# Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions

प्रतिबंधित सिंचाई स्थितियों के तहत गेहूँ (*ट्रिटिकम एस्टिवम* एल.) की नत्रजन उपयोग क्षमता (एनयूई) और उत्पादकता पर नैनो यूरिया का प्रभाव

**RITESH PATIDAR**

**Thesis**

## Master of Science in Agriculture

**(Agronomy)**

**2022**

**DEPARTMENT OF AGRONOMY**
**RAJASTHAN COLLEGE OF AGRICULTURE**
**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE & TECHNOLOGY UDAIPUR – 313 001 (RAJASTHAN)**

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Thesis

Submitted to the

**Maharana Pratap University of Agriculture and Technology, Udaipur**

In Partial Fulfillment of the Requirement for the Degree of

# Master of Science in Agriculture

**(Agronomy)**


**By**

**RITESH PATIDAR**


**2022**

**RAJASTHAN COLLEGE OF AGRICULTURE**
**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE & TECHNOLOGY, UDAIPUR – 313 001 (RAJASTHAN)**

# CERTIFICATE-I

## CERTIFICATE OF ORIGINILTY

The research work embodied in this thesis entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** submitted for the award of degree of **Master of Science in Agriculture** in the subject of **Agronomy** to Maharana Pratap University of Agriculture and Technology, Udaipur (Raj.), is original and bonafide record of research work carried out by me under the supervision of **Dr. J. Choudhary**, Associate Professor, Department of Agronomy, Rajasthan College of Agriculture, Udaipur. The contents of the thesis, either partially of fully, have not been submitted or will not be submitted to any other Institute or University for the award of any degree or diploma.

The work embodied in the thesis represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original source. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the University and can also evoke penal action from the sources which have thus not been properly cited of from whom proper permission has not been taken when needed.

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Date: / /2022 **RITESH PATIDAR**

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# CERTIFICATE-II

Date: / /2022

This is to certify that this thesis entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** submitted for the degree of **Master of Science in Agriculture** in the subject of **Agronomy**, embodies bonafide research work carried out by **Mr. Ritesh Patidar** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of this thesis was also approved by the advisