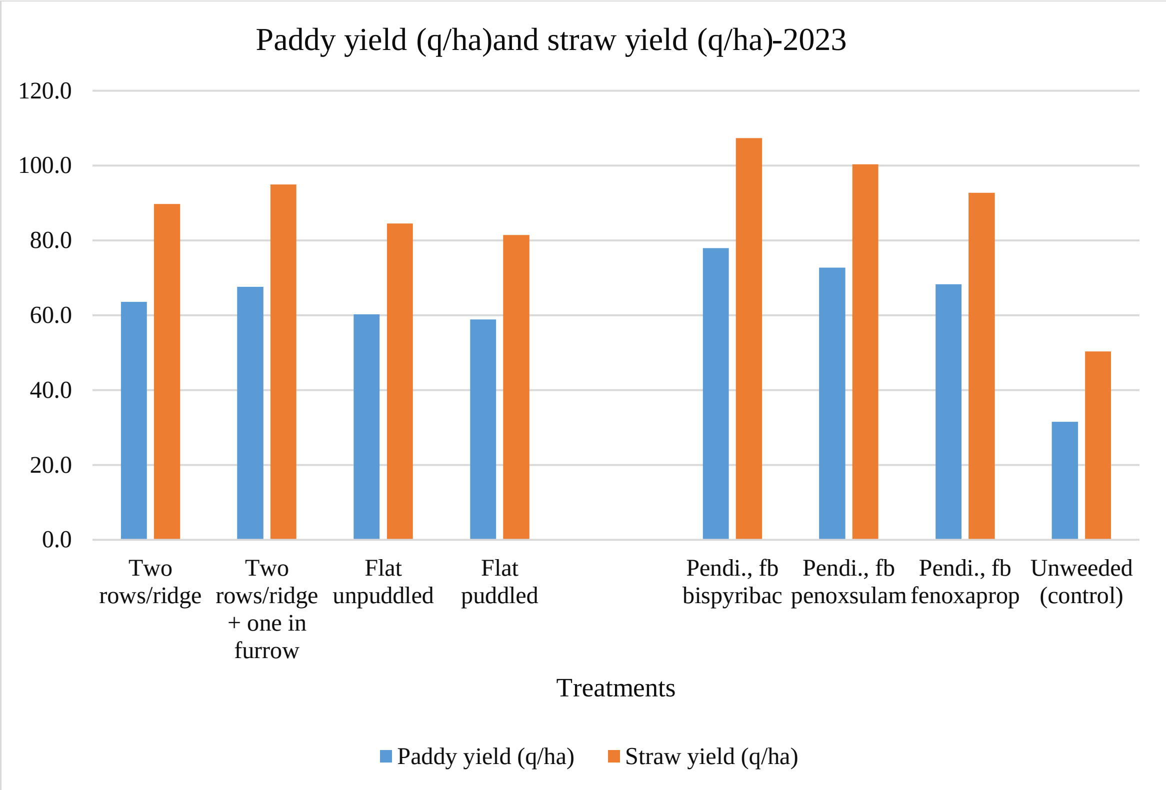
Table 4.3.4: Interactive effect of planting patterns and weed control treatments on paddy yield (q/ha) during 2023 and 2024.

Paddy yield (q/ha)- 2023

	Pendi., pre-em *fb* bispyribac sodium	**Pendi., pre-em *fb* penoxsulam**	**Pendi., pre-em *fb* fenoxaprop-p-ethyl**	**Unweeded (control)**	**Mean A**
Two rows/ridge	80.7	75.2	68.0	30.5	**63.6**
Two rows/ridge + one in furrow	83.3	78.6	73.6	34.9	**67.6**
Flat unpuddled	74.8	71.8	64.2	30.1	**60.2**
Flat puddled	72.7	65.2	67.5	30.5	**59.0**
Mean B	**77.9**	**72.7**	**68.3**	**31.5**	
SEm (±)	**1.20**				
C.D. (5%)	**4.21**				

Paddy yield (q/ha)- 2024

	Pendi., pre-em *fb* bispyribac sodium	**Pendi., pre-em *fb* penoxsulam**	**Pendi., pre-em *fb* fenoxaprop-p-ethyl**	**Unweeded (control)**	**Mean A**
Two rows/ridge	79.2	77.0	69.2	33.5	**64.7**
Two rows/ridge + one in furrow	80.1	77.6	76.8	35.6	**67.5**
Flat unpuddled	74.8	72.0	66.5	32.2	**61.4**
Flat puddled	73.3	69.8	66.7	32.5	**60.6**
Mean B	**76.9**	**74.1**	**69.8**	**33.4**	
SEm (±)	**0.84**				
C.D. (5%)	**3.55**				



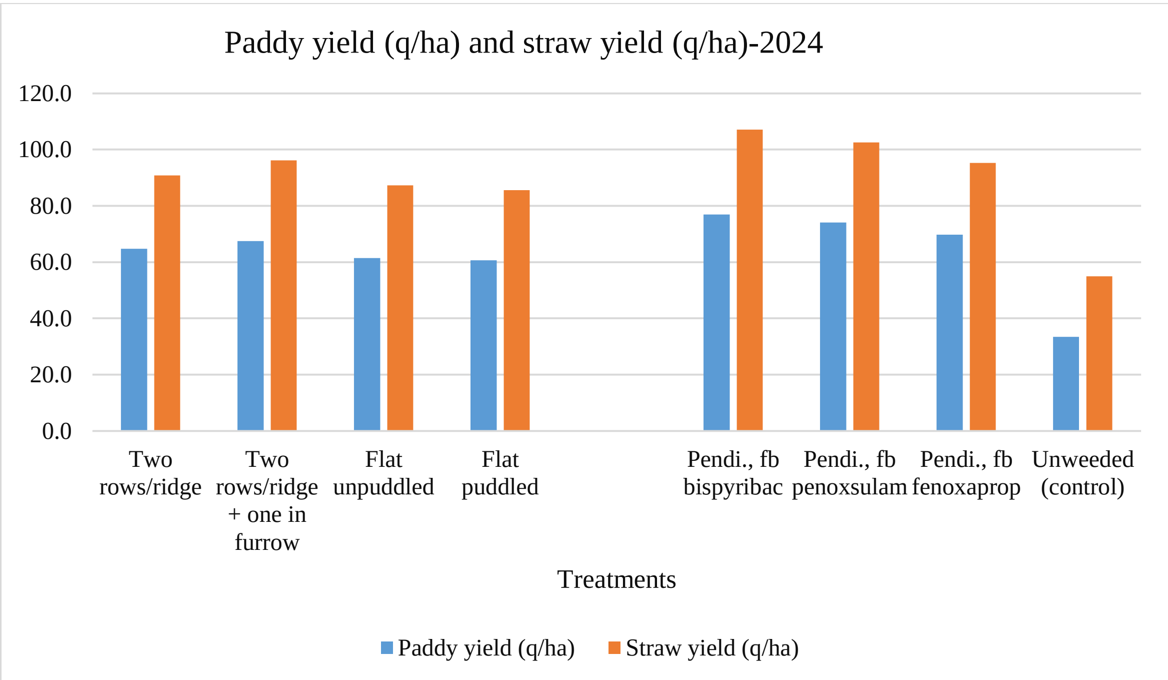


Fig 4.3.3: Effect of planting patterns and weed control treatments on paddy yield (q/ha) and straw yield (q/ha).

4.3.4 Biological yield (q/ha) and Harvest Index (%):

Biological yield (q/ha) of rice measures the total biomass produced by the crop, including both grain and straw yield. Harvest index is an important measure for assessing the balance between grain and straw production in rice. It identifies the effectiveness of crop management practices, with higher values indicating improves grain output relative to total biomass. Data pertaining to biological yield and harvest index of rice, as influenced by different planting patterns and weed control treatments during 2023 and 2024 has been compiled in Table 4.3.5.

Perusal of data at harvest during 2023 revealed that there was significant effect of planting patterns and weed control treatments on biological yield (Table 4.3.5). The planting pattern with two rows/ridge + one in furrow produced significantly highest biological yield as compared to other planting patterns. The biological yield in two rows/ridge was significantly more than flat puddled and flat unpuddled methods. However, flat puddled and flat unpuddled were at par with each other and produced significantly less biological yield when compared to both ridge-based planting patterns. Among the weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly more biological yield than all other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence produced significantly more biological yield than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence. However, significantly low biological yield was recorded in unweeded (control) than all other herbicidal treatments. Similar outcomes were observed in 2024 as well.

Data at harvest showed that the difference in harvest index among the planting patterns was non-significant during both years (Table 4.3.5). Regarding the sub plots, treatments comprising pendimethalin pre-emergence *fb* penoxsulam post-emergence, pendimethalin pre-emergence *fb* bispyribac sodium post-emergence and pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence were observed to have significantly higher values of harvest index as compared to unweeded (control) and all the former treatments were statistically at par with each other.

The planting pattern with two rows/ridge + one in furrow likely increased the surface area and provided better soil aeration, promoting the growth and biomass of crop plants. Additionally, early canopy closure in this treatment restricted the weed growth, increasing the availability of resources to crop plants, enhancing the tiller production and dry matter accumulation, thereby increasing overall biological yield. The results are in congruity with Vethaiya *et al.* (2003) and Jat and Sharma (2013). Due to their broad-spectrum efficacy pendimethalin pre-emergence *fb* bispyribac sodium post-emergence controlled diverse range of weed species, resulting in reduced crop-weed competition which increased the availability of light, water and nutrients to the crop plants, promoting better tiller production and dry matter accumulation ultimately increasing biological yield. Similar findings were reported by Dhanpal *et al.* (2018).

The interactive effects of planting patterns and weed control treatments on biological yield and harvest index of rice were found to be non-significant during both the years of study (Table 4.3.5).

Table 4.3.5: Influence of planting patterns and weed control treatments on biological yield (q/ha) and harvest index (%) of rice.

Treatments	Biological yield (q/ha)		Harvest index (%)	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	153.3	155.5	41.1	41.2
Two rows/ridge + one in furrow	162.4	163.7	41.2	40.8
Flat unpuddled	144.7	148.7	41.2	40.8
Flat puddled	140.3	146.1	41.6	41.1
SEm (±)	1.68	1.31	0.13	0.18
C.D. (5%)	**5.38**	**4.18**	**NS**	**NS**
Sub-plots (Weed control treatments)				
Pendi., pre-em *fb* bispyribac sodium	185.1	184.0	42.1	41.8
Pendi., pre-em *fb* penoxsulam	173.0	176.6	42.0	42.0
Pendi., pre-em *fb* fenoxaprop-p-ethyl	161.0	165.0	42.5	42.3
Unweeded (control)	81.8	88.4	38.5	37.9
SEm (±)	1.88	1.77	0.22	0.18
C.D. (5%)	**5.39**	**5.07**	**0.63**	**0.51**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**

4.4 Economics:

The successful adoption of any modern agricultural technology by farmers depends largely on its economic viability, which is determined by factors such as cost of cultivation, gross returns, net returns, and the benefit–cost ratio which are used to assess the impact of various treatments during experimentation. Data regarding economics of various main and sub-plot treatments during 2023 and 2024 has been presented in Table 4.4.1.

Perusal of data during 2023 and 2024 indicated that maximum cost of cultivation was incurred under the planting pattern of flat puddled which was followed by two rows/ridge + one in furrow and two rows/ridge transplanting methods, whereas flat unpuddled method recorded with minimum cost of cultivation. Among weed control treatments, highest cost of cultivation was observed with application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence followed by pendimethalin pre-emergence *fb* bispyribac sodium post-emergence and pendimethalin pre-emergence *fb* penoxsulam post-emergence. Conversely, lowest cost of cultivation was recorded in control (unweeded) treatment during both the years of study.

Data obtained during 2023 and 2024 showed that the highest gross return was obtained in the planting pattern with two rows/ridge + one in furrow followed by two rows/ridge, while the lowest gross returns were recorded under flat puddled method. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded highest gross returns among the weed control treatments, which was followed by pendimethalin pre-emergence *fb* penoxsulam post-emergence, whereas lowest gross returns were observed in control (unweeded) during both the years of study.

Highest net returns of Rs 119126 and Rs 118630 during 2023 and 2024 respectively were observed under the planting pattern comprising two rows/ridge + one in furrow, followed by two rows/ridge method. In contrast, lowest net returns were obtained under flat puddled during both the years. Among weed control treatments, highest net returns of Rs 144322 and Rs 141872 during 2023 and 2024 respectively were observed with the application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence and this treatment was followed by pendimethalin pre-emergence *fb* penoxsulam post-emergence, while lowest net returns were observed in control (unweeded) treatment during both the years.

Perusal of data during 2023 and 2024 revealed that planting pattern of two rows/ridge + one in furrow recorded highest B:C ratio of 2.4 and 2.2 during 2023 and 2024 respectively, which was followed by two rows/ridge and flat unpuddled, whereas lowest B:C ratio was observed in flat puddled transplanting method. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded highest B:C ratio of 2.9 and 2.7 during 2023 and 2024 respectively, followed by pendimethalin pre-emergence *fb* penoxsulam post-emergence whereas, lowest B:C ratio was recorded under control (unweeded) treatment during both years.

Table 4.4.1: Influence of planting patterns and weed control treatments on cost of cultivation (Rs/ha), gross returns (Rs/ha), net returns (Rs/ha) and B:C ratio of rice

Treatments	**Cost of Cultivation (Rs/ha)**		**Gross returns (Rs/ha)**		**Net returns (Rs/ha)**		**B:C ratio**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	49638	53321	158896	164593	109258	111272	2.2	2.1
Two rows/ridge + one in furrow	49638	53321	168764	171951	119126	118630	2.4	2.2
Flat unpuddled	48138	51821	150432	156311	102294	104490	2.1	2.0
Flat puddled	50138	53821	147009	154184	96871	100363	1.9	1.9
Sub-plots (Weed control treatments)								
Pendi., pre-em *fb* bispyribac sodium	49828	53511	194150	195383	144322	141872	2.9	2.7
Pendi., pre-em *fb* penoxsulam	49358	53041	181246	188197	131888	135156	2.7	2.5
Pendi., pre-em *fb* fenoxaprop-p-ethyl	50458	54141	170110	177071	119652	122930	2.4	2.3
Unweeded (control)	47908	51591	79595	86389	31687	34798	0.7	0.7

4.5 Quality parameters:

4.5.1 Nitrogen content of grains (%)

Nitrogen content in rice grains helps determine the nutritional quality of rice, as nitrogen is a critical component of proteins. Data pertaining to nitrogen content of grains (%) as influenced by various planting patterns and weed control treatments during 2023 and 2024 has been presented in Table 4.5.1.

Analysis of data at harvest during 2023 indicated that the differences in nitrogen content of grains among the planting patterns was non-significant (Table 4.5.1). Likewise, weed control treatments had no significant impact on nitrogen content of grains. Similar findings were noticed during 2024 also.

Across both the years of study, the interactive effect of planting patterns and weed control treatments on nitrogen content of grains was found to be non-significant (Table 4.5.1).

4.5.2 Protein content in grains (%)

Measuring protein content in grains is essential as it impacts the crop's nutritional profile, making it beneficial for human health. Data regarding protein content in grains (%) as influenced by various planting patterns and weed control treatments during 2023 and 2024 has been summarized in Table 4.5.1.

Perusal of data at harvest during 2023 and 2024 revealed that there was no significant impact of planting patterns and weed control treatments on protein content in grains (Table 4.5.1).

The interactive effect of planting patterns and weed control treatments on protein content remained non-significant during both the years of study (Table 4.5.1)

4.5.3 Nitrogen uptake by grains (kg/ha)

Evaluating nitrogen uptake by grains helps in determining the efficiency of nitrogen use and its allocation for grain formation. Data on nitrogen uptake by grains (kg/ha) under varying planting patterns and weed control treatments during 2023 and 2024 has been compiled in Table 4.5.1 and Figure 4.4.1

Data collected at harvest during 2023 demonstrated that planting patterns had significant impact on nitrogen uptake by grains (Table 4.5.1). Adopting two rows/ridge + one in furrow significantly increased the nitrogen uptake as compared to other treatments. Meanwhile, two rows/ridge, flat puddled and flat unpuddled remained statistically at par with each other. Among the sub plots, application of pendimethalin pre-emergence fb bispyribac sodium post-emergence recorded significantly higher nitrogen uptake by grains in comparison to other weed control treatments. Pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more nitrogen uptake by grains than pendimethalin pre-emergence fb fenoxaprop-p-ethyl post-emergence. Conversely, unweeded (control) recorded significantly less nitrogen uptake by grains as compared to all other treatments. During 2024, planting pattern with two rows/ridge + one in furrow recorded significantly more nitrogen uptake by grains as compared to other planting methods. Planting pattern of two rows/ridge recorded significantly more nitrogen uptake by grains than flat unpuddled and flat puddled which remained at par with each other. Amongst the weed control treatments, application of pendimethalin pre-emergence *fb* bispyribac sodium post emergence significantly increased the nitrogen uptake by grains as compared to other treatments. Whereas application of pendimethalin pre-emergence *fb* penoxsulam post-emergence recorded significantly more nitrogen uptake by grains than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post- emergence. Contrarily, significantly less nitrogen uptake by grains was observed in unweeded (control) as compared to all herbicidal treatments.

The increased nitrogen uptake in rice grains can be attributed to reduced competition among plants for nutrients and water in the two rows/ridge + one in the furrow system, allowing the roots to access adequate nitrogen from the soil. Also crop enjoyed better soil physical conditions in this treatment. The results are in conformity with Singh *et al.* (2008). The higher nitrogen uptake in rice grains may have resulted from effective weed control by the sequential application of pendimethalin *fb* bispyribac sodium, which likely reduced competition for nitrogen between weeds and the rice crop. Similar findings were reported by Singh *et al.* (2023).

The interactive effect of planting patterns and weed control treatments had non-significant impact on nitrogen uptake by grains during both the years of study (Table 4.5.1).

Table 4.5.1: Influence of planting patterns and weed control treatments on nitrogen content of grains (%), protein content of grains (%) and nitrogen uptake by grains (kg/ha).

Treatments	**Nitrogen content of grains (%)**		**Protein content of grains (%)**		**Nitrogen uptake by grains (kg/ha)**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	1.21	1.27	7.58	7.93	78.7	82.4
Two rows/ridge + one in furrow	1.26	1.25	7.88	7.80	85.6	84.5
Flat unpuddled	1.24	1.24	7.77	7.75	75.1	76.2
Flat puddled	1.23	1.23	7.69	7.72	73.8	75.1
SEm (±)	0.02	0.01	0.15	0.05	1.89	0.58
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**6.56**	**2.02**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	1.28	1.27	7.97	7.94	99.5	98.0
Pendi., pre-em *fb* penoxsulam	1.24	1.25	7.77	7.83	91.3	92.9
Pendi., pre-em *fb* fenoxaprop-p-ethyl	1.24	1.24	7.76	7.77	84.7	86.6
Unweeded (control)	1.19	1.23	7.42	7.66	37.7	40.6
SEm (±)	0.02	0.01	0.13	0.07	1.73	1.35
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**5.04**	**3.93**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.5.4 Nitrogen content of straw (%)

Nitrogen content of straw is essential for understanding nutrient cycling as straw contains a significant amount of nitrogen, and its decomposition contributes to soil fertility by releasing nitrogen for subsequent crops. Data regarding nitrogen content in straw (%) under varying planting patterns and weed control treatments during 2023 and 2024 has been compiled in Table 4.5.2.

Data obtained at harvest during 2023 and 2024 revealed that there was no significant impact of planting patterns on nitrogen content of straw (Table 4.5.2). Likewise, the differences in nitrogen content of straw among the weed control treatments were non-significant during both the years of study.

Both the years of study revealed that the interactive effect of planting patterns and weed control had no significant impact on nitrogen content of straw (Table 4.5.2).

4.5.5 Nitrogen uptake by straw (kg/ha)

Recording nitrogen uptake by straw is very crucial, as it helps assess the efficiency of nitrogen utilization by the plant. Data pertaining to nitrogen uptake by straw (%) as influenced by various planting patterns and weed control treatments during 2023 and 2024 has been presented in Table 4.5.2 and Figure 4.4.1.

Perusal of data at harvest during 2023 indicated that planting pattern with two rows/ridge + one in furrow recorded significantly higher nitrogen uptake by straw in comparison with flat puddled, flat unpuddled and two rows/ridge which remained at par with each other (Table 4.5.2). Among the weed control treatments, significantly higher nitrogen uptake by straw was observed with the application of pendimethalin pre-emergence *fb* bispyribac sodium post emergence as compared to other treatments. Application of pendimethalin pre-emergence *fb* penoxsulam post emergence recorded significantly more nitrogen uptake by straw than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post emergence. In contrast, significantly less nitrogen uptake by straw was observed in unweeded (control) in comparison to other weed control treatments. These trends remained consistent in 2024 as well.

Higher nitrogen uptake may have been influenced by better root proliferation in the two rows/ridge + one in furrow system, which allowed the plants to access deeper soil layers rich in nitrogen which improved nitrogen availability and absorption by the rice plants. The results are in congruity with Tang *et al.* (2005). The increased nitrogen uptake by straw is likely due to the combined action of pendimethalin *fb* bispyribac sodium, which controlled weeds during critical growth stages, ensuring that rice plants had uninterrupted access to nitrogen for optimal growth and biomass accumulation. Similar findings were reported by Mitra *et al.* (2022).

The interactive effect of planting patterns and weed control treatments on nitrogen uptake by straw remained non-significant during both the years of study (Table 4.5.2)

4.5.6 Total nitrogen uptake by crop (kg/ha)

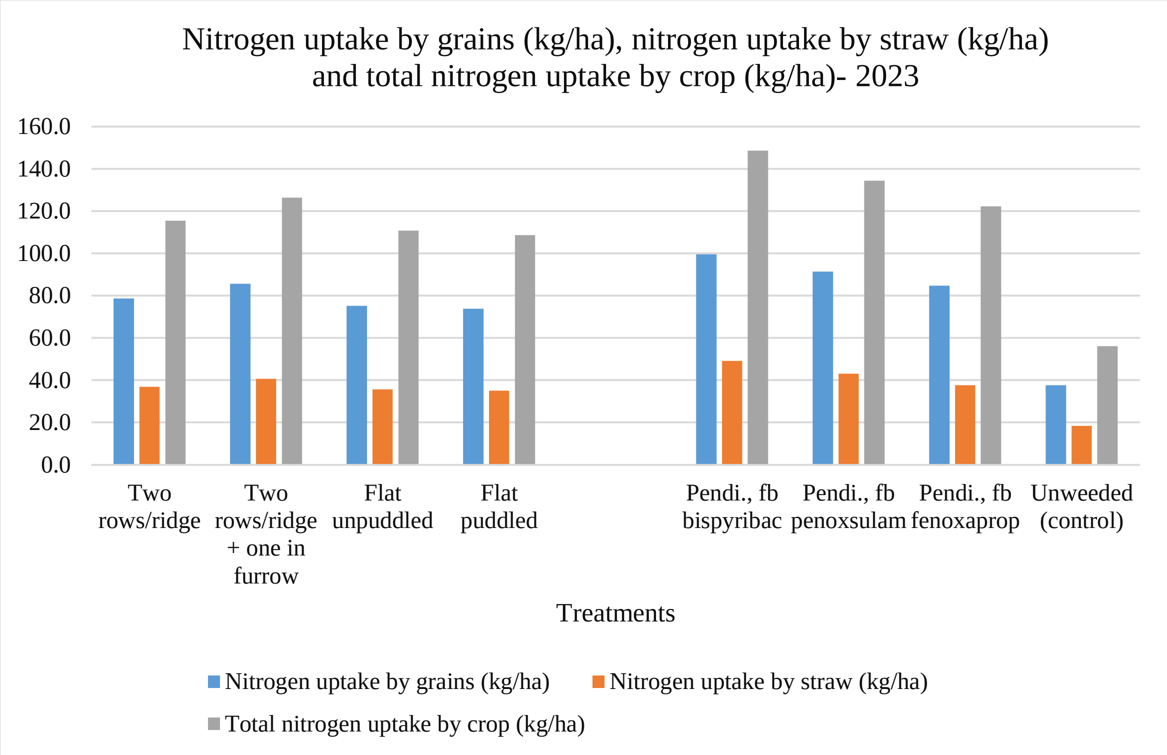
Total nitrogen uptake by crop helps in determining the nitrogen utilized by plant (grain and straw). Data on total nitrogen uptake by crop under varying planting patterns and weed control treatments during 2023 and 2024 has been compiled in Table 4.5.2 and Figure 4.4.1.

Analysis of data at harvest during 2023 indicated that there was significant impact of planting patterns on total nitrogen uptake by crop. Planting pattern of two rows/ridge + one in furrow significantly increased the total nitrogen uptake by crop than two rows/ridge, flat puddled and flat unpuddled which remained statistically at par with each other. Amongst the weed control treatments, significantly higher total nitrogen uptake by crop was observed with the application of pendimethalin pre-emergence *fb* bispyribac sodium post emergence. Application of pendimethalin pre-emergence *fb* penoxsulam post emergence recorded significantly more total nitrogen uptake by crop than pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post emergence. Conversely, unweeded (control) recorded significantly less total nitrogen uptake by crop in comparison to all other herbicidal treatments. Similar trends in results were noticed in 2024 also.

Across both the years of study, the interactive effect of planting patterns and weed control treatments had no significant impact on total nitrogen uptake by crop (Table 4.5.2).

Table 4.5.2: Influence of planting patterns and weed control treatments on nitrogen content of straw (%), nitrogen uptake by straw (kg/ha) and total nitrogen uptake by crop (kg/ha).

Treatments	Nitrogen content of straw (%)		Nitrogen uptake by straw (kg/ha)		Total nitrogen uptake by crop (kg/ha)	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	0.41	0.42	36.8	36.3	115.5	118.6
Two rows/ridge + one in furrow	0.42	0.42	40.7	40.7	126.4	125.1
Flat unpuddled	0.41	0.42	35.6	35.3	110.7	111.5
Flat puddled	0.41	0.43	35.0	35.9	108.7	110.9
SEm (±)	0.01	0.01	0.94	1.05	2.05	0.95
C.D. (5%)	**NS**	**NS**	**3.26**	**3.65**	**7.09**	**3.28**
Sub-plots (Weed control treatments)						
Pendi., pre-em *fb* bispyribac sodium	0.46	0.44	49.1	46.1	148.6	144.1
Pendi., pre-em *fb* penoxsulam	0.43	0.42	43.0	42.2	134.3	135.1
Pendi., pre-em *fb* fenoxaprop-p-ethyl	0.41	0.41	37.6	38.2	122.3	124.7
Unweeded (control)	0.36	0.41	18.4	21.6	56.1	62.3
SEm (±)	0.01	0.01	1.40	1.09	2.02	2.02
C.D. (5%)	**NS**	**NS**	**4.09**	**3.18**	**5.89**	**5.91**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



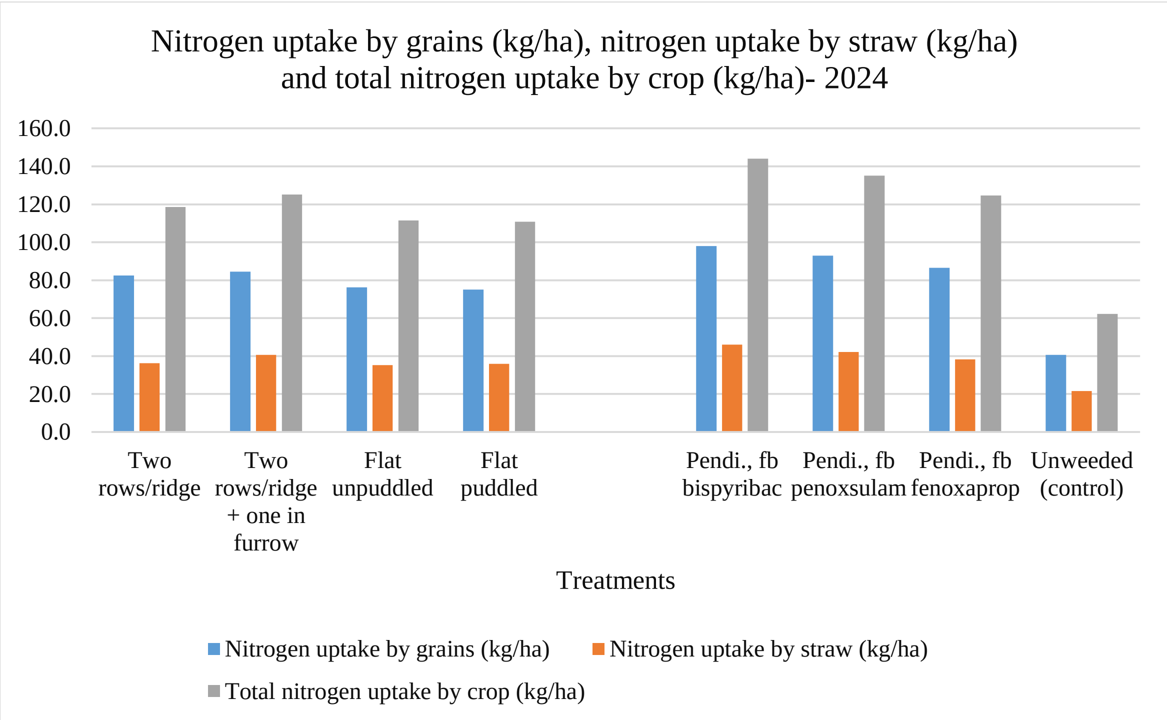


Fig 4.5.1: Effect of planting patterns and weed control treatments on nitrogen uptake by grains (kg/ha), nitrogen uptake by straw (kg/ha) and total nitrogen uptake by crop (kg/ha).

4.5.7 Nitrogen content of weeds (%)

Recording nitrogen content in weeds during rice cultivation is essential for assessing their competitive impact on nutrient availability. Data pertaining to nitrogen content of weeds (%) under varying planting patterns and weed control treatments during 2023 and 2024 has been compiled in Table 4.5.3.

Analysis of data at harvest revealed that the differences in nitrogen content of weeds among the planting patterns and weed control treatments remained non-significant during both the years of study (Table 4.5.3).

The interactive effect of planting patterns and weed control treatments on nitrogen content of weeds was found to be non-significant during both the years of study (Table 4.5.3)

4.5.8 Nitrogen uptake by weeds (kg/ha)

Nitrogen uptake by weeds (kg/ha) is essential as it helps to quantify the nutrient loss caused by weed competition. Data on nitrogen uptake by weeds (kg/ha) as influenced by planting patterns and weed control treatments during 2023 and 2024 has been summarized in Table 4.5.3 and Figure 4.4.2.

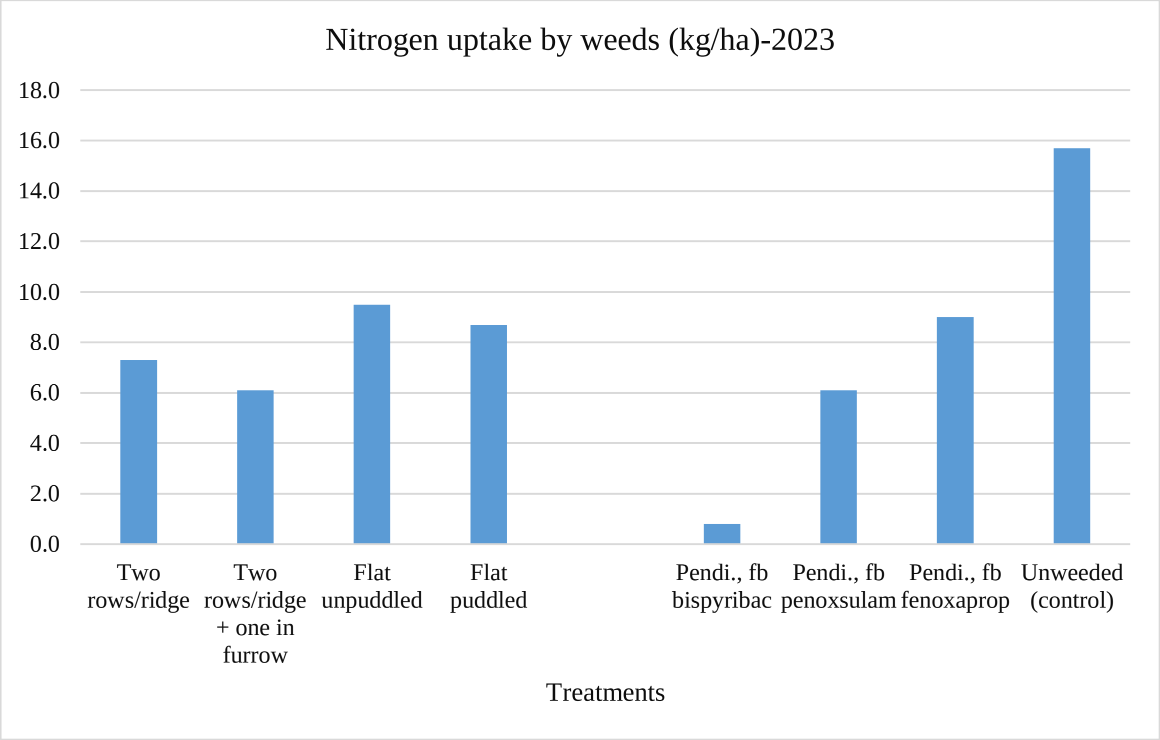
Perusal of data at harvest during 2023 and 2024 showed that implementing the planting pattern with two rows/ridge + one in furrow significantly reduced the nitrogen uptake by weeds as compared to other treatments (Table 4.5.3). Meanwhile, flat unpuddled recorded significantly more nitrogen uptake by weeds than flat puddled. However, flat unpuddled recorded significantly higher nitrogen uptake by weeds as compared to other planting methods. Among sub plots, application of pendimethalin pre-emergence *fb* bispyribac sodium post emergence recorded significantly lower nitrogen uptake by weeds in comparison to other treatments. Meanwhile, application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post emergence recorded significantly more nitrogen uptake by weeds than pendimethalin pre-emergence *fb* penoxsulam post emergence. In contrast, unweeded (control) recorded significantly higher nitrogen uptake by weeds as compared to other weed control treatments. Similar findings were obtained in 2024 as well.

This increase in nitrogen uptake by weeds is likely due to their aggressive growth and ability to quickly absorb nutrients in the absence of competition or suppression, as no herbicides were applied to the control plots. Similar findings were reported by Burgos *et al.* (2006).

The interactive effect of planting patterns and weed control treatments on nitrogen uptake by weeds was found to be non-significant during both the years of study (Table 4.5.3)

Table 4.5.3: Influence of planting patterns and weed control treatments on nitrogen content of weeds (%) and nitrogen uptake by weeds (kg/ha).

Treatments	**Nitrogen content of weeds (%)**		**Nitrogen uptake by weeds (kg/ha)**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	0.41	0.42	7.3	7.6
Two rows/ridge + one in furrow	0.42	0.40	6.1	6.5
Flat unpuddled	0.43	0.42	9.5	9.8
Flat puddled	0.44	0.42	8.7	8.7
SEm (±)	0.01	0.01	0.20	0.31
C.D. (5%)	**NS**	**NS**	**0.70**	**1.06**
Sub-plots (Weed control treatments)				
Pendi., pre-em *fb* bispyribac sodium	0.43	0.41	0.8	1.3
Pendi., pre-em *fb* penoxsulam	0.41	0.40	6.1	6.1
Pendi., pre-em *fb* fenoxaprop-p-ethyl	0.42	0.42	9.0	9.1
Unweeded (control)	0.44	0.43	15.7	16.1
SEm (±)	0.01	0.01	0.35	0.34
C.D. (5%)	**NS**	**NS**	**1.02**	**0.99**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**



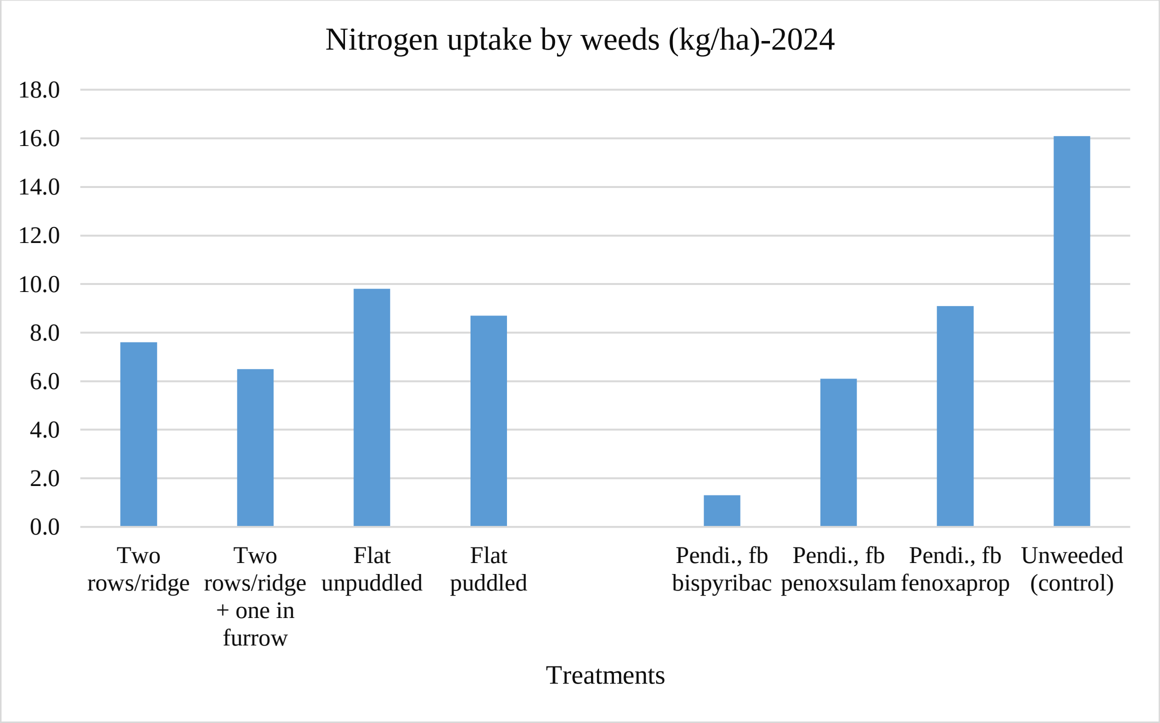


Fig 4.5.2: Effect of planting patterns and weed control treatments on nitrogen uptake by weeds (kg/ha)

Experiment II: Influence of planting patterns and nitrogen levels on the yield of transplanted rice under unpuddled conditions

The findings of this experiment are presented under the following subheadings.

4.1 Weed dynamics:

Weed count/m^2 serves as a critical parameter for assessing the severity of weed interference and its competitive impact on crop growth. High densities of weeds compete aggressively with the crop for nutrients and water during critical growth stage, leading to reduced photosynthetic activity and substantial yield penalties.

4.1.1 Count of grassy weeds (m^{-2}):

Data pertaining to periodic grassy weed count/m^2 at 60, 90 DAT and harvest as influenced by planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.1.1.

Perusal of data at 60, 90 DAT and at harvest during 2023 and 2024 indicated that there was no significant impact of planting patterns on grassy weed count/m^2 (Table 4.1.1). Likewise, the difference in grassy weed count/m^2 among the nitrogen levels was non-significant during both the years of study at all periodic intervals.

The interactive effect of planting patterns and nitrogen levels on periodic weed count/m^2 of grassy weeds remained non-significant at 60, 90 DAT and at harvest during both the years of study (Table 4.1.1).

Table 4.1.1: Impact of planting patterns and nitrogen levels on periodic count of grassy weeds/m^2.

	Count of grassy weeds (m^{-2})					
Treatments	**60 DAT**		**90 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	1.4	2.4	5.8	13.4	6.5	10.4
Two rows/ridge + one in furrow	0.7	1.7	7.2	12.0	7.9	10.8
Flat unpuddled	0.3	1.4	10.0	15.5	11.0	14.2
Flat puddled	0.3	2.1	7.6	12.7	8.9	11.4
SEm (±)	0.51	0.83	2.15	1.32	1.32	1.47
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Nitrogen levels)						
0 kg N/ha	0.0	1.0	6.5	11.7	7.6	10.1
80 kg N/ha	1.4	2.4	7.9	14.8	9.6	12.5
120 kg N/ha	1.0	1.7	8.9	14.4	8.9	13.5
160 kg N/ha	0.3	2.4	7.2	12.7	8.3	10.8
SEm (±)	0.62	0.77	1.63	1.02	1.69	1.26
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.1.2 Count of broadleaf weeds (m^{-2}):

Data on periodic count of broadleaf weeds (m^{-2}) at 60, 90 DAT and at harvest under varying planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.1.2.

Data recorded at 60, 90 DAT and harvest during 2023 revealed that the difference in broadleaf weed count/m^2 among the planting patterns was found to be non-significant (Table 4.1.2). Similarly, different nitrogen levels had non-significant impact on the broadleaf weed count/m^2. These trends remained consistent in 2024 as well.

The interaction between planting patterns and nitrogen levels at 60, 90 DAT and at harvest showed non-significant effects on periodic count of broadleaf weeds (m^{-2}) during both years of the study (Table 4.1.2).

Table 4.1.2: Impact of planting patterns and nitrogen levels on periodic count of broadleaf weeds/m^2.

	Count of broadleaf weeds (m^{-2})					
Treatments	**60 DAT**		**90 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	1.4	1.7	3.8	5.2	5.2	7.2
Two rows/ridge + one in furrow	1.0	1.4	6.9	9.3	7.9	9.6
Flat unpuddled	1.4	1.0	6.9	9.6	8.9	8.9
Flat puddled	0.3	1.7	7.2	7.9	7.9	10.7
SEm (±)	0.83	0.37	1.15	1.12	1.20	0.97
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Nitrogen levels)						
0 kg N/ha	0.3	0.3	3.8	4.8	5.8	6.5
80 kg N/ha	1.0	2.1	7.6	9.3	8.3	9.3
120 kg N/ha	2.4	2.1	8.9	9.3	8.6	10.0
160 kg N/ha	0.3	1.4	4.5	8.6	7.2	10.7
SEm (±)	0.81	0.71	1.56	1.43	1.28	1.45
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.1.3 Dry matter of grassy weeds (q/ha):

Weed dry matter in rice cultivation is crucial as it quantifies the total biomass of weeds competing with the crop. High biomass accumulation by weeds not only reduces nutrient availability but also hampers root development resulting in stunted plant growth and lower grain yields. Recording dry matter accumulation by weeds is more valid parameter than weed count as losses in crop yield are directly related to weed dry matter. Data regarding periodic weed dry matter of grassy weeds (q/ha) at 60, 90 DAT and at harvest as influenced by planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.1.3.

Perusal of data at 60, 90 DAT and at harvest during 2023 showed that there was non-significant effect of planting patterns on weed dry matter of grassy weeds (Table 4.1.3). Likewise, non-significant differences in weed dry matter of grassy weeds was observed among the nitrogen levels. These findings were replicated during the year 2024, showing similar outcomes.

Both years of the study revealed that the interactive effects between planting patterns and nitrogen levels did not have a significant impact on periodic weed dry matter of grassy weeds (Table 4.1.3).

Table 4.1.3: Impact of planting patterns and nitrogen levels on periodic dry matter of grassy weeds (q/ha).

	Dry matter of grassy weeds (q/ha)					
Treatments	**60 DAT**		**90 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	0.2	0.4	0.6	1.3	0.9	1.3
Two rows/ridge + one in furrow	0.1	0.3	0.8	1.0	1.0	1.4
Flat unpuddled	0.0	0.3	1.2	1.5	1.3	1.8
Flat puddled	0.0	0.3	0.9	1.1	1.0	1.6
SEm (±)	0.05	0.13	0.21	0.24	0.18	0.23
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Nitrogen levels)						
0 kg N/ha	0.0	0.1	0.8	1.0	0.9	1.4
80 kg N/ha	0.1	0.5	0.9	1.4	1.1	1.5
120 kg N/ha	0.1	0.3	1.1	1.5	1.1	1.9
160 kg N/ha	0.0	0.4	0.7	1.1	1.0	1.3
SEm (±)	0.06	0.13	0.17	0.21	0.19	0.22
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.1.4 Dry matter of broadleaf weeds (q/ha):

Data pertaining to periodic weed dry matter of broadleaf weeds (q/ha) at 60, 90 DAT and at harvest under various planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.1.4.

During 2023, there was not any notable impact of planting patterns on weed dry matter of broadleaf weeds at 60, 90 DAT and harvest (Table 4.1.4). Likewise, there was non-significant impact of nitrogen levels on weed dry matter of broadleaf weeds. These trends remained consistent during 2024 as well.

Across both years, the interactive effect of planting patterns and nitrogen levels on periodic weed dry matter of broadleaf weeds was found to be non-significant (Table 4.1.4).

Table 4.1.4: Periodic dry matter of broadleaf weeds (q/ha) as influenced by planting patterns and nitrogen levels.

	Dry matter of broadleaf weeds (q/ha)					
Treatments	**60 DAT**		**90 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	0.2	0.2	0.3	0.6	0.6	1.4
Two rows/ridge + one in furrow	0.1	0.2	0.7	1.3	0.8	1.7
Flat unpuddled	0.2	0.2	0.6	1.5	1.0	1.4
Flat puddled	0.0	0.3	0.8	1.0	0.8	1.5
SEm (±)	0.08	0.07	0.09	0.18	0.14	0.19
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Nitrogen levels)						
0 kg N/ha	0.1	0.1	0.4	0.6	0.6	1.0
80 kg N/ha	0.1	0.3	0.7	1.2	0.9	1.6
120 kg N/ha	0.2	0.3	0.9	1.3	0.9	1.7
160 kg N/ha	0.0	0.2	0.4	1.2	0.8	1.6
SEm (±)	0.08	0.11	0.14	0.21	0.15	0.24
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.2 Plant growth parameters:

4.2.1 Establishment percentage:

Establishment percentage per unit area serves as an indicator of seedling survival and field adaptability. A higher establishment percentage ensures uniform crop growth and optimal resource utilization, which directly impacts yield. Data pertaining to establishment percentage of rice at 20 DAT under varying planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.2.1.

Data recorded at 20 DAT during 2023 demonstrated that there was not any significant effect of planting patterns on establishment percentage of rice (Table 4.2.1). Likewise, the differences in the establishment percentage among the nitrogen levels was found to be non-significant. Similar findings were observed during 2024 also.

The interactive effect of planting patterns and nitrogen levels was found to be non-significant during both the years of study (Table 4.2.1) for establishment percentage recorded 20 DAT.

Table 4.2.1: Impact of planting patterns and nitrogen levels on establishment percentage of rice.

Treatments	Establishment percentage (20 DAT)	
Main plots (Planting patterns)	**2023**	**2024**
Two rows/ridge	87.8	88.1
Two rows/ridge + one in furrow	91.8	91.8
Flat unpuddled	85.6	88.9
Flat puddled	83.6	88.4
SEm (±)	2.34	2.19
C.D. (5%)	**NS**	**NS**
Sub-plots (Nitrogen levels)		
0 kg N/ha	88.5	92.7
80 kg N/ha	87.1	88.0
120 kg N/ha	86.7	89.6
160 kg N/ha	86.5	86.9
SEm (±)	1.94	1.67
C.D. (5%)	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**

4.2.2 Plant height (cm):

Plant height serves as a measure of growth dynamics, reflecting the plant's ability to utilize resources efficiently. Generally, taller plants often lead to better reproductive development, contributing to higher yields. Data on periodic plant height of rice at 30, 60 DAT and at harvest as influenced by planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.2.2 and depicted in figure 4.2.1.

At 30 DAT, during 2023 there was no significant impact of planting patterns on plant height (cm) of rice (Table 4.2.2). Among the nitrogen levels, plant height recorded at 30 DAT with application of 120 kg N/ha was statistically at par with 160 kg N/ha and was significantly more as compared to other nitrogen levels. However, significantly lowest plant height was observed in 0 kg N/ha (control). Similar findings were observed in 2024 as well.

Perusal of data at 60 DAT during 2023 and 2024 revealed that non-significant difference in plant height (cm) were observed among the planting patterns (Table 4.2.2). Among the subplots, plant height observed at 60 DAT with application of 160 kg N/ha was at par with 120 kg N/ha and both the treatments recorded significantly more plant height when compared to other treatments. Meanwhile, significantly lower plant height was recorded in 0 kg N/ha (control) during both the years of study.

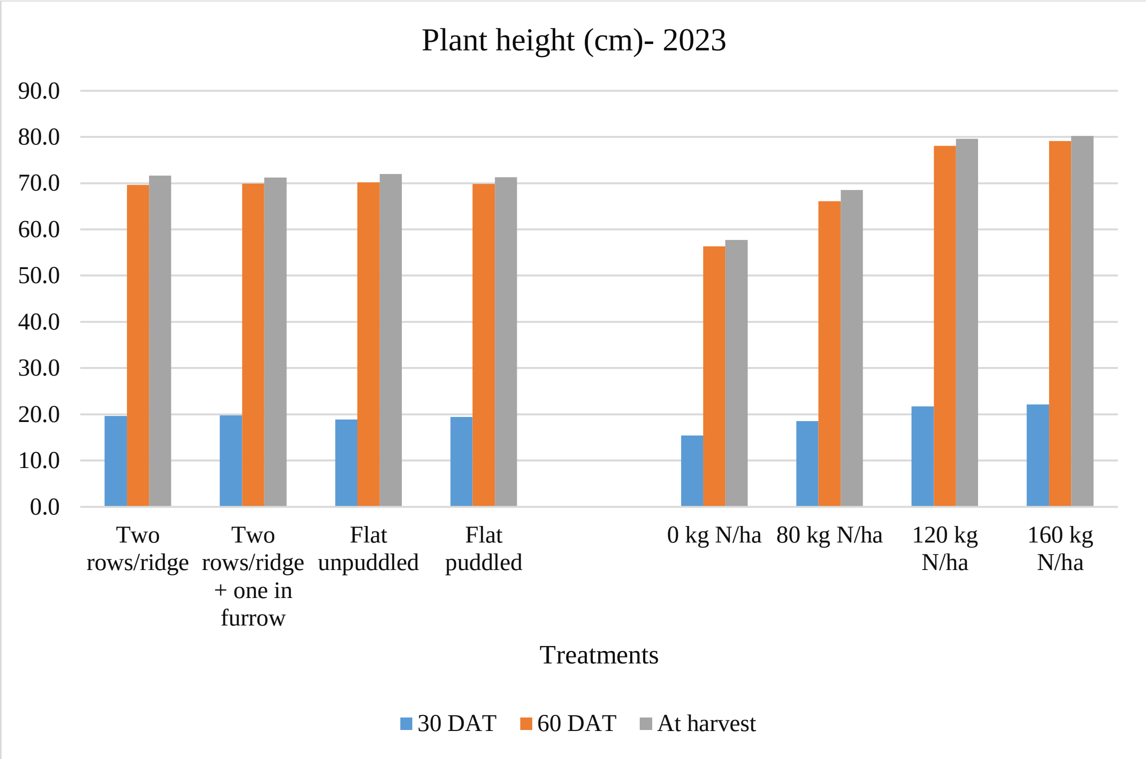
Data recorded at harvest during 2023 showed that the differences in plant height among the planting patterns were non-significant (4.2.2). Among the nitrogen levels, plant height recorded with application of 160 kg N/ha at harvest was statistically comparable with 120 kg N/ha and it was significantly higher as compared to other nitrogen levels. Conversely, 0 kg N/ha (control) recorded significantly lower plant height in comparison to other treatments. Similar trends in observations were recorded during 2024 as well.

The plant height in the main plot treatments showed non-significant variation, likely due to the minimal impact of planting patterns on this parameter. The increased plant height in 160 kg N/ha and 120 kg/ha could be attributed to the enhanced availability of nitrogen in required amount to the plant. This nitrogen uptake facilitated protoplasm synthesis, promoting rapid cell division and ultimately leading to increased plant height and overall plant growth. These results align with the findings reported by Singh *et al.* (2018).

During both the years of study the interactive effect of planting patterns and nitrogen levels on periodic plant height of rice remained non-significant (Table 4.2.2).

Table 4.2.2: Periodic plant height (cm) of rice as influenced by planting patterns and nitrogen levels.

	Plant height (cm) of rice					
Treatments	**30 DAT**		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	19.6	19.8	69.6	69.8	71.6	71.0
Two rows/ridge + one in furrow	19.8	19.6	69.9	69.8	71.2	71.1
Flat unpuddled	18.9	20.0	70.2	70.5	72.0	71.6
Flat puddled	19.4	20.1	69.8	69.9	71.3	71.6
SEm (±)	0.28	0.14	0.40	0.25	0.52	0.38
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Nitrogen levels)						
0 kg N/ha	15.4	16.0	56.3	55.7	57.7	56.8
80 kg N/ha	18.5	19.1	66.1	65.4	68.5	67.0
120 kg N/ha	21.7	22.0	78.1	79.0	79.6	80.2
160 kg N/ha	22.1	22.4	79.1	79.8	80.2	81.3
SEm (±)	0.37	0.23	0.47	0.40	0.56	0.48
C.D. (5%)	**1.05**	**0.66**	**1.36**	**1.15**	**1.61**	**1.38**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



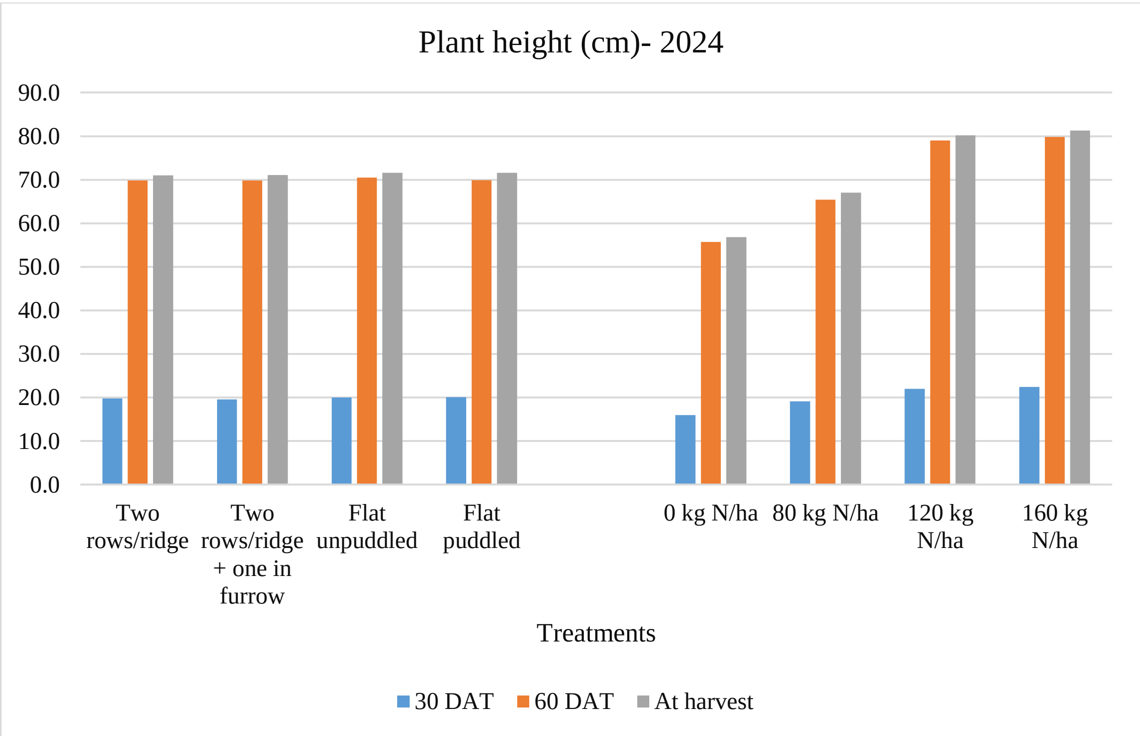


Fig 4.2.1: Influence of planting patterns and nitrogen levels on periodic plant height (cm) of rice.

4.2.3 Total number of tillers/m^2:

Recording total number of tillers per unit area is vital as it directly reflects the crop's vegetative performance. A higher density of tillers ensures greater panicle production, which is directly proportional to improved grain yield. Data regarding periodic count of total number of tillers/m^2 at 30, 60 DAT and at harvest as influenced by planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.2.3 and depicted in Figure 4.2.2.

Perusal of data at 30 DAT during 2023 showed that planting patterns had non-significant impact on total number of tillers/m^2 (Table 4.2.3). Among the nitrogen levels, total number of tillers/m^2 recorded at 30 DAT with the application of 160 kg N/ha were at par with 120 kg N/ha and both these treatments were significantly superior over the other nitrogen levels. In contrast, total number of tillers/m^2 recorded in 0 kg N/ha (control) were significantly less as compared to other treatments. Consistent trends in the results were observed during 2024 as well.

Data recorded at 60 DAT during 2023 and 2024 revealed that among the planting patterns, two rows/ridge + one in furrow significantly enhanced total number of tillers/m^2 as compared to other methods of planting (Table 4.2.3). Meanwhile flat puddled and flat unpuddled were at par with each other and recorded significantly less count of total number of tillers/m^2 as compared to both ridge based planting methods. Application of 160 kg N/ha significantly increased the count of total number of tillers/ m^2 as compared to other nitrogen levels. Application of 120 kg N/ha produced significantly more total number of tillers/m^2 than 80 kg N/ha. Conversely, 0 kg N/ha (control) recorded significantly less count of total number of tillers/m^2 as compared to all other nitrogen levels during both the years of study.

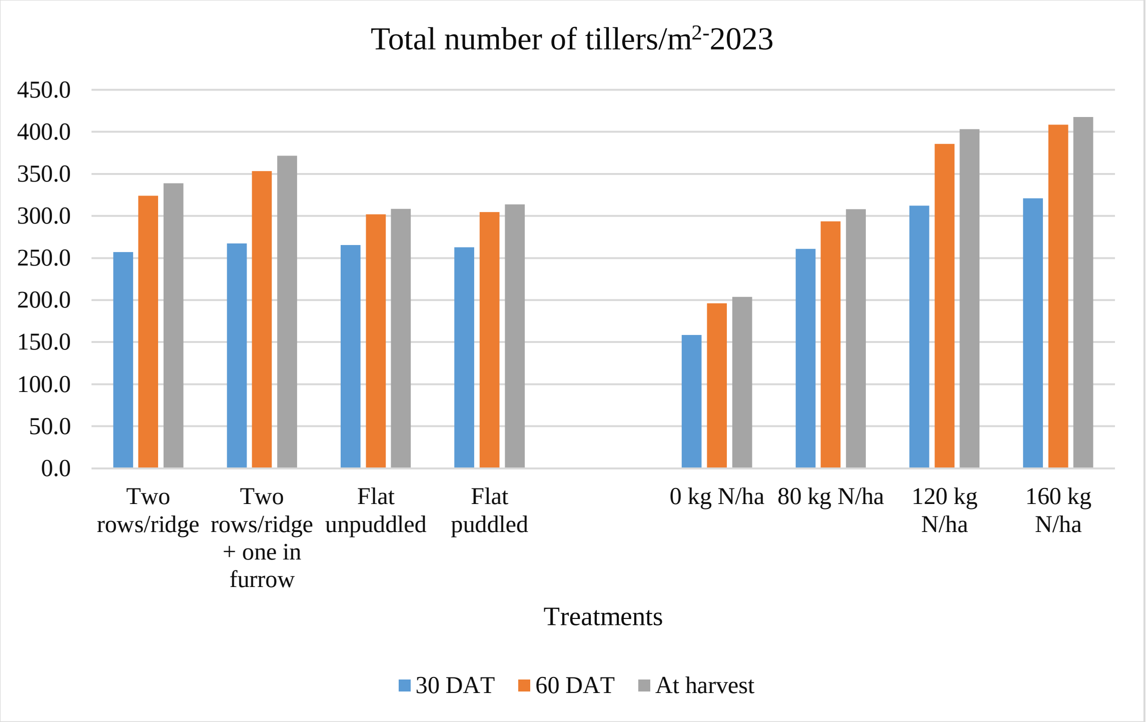
During 2023, data collected at harvest showed that planting pattern with two rows/ridge + one in furrow recorded significantly higher count of total number of tillers/m^2 as compared to other planting patterns (Table 4.2.3). Flat unpuddled and flat puddled recorded significantly less count of total number of tillers/m^2 when compared to other planting patterns. Total number of tillers/m^2 were significantly more in two rows/ridge + one in furrow as compared to two rows/ridge only. Among sub plots, application of 160 kg N/ha significantly improved the count of total number of tillers/m^2 as compared to other treatments whereas, application of 120 kg N/ha recorded significantly more count of total number of tillers/m^2 than 80 kg N/ha. In contrast, substantially less count of total number of tillers/m^2 were observed in 0 kg N/ha (control) than other treatments. These trends remained consistent in 2024 as well.

Increased tiller production in the two rows per ridge + one in furrow planting system was likely due to the improved soil conditions and a larger surface area. This may have facilitated deeper root penetration, enhancing nutrient and water uptake, which might have improved tiller production over flat transplanting systems. Similar findings were reported by Singh *et al.* (2009). The increased number of tillers with the application of 160 kg N/ha can be attributed to role of nitrogen in promoting vegetative growth. Nitrogen likely enhanced leaf area development, enabling better light interception and photosynthesis, which are essential for tiller production. Furthermore, adequate nitrogen availability may have reduced competition for nutrients between developing tillers, allowing more tillers to grow successfully. These results are in congruity with Meena *et al.* (2014).

Across both the years of study, the interactive effect of planting patterns and nitrogen levels on periodic count of total number of tillers/m^2 remained non-significant during both the years. (Table 4.2.3).

Table 4.2.3: Impact of planting patterns and nitrogen levels on periodic count of total number of tillers/m^2.

	Total number of tillers/m^2					
Treatments	**30 DAT**		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	257.0	258.2	323.8	320.7	338.9	332.8
Two rows/ridge + one in furrow	267.2	252.5	353.1	343.8	371.6	355.6
Flat unpuddled	265.3	259.4	301.9	294.1	308.4	303.8
Flat puddled	262.8	254.4	304.7	298.4	313.8	305.6
SEm (±)	4.21	5.43	4.14	6.23	6.66	3.81
C.D. (5%)	**NS**	**NS**	**13.26**	**19.93**	**21.31**	**12.20**
Sub-plots (Nitrogen levels)						
0 kg N/ha	158.7	152.2	196.2	190.3	204.0	198.2
80 kg N/ha	260.7	255.5	293.4	287.1	308.2	296.7
120 kg N/ha	312.1	306.3	385.6	379.8	403.0	391.9
160 kg N/ha	320.8	310.5	408.3	399.8	417.4	411.0
SEm (±)	4.98	5.39	4.82	4.65	6.34	3.95
C.D. (5%)	**14.28**	**15.47**	**13.82**	**13.33**	**18.19**	**11.32**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



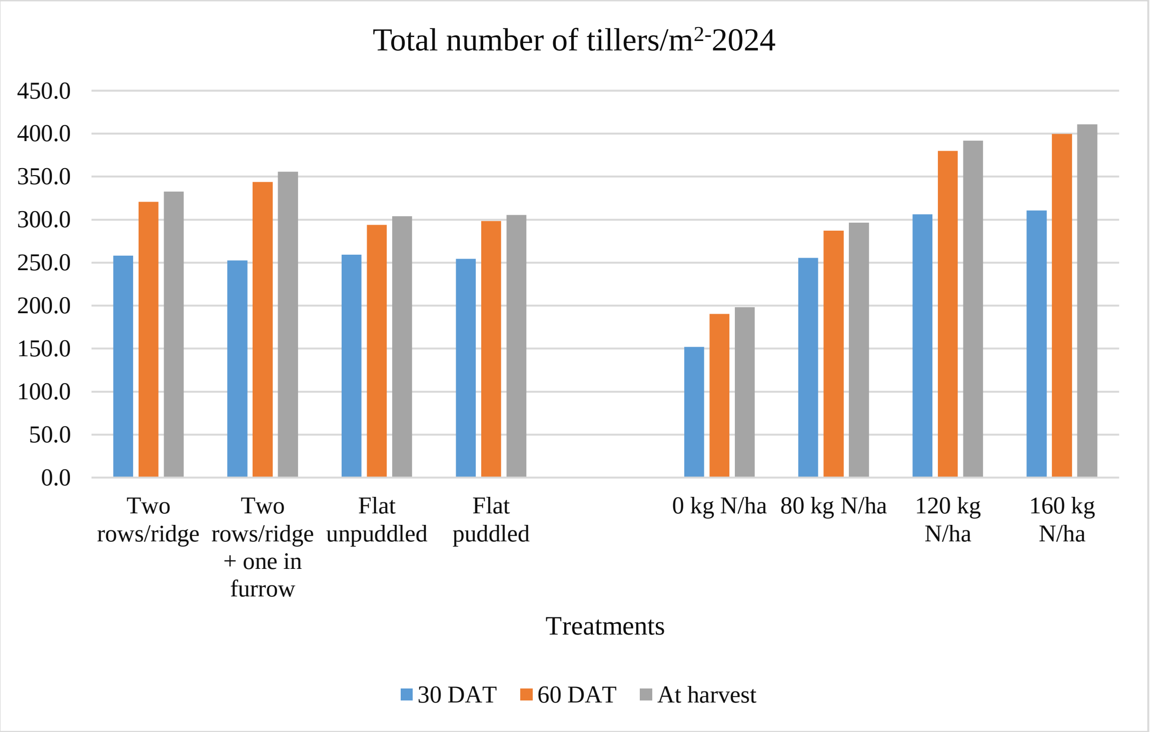


Fig 4.2.2: Influence of planting patterns and nitrogen levels on periodic count of total number of tillers/m^2.

4.2.4 Crop dry matter accumulation (q/ha):

Measuring dry matter accumulation by crop is essential for evaluating crop performance. It reflects the plant's capacity for photosynthesis and nutrient uptake, with greater accumulation leading to enhanced growth and yield attributes. Data regarding the periodic crop dry matter accumulation (q/ha) at 30, 60 DAT and at harvest under varying planting patterns and nitrogen levels has been detailed in Table 4.2.4 and Figure 4.2.3.

During 2023, there was non-significant effect of planting patterns on crop dry matter accumulation (q/ha) at 30 DAT (Table 4.2.4). Crop dry matter at 30 DAT with application of 120 kg N/ha was statistically at par with 160 kg N/ha and both these treatments were significantly higher as compared to other treatments with respect to crop dry matter accumulation. Meanwhile, 0 kg N/ha (control) recorded significantly less dry matter accumulation than all other nitrogen levels. Similar findings were obtained in 2024 also.

Perusal of data at 60 DAT during 2023 showed that planting pattern with two rows/ridge + one in furrow recorded significantly higher crop dry matter accumulation (q/ha) as compared to other planting methods (Table 4.2.4). Meanwhile, flat puddled and flat unpuddled recorded significantly less crop dry matter accumulation than two rows/ridge. Among the sub plots, application of 160 kg N/ha significantly increased the crop dry matter accumulation as compared to other nitrogen levels. Significantly more crop dry matter accumulation was observed with application of 120 kg N/ha than 80 kg N/ha. Contrarily, 0 kg N/ha (control) recorded significantly less crop dry matter accumulation than all other treatments. These trends in the results were consistent in 2024 as well.

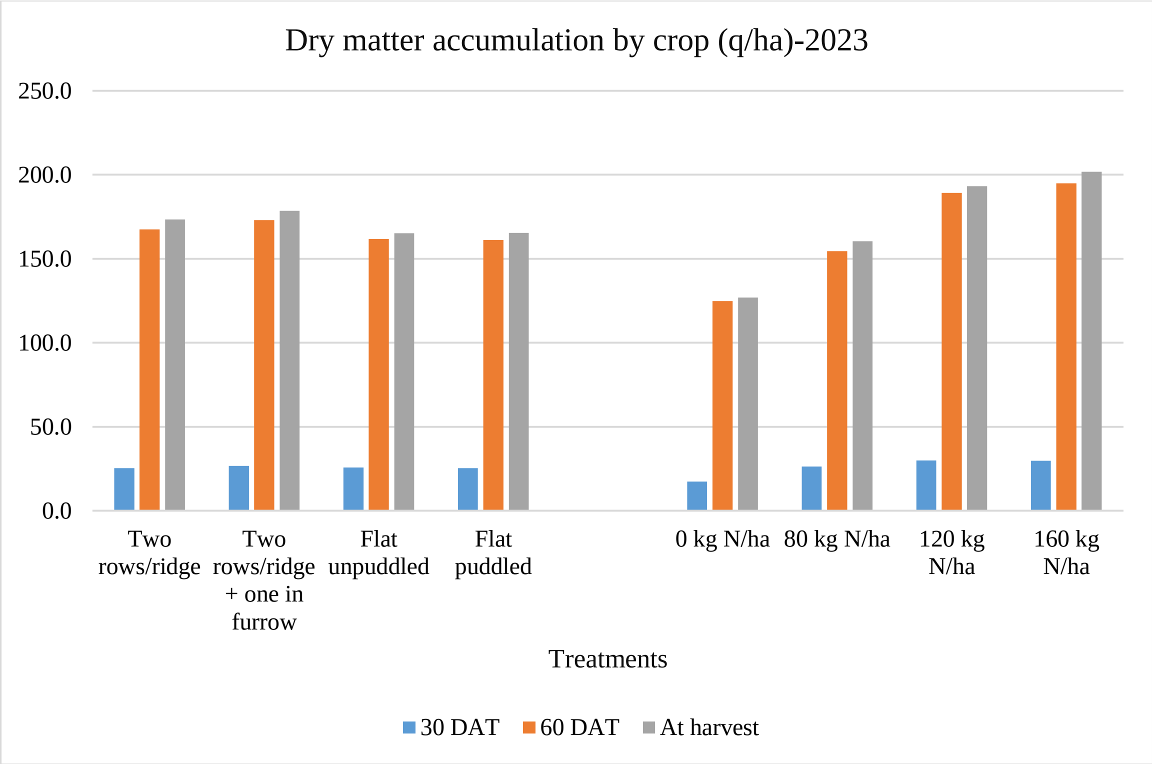
Data recorded at harvest during 2023 and 2024 revealed that adopting planting pattern with two rows/ridge + one in furrow significantly improved the crop dry matter accumulation when compared to other methods (Table 4.2.4). Two rows/ridge recorded significantly more crop dry matter accumulation as compared to flat puddled and flat unpuddled which remained at par with each other. Among the nitrogen levels, application of 160 kg N/ha recorded significantly higher crop dry matter accumulation as compared to other nitrogen level treatments. Application of 80 kg N/ha recorded significantly less crop dry matter accumulation than 120 kg N/ha. In contrast, 0 kg N/ha (control) was observed to have substantially lower crop dry matter accumulation than all other nitrogen levels during both the years of study.

Adopting planting pattern with two rows/ridge + one in furrow enhances soil aeration and improves soil structure, creating favourable conditions for root growth. This deeper root penetration allows plants to access nutrients and water more effectively, boosting tiller production and ultimately leading to increased dry matter accumulation. Similar results were reported by Baurai *et al.* (2020) Higher dry matter accumulation in rice plants with the application of 160 kg N/ha followed by 120 kg N/ha can be attributed to the role of nitrogen in promoting cell division, protein synthesis, and chlorophyll production. This leads to improved photosynthetic efficiency and greater assimilation of nutrients, fostering robust vegetative growth. Similar findings were reported by Gill *et al.* (2013).

Interactive effect of planting patterns and nitrogen levels on periodic crop dry matter accumulation at all periodic intervals were found to be non-significant during both the years of study (Table 4.2.4).

Table 4.2.4: Impact of planting patterns and nitrogen levels on periodic crop dry matter accumulation (q/ha).

	Dry matter accumulation (q/ha)					
Treatments	**30 DAT**		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	25.4	23.6	167.4	163.9	173.3	167.8
Two rows/ridge + one in furrow	26.7	24.5	173.0	168.0	178.5	172.5
Flat unpuddled	25.8	24.9	161.8	159.9	165.1	163.2
Flat puddled	25.4	25.1	161.1	159.4	165.3	162.5
SEm (±)	0.38	0.38	1.22	1.79	0.88	1.35
C.D. (5%)	**NS**	**NS**	**3.89**	**5.73**	**2.83**	**4.33**
Sub-plots (Nitrogen levels)						
0 kg N/ha	17.3	16.0	124.8	120.8	126.8	124.3
80 kg N/ha	26.3	24.9	154.5	149.5	160.5	153.2
120 kg N/ha	30.0	28.2	189.2	188.2	193.2	191.4
160 kg N/ha	29.8	29.0	194.9	192.7	201.8	197.1
SEm (±)	0.30	0.46	1.67	1.35	0.80	1.57
C.D. (5%)	**0.86**	**1.33**	**4.78**	**3.88**	**2.29**	**4.51**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



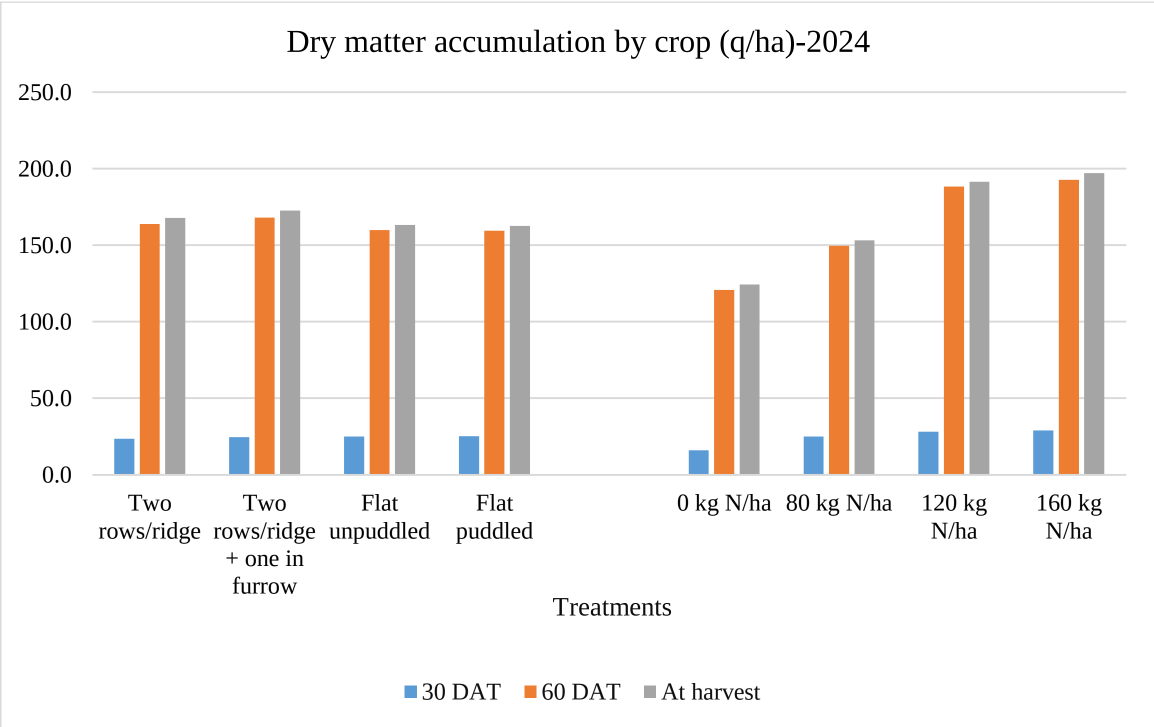


Fig 4.2.3: Influence of planting patterns and nitrogen levels on periodic dry matter accumulation (q/ha) of rice.

4.2.5 Chlorophyll index:

Chlorophyll index is an essential parameter as it reflects the plant's photosynthetic capacity, which is directly influenced by nitrogen. Nitrogen is integral to chlorophyll formation and photosynthesis; thus, maintaining an optimal chlorophyll index helps ensure efficient nutrient utilization and maximized grain yield**.** Data pertaining to periodic chlorophyll index of rice at 30, 60 DAT and at harvest as influenced by planting patterns and nitrogen levels has been summarized in Table 4.2.5 and Figure 4.2.4.

Perusal of data at 30 DAT during 2023 revealed that planting patterns did not significantly influence the chlorophyll index of rice (Table 4.2.5). Among the nitrogen levels, chlorophyll index with application of 160 kg N/ha was at par with 120 kg N/ha and significantly higher as compared to other nitrogen level treatments. However, 0 kg N/ha (control) recorded significantly lower chlorophyll index in comparison to other nitrogen levels. Similar findings were noticed in 2024 also.

Data collected at 60 DAT during 2023 and 2024 demonstrated that the differences in chlorophyll index among the planting patterns was non-significant (Table 5.2.5). Among the sub plots, application of 120 kg N/ha recorded statistically at par values of chlorophyll index with 160 kg N/ha. Conversely, significantly less chlorophyll index was observed in 0 kg N/ha (control) as compared to other treatments during both the years of study.

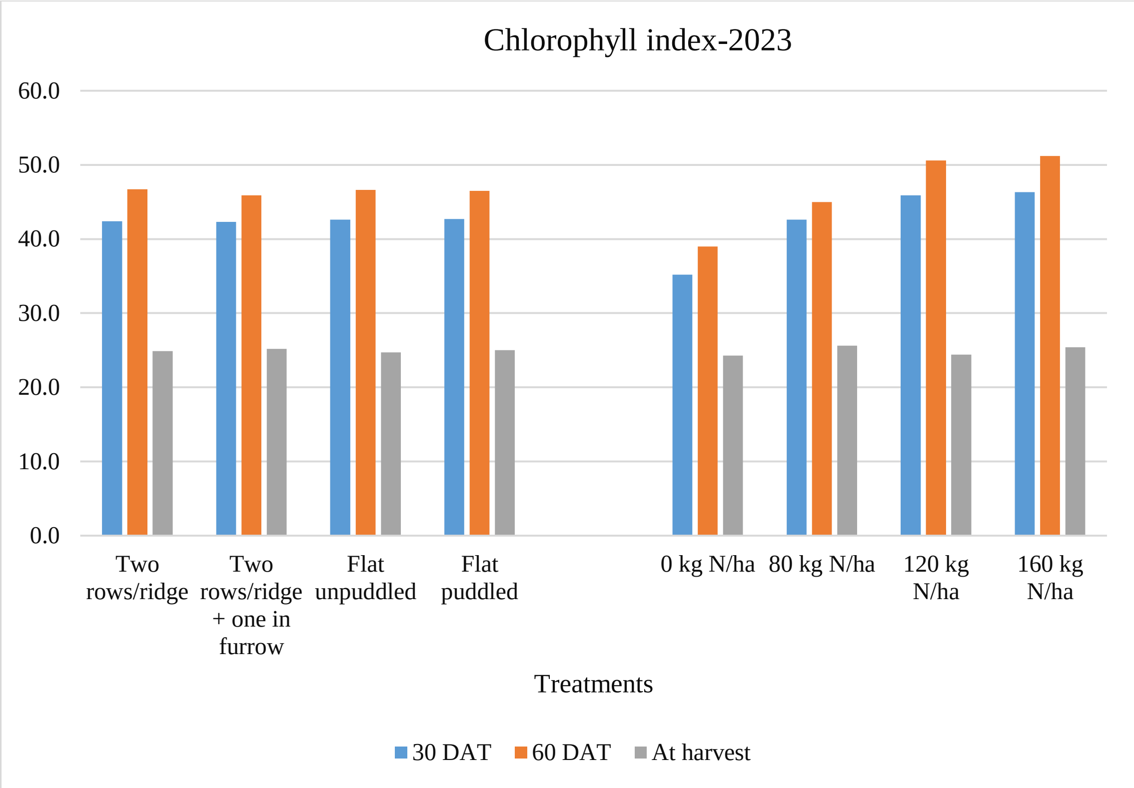
Data recorded at harvest showed that there was no notable impact of planting patterns on chlorophyll index of rice (Table 4.2.5). Likewise, the differences in chlorophyll index among the nitrogen levels was non-significant. These results hold good during both the years of study.

Chlorophyll index did not vary significantly across the planting methods, possibly due to the limited effect of planting patterns on this trait. The higher chlorophyll index was observed in rice crop with the application of 160 kg N/ha and 120 kg N/ha can be attributed to adequate availability of nitrogen which may have ensured better leaf development and higher chlorophyll content, enabling the plants to capture more sunlight for photosynthesis. The results are in congruity with Shrestha *et al.* (2012).

The interaction between planting patterns and nitrogen levels for chlorophyll index at all periodic intervals showed non-significant effects on chlorophyll index during both years of the study (Table 4.2.5).

Table 4.2.5: Impact of planting patterns and nitrogen levels on periodic chlorophyll index of rice.

	Chlorophyll Index					
Treatments	**30 DAT**		**60 DAT**		**At harvest**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	42.4	41.9	46.7	46.8	24.9	26.1
Two rows/ridge + one in furrow	42.3	41.7	45.9	46.9	25.2	25.6
Flat unpuddled	42.6	42.1	46.6	46.6	24.7	25.1
Flat puddled	42.7	42.1	46.5	46.8	25.0	25.6
SEm (±)	0.37	0.33	0.25	0.33	0.47	0.46
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Sub-plots (Nitrogen levels)						
0 kg N/ha	35.2	33.3	39.0	37.6	24.3	25.3
80 kg N/ha	42.6	41.7	45.0	46.1	25.6	26.1
120 kg N/ha	45.9	46.2	50.6	51.9	24.4	24.9
160 kg N/ha	46.3	46.5	51.2	51.5	25.4	26.0
SEm (±)	0.30	0.32	0.44	0.35	0.50	0.50
C.D. (5%)	**0.86**	**0.93**	**1.28**	**1.00**	**NS**	**NS**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



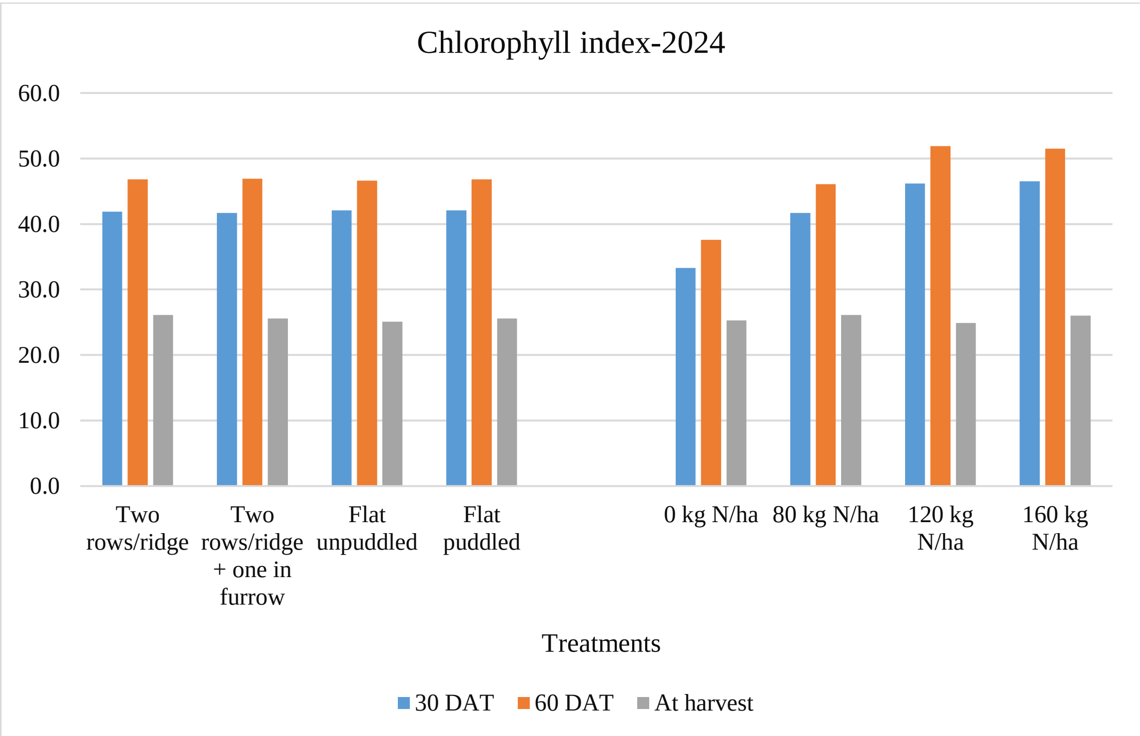


Fig 4.2.4: Influence of planting patterns and nitrogen levels on periodic chlorophyll index of rice.

4.3 Yield components:

4.3.1 Number of panicles/m^2 and panicle length (cm)

Recording the number of panicles per unit area is crucial in rice cultivation as it directly reflects the reproductive potential of the crop and its capacity to produce grains. Panicle length (cm), on the other hand, determines the grain-bearing ability of each panicle. These traits are strongly correlated with yield, as more number of panicles per unit area and longer panicles typically result in higher grain numbers and improved productivity. Data pertaining to the number of panicles/m^2 and panicle length (cm) as influenced by various planting patterns and nitrogen levels during 2023 and 2024 has been summarized in Table 4.3.1 and depicted in Figure 4.3.1.

Data collected at harvest during 2023 and 2024 revealed that the number of panicles/m^2 were significantly influenced by planting patterns. Two rows/ridge + one in furrow produced significantly higher number of panicles/m^2 as compared to other planting methods (Table 4.3.1). Meanwhile, two rows/ridge produced significantly more number of panicles/m^2 than flat puddled and flat unpuddled methods. Both flat planting patterns remained at par with each other and produced significantly less number of panicles/m^2 as compared to both ridge based planting patterns. Amongst the nitrogen levels, significantly higher number of panicles/m^2 were observed with the application of 160 kg N/ha as compared to other120 kg N/ha, 80 kg N/ha and 0 kg N/ha. Application of 80 kg N/ha recorded significantly lower number of panicles/m^2 than 120 kg N/ha. However, 0 kg N/ha (control) recorded significantly less number of panicles/m^2 in comparison to other nitrogen levels. These findings hold good during both years.

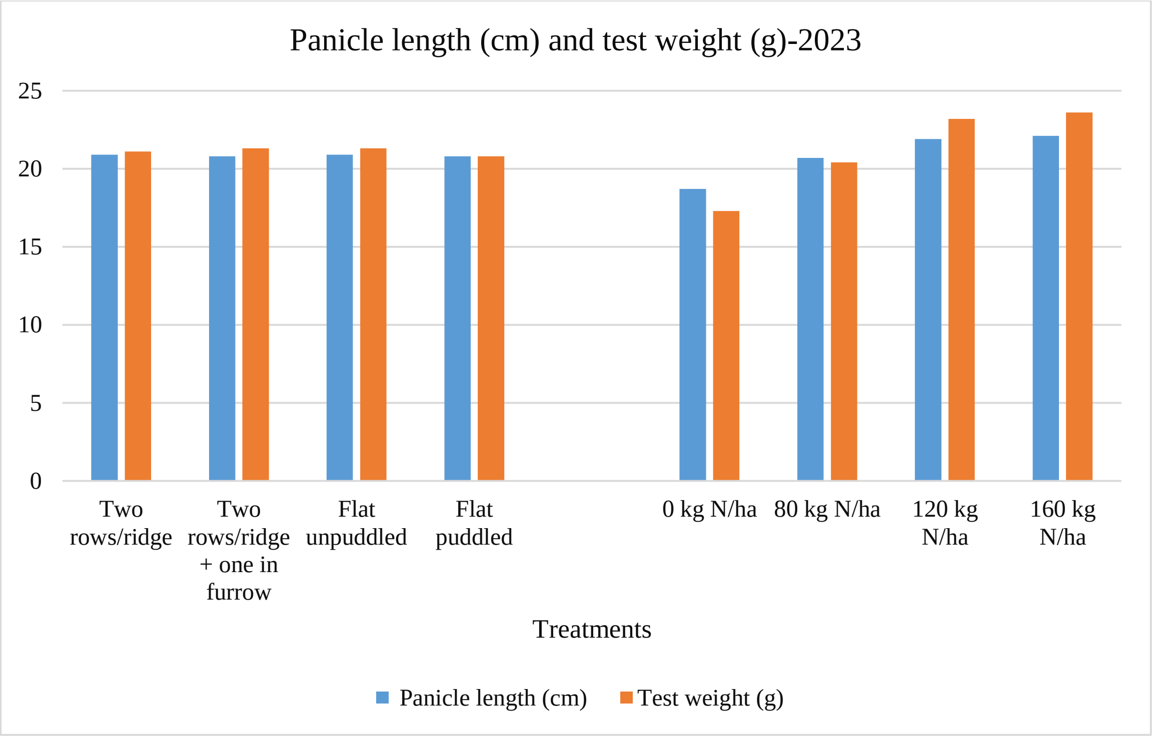
Perusal of data at harvest during 2023 indicated that there was no significant impact of planting patterns on panicle length (cm) of rice (Table 4.3.1). Among the sub plots, application of 120 kg N/ha recorded panicle length which was statistically comparable with 160 kg N/ha and was significantly higher as compared to other treatments. Contrarily, 0 kg N/ha (control) recorded significantly less panicle length as compared to other nitrogen levels. These findings remained consistent during the year 2024 as well.

Improved soil physical conditions and larger surface area in the two rows per ridge + one in the furrow planting method likely enhanced root concentration, leading to better tiller production and a higher panicle density per square meter. These findings align with the results reported by Singh *et al.* (2009). The higher number of panicles/m^2 and increased panicle length with the application of 160 kg N/ha may be due to improved nitrogen availability, which enhances vegetative growth and tillering capacity. This can be attributed to nitrogen's role in promoting cell division and elongation, leading to better panicle development. Similar results were reported by Giri *et al.* (2022) and Sharma *et al.* (2007)

Both years of the study revealed that the interaction between planting patterns and nitrogen levels did not have any significant impact on number of panicles/m^2 and panicle length (cm) (Table 4.3.1).

Table 4.3.1: Impact of planting patterns and nitrogen levels on number of panicles/m^2 and panicle length (cm) rice.

Treatments	Number of panicles/m^2		Panicle length (cm)	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	324.0	323.5	20.9	21.6
Two rows/ridge + one in furrow	347.8	343.4	20.8	21.3
Flat unpuddled	301.6	293.1	20.9	21.8
Flat puddled	304.1	297.5	20.8	21.6
SEm (±)	5.38	4.84	0.24	0.22
C.D. (5%)	**17.22**	**15.49**	**NS**	**NS**
Sub-plots (Nitrogen levels)				
0 kg N/ha	196.2	187.9	18.7	18.3
80 kg N/ha	301.2	289.1	20.7	21.0
120 kg N/ha	381.5	381.1	21.9	23.8
160 kg N/ha	398.6	399.5	22.1	23.2
SEm (±)	5.07	3.83	0.31	0.21
C.D. (5%)	**14.54**	**10.97**	**0.89**	**0.62**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**



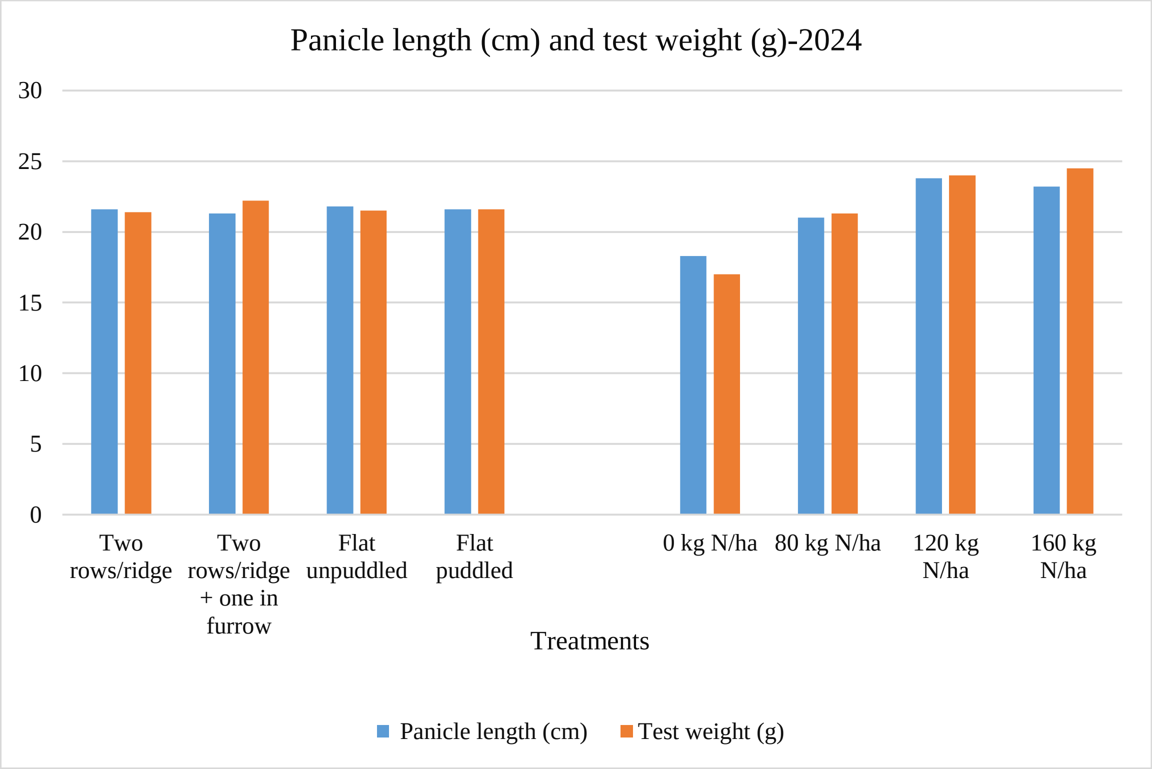


Fig 4.3.1: Influence of planting patterns and nitrogen levels on panicle length (cm) and test weight (g).

4.3.2 Total number of grains/panicle, number of filled grains/panicle and test weight (g):

Recording the total number of grains/panicle and the number of filled grains/panicle is crucial as these parameters directly influence yield. The total grain count/panicle reflects the crop's reproductive potential, while the number of filled grains indicates the efficiency of grain filling and nutrient translocation. A higher proportion of filled grains ensures better grain weight and yield potential. Recording test weight (g) is essential for understanding grain filling efficiency and overall productivity. Data regarding total number of grains/panicle, number of filled grains/panicle and test weight (g) under varying planting patterns and nitrogen levels during 2023 and 2024 has been detailed in Table 4.3.2 and Figure 4.3.2.

Data collected at harvest during 2023 showed that planting pattern with two rows/ridge + one in furrow exhibited significantly higher count of total number of grains/panicle as compared to other planting patterns (Table 4.3.2). Flat unpuddled and flat puddled were observed to be at par with each other and recorded significantly lower count of total number of grains/panicle than two rows/ridge. Application of 160 kg N/ha significantly increased the total number of grains/panicle as compared to other nitrogen levels. Applying 80 kg N/ha recorded significantly lower count of total number of grains/panicle than 120 kg N/ha. Conversely, 0 kg N/ha (control) recorded significantly less count of total number of grains/panicle as compared to other nitrogen level treatments. Consistent trends in the results were observed during 2024 as well

Data recorded at harvest during 2023 and 2024 revealed that among the planting patterns adopting two rows/ridge + one in furrow significantly increased number of filled grains/panicle as compared to other planting patterns (Table 4.3.2). Meanwhile, flat puddled and flat unpuddled were observed to be statistically at par with each other and recorded significantly lower number of filled grains/panicle than two rows/ridge. Among sub plots, application of 160 kg N/ha recorded significantly higher number of filled grains/panicle as compared to other nitrogen levels, whereas application of 120 kg N/ha recorded significantly more number of filled grains/panicle than 80 kg N/ha. In contrast, 0 kg N/ha (control) recorded significantly lower number of filled grains/panicle as compared to other nitrogen levels during both the years of study.

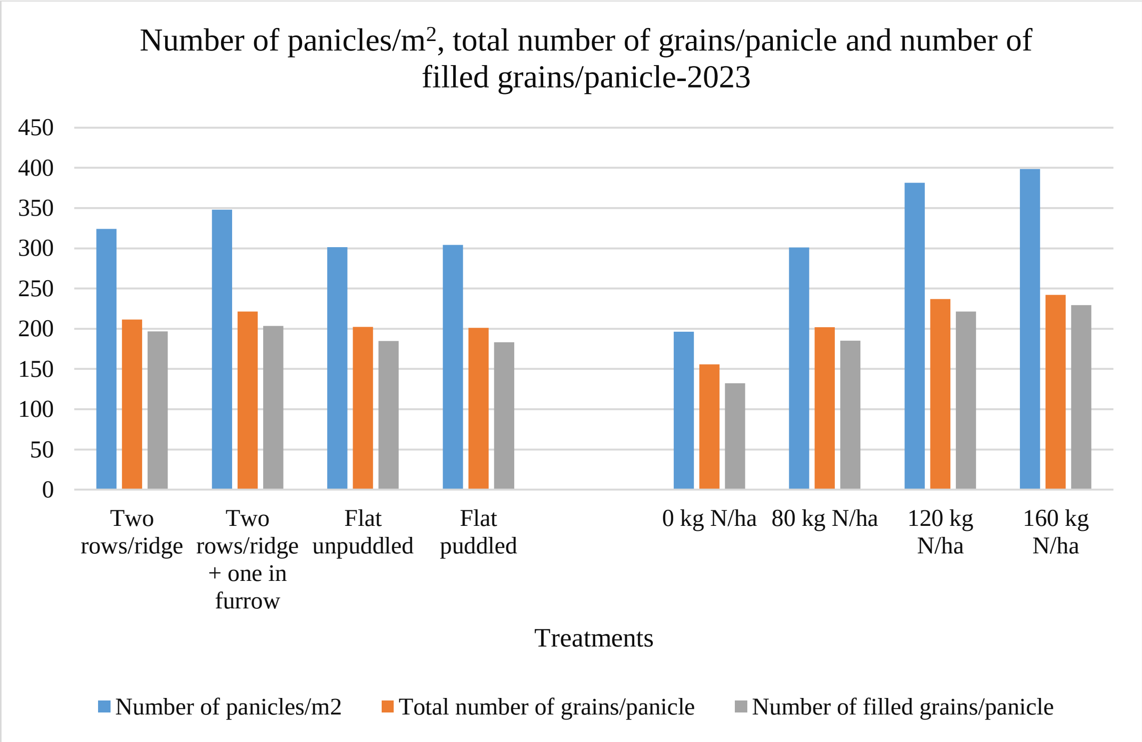
Perusal of data at harvest during 2023 revealed that the differences in test weight (g) among the planting patterns remained non-significant (Table 4.3.2). Among the nitrogen levels, test weight recorded with application of 160 kg N/ha was statistically at par with 120 kg N/ha and both these treatments recorded significantly more test weight as compared to other treatments. However, significantly less test weight was observed in 0 kg N/ha when compared to other nitrogen levels. These findings remained consistent in 2024 as well.

The increased number of total grains and filled grains per panicle can be attributed to the planting pattern of two rows per ridge and one in the furrow, which may have improved soil physical conditions and created good crop geometry which enhanced crop growth. These conditions likely enhanced root activity, nutrient absorption, and photosynthetic efficiency, ensuring better grain formation and filling. Similar findings were reported by Borrell *et al.* (1998). Increased count of total number of grains/panicle, number of filled grains/panicle and test weight with the application of 160 kg N/ha followed by 120 kg N/ha can be attributed to nitrogen's role in increasing tiller production and panicle size, leading to more grain-bearing spikelets. Additionally, the enhanced nitrogen supply likely improved nutrient translocation to developing grains, ensuring better grain filling. The results are in congruity with Preethika *et al.* (2022) and Bokado *et al.* (2020).

The interactive effect of planting patterns and nitrogen levels had non-significant impact on total number of grains/panicle, number of filled grains/panicle and test weight during both the years of study (Table 4.3.2).

Table 4.3.2: Impact of planting patterns and nitrogen levels on total number of grains/panicle, number of filled grains/panicle and test weight (g) of rice.

Treatments	Total number of grains/panicle		Number of filled grains/panicle		Test weight (g)	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	211.6	220.8	196.6	203.8	21.1	21.4
Two rows/ridge + one in furrow	221.6	230.9	203.5	215.3	21.3	22.2
Flat unpuddled	202.5	208.4	184.8	190.4	21.3	21.5
Flat puddled	201.1	210.8	183.3	193.6	20.8	21.6
SEm (±)	0.93	2.65	1.02	2.68	0.26	0.29
C.D. (5%)	**2.97**	**8.47**	**3.27**	**8.58**	**NS**	**NS**
Sub-plots (Nitrogen levels)						
0 kg N/ha	155.9	160.7	132.2	140.4	17.3	17.0
80 kg N/ha	202.0	212.7	185.3	196.6	20.4	21.3
120 kg N/ha	236.8	243.2	221.5	228.2	23.2	24.0
160 kg N/ha	242.0	254.3	229.3	237.9	23.6	24.5
SEm (±)	1.44	2.62	1.52	2.49	0.27	0.24
C.D. (5%)	**4.14**	**7.51**	**4.35**	**7.15**	**0.78**	**0.70**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



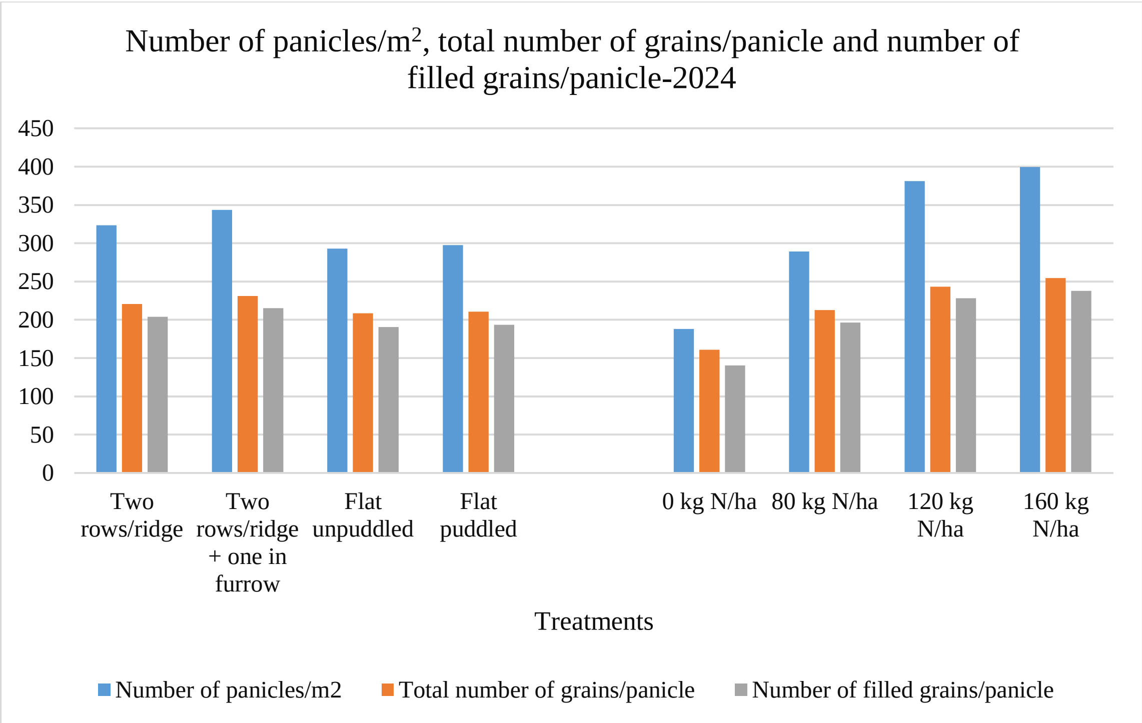


Fig 4.3.2: Influence of planting patterns and nitrogen levels on number of panicles/m^2, total number of grains/panicle and number of filled grains/panicle.

4.3.3 Paddy yield (q/ha) and straw yield (q/ha):

A comprehensive evaluation of crop productivity can be assessed through paddy yield and straw yield, where paddy yield measures economic output and straw yield indicates biomass production capacity. Data on paddy yield (q/ha) and straw yield (q/ha) as influenced by various planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.3.3 and depicted in Figure 4.3.3.

Perusal of data at harvest during 2023 indicated that implementing the planting pattern with two rows/ridge + one in furrow recorded significantly higher paddy yield as compared to other planting patterns *viz.*, two rows/ridge, flat unpuddled and flat puddled (Table 4.3.3). Conversely, flat unpuddled and flat puddled remained at par with each other and recorded significantly lower paddy yield than two rows/ridge planting pattern. Among the nitrogen levels, application of 160 kg N/ha significantly increased the paddy yield as compared to other treatments. Application of 80 kg N/ha significantly reduced the paddy yield as compared to 120 kg N/ha. However, significantly less paddy yield was observed in treatment with 0 kg N/ha (control) as compared to other nitrogen levels. Similar trends in the observations were noticed in 2024 also.

Pooled data of paddy yield during both the years of study suggested that planting pattern involving two rows/ridge + one in furrow significantly increased the paddy yield as compared to other planting methods. Contrarily, flat puddled and flat unpuddled recorded significantly lower paddy yield than two rows/ridge and remained statistically at par with each other. Among the sub plots, application of 160 kg N/ha recorded significantly higher paddy yield than other nitrogen level treatments. Application of 120 kg N/ha produced significantly more paddy yield than 80 kg N/ha. Conversely, 0 kg N/ha recorded significantly less paddy yield as compared to other treatments during both the years of study.

Higher yield of paddy in the planting pattern of two rows/ridge + one in furrow may be due to better growth factors (Table 4.2.2 to 4.2.5) and good yield attributes (4.3.1 to 4.3.2). Two rows/ridge + one in furrow, two rows/ridge and flat unpuddled planting patterns increased by paddy yield by 13.2%, 8.4% and 1.0% than standard practice of flat puddled method respectively on the basis of pooled data. Among sub plots, highest yield in 160 kg N/ha and 120 kg N/ha may be due to better growth factors (Table 4.2.2 and 4.2.5) and good yield attributes (Table 4.3.1 and 4.3.2). On the basis of pooled data application of 160 kg N/ha, 120 kg N/ha and 80 kg N/ha increased paddy yield by 187.5%, 174.3 and 105% than 0 kg N/ha respectively.

Perusal of data at harvest during 2023 and 2024 demonstrated that the differences in straw yield (q/ha) among the planting patterns was significant. Adopting two rows/ridge + one in furrow significantly improved the straw yield as compared to other planting methods (Table 4.3.3). Two rows/ridge produced significantly more straw yield than flat unpuddled and flat puddled which recorded significantly less straw yield as compared to other planting patterns. Moreover, both flat based planting patterns remained at par with each other. Among the nitrogen levels, significantly higher straw yield was obtained with the application of 160 kg N/ha when compared to other treatments. Meanwhile, application of 120 kg N/ha recorded significantly more straw yield than 80 kg N/ha. Conversely, 0 kg N/ha (control) produced significantly less straw yield as compared to other nitrogen levels during both the years of study.

The interactive effect of planting patterns and nitrogen levels had significant impact on paddy yield (q/ha) during both the years of study (Table 4.3.4). Data pertaining to the interactive effect of planting patterns and nitrogen levels during 2023 and 2024 has been compiled in Table 4.3.4. During both the years of study, application of 160 kg N/ha to flat unpuddled crop produced paddy yield statistically at par with application of 120 kg N/ha to crop involving two rows/ridge + one in furrow (Table 4.3.4). Also during both the years, paddy yield obtained with application of 120 kg N/ha to flat puddled crop was statistically on par with application of 120 kg N/ha compared to crop under two rows/ridge. Additionally, during both the years, application of 160 kg N/ha to flat puddled crop was statistically at par with application of 120 kg N/ha to crop under two rows/ridge + one in furrow (Table 4.3.4). Application of 80 kg N/ha to the planting pattern of two rows/ridge + one in furrow recorded significantly higher yield than flat puddled and flat unpuddled method under same nitrogen dose indicating that nitrogen use efficiency is higher in two rows/ridge + one in furrow method.

The higher straw yield of paddy was observed in planting pattern of two rows per ridge + one in furrow may have resulted from improved soil aeration and root development, which enhanced vegetative growth (Table 4.3.3 and Figure 4.3.3). This can be attributed to better access to nutrients and water due to the increased surface area in ridge-furrow configuration. Additionally, it likely facilitated efficient resource utilization, thereby enhancing overall biomass production. Similar findings were reported by Tang *et al.* (2005). The increased straw yield at 160 kg N/ha may have been due to enhanced nutrient uptake, which stimulated robust vegetative growth. This can be attributed to nitrogen's critical role in protein synthesis and photosynthesis, which are essential for biomass production. Additionally, it is likely that the increased nitrogen supply supported better tillering and leaf area development, contributing to greater straw production. Similar results were reported by Yadav *et al.* (2023).

Interactive effect of planting patterns and nitrogen levels on straw yield remained non-significant during both the years of study (Table 4.3.3).

Table 4.3.3: Impact of planting patterns and nitrogen levels on paddy yield (q/ha) and straw yield (q/ha).

Treatments	Paddy yield (q/ha)			Straw yield (q/ha)	
Main plots (Planting patterns)	**2023**	**2024**	**Pooled**	**2023**	**2024**
Two rows/ridge	61.7	62.6	62.2	90.0	88.9
Two rows/ridge + one in furrow	65.6	64.5	65.0	95.0	93.0
Flat unpuddled	57.9	58.1	58.0	84.7	84.5
Flat puddled	56.5	58.3	57.4	82.1	85.0
SEm (±)	0.90	0.55	0.73	1.48	1.07
C.D. (5%)	**2.86**	**1.75**	**2.31**	**4.74**	**3.42**
Sub-plots (Nitrogen levels)					
0 kg N/ha	29.0	27.0	28.0	46.7	43.3
80 kg N/ha	56.9	57.8	57.4	80.2	81.9
120 kg N/ha	76.0	77.6	76.8	109.1	110.1
160 kg N/ha	79.8	81.1	80.5	115.8	116.1
SEm (±)	0.52	0.66	0.59	0.95	1.09
C.D. (5%)	**1.49**	**1.89**	**1.69**	**2.72**	**3.12**
Interaction C.D. (5%) (A × B)	**3.16**	**3.87**	**3.52**	**NS**	**NS**

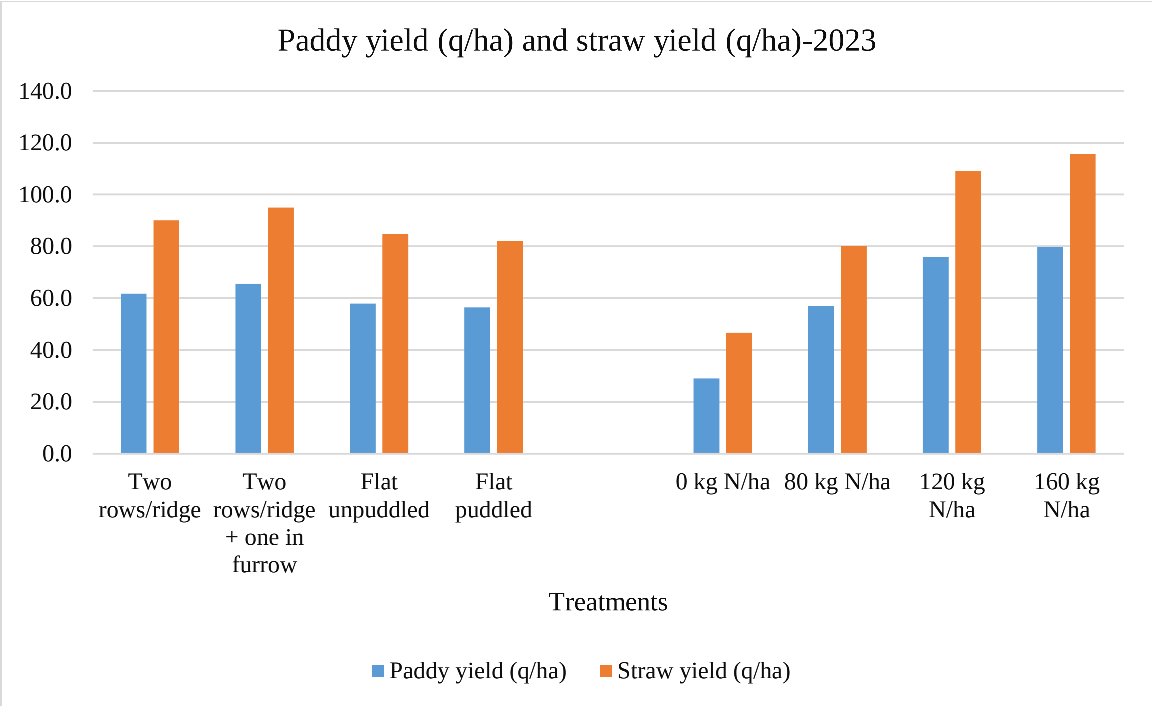
Table 4.3.4: Interactive effect of planting patterns and nitrogen levels on paddy yield (q/ha).

Paddy yield (q/ha)- 2023

	0 kg N/ha	80 kg N/ha	120 kg N/ha	160 kg N/ha	Mean A
Two rows/ridge	30.0	58.2	76.8	81.7	**61.7**
Two rows/ridge + one in furrow	35.9	63.3	78.3	84.9	**65.6**
Flat unpuddled	25.6	53.9	74.9	77.2	**57.9**
Flat puddled	24.5	52.3	73.9	75.3	**56.5**
Mean B	**29.0**	**56.9**	**76.0**	**79.8**	
SEm (±)	1.78				
C.D. (5%)	**3.16**				

Paddy yield (q/ha)- 2024

	0 kg N/ha	80 kg N/ha	120 kg N/ha	160 kg N/ha	Mean A
Two rows/ridge	28.4	59.2	78.6	84.1	**62.6**
Two rows/ridge + one in furrow	29.4	64.0	79.6	85.1	**64.5**
Flat unpuddled	26.4	54.1	73.8	78.0	**58.1**
Flat puddled	23.7	54.0	78.4	77.2	**58.3**
Mean B	**27.0**	**57.8**	**77.6**	**81.1**	
SEm (±)	1.09				
C.D. (5%)	**3.87**				



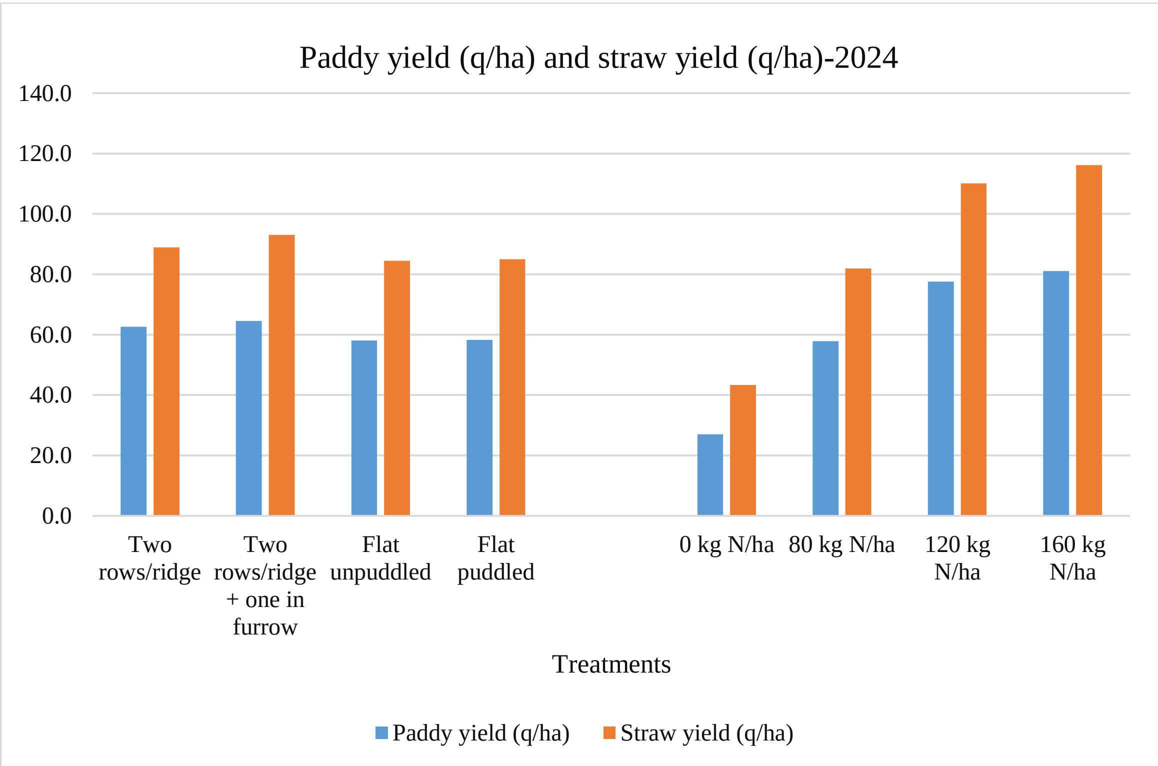


Fig 4.3.3: Influence of planting patterns and nitrogen levels on paddy yield (q/ha) and straw yield (q/ha).

4.3.4 Biological yield (q/ha) and Harvest Index:

Biological yield refers to the total biomass output from the crop, consisting of both its grain and straw portions. Harvest index is a key metric for assessing productivity efficiency, where higher values reflect better conversion of biomass into grain yield. Data pertaining to biological yield (q/ha) and harvest index of rice as influenced by planting patterns and nitrogen levels during 2023 and 2024 has been summarized in Table 4.3.5.

Data collected at harvest during 2023 revealed that there was significant impact of planting patterns on biological yield (q/ha) of rice (Table 4.3.5). Planting pattern involving two rows/ridge + one in furrow produced significantly higher biological yield as compared to other planting methods. Meanwhile, flat puddled and flat unpuddled produced significantly lower biological yield than two rows/ridge. Moreover, both the flat based treatments remained at par with each other. Amongst the nitrogen levels, significantly higher biological yield was obtained with the application of 160 kg N/ha as compared to other treatments. Biological yield obtained with application of 80 kg N/ha was significantly lower than 120 kg N/ha. However, 0 kg N/ha produced significantly less biological yield when compared to other nitrogen levels. Similar outcomes were observed in 2024 as well.

Perusal of data at harvest during 2023 and 2024 indicated that there was no notable effect of planting patterns on harvest index of rice (Table 4.3.5) as the differences were non-significant. Among the sub plots, harvest index recorded with application 160 kg N/ha, 120 kg N/ha, 80 kg N/ha was significantly higher than 0 kg N/ha (control) and all these treatments remained statistically at par with each other during both the years of study.

The higher biological yield of rice plants under the planting pattern with two rows per ridge + one in the furrow may have resulted from improved soil physical conditions, which enhanced root development and nutrient uptake. This can be attributed to the good growth of crop due to increased surface area that reduced competition among plants for resources such as light, water, and nutrients. Similar results were reported by Meisner *et al.* (2006). The higher biological yield of rice plants with the application of 160 kg N/ha may have resulted from improved nitrogen availability, which enhanced photosynthetic activity and biomass accumulation. This can be attributed to nitrogen's role in promoting vigorous vegetative growth, leading to an increase in tiller production and leaf area. The results are in congruity with Meena *et al.* (2014).

The study revealed that the interactive effect of planting patterns and nitrogen levels had no significant impact on biological yield and harvest index of rice during both the years (Table 4.3.5).

Table 4.3.5: Impact of planting patterns and nitrogen levels on biological yield (q/ha) and harvest index (%).

Treatments	Biological yield (q/ha)		Harvest Index (%)	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	151.6	151.5	40.5	41.0
Two rows/ridge + one in furrow	160.6	157.6	40.6	40.6
Flat unpuddled	142.6	142.5	40.4	40.3
Flat puddled	138.6	143.3	40.6	40.3
SEm (±)	2.38	1.60	0.09	0.23
C.D. (5%)	**7.60**	**5.12**	**NS**	**NS**
Sub-plots (Nitrogen levels)				
0 kg N/ha	75.7	70.3	38.3	38.4
80 kg N/ha	137.1	139.7	41.5	41.4
120 kg N/ha	185.1	187.7	41.0	41.3
160 kg N/ha	195.5	197.2	41.2	41.1
SEm (±)	1.45	1.72	0.21	0.15
C.D. (5%)	**4.16**	**4.94**	**0.64**	**0.47**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**

4.4 Economics:

Data pertaining to economics of various main plots and sub-plot treatments has been summarized in Table 4.4.1.

Data collected during 2023 and 2024 showed that highest cost of cultivation was recorded under flat puddled, followed by two rows/ridge + one in furrow and two rows/ridge transplanting method. Conversely, lowest cost of cultivation was recorded in flat unpuddled method of transplanting Application of 160 kg N/ha incurred highest cost of cultivation among the sub-plots, followed by 120 kg N/ha and 80 kg N/ha whereas lowest cost of cultivation was recorded in 0 kg N/ha (control).

Perusal of data during 2023 and 2024 demonstrated that maximum gross return (Rs/ha) were obtained under the planting pattern of two rows/ridge + one in furrow which was followed by two rows/ridge. In contrast, minimum gross returns were observed under flat puddled. Among the sub-plots, highest gross returns were recorded with the application of 160 kg N/ha, followed by 120 kg N/ha and 80 kg N/ha. Conversely, 0 kg N/ha (control) recorded lowest gross returns.

Analysis of data during 2023 and 2024 revealed that highest net returns of Rs 114487 and Rs 111021 during 2023 and 2024 respectively were recorded under the planting pattern of two rows/ridge + one in furrow followed by two rows/ridge, whereas lowest net returns were recorded under flat puddled method (standard). Application of 160 kg N/ha recorded highest net returns of Rs 149216 and Rs 152505 during 2023 and 2024 respectively followed by 120 kg N/ha and 80 kg N/ha. Meanwhile, lowest net returns were recorded in 0 kg N/ha during both the years of study.

During both the years of study, highest B:C ratio of 2.3 and 2.1 during 2023 and 2024 respectively was observed in planting pattern of two rows/ridge + one in furrow followed by two rows/ridge whereas lowest B:C ratio was recorded in flat puddled method of rice transplanting. Among the sub-plots, application of 160 kg N/ha recorded highest B:C ratio of 3.0 and 2.8 during 2023 and 2024 respectively, followed by 120 kg N/ha and 80 kg N/ha. Conversely, lowest B:C ratio was observed in 0 kg N/ha (control) during both the years of study.

Table 4.4.1: Impact of planting patterns and nitrogen levels on cost of cultivation (Rs/ha), gross returns (Rs/ha), net returns (Rs/ha) and B:C ratio of rice

Treatments	**Cost of Cultivation (Rs/ha)**		**Gross returns (Rs/ha)**		**Net returns (Rs/ha)**		**B:C ratio**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	49687	53512	154493	159293	104806	105781	2.1	2.0
Two rows/ridge + one in furrow	49687	53512	164174	164533	114487	111021	2.3	2.1
Flat unpuddled	48187	51915	145131	148194	96944	96279	2.0	1.8
Flat puddled	50187	53915	141527	148902	91340	94988	1.8	1.7
Sub-plots (Nitrogen levels)								
0 kg N/ha	48284	51990	73419	69483	25157	17493	0.5	0.3
80 kg N/ha	49306	53078	142179	147163	92873	94086	1.9	1.8
120 kg N/ha	49828	53621	190161	197606	140333	143985	2.8	2.7
160 kg N/ha	50350	54165	199566	206670	149216	152505	3.0	2.8

4.5 Quality parameters:

4.5.1 Nitrogen content of grains (%)

The nutritional quality of rice is closely linked to its nitrogen content, as nitrogen is fundamental to the protein composition of the grains. Data pertaining to nitrogen content of grains as influenced by planting patterns and nitrogen levels during 2023 and 2024 has been compiled in Table 4.5.1.

Perusal of data at harvest during 2023 indicated that the difference in nitrogen content of grains among the planting patterns was non-significant (Table 4.5.1). Amongst the nitrogen levels, application of 160 kg N/ha was statistically at par with 120 kg N/ha and both these treatments recorded significantly higher nitrogen content of grains as compared to other nitrogen levels. Conversely, significantly less nitrogen content was observed in 0 kg N/ha (control) as compared to other nitrogen levels. Similar findings were noticed in 2024 as well.

Applying 160 kg N/ha and 120 kg N/ha likely increased the nitrogen content in the grains because these higher application rates enhanced soil nitrogen availability, which in turn improved the plants' ability to absorb and transport nitrogen to the grains. These findings are in conformity with Sharma *et al.* (2007).

The interactive effect of planting patterns and nitrogen levels on nitrogen content of grains was found to be non-significant during both the years of study (Table 4.5.1).

4.4.2 Protein content in grains (%)

Analysing protein content in grains is key to understanding their nutritional benefits, which play a significant role in promoting human health. Data regarding protein content in grains as influenced by planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.5.1.

Data collected at harvest during 2023 and 2024 showed that planting patterns had no significant impact on the protein content (Table 4.5.1). Among the sub plots, protein content recorded with application of 160 kg N/ha was at par with 120 kg N/ha and both these treatments were observed with significantly higher protein content than other nitrogen levels. However, 0 kg N/ha (control) recorded significantly less protein content as compared to other treatments during both the years of study.

The higher protein content with the application of 160 kg N/ha and 120 kg/ha may be due to the higher nitrogen availability in the soil, which likely improved nitrogen absorption and translocation to the grains, increased protein synthesis ultimately boosting paddy yield. Similar findings were reported by Marlar *et al.* (2007).

Across both the years, the interactive effect of planting patterns and nitrogen levels had no significant impact on protein content in grains (Table 4.5.1)

4.4.3 Nitrogen uptake by grains (kg/ha)

The assessment of nitrogen uptake by grains serves as a key indicator of nitrogen utilization efficiency and its targeted distribution for productive grain formation. Data on nitrogen uptake by grains under varying planting patterns and nitrogen levels during 2023 and 2024 has been summarized in Table 4.5.1 and Figure 4.4.1.

Perusal of data at harvest during 2023 revealed that adopting the planting pattern with two rows/ridge + one in furrow significantly increased the nitrogen uptake by grains as compared to other planting methods (Table 4.5.1). Planting pattern of two rows/ridge recorded significantly more nitrogen uptake by grains than flat puddled and flat unpuddled which remained statistically at par with each other. Application of 160 kg N/ha recorded significantly higher nitrogen uptake by grains as compared to other nitrogen levels. Application of 120 kg N/ha recorded significantly more nitrogen uptake by grains than 80 kg N/ha. Contrarily, 0 kg N/ha (control) recorded significantly less nitrogen uptake by grains in comparison to other nitrogen level treatments. Consistent trends in the results were observed during 2024 as well.

The increased nitrogen uptake by grains by two rows/ridge + one in furrow may have been facilitated by better root growth and concentration, which likely allowed rice plants to access deeper soil layers rich in nutrients. The results are in congruity with Hobbs and Gupta (2003). The increased nitrogen uptake by rice grains with application of 160 kg N/ha is likely because higher nitrogen levels improve plants' ability to absorb and transport nitrogen to the grains. Similar findings were reported by Marlar *et al.* (2007).

Across both the years, the interactive effect of planting patterns and nitrogen levels on nitrogen uptake by grains was found to be non-significant (Table 4.5.1).

Table 4.5.1: Impact of planting patterns and nitrogen levels on nitrogen content of grains (%), protein content in grains (%) and nitrogen uptake by grains (kg/ha).

Treatments	Nitrogen content of grains (%)		Protein content in grains (kg/ha)		Nitrogen uptake by grains (kg/ha)	
Main plots (Planting patterns)	**2023**	**2023**	**2023**	**2023**	**2023**	**2024**
Two rows/ridge	1.14	1.14	7.15	7.11	73.6	74.6
Two rows/ridge + one in furrow	1.15	1.16	7.17	7.22	78.6	78.5
Flat unpuddled	1.15	1.14	7.19	7.10	69.4	69.8
Flat puddled	1.13	1.14	7.05	7.10	67.6	69.7
SEm (±)	0.01	0.01	0.05	0.06	0.96	1.07
C.D. (5%)	**NS**	**NS**	**NS**	**NS**	**3.33**	**3.70**
Sub-plots (Nitrogen levels)						
0 kg N/ha	0.91	0.89	5.70	5.58	26.6	24.2
80 kg N/ha	1.06	1.07	6.62	6.71	60.4	62.0
120 kg N/ha	1.29	1.29	8.08	8.07	98.4	100.2
160 kg N/ha	1.30	1.31	8.15	8.17	103.8	106.2
SEm (±)	0.02	0.01	0.11	0.08	1.40	1.13
C.D. (5%)	**0.05**	**0.04**	**0.32**	**0.23**	**4.10**	**3.31**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.5.4 Nitrogen content of straw (%)

Nitrogen content of straw is crucial for nutrient cycling analysis, as straw releases significant nitrogen during decomposition, enhancing soil fertility for growth of succeeding crops. Data on nitrogen content of straw under varying planting patterns and nitrogen levels during 2023 and 2024 has been summarized in Table 4.5.2.

Analysis of data at harvest during 2023 and 2024 revealed that there was no significant impact of planting patterns and nitrogen levels on nitrogen content of straw (%) during both the years of study (Table 4.5.2)

The interactive effect of planting patterns and nitrogen levels on nitrogen content of straw remained non-significant during both the years of study (Table 4.5.2).

4.4.5 Nitrogen uptake by straw (kg/ha)

Evaluating nitrogen uptake by straw is crucial for assessing the plant's nitrogen utilization efficiency**.** Data pertaining to nitrogen uptake by straw as influenced by various planting patterns and nitrogen levels during 2023 and 2024 has been compiled in Table 4.5.2 and Figure 4.4.1.

Perusal of data at harvest during 2023 demonstrated that there was significant effect of planting patterns on the nitrogen uptake by straw (Table 4.5.2). Planting pattern of two rows/ridge + one in furrow recorded significantly higher nitrogen uptake by straw as compared to other treatments. It was followed by two rows/ridge which recorded significantly more nitrogen uptake than both flat planting systems. However, flat puddled and flat unpuddled recorded significantly less nitrogen uptake by straw and remained at par with each other. Amongst the sub plots, application 160 kg N/ha significantly increased the nitrogen uptake by straw in comparison to other treatments. Application of 120 kg N/ha recorded significantly more nitrogen uptake by straw than 80 kg N/ha. Conversely, 0 kg N/ha recorded significantly less nitrogen uptake by straw as compared to other nitrogen levels. These trends remained consistent in 2024 as well.

The enhanced nitrogen absorption by straw in the two rows per ridge plus one in the furrow setup may be attributed to improved root development and density, enabling rice plants to reach nutrient-rich deeper soil layers These results corroborate the findings of Hobbs and Gupta (2003). Application of 160 kg N/ha likely promoted greater vegetative growth, which is stored in straw tissues during plant development. Similar results were reported by Raj *et al.* (2017).

Both the years of study revealed that the interactive effect of planting patterns and nitrogen levels had no significant impact on nitrogen uptake by straw (Table 4.5.2)

4.4.6 Total nitrogen uptake by crop (kg/ha)

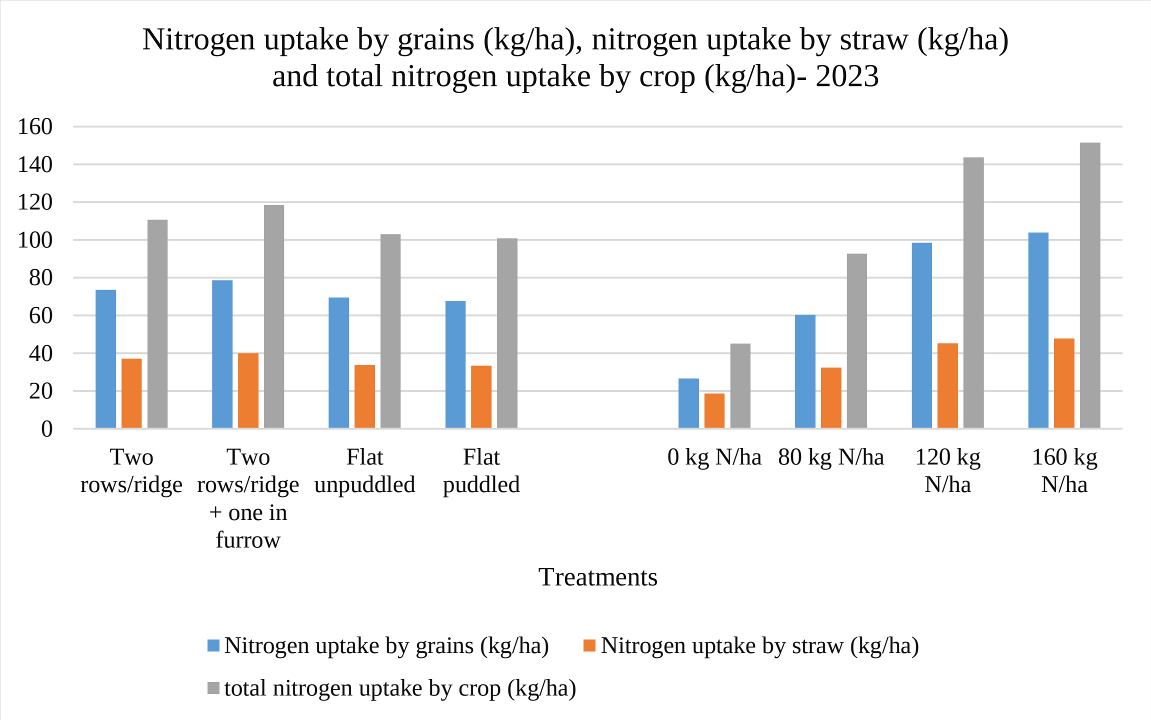
Total nitrogen uptake by crop helps in determining the nitrogen utilized by plant (grain and straw). Data on nitrogen uptake by grains, nitrogen uptake by straw and total nitrogen uptake by crop under varying planting patterns and nitrogen levels during 2023 and 2024 has been summarized in Table 4.5.2 and Figure 4.4.1.

Analysis of data at harvest indicated that planting pattern with two rows/ridge + one in furrow recorded significantly higher total nitrogen uptake by crop as compared to other planting methods. Two rows/ridge recorded significantly more total nitrogen uptake by crop than flat puddled and flat unpuddled which remained at par with each other. Among the nitrogen levels, application of 160 kg N/ha significantly increased the total nitrogen uptake by crop in comparison to other nitrogen levels. Application of 120 kg N/ha recorded significantly more total nitrogen uptake by crop than 80 kg N/ha. However, significantly less total nitrogen uptake by crop was observed in 0 kg N/ha as compared to other nitrogen levels.

The interactive effect of planting patterns and nitrogen levels had no significant impact on total nitrogen uptake by crop during both the years of study (Table 4.5.2).

Table 4.5.2: Impact of planting patterns and nitrogen levels on nitrogen content of straw (%), nitrogen uptake by straw (kg/ha) and total nitrogen uptake by crop (kg/ha).

Treatments	**Nitrogen content of straw (%)**		**Nitrogen uptake by straw (kg/ha)**		**Total nitrogen uptake by crop (kg/ha)**	
Main plots (Planting patterns)	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Two rows/ridge	0.41	0.40	37.1	35.8	110.6	110.4
Two rows/ridge + one in furrow	0.42	0.41	40.0	38.7	118.5	117.2
Flat unpuddled	0.40	0.38	33.7	32.4	103.1	102.2
Flat puddled	0.40	0.38	33.3	32.7	100.8	102.3
SEm (±)	0.01	0.01	0.56	0.74	1.33	1.67
C.D. (5%)	**NS**	**NS**	**1.94**	**2.57**	**4.60**	**5.77**
Sub-plots (Nitrogen levels)						
0 kg N/ha	0.40	0.38	18.6	16.6	45.1	40.8
80 kg N/ha	0.40	0.39	32.4	31.7	92.7	93.7
120 kg N/ha	0.42	0.40	45.3	44.5	143.7	144.7
160 kg N/ha	0.42	0.40	47.7	46.9	151.5	152.9
SEm (±)	0.01	0.01	0.71	0.77	1.62	1.59
C.D. (5%)	**NS**	**NS**	**2.07**	**2.26**	**4.73**	**4.65**
Interaction C.D. (5%) (A × B)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**



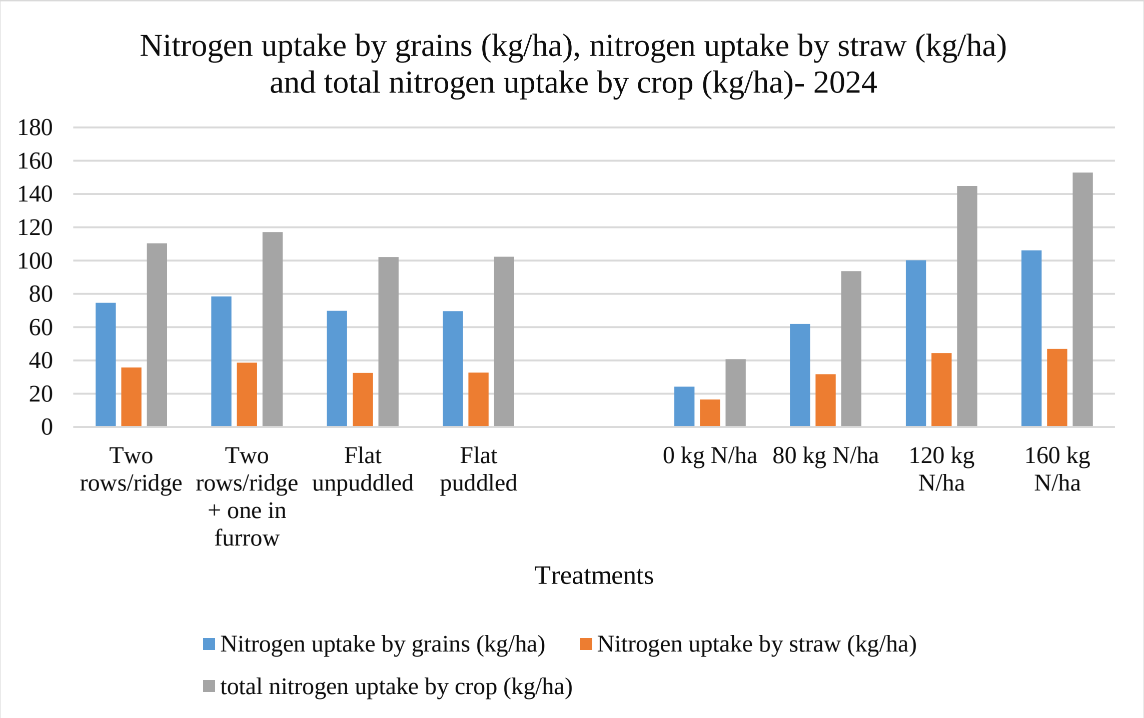


Fig 4.4.1: Influence of planting patterns and nitrogen levels on nitrogen uptake by grains (kg/ha), nitrogen uptake by straw (kg/ha), total nitrogen uptake by crop (kg/ha).

4.5.7 Agronomic nitrogen use efficiency (%)

Data pertaining to agronomic nitrogen use efficiency (%) as influenced by various planting patterns and nitrogen levels during 2023 and 2024 has been presented in Table 4.5.3.

Perusal of data at harvest during 2023 indicated that among the planting patterns maximum agronomic nitrogen use efficiency (%) was observed in two rows/ridge + one in furrow (40.6%), this was followed by two rows/ridge (36.3%) and flat unpuddled (32.1%). However, minimum agronomic nitrogen use efficiency was observed in flat puddled (30.5%). Among the nitrogen levels, maximum agronomic nitrogen use efficiency was observed with the application of 120 kg N/ha (39.1%), which was followed by 80 kg N/ha (34.9%). Lowest agronomic nitrogen use efficiency was observed with application of 160 kg N/ha (31.7%). During 2024, highest agronomic nitrogen use efficiency was recorded in two rows/ridge + one in furrow (41.7%) among the planting patterns, which was followed by two rows/ridge (39.6%) and flat puddled (34.8%). Meanwhile, minimum agronomic nitrogen use efficiency was recorded in flat unpuddled (34.5%). Among the sub plots, maximum agronomic nitrogen use efficiency was recorded with the application of 120 kg N/ha (42.2%), this was followed by 80 kg N/ha (38.6%), whereas minimum agronomic nitrogen use efficiency was observed with the application of 160 kg N/ha (33.8%).

Table 4.5.3: Impact of planting patterns and nitrogen levels on agronomic nitrogen use efficiency (%)

Treatments	**Agronomic nitrogen use efficiency (%)**	
Main plots (Planting patterns)	**2023**	**2024**
Two rows/ridge	36.3	39.6
Two rows/ridge + one in furrow	40.6	41.7
Flat unpuddled	32.1	34.5
Flat puddled	30.5	34.8
Sub-plots (Nitrogen levels)		
0 kg N/ha	-	-
80 kg N/ha	34.9	38.6
120 kg N/ha	39.1	42.2
160 kg N/ha	31.7	33.8
• Agronomic nitrogen use efficiency (%) was calculated from the values of paddy yield (kg/ha)		

SUMMARY AND CONCLUSION

The current investigation entitled "**Impact of planting patterns, nitrogen levels and weed control treatments on the growth and yield of unpuddled transplanted rice (*Oryza sativa* L.)**" was carried out at Agriculture Teaching and Research Farm of Lovely Professional University, Phagwara during *kharif* seasons of 2023 and 2024 respectively. The research consisted of two distinct experiments, each designed using a Split-Plot Design with four replications. Both experiments featured four main plots and four sub-plots. This chapter presents a comprehensive summary of the findings obtained during the course of investigation.

Experiment-1: Role of planting patterns and weed control treatments on yield of unpuddled transplanted rice.

5.1 Weed dynamics:

- Two rows/ridge + one in furrow recorded significantly less count of grassy weeds/m^2 than two rows/ridge and flat puddled at all periodic intervals, while significantly more count of grassy weeds/m^2 was observed in flat unpuddled during both the years. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence significantly reduced count of grassy weeds/m^2 at all periodic intervals in comparison to other herbicidal treatments, whereas unweeded (control) recorded significantly more count of grassy weeds/m^2 during both the years.
- During both the years, adopting two rows/ridge + one in furrow significantly reduced the count of broadleaf weeds/m^2 as compared to two rows/ridge and flat puddled at all periodic intervals, while significantly higher count of broadleaf weeds was recorded in flat unpuddled during both the years. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less count of broadleaf weeds/m^2 at all periodic intervals among the herbicidal treatments. Unweeded (control) was at par with the application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl as post-emergence and recorded significantly higher count of broadleaf weeds/m^2 during both the years.

- Two rows/ridge + one in furrow recorded significantly less dry matter of grassy weeds (q/ha) at all periodic intervals than two rows/ridge and flat puddled. Meanwhile, flat unpuddled recorded significantly higher dry matter of grassy weeds during both the years. Duirng both the years, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence was observed with significantly less dry matter of grassy weeds at all periodic intervals in comparison to other herbicidal treatments, while unweeded (control) recorded significantly more dry matter of grassy weeds.
- During both the years, significantly less dry matter of broadleaf weeds (q/ha) was recorded in two rows/ridge + one in furrow at all periodic intervals in comparison to other planting patterns, whereas flat unpuddled recorded significantly higher dry matter of broadleaf weeds. At all periodic intervals, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less dry matter of broadleaf weeds (q/ha) than other herbicidal treatments, while application of pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence and unweeded (control) remained at par and recorded significantly more dry matter of broadleaf weeds during both the years in comparison to other weed control treatments.
- Maximum weed control efficiency was observed in planting pattern of two rows/ridge + one in furrow, while minimum weed control efficiency was observed in flat unpuddled during both the years. Pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded highest weed control efficiency whereas pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence recorded lowest weed control efficiency among the herbicidal treatments during both the years.

5.2 Growth parameters:

- Establishment percentage of rice was not influenced by planting patterns during both the years. Likewise, weed control treatments had no notable impact on establishment percentage during both the years.
- Plant height (cm) was not significantly influenced by planting patterns during both the years. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-

emergence recorded significantly more plant height than other herbicidal treatments at, while unweeded (control) recorded significantly less plant height compared to other weed control treatments all periodic intervals during both the years.

- Total number of tillers/m^2 were significantly more in two rows/ridge + one in furrow at all periodic intervals in comparison to other planting patterns. Significantly less count of total number of tillers/m^2 were observed in flat puddled and flat unpuddled and they were statistically at par with each other. Among sub plots, application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly higher count of total number of tillers/m^2 than other herbicidal treatments at all periodic intervals, while unweeded (control) had singnificantly less count of total number of tillers/m^2 during both the years as compared to other treatments.
- Dry matter accumulation by crop (q/ha) was significantly higher in planting pattern of two rows/ridge + one in furrow than other planting patterns at all periodic intervals, whereas flat puddled and flat unpuddled remained at par with significantly less dry matter accumulation during both the years as compared to other methods. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly more dry matter accumulation than other herbicidal treatments at all periodic inervals, while unweeded (control) was observed with significantly less dry matter during both the years.
- Chlorophyll index was not significantly influenced by planting patterns during both the years. All the herbicidal treatments remained statistically at par with each other and also recorded significantly more chlorophyll index than unweeded (control) during both the years.

5.3 Yield components:

- Number of panicles/m^2 were significantly more in planting pattern of two rows/ridge + one in furrow, while flat puddled and flat unpuddled recorded significantly less number of panicles/m^2 as compared to other treatments and also remained at par with each other during both the years. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly higher number of panicles/m^2 in comparison with other herbicidal treatments, whereas unweeded (control) recorded significantly less number of panicles/m^2 during both the years of study.

- Panicle length (cm) was not significantly influenced by planting patterns and weed control treatments during both the years of study.
- Total number of grains/panicle were significantly higher in two rows/ridge + one in furrow during both the years, while flat unpuddled and flat puddled recorded significantly less count of total number of grains/panicle than other methods. Pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly more count of total number of grains/panicle as compared to other herbicidal treatments. Unweeded (control) recorded significantly less count of total number of grains/panicle during both the years compared to other treatments.
- Number of filled grains/panicle were significantly more in planting pattern of two rows/ridge + one in furrow, whereas flat puddled and flat unpuddled recorded significantly less number of filled grains/panicle and remained statistically at par with each other during both the years. Pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly higher number of filled grains/panicle in comparison to other herbicidal treatments, while unweeded (control) had significantly less number of filled grains/panicle during both the years as compared to other treatments.
- Test weight (g) was not significantly affected by planting patterns. All the herbicidal treatments recorded significantly more test weight than unweeded (control) and remained statistically at par with each other during both the years.
- Paddy yield (q/ha) was significantly higher in two rows/ridge + one in furrow, while flat puddled and flat unpuddled recorded significantly less paddy yield than other methods and were statistically at par with each other during both the years. Significantly more paddy yield was obtained with the application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence in comparison to other herbicidal treatments, whereas significantly less paddy yield was recorded in unweeded (control) during both the years. On an average two rows/ridge, two rows/ridge + one in furrow, flat unpuddled showed an increase in paddy yield by 7.4%, 13.0%, 1.7% respectively in comparison to flat puddled

during both the years. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence, pendimethalin pre-emergence *fb* penoxsulam post-emergence, pendimethalin pre-emergence *fb* fenoxaprop-p-ethyl post-emergence increased the paddy yield by 138.2%, 125.8%, 112.6% respectively over unweeded (control) during both the years.

- Straw yield (q/ha) was significantly more in planting pattern of two rows/ridge + one in furrow, while significantly less straw yield was observed in flat unpuddled and flat puddled which also remained at par during both the years. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly more straw yield when compared to other herbicidal treatments, while unweeded (control) recorded significantly less straw yield during both the years of study than other treatments.
- Biological yield (q/ha) was significantly higher in two rows/ridge + one in furrow, while flat puddled and flat unpuddled recorded significantly less biological yield and remained statistically at par with each other during both the years of study. Significantly more biological yield was observed in pendimethalin pre-emergence *fb* bispyribac sodium post-emergence among the herbicidal treatments, whereas unweeded (control) recorded significantly less biological yield during both the years.
- Harvest index was not significantly influenced by different planting patterns, whereas all the herbicidal treatments were found to be at par and recorded significantly higher harvest index than unweeded (control).

5.4 Quality parameters:

- Nitrogen content of grains was not significantly influenced by planting patterns and weed control treatments during both the years.
- Protein content in grains showed no significant variation across various planting patterns and weed control treatments during both the years.
- Nitrogen uptake by grains (kg/ha) was significantly more in two rows/ridge + one in furrow as compared to other planting patterns during both the years. Significantly higher nitrogen uptake by grains was observed with the application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence than other

herbicidal treatments, while unweeded (control) recorded significantly less nitrogen uptake by grains during both the years of study.

- Nitrogen content of straw was not significantly influenced by planting patterns and weed control treatments during both the years.
- Nitrogen uptake by straw (kg/ha) was significantly higher in two rows/ridge + one in furrow, while flat puddled and flat unpuddled recorded significantly less nitrogen uptake by straw and they also remained at par with each other. Significantly more nitrogen uptake by straw was observed with the application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence in comparison to other herbicidal treatments, whereas unweeded (control) recorded significantly less nitrogen uptake by straw during both the years.
- Nitrogen content of weeds was not significantly affected by planting patterns and weed control treatments during both the years.
- Nitrogen uptake by weeds was significantly less in two rows/ridge + one in furrow, while significantly more uptake was recorded in flat unpuddled during both the years of study. Application of pendimethalin pre-emergence *fb* bispyribac sodium post-emergence recorded significantly less nitrogen uptake by weeds, whereas significantly more nitrogen uptake by weeds was observed in unweeded (control) during both the years.

Experiment-2: Influence of planting patterns and nitrogen levels on the yield of transplanted rice under unpuddled conditions

5.1 Weed dynamics:

- Count of grassy weeds/m^2 was not significantly affected by planting patterns and nitrogen levels during both the years.
- Count of broadleaf weeds/m^2 showed no significant variation across various planting patterns and nitrogen levels during both the years.
- Dry matter of grassy weeds was not significantly influenced by planting patterns and nitrogen levels during both the years.

- Dry matter of broadleaf weeds was not notably influenced by planting patterns and nitrogen levels during both the years.

5.2 Growth parameters:

- Establishment percentage of rice was not significantly influenced by planting patterns and nitrogen levels during both the years of study.
- Plant height (cm) showed no significant variation across different planting patterns during both the years. Application of 160 kg N/ha and 120 kg N/ha recorded significantly more plant height and both these treatments were at par with each other at all periodic intervals, while 0 kg N/ha (control) recorded significantly less plant height during both the years of study as compared to other nitrogen levels.
- Total number of tillers/m^2 were significantly more in two rows/ridge + one in furrow, whereas flat puddled and flat unpuddled recorded significantly less count of total number of tillers/m^2 and both these treatments remained at par at all periodic intervals during both the years. Application of 160 kg N/ha recorded significantly higher count of total number of tillers/ m^2 in comparison to other nitrogen doses, while 0 kg N/ha (control) recorded significantly less count of total number of tillers/m^2 at all periodic intervals during both the years of study.
- Dry matter accumulation by crop (q/ha) was significantly higher in planting pattern of two rows/ridge + one in furrow, while significantly less dry matter accumulation was observed in flat puddled and flat unpuddled and both these treatments remained at par with each other at all periodic intervals during both the years. Application of 160 kg N/ha recorded significantly higher dry matter accumulation than lower nitrogen levels and significantly less dry matter accumulation was observed in 0 kg N/ha during both the years of study.
- Chlorophyll index of rice was not significantly influenced by planting patterns. Application of 120 kg N/ha and 160 kg N/ha recorded significantly more chlorophyll index and remained at par with each other, whereas 0 kg N/ha (control) recorded significantly less chlorophyll index during both the years.

5.3 Yield components:

- Number of panicles/m^2 were significantly more in two rows/ridge + one in furrow, while significantly lower number of panicles/m^2 were observed in flat puddled and flat unpuddled and both these treatments were at par with each other during both the years of study. Application of 160 kg N/ha recorded significantly higher number of panicles/m^2, whereas 0 kg N/ha (control) was observed with significantly less number of panicles/m^2 during both the years.
- Panicle length (cm) was not significantly influenced by planting patterns. Panicle length with application of 120 kg N/ha and 160 kg N/ha was significantly more and both these treatments remained at par with each other, while 0 kg N/ha (control) recorded significantly less panicle length during both the years.
- Total number of grains/panicle and number of filled grains/panicle were significantly more in two rows/ridge + one in furrow. Also these attributes were significantly more in 160 kg N/ha, whereas significantly less count of total number of grains/panicle and number of filled grains/panicle were observed in 0 kg N/ha (control).
- Test weight (g) was not significantly influenced by planting patterns. Significantly more test weight (g) was recorded with the application of 160 kg N/ha and 120 kg N/ha, both these treatments were at par, whereas significantly less test weight was observed in 0 kg N/ha during both the years of study.
- Paddy yield (q/ha) was significantly higher in two rows/ridge + one in furrow, while flat puddled and flat unpuddled recorded significantly less paddy yield and remained at par with each other during both the years. Application of 160 kg N/ha recorded significantly higher paddy yield, whereas 0 kg N/ha (control) recorded significantly less paddy yield during both the years. On an average two rows/ridge, two rows/ridge + one in furrow, flat unpuddled increased the paddy yield by 8.4%, 13.2%, 1.0% respectively over flat puddled. Application of 80 kg N/ha, 120 kg N/ha, 160 kg N/ha showed an increase in paddy yield by 105.0%, 174.3%, 187.5% respectively in comparison to 0 kg N/ha (control) during both the years.
- Straw yield (q/ha) was significantly more in two rows/ridge + one in furrow, while flat puddled and flat unpuddled remained at par with each other and recorded significantly less straw yield during both the years. Meanwhile, application of 160

kg N/ha resulted in significantly higher straw yield, while 0 kg N/ha (control) recorded significantly less straw yield during both the years of study.

- Biological yield (q/ha) was significantly more in two rows/ridge + one in furrow, while flat puddled and flat unpuddled remained at par with each other and recorded significantly less biological yield during both the years. Application of 160 kg N/ha recorded significantly higher biological yield, whereas 0 kg N/ha (control) recorded significantly less biological yield during both the years.
- Harvest index showed no significant variation across the planting patterns. Harvest index with application of 160 kg N/ha, 120 kg N/ha, 80 kg N/ha was significantly more than 0 kg N/ha (control) and all the three treatments remained at par with each other during both the years of study.

5.4 Quality parameters:

- Nitrogen content of grains was not significantly affected by planting patterns. Application of 120 kg N/ha and 160 kg N/ha remained at par and recorded significantly higher nitrogen content in grains, whereas 0 kg N/ha (control) recorded significantly less nitrogen content in grains during both the years of study.
- Protein content of grains showed no significant variation among the planting patterns. Application of 160 kg N/ha and 120 kg N/ha recorded significantly higher protein content in grains and both these treatments were at par with each other, while significantly less protein content was observed in 0 kg N/ha (control) during both the years of study.
- Nitrogen uptake by grains was significantly higher in two rows/ridge + one in furrow, whereas flat puddled and flat unpuddled recorded significantly less nitrogen uptake by grains and both these treatments remained at par with each other during both the years of study. Application of 160 kg N/ha recorded significantly more nitrogen uptake by grains in comparison to lower nitrogen levels, whereas 0 kg N/ha recorded significantly less nitrogen uptake by grains during both the years.
- Nitrogen content of straw was not notably influenced by planting patterns and nitrogen levels during both the years of study.
- Nitrogen uptake by straw was significantly higher in two row/ridge + one in furrow, while flat puddled and flat unpuddled remained at par and recorded significantly

lower nitrogen uptake by straw during both the years of study. Significantly more nitrogen uptake by straw was observed with application of 160 kg N/ha, whereas 0 kg N/ha recorded significantly less nitrogen uptake by straw during both the years.

- Agronomic nitrogen use efficiency was highest in two rows/ridge + one in furrow while lowest agronomic nitrogen use efficiency was observed in flat unpuddled. Application of 120 kg N/ha recorded maximum agronomic nitrogen use efficiency, whereas lowest agronomic nitrogen use efficiency was observed in 160 kg N/ha during both the years.

CONCLUSION:

The results of our research in Experiment-I show that unpuddled rice cultivation has the potential to achieve yields equal to or better than those of conventional puddled transplanted rice by employing a synergistic approach. This approach involves implementing the planting pattern of two rows/ridge + one in furrow combined with sequential herbicide program comprising both pendimethalin as pre-emergence *fb* bispyribac sodium as post-emergence. This approach has resulted in better growth parameters, yield attributes and higher net returns as compared to other weed control treatments. This comprehensive method effectively manages both grassy and broadleaf weed populations throughout different growth phases, ensuring reliable productivity while potentially reducing water and labour requirements.

The outcomes of Experiment-II show that in unpuddled rice cultivation, implementing minor land configuration changes, adopting the planting pattern of two rows per ridge + one in furrow combined with optimal nitrogen application i.e. 120 kg N/ha, has the potential to produce paddy yields comparable to conventional puddled transplanted rice with the application of 160 kg N/ha. Furthermore, this approach is effective in obtaining higher net returns and mitigating nitrogen losses that occur during puddling.

References

Adhikari, J., Sarkar, A. R., Uddin, M. R., Sarker, U. K., Hossen, K., & Rosemila, U. 2018. Effect of nitrogen fertilizer and weed management on the yield of transplant aman rice. *Journal of the Bangladesh Agricultural University*, **16** (1), 12-16.

Ahmed, S., Alam, M.J., Hossain, A., Islam, A.M., Awan, T.H., Soufan, W., Qahtan, A.A., Okla, M.K. and El Sabagh, A.2020. Interactive effect of weeding regimes, rice cultivars, and seeding rates influence the rice-weed competition under dry direct-seeded condition. *Sustainability*, **13** (1), 317.

Alagbo, O., Spaeth, M., Saile, M., Schumacher, M., & Gerhards, R. 2022. Weed Management in Ridge Tillage Systems—A Review. *Agronomy*, **12** (4), 910.

Ameena, M. 2024. Growth, nutrient uptake and yield of direct seeded rice as influenced by weed management practices. *Indian Journal of Agronomy*, **69** (3), 233-240.

Anil, D., Siddi, S., Prakash, R.T., Reddy, P.R.R. 2024. Herbicide options for weed management in dry direct-seeded rice. *Agriculture Association of Textile Chemical and Critical Reviews Journal*. **12** (4), 454-458.

Anonymous, 2024. Package of Practices for Crops of Punjab *Kharif*, Punjab Agricultural University, Ludhiana, Punjab.

Arya, S. R., & Ameena, M. 2016. Efficacy of new generation herbicides for weed management in semi dry rice. *Journal of Tropical Agriculture*, **54** (1), 55-55.

Aslam, M., Hussain, S., Ramzan, M., & Akhter, M. 2008. Effect of different stand establishment techniques on rice yields and its attributes. *Journal of Animal and Plant Sciences*, **18** (2-3), 80-82.

Baloch, M. S., Hassan, G. U. L., & Morimoto, T. 2005. Weeding techniques in transplanted and direct wet-seeded rice in Pakistan. *Weed Biology and Management*, **5** (4), 190-196.

Bama, K. S., Babu, K. R., Sharmila, R., & Anuradha, A. 2021. Influence of nitrogen application on direct seeded rice in old and new Cauvery Delta zone of Tamil Nadu, India. *Journal of Applied and Natural Science*, **13** (4), 1462-1469.

Baurai, R., Chandra, S., & Singh, G. 2020. Impact of different crop-establishment methods and cono weeding on growth, productivity and water economy of rice (*Oryza sativa*). *Indian Journal of Agronomy*, **65** (2), 166-170.

Bhattarai, R.K., Chaulagain, B., Gyawaly, P., Karki, T.B., Neupane, R., Das, S.K., Kaduwal, S., Acharya, R., Paneru, P., Thapa, A. and Adhikari, K., & Shah, P. 2023. Effect of Different Herbicides in Weed Management in Transplanted Rice. *Agronomy Journal of Nepal*, **7**,121-126.

Bhatt, R., & Kukal, S. S. 2015. Soil physical environment as affected by double zero tillage in rice-wheat cropping system of North-West India. *Asian Journal of Soil Science*, **10** (1), 166-172.

Bhuiyan, M. K. A., Salam, M. U., & Kabir, M. S. 2020. Integrated weed management strategies for sustainable rice production in Bangladesh. *Bangladesh Rice Journal,* **24** (2), 133-159.

Bhullar, M.S., Kumar, S., Kaur, S., Kaur, T., Singh, J., Yadav, R., Chauhan, B.S. and Gill, G. 2016. Management of complex weed flora in dry-seeded rice. *Crop Protection*, **83**, 20-26.

Bhuyan, M. H. M., Ferdousi, M. R., & Iqbal, M. T. 2012. Yield and growth response to transplanted aman rice under raised bed over conventional cultivation method. *International Scholarly Research Notices*, **2012** (1), 646859.

Biswas, B., Timsina, J., Garai, S., Mondal, M., Banerjee, H., Adhikary, S., & Kanthal, S. 2023. Weed control in transplanted rice with post-emergence herbicides and their effects on subsequent rapeseed in Eastern India. *International Journal of Pest Management*, **69** (1), 89-101.

Bokado, K., Singh, V., & Khwairakpam, R. 2020. Influence of nitrogen levels and seed rates on growth and yield of puddled direct seeded rice (*Oryza sativa* L.). *International Journal of Chemical Studies,* **8** (6), 2035-2039.

Borrell, A. K., Kelly, R. M., & Van Cooten, D. E. 1998. Improving management of rice in semi-arid eastern Indonesia: responses to irrigation, plant type and nitrogen. *Australian Journal of Experimental Agriculture*, **38** (3), 261-271.

BRRI (Bangladesh Rice Research Institute), Bangladesh Rice Knowledge Bank, Bangladesh Rice Research Institute, https://knowledgebank-brri.org/, 2006.

Burgos, N. R., Norman, R. J., Gealy, D. R., & Black, H. 2006. Competitive N uptake between rice and weedy rice. *Field crops research*, **99** (2-3), 96-105.

Cassman, K. G., Dobermann, A., & Walters, D. T. 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO: *A Journal of the Human Environment*, **31** (2), 132-140.

Chaki, A. K., Gaydon, D. S., Dalal, R. C., Bellotti, W. D., Gathala, M. K., Hossain, A., & Menzies, N. W. 2021. Puddled and zero-till unpuddled transplanted rice are each best suited to different environments–An example from two diverse locations in the Eastern Gangetic Plains of Bangladesh. *Field Crops Research*, **262**, 108031.

Chandna, P., Khurana, M. L., Ladha, J. K., Punia, M., Mehla, R. S., & Gupta, R. 2011. Spatial and seasonal distribution of Nitrate-N in groundwater beneath the rice–wheat cropping system of India: a geospatial analysis. *Environmental monitoring and assessment*, **178**, 545-562.

Chauhan, B. S. 2012. Weed ecology and weed management strategies for dry seeded rice in Asia. *Weed Technology*, **26** (1), 1–13.

Chauhan, B. S., & Johnson, D. E. 2011. Ecological studies on *Echinochloa crus-galli* and the implications for weed management in direct-seeded rice. *Crop Protection*, **30** (11), 1385-1391.

Chhokar, R. S., Sharma, R. K., Gathala, M. K., & Pundir, A. K. 2014. Effects of crop establishment techniques on weeds and rice yield. *Crop Protection*, **64**, 7-12.

Choudhary, V. K., & Dixit, A. N. I. L. 2021. Bio-efficacy of sequential herbicide application for weed management in dry direct seeded rice. *Indian Journal of Agricultural Sciences*, **91** (1), 79-83.

Choudhury, A. T. M. A., & Khanif, Y. M. 2004. Effects of nitrogen and copper fertilization on rice yield and fertilizer nitrogen efficiency: A 15 N tracer study. *Biological Sciences-PJSIR*, **47** (1), 50-55.

Chowdhury, M., Khura, T.K., Parray, R.A., Upadhyay, P.K., Kushwaha, H.L., Lama, A., Chaudhary, S. and Ansh, A.K. 2025. Impact of Nitrogen Variability on Yield Dynamics and Economics Viability of Transplanted and Direct Seeded Rice. *Journal of Experimental Agriculture International*, **47** (1), 207-217.

Dahipahle, A. V., & Singh, U. P. 2018. Effect of crop establishment, nitrogen levels and time of nitrogen application on growth and yield attributing parameters of direct seeded rice (*Oryza sativa* L.). *International Journal of Chemical Studies*, **6** (2), 2889-2893.

Debbarma, L. L., Dey, D., & Nath, D. 2021. Weed Survey in Different Fields of Transplanted Rice (*Oryza sativa* L.) in North Pulinpur Area under Khowai District of Tripura. *Research Biotica*, **3** (1), 37-43.

Denesh, G. R., Reddy, R., & Savitha, H. R. 2022. Studies on nutrient management in transplanted rice for higher production. International Conference on System of Crop Intensification for Climate-Smart Livelihood and Nutritional Security.

Devi, M. G., Reddy, S. T., Sumati, V., Pratima, T., & John, K. 2012. Nitrogen management to improve the nutrient uptake, yield and quality parameters of scented rice under aerobic culture. *International Journal of Applied Biology and Pharmaceutical Technology*, **3** (1), 340-344.

Dobermann, A., & Cassman, K. G.2004. Environmental dimensions of fertilizer nitrogen: What can be done to increase nitrogen use efficiency and ensure global food security. Agriculture and the nitrogen cycle: Assessing the Impacts of Fertilizer use on Food Production and the Environment, *Island Press*, **65**, 261-278.

Ejaz, K., & Ashraf, M. 2023. Water Productivity and Economic Feasibility of Growing Rice and Wheat on Beds in Central Punjab, Pakistan. *Pakistan Council of Research in Water Resources (PCRWR), Islamabad*, 53.

Fahad, S., Adnan, M., Noor, M., Arif, M., Alam, M., Khan, I.A., Ullah, H., Wahid, F., Mian, I.A., Jamal, Y. and Basir, A. 2019. Major constraints for global rice production. In *Advances in rice research for abiotic stress tolerance* (pp. 1-22). Woodhead Publishing.

Food and Agriculture Organization of the United Nations (FAO). Nutritional composition of rice. https://www.fao.org/4/t0567e/t0567e08.htm

Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Kumar, V., Kumar, V., Sharma, P.K. 2011b. Effect of tillage and crop establishment methods on physical properties of a medium- textured soil under a seven-year rice-wheat rotation. *Soil Science Society American Journal*, **75**, 1851–1862.

Gathala, M.K., Laing, A.M., Tiwari, T.P., Timsina, J., Islam, S., Bhattacharya, P.M., Dhar, T., Ghosh, A., Sinha, A.K., Chowdhury, A.K., Hossain, S., Hossain, I., Molla, S., Rashid, M., Kumar, S., Kumar, R., Dutta, S.K., Srivastwa, P.K., Chaudhary, B., Jha, S. K., Ghimire, P., Bastola, B., Chaubey, R.K., Kumar, U., G´ erard, B. 2020 (b). Energy- efficient, sustainable crop production practices benefit smallholder farmers and the environment across three countries in the Eastern Gangetic Plains, South Asia. *Journal of cleaner production*, **246**, 118982.

Gautam, A. K., Kumar, D., Shivay, Y. S., & Mishra, B. N. 2008. Influence of nitrogen levels and plant spacing on growth, productivity and quality of two inbred varieties and a hybrid of aromatic rice. *Archives of Agronomy and Soil Science*, **54** (5), 515-532.

Gharde, Y., Singh, P. K., Dubey, R. P., & Gupta, P. K. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection*, **107**, 12-18.

Ghosh, S., Malik, G. C., & Banerjee, M. 2016. Weed management and biofertilizer effects on productivity of transplanted rice. *Indian Journal of Weed Science*, **48** (2), 148-151.

Gill, J. S., & Walia, S. S. 2013. Effect of establishment methods and nitrogen levels on basmati rice (*Oryza sativa*). *Indian Journal of Agronomy*, **58** (4), 506-511.

Giri, D., Dhital, M., Chaudhary, B., Pandey, R., Bastakoti, B., & Shrestha, S. 2022. Effect of different nitrogen levels on yield and yield attributes of different rice varieties in DDSR condition at Kanchanpur, Nepal. *Archives of Agriculture and Environmental Science*, **7** (3), 310-317.

Gyawali, C., Upadhayaya, B. T., Pokharel, B., Pandey, B. P., Gyawaly, P., & Moi, T. 2025. Effect of Different Nitrogen Levels on Growth, Yield, and Nitrogen Use

Efficiency (NUE) of Hardinath Hybrid Dhan-1 in Madhesh Province, Nepal. *International Journal of Plant and Soil Science*, **37** (1), 56-66.

Hashim, M., Singh, V.K., Singh, K.K. and Dhar, S. 2022. Herbicidal weed-management options for dry direct-seeded rice (*Oryza sativa*) in North-Eastern Plains of India. *Indian Journal of Agronomy*, **67** (4), 337–342.

Haque, M. E., Bell, R. W., Islam, M. A., & Rahman, M. A. 2016. Minimum tillage unpuddled transplanting: An alternative crop establishment strategy for rice in conservation agriculture cropping systems. *Field crops research*, **185**, 31-39.

He, X., Zhu, H., Shi, A., & Wang, X. 2024. Optimizing Nitrogen Fertilizer Management Enhances Rice Yield, Dry Matter, and Nitrogen Use Efficiency. *Agronomy*, **14** (5), 919.

Hobbs, P. R., & Gupta, R. K. 2003. Resource-Conserving Technologies for Wheat in the Rice–Wheat System. *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts*, **65**, 149-171.

Hobbs, P.R., Singh, Y., Giri, G.S., Lauren, J.G., Duxbury, J.M. 2002. Direct seeding and reduced tillage options in the rice-wheat systems of the indo-gangetic plains of South Asia. In: Pandey, S., Mortimer, M., Wade, L., Tuong, T.P., Lopez, K., Hardy, B. (Eds.), Direct Seeding: Research Strategies and Opportunities. IRRI, Los Baños, pp. 201–215.

Hou, A. X., Chen, G. X., Wang, Z. P., Van Cleemput, O., & Patrick Jr, W. H. 2000. Methane and nitrous oxide emissions from a rice field in relation to soil redox and microbiological processes. *Soil Science Society of America Journal*, **64** (6), 2180-2186.

Hussain, A., Khathian, M. A., Ullah, S., & Ullah, S. 2019. Increasing Crop Profitability through Adoption of Ridge Planting of Rice Crop in Punjab, and Wheat & Banana Crops in Sindh Province of Pakistan: Ridge Planting of Rice, Wheat & Banana Crops in Pakistan. *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, **56** (4), 25-38.

Hussain, I., Ali, A., Ahmed, A., Nasrullah, H., Khokhar, B.U.D., Iqbal, S., Aulakh, A.M., Khan, A.U., Akhter, J. and Ahmed, G., 2018. Impact of Ridge-Furrow Planting in Pakistan: Empirical Evidence from the Farmers Field. *International Journal of Agronomy*, **2018** (1), 3798037.

Jat, M. L., & Sharma, S. K. 2013. On-farm studies on FIRB system for improving crop and water productivity and profitability in rice-wheat cropping system. In *Proceedings of the "Agenda Notes", 3rd Regional Technical Conrdination Committee Meeting of RWC for the IGP*.

Jat, M. L., Singh, S., Rai, H. K., Chhokar, R. S., Sharma, S. K., & Gupta, R. K. 2005. Furrow irrigated raised bed planting technique for diversification of rice-wheat system of Indo-Gangetic Plains. *Journal of Japan Association for International Cooperation for Agriculture and Forestry*, **28** (1), 25-42.

Jehangir, I.A., Hussain, A., Sofi, N.R., Wani, S.H., Ali, O.M., Abdel Latef, A.A.H., Raja, W. and Bhat, M.A. 2021. Crop establishment methods and weed management practices affect grain yield and weed dynamics in temperate rice. *Agronomy*, **11** (11), 2137.

Kabat, B., & Satapathy, M. R. 2011. Effect of planting date and nitrogen level on grain yield of hybrid rice. *ORYZA-An International Journal on Rice*, **48** (2), 186-187.

Kashid, N. V., Jadhav, V. T., & Patil, Y. J. 2019. Herbicides for weed management in dry direct-seeded rice. *Indian Journal of Weed Science*, **51** (1), 72-74.

Kashyap, S., Singh, V. P., Guru, S. K., Pratap, T., Singh, S. P., & Kumar, R. 2022. Effect of integrated weed management on weed and yield of direct seeded rice. *Indian Journal of Agricultural Research*, **56** (1), 33-37.

Kaur, J., & Mahal, S. S. 2014. Effect of irrigation schedules and nitrogen levels on direct seeded scented basmati rice (*Oryza sativa* L.). *Journal of Research*, **51** (2), 119–123.

Khattak, S. I., Khalid Usman, K. U., Qasim Khan, Q. K., & Abdul Qayyum, A. Q. 2006. Impact of various planting techniques on yield and yield components of rice. *Indus Journal of Plant Sciences*, **5** (1), 753.-756.

Kim, K.U. 1996. Ecological forces influencing weed competition and herbicide resistance. In: Naylor, R. (Ed.), Herbicides in Asian Rice: Transitions in Weed Management. Stanford University, California and IRRI, Philippines, pp. 129-142.

Kiran, Y. D., & Subramanyam, D. 2010. Performance of pre-and post-emergence herbicides on weed flora and yield of transplanted rice (*Oryza sativa*). *Indian Journal of Weed Science*, **42** (3&4), 229-231.

Kokilam, M. V., Rathika, S., Ramesh, T., & Baskar, M. 2023. Weed dynamics and productivity of direct wet seeded rice under different weed management practices. *Indian Journal of Agricultural Research*, **57** (3), 347-351.

Kolo, E., Adigun, J. A., Daramola, O. S., Adeyemi, O. R., & Olorunmaiye, P. M. 2021. Nitrogen effect on weed management in rice in a tropical forest-savanna transition zone of Nigeria. *Journal of Crop Improvement*, **35** (2), 169-183.

Krishnaprabu, S. 2019. Influence of weed management and planting methods for improving yield of dry seeded rice. In *Journal of Physics*: Conference Series, **1362** (1), 012019.

Kumar, A. R., Madhavi, M., Pratibha, G., & Prakash, T. R. 2017. Effect of different crop establishment methods and weed management options on growth and control of weeds in rice. *International Journal of Chemical Studies*, **5** (5), 998-1002.

Kumar, R., Mishra, J.S., Kumar, S., Choudhary, A.K., Singh, A.K., Hans, H., Srivastava, A.K. & Singh, S., 2023. Weed competitive ability and productivity of transplanted rice cultivars as influenced by weed management practices. *Indian Journal of Weed Science,* **55** (1), 13–17.

Kumar, R., Mishra, J.S., Kumar, S., Rao, K.K., Hans, H., Bhatt, B.P., Srivastava, A.K. and Singh, S., 2020. Evaluation of weed competitiveness of direct-seeded rice (*Oryza sativa*) genotypes under different weed management practices. *Indian Journal of Agricultural Sciences,* **90** (5), 914-918.

Kumar, S., Shivani, J. M., Mishra, J. S., Kumar, S., Kumar, U., & Bharati, R. C. 2011. Efficacy of pre-and post-emergence herbicides on complex weed flora in direct-seeded rice (*Oryza sativa*) in the eastern plains. *Indian Journal of Agricultural Sciences*, **88** (3), 387-392.

Kumar, N., Nandal, D.P., Kumar, A. and Kumar, M. 2018. Effect of Different Doses of Herbicides on Weed Control Efficiency, growth and productivity of Transplanted Rice (*Oryza sativa*), *International Journal of Pure and Applied Bioscience*. **6** (1), 475-480.

Kumar, V., Kumar, P., & Singh, R. 2013. Growth and yield of rice-wheat cropping sequence in raised bed planting system. *Indian Journal of Agricultural Research*, **47** (2), 157.

Kumawat, A., Sepat, S., Kumar, D., Singh, S., Jinger, D., Bamboriya, S. D., & Verma, A. K. 2017. Effect of irrigation scheduling and nitrogen application on yield, grain quality and soil microbial activities in direct-seeded rice. *International Journal of Current Microbiology and Applied Sciences*, **6** (5), 2855-2860.

Lan, Y., Sui, X., Wang, J., Duan, Q., Wu, C., Ding, C., & Li, T. 2021. Effects of nitrogen application rate on protein components and yield of low-gluten rice. *Agriculture*, **11** (4), 302.

Lathwal, O. P., Dhaka, A. K., Sutaliya, J. M., Garhwal, R. S., Kumar, P., & Phogat, P. 2024. Effect of Crop Establishment Methods and Nitrogen Levels on Phenology, Quality, Nutrient Content and Uptake of Coarse Rice. *Journal of Scientific Research and Reports*, **30** (3), 144-149.

Liang, H., Gao, S., Ma, J., Zhang, T., Wang, T., Zhang, S., & Wu, Z. 2021. Effect of nitrogen application rates on the nitrogen utilization, yield and quality of rice. *Food and Nutrition Sciences*, **12** (1), 13.

Linu, C., & Girija, T. 2021. Physiological response of rice to herbicide application. *Indian Journal of Weed Science*, **53** (1), 85–87.

Liu, Z., Li, W., Geng, S., Zhang, R., Dou, M., Wu, M., Li, L., Wang, D., Wei, X., Tian, P. and Yang, M. 2024. Improvement of Transplanting Rice Yield and Nitrogen Use Efficiency by Increasing Planting Density in Northeast China Under the Optimal Nitrogen Split-Fertilizer Applications. *Agriculture*, **14** (11), 2015.

Mahajan, G., & Chauhan, B. S. 2011. Effects of planting pattern and cultivar on weed and crop growth in aerobic rice system. *Weed Technology*, **25** (4), 521-525.

Mahajan, G., & Chauhan, B. S. 2013. Herbicide options for weed control in dry-seeded aromatic rice in India. *Weed Technology*, **27** (4), 682-689.

Mahajan, G., Chauhan, B. S., & Johnson, D. E. 2009. Weed management in aerobic rice in Northwestern Indo-Gangetic Plains. *Journal of Crop Improvement*, **23** (4), 366-382.

Mahajan, G., & Chauhan, B. S. 2015. Weed control in dry direct-seeded rice using tank mixtures of herbicides in South Asia. *Crop Protection*, **72**, 90-96.

Mahajan, G., Timsina, J., & Kuldeep-Singh. 2011. Performance and water-use efficiency of rice relative to establishment methods in northwestern indo-gangetic plains. *Journal of Crop Improvement*, **25** (5), 597-617.

Maity, S.K., & Mukherjee, P.K. 2008. Integrated weed management in dry direct-seeded rainy season rice (*Oryza sativa*). *Indian Journal of Agronomy*. **53** (2), 116–120.

Mallareddy, M., & Padmaja, B. 2013. Response of rice (*Oryza sativa*) varieties to nitrogen under aerobic and flooded conditions. *Indian Journal of Agronomy,* **58** (4), 500-505.

Manjunatha, K. B., Hanumanthappa, M., Nagesha, L., Kalyanamurthy, K. N., & Kamath, K. V. S. 2012. Effect of new herbicide molecules on nutrient uptake in transplanted rice (*Oryza sativa* L.) in coastal Karnataka. *Mysore Journal of Agricultural Sciences,* **46** (4), 928-930.

Maqsood, M., Shehzad, M. A., ALI, S. N., & Iqbal, M. 2013. Rice cultures and nitrogen rate effects on yield and quality of rice (*Oryza sativa* L.). *Turkish Journal of Agriculture and Forestry,* **37** (6), 665-673.

Maurya, R., Singh, M. K., Singh, N. K., Singh, M. K., & Singh, A. K. 2021. Effect of nitrogen levels on growth attributes, yield and nutrient uptake of different rice (*Oryza sativa* L.) varieties under the transplanted condition. *Journal of Experimental Biology and Agricultural Sciences,* **9** (3), 336-342.

Meena, M., Patel, M. V., Das, T., & Verma, H. P. 2014. Effect of organic sources and nitrogen levels on growth and yield of *kharif* rice (*Oryza sativa* L.) under SRI technique. *Agriculture for Sustainable Development*, **2** (1), 39-42.

Meisner, C.A., Talukder, A.S.M.H.M., Hossain, I., Hossain, I., Gill, M., Rehman, H.M., Baksh, E., Justice, S., Sayre, K. and Haque, E., 2006. Permanent bed systems in the rice–wheat cropping pattern in Bangladesh and Pakistan. *Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico*.

Mir, M.S., Singh, P., Kanth, R.H., Shah, Z.A., Dar, E.A., Bhat, J.A., Nazir, A., Amin, Z., Lone, A.H., Nain, M.S. and Yousuf, D., 2024. Influence of sowing dates and weed management practices on weed dynamics, productivity and profitability of direct seeded rice. *Scientific Reports*, **14** (1), 18877.

Mishra, D., Sharma, J. D., Pandey, A. K., Mishra, R. K., Shukla, U. N., & Kumar, J. 2015. Effect of nitrogen levels on yield, quality and economics of rice (*Oryza sativa* L.) varieties. *International Journal of Agricultural and Statistical Sciences*. **11** (1), 2015.

Mitra, B., Patra, K., Bhattacharya, P.M., Ghosh, A., Chowdhury, A.K., Dhar, T., Islam, S., Laing, A.M., & Gathala, M.K. 2022. Efficacy of pre-and post-emergence herbicide combinations on weed control in no-till mechanically transplanted rice. *Cogent Food & Agriculture*, **8** (1), 2139794.

Mondal, D., Ghosh, A., Roy, D., Kumar, A., Shamurailatpam, D., Bera, S., Ghosh, R., Bandopadhyay, P. and Majumder, A. 2017. Yield loss assessment of rice (*Oryza Sativa* L.) due to different biotic stresses under system of rice intensification (SRI). *Journal of Entomology and Zoology Studies*, **5** (4):1974-1980.

Mukherjee, P. K., Sarkar, A., & Maity, S. K. 2008. Critical period of crop-weed competition in transplanted and wet-seeded kharif rice (*Oryza sativa* L.) under terai conditions. *Indian Journal of Weed Science*, **40** (3&4), 147-152.

Nazir, A., Bhat, M. A., Bhat, T. A., Rashid, Z., Mohi-Ud-Din, R., Fayaz, S., & Wani, S. A. 2020. Crop establishment and weed management effect on weed parameters and rice yield under temperate zone of Kashmir. *Indian Journal of Weed Science*, **52** (3), 217–221.

Nirmagustina, D. E., & Handayani, S. 2023. Nutritional Content of Brown Rice and White Rice from Organic Rice of Mentik Susu Varieties with Parboiled Method. *International Journal of Life Science and Agriculture Research*, **2** (11), 418-426.

Ockerby, S. E., & Fukai, S. 2001. The management of rice grown on raised beds with continuous furrow irrigation. *Field Crops Research*, **69** (3), 215-226.

Patel, T. U., Vihol, K. J., Thanki, J. D., Gudaghe, N. N., & Desai, L. J. 2018. Weed and nitrogen management in direct-seeded rice. *Indian Journal of Weed Science*, **50** (4), 320-323.

Pattanayak, S., Jena, S., Das, P., Maitra, S., Shankar, T., Praharaj, S., Mishra, P., Mohanty, S., Pradhan, M., Swain, D. K., Pramanick, B., Gaber, A., & Hossain, A. 2022. Weed management and crop establishment methods in rice (*Oryza sativa* L.) influence the soil microbial and enzymatic activity in sub-tropical environment. *Plants*, **11** (8), 1071.

Pooja, K., & Saravanane, P. 2021. Performance of rice cultivars with weed management practices in dry direct-seeded rice. *Indian Journal of Weed Science*, **53** (1), 92–94.

Pradhan, A., Dixit, A., Keram, K. S., & Dewangan, P. K. 2023. Weed management in dry direct-seeded rice under rainfed ecology of Southern Chhattisgarh. *Indian Journal of Weed Science*, **55** (2), 149–152.

Pradhan, A., Thakur, A., & 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), 50-53.

Preethika, K., Vani, K. P., Madhavi, M., Jayasree, G., & Saida Naik, D. 2022. Effect of Nitrogen Levels and Weed Management Practices on Yield and Yield Attributes of Drum Seeded rabi Rice. *Biological Forum – An International Journal*, **14** (3), 1129-1134.

Qiao, J., Liu, Z., Deng, S., Ning, H., Yang, X., Lin, Z., Li, G., Wang, Q., Wang, S. and Ding, Y. 2011. Occurrence of perfect and imperfect grains of six japonica rice cultivars as affected by nitrogen fertilization. *Plant and soil*, **349**, 191-202.

Raj, S. K., & Syriac, E. K. 2017. Nutrient availability and nutrient uptake as influenced by the post emergence application of herbicide mixtures. *Journal of Tropical Agriculture*, **55**(2), 152-160.

Reuben, P., Kahimba, F. C., Katambara, Z., Mahoo, H. F., Mbungu, W., Mhenga, F., Nyarubamba, A & Maugo, M. 2016. Optimizing plant spacing under the systems of rice intensification (SRI). *Agricultural Sciences*, **7** (4), 270-278.

Raj, S. K., Mathew, R., Jose, N., & Leenakumary, S. 2013. Evaluation of early post emergence and post emergence herbicides on weed control and productivity of direct seeded puddled rice in Kuttanad. *Madras Agricultural Journal*, **100** (7-9), 737-742.

Ramachandiran, K., & Balasubramanian, R. 2012. Effect of weed management on growth, yield attributes and yield of aerobic rice. Madras Agricultural Journal, **99** (1-3), 96-98.

Rao, A. N., Wani, S. P., Ahmed, S., Haider Ali, H., & Marambe, B. 2017. An overview of weeds and weed management in rice of South Asia. In: Weed management in rice in the Asian-Pacific region. Asian-Pacific Weed Science Society (APWSS), Hyderabad, 247-281.

Reddy, B. M., Guruprased, G. S., Paramesh, D., Mahantashivayogayya, K., & Ibrahim, M. 2017. Nitrogen management for optimum productivity of dry direct seeded rice (*Oryza sativa* L.) Under medium deep black soils. *Journal of Farm Sciences*, **30** (2), 177-180.

Saha, M., Banerjee, H., & Pal, S. 2006. Relative efficacy of herbicides in wheat. *Indian Journal of Weed Science*, **38** (1&2), 127-128.

Saharawat, Y. S., Singh, B., Malik, R. K., Ladha, J. K., Gathala, M., Jat, M. L., & Kumar, V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP. *Field Crops Research*, **116** (3), 260-267.

Saikia, N., Singh, M.K., Pooniya, V., Govindasamy, P., Dendukuri, U.L., Nithinkumar, K., Bagrecha, S., Ali, S.A. & Prajapati, S.K. 2024. Effects of pre-mix herbicide combinations on weed management in transplanted rice (*Oryza sativa*). The *Indian Journal of Agricultural Sciences*, **94** (12), 1377-1380.

Sandhu, S. S., & Mahal, S. S. 2014. Performance of rice (*Oryza sativa*) under different planting methods, nitrogen levels and irrigation schedules. *Indian Journal of Agronomy*, **59** (3), 392-397.

Sandhu, S. S., Mahal, S. S., Vashist, K. K., Buttar, G. S., Brar, A. S., & Singh, M. 2012. Crop and water productivity of bed transplanted rice as influenced by various levels of nitrogen and irrigation in northwest India. *Agricultural Water Management*, **104**, 32-39.

Saravanane, P. 2020. Effect of different weed management options on weed flora, rice grain yield and economics in dry direct-seeded rice. *Indian journal of weed science*, **52** (2), 102-106.

Sarma, H. H., Dutta, S. K., Konwar, M. J., Rafique, N. T., Saikia, M., Borah, S. R., & Medhi, A. K. 2024. Evaluation of crop establishment techniques and weed management tactics on weed population dyanamics and crop productivity in wet direct seeded winter rice. *Plant Archives*, **24** (2), 319-324.

Sar, K., Mishra, G., Rath, S., & Padhi, I. 2024. Weed growth and productivity of direct seeded rice under different weed management practices. *Indian Journal of Weed Science*, **56** (1), 8–11.

Sen, S., Kaur, R., & Das, T. K. 2020. Weed management in dry direct-seeded rice: Assessing the impacts on weeds and crop. *Indian Journal of Weed Science*, **52** (2), 169-174.

Sharma, R. P., Pathak, S. K., & Singh, R. C. 2007. Effect of nitrogen and weed management in direct-seeded rice (*Oryza sativa*) under upland conditions. *Indian Journal of Agronomy*, **52** (2), 114-119.

Shrestha, S., Brueck, H., & Asch, F. 2012. Chlorophyll index, photochemical reflectance index and chlorophyll fluorescence measurements of rice leaves supplied with different N levels. *Journal of Photochemistry and Photobiology B: Biology*, **113**, 7-13.

Singh, A. K., Singh, M. K., & Kumari, S. 2018. Effects of nitrogen levels and weed management in direct-seeded rice. *Indian Journal of Weed Science*, **50** (3), 290–293

Singh, D.K., Yadav, S.K., Krishna, M., Rawat, S., Tripathi, S., Pun, M., Singh, P.K., & Sharma, Y., 2023. Growth and yield of rice (*Oryza sativa*) under different establishment methods and weed management practices in Uttarakhand. *Indian Journal of Agricultural Sciences*, **93** (12), 1279-1283.

Singh, K. K., Singh, K., Singh, R., Singh, Y., & Singh, C. S. 2006. Response of nitrogen and silicon levels on growth, yield and nutrient uptake of rice (*Oryza sativa* L.). *ORYZA-An International Journal on Rice*, **43** (3), 220-223.

Singh, R. P., Singh, P. K., & Singh, A. K. 2009. Effect of green manuring on physico-chemical properties of soil and productivity of rice. *ORYZA-An International Journal on Rice*, **46** (2), 120-123.

Singh, S., Ladha, J. K., Gupta, R. K., Bhushan, L., & Rao, A. N. (2008). Weed management in aerobic rice systems under varying establishment methods. *Crop protection*, **27** (3-5), 660-671.

Singh, T. 2022. Assessment of critical period for weeding and yield loss in direct seeded rice (*Oryza sativa*). *Indian Journal of Agricultural Sciences*, **92** (2), 212-216.

Singh, V., Jat, M. L., Ganie, Z. A., Chauhan, B. S., & Gupta, R. K. 2016. Herbicide options for effective weed management in dry direct-seeded rice under scented rice-wheat rotation of western Indo-Gangetic Plains. *Crop Protection*, **81**, 168-176.

Singh, V. P., Singh, S. P., Dhyani, V. C., Banga, A., Kumar, A., Satyawali, K., & Bisht, N. 2016. Weed management in direct-seeded rice. *Indian Journal of Weed Science*, **48** (3), 233–246.

Singh, V., Sepat, S., Singh, J., Gautam, A., & Aulakh, G. S. 2023. Effect of nitrogen levels and weed management on weed flora and yield of direct-seeded rice (*Oryza sativa*) in southern part of Punjab. *Indian Journal of Agricultural Sciences*, **93** (10), 1055-1060.

Singh, Y., Gupta, R., Singh, B., & Gupta, S. 2011. Efficient management of fertilizer nitrogen in wet direct-seeded rice (*Oryza sativa*) in northwest India. *Indian Journal of Agricultural Sciences*, **77** (9), 561-564.

Singh, Y., Humphreys, E., Kukal, S.S., Singh, B., Kaur, A., Thaman, S., Prashar, A., Yadav, S., Timsina, J., Dhillon, S.S. and Kaur, N., 2009. Crop performance in permanent raised bed rice–wheat cropping system in Punjab, India. *Field Crops Research*, **110** (1), 1-20.

Singh, Y., Singh, V. P., Singh, G., Yadav, D. S., Sinha, R. K. P., Johnson, D. E., & Mortimer, A. M. 2011. The implications of land preparation, crop establishment method and weed management on rice yield variation in the rice–wheat system in the Indo-Gangetic plains. *Field Crops Research*, **121** (1), 64-74.

Sreelakshmi, K., Balasubramanian, R., Babu, R., & Balakrishnan, K. 2016. Herbicide combinations for weed management in transplanted rice. *Indian Journal of Weed Science* **48** (1), 60–63.

Tang, J. C., Chen, Q. H., Hao, R. Q., Li, Z. X., & Lu, B. L. 2021. The effects of different nitrogen application and seeding rates on the yield and growth traits of direct seeded rice (*Oryza sativa* L.) using correlation analysis. *Applied Ecology and Environmental Research*, **19** (1), 667-681.

Tang, Y. L., Zheng, J. G., & Huang, G. 2005. Studies on permanent-bed-planting with double zero tillage for rice and wheat in Sichuan basin. *Southwest China Journal of Agricultural Sciences*, **18** (1), 25-28.

Teja, K. C., Duary, B., & Dash, S. 2017. Efficacy of herbicides and their combination on weed management in transplanted *kharif* rice. *Journal of Crop and Weed*, **13** (2), 175-179.

United States Department of Agriculture. 2024, https://www.fas.usda.gov/data

Verma, B., Bhan, M., Jha, A. K., Porwal, M., & Patel, R. 2023. Assessment of different herbicides for effective weed management in direct seeded rice technology. *Ecology, Environment and Conservation Journal*, **29** (3), 1202-1208.

Verma, B., Bhan, M., Jha, A.K., Singh, V., Patel, R., Sahu, M.P., and Kumar, V. 2022. Weed management in direct-seeded rice through herbicidal mixtures under diverse agroecosystems. AMA, *Agricultural Mechanization in Asia, Africa and Latin America*. **53** (4): 7299-7306.

Vethaiya, B., Ladha, J. K., Gupta, R. K., Naresh, R. K., & Mehla, R. S. 2003. Technology Options for Rice in the Rice–Wheat System in South Asia. *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts*, 65, 115-147.

Vibhajam, S. K. B., & Murthy, V. R. K. 2019. Growth, yield and nitrogen uptake of direct seeded rice varieties under variable nitrogen rates. *International Journal of Chemical Studies*, **7**, 198-201.

Vikram Sai, M., Murugan, G., & Sai Kumar, M. 2023. Evaluation of Weed Management Approaches on Weed Dynamics, Yield and Economics of Puddled Rice under different Plant Techniques. *ORYZA-An International Journal of Rice*, **60** (4), 597-602.

Walia, U. S., Bhullar, M. S., Nayyar, S., & Walia, S. S. 2008. Control of complex weed flora of dry-seeded rice (*Oryza sativa* L.) with pre-and post-emergence herbicides. *Indian Journal of Weed Science*, **40** (3&4), 161-164.

Wang, J., Zhang, X., Xiao, Y., Chen, H., Wang, X., & Hu, Y. 2024. Effect of nitrogen fertilizer on the quality traits of Indica rice with different amylose contents. *Journal of the Science of Food and Agriculture*, **104** (14), 8492-8499.

Xing, G. X., & Zhu, Z. L. 2000. An assessment of N loss from agricultural fields to the environment in China. *Nutrient Cycling in Agroecosystems*, **57**, 67-73.

Yadav, R. I., Singh, M. K., Singh, R. K., & Nagargade, M. 2018. Planting methods and weed management to improve yield in dry-seeded rice. *Indian Journal of Weed Science,* **50** (1), 22–26

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

Yadav, V. R., Singh, V. P., & Guru, S. K. 2017. Weed management approaches in transplanted rice in Mollisols of Uttarakhand. *Indian Journal of Weed Science,* **49** (3), 279-282.

Yuan-zhi, Y. 2015. Effects of ridge tillage on photosynthesis and root characters of rice. *Chilean journal of agricultural research*, **75** (1), 35-41.

Zaidi, S. F. A., & Tripathi, H. P. 2007. Effect of nitrogen levels on yield, N uptake and nitrogen use efficiency of hybrid rice. *ORYZA-An International Journal on Rice*, **44** (2), 181- 183.

Zhou, C., Huang, Y., Jia, B., Wang, Y., Wang, Y., Xu, Q., Li, R., Wang, S. and Dou, F., 2018. Effects of cultivar, nitrogen rate, and planting density on rice-grain quality. *Agronomy*, **8** (11), 246.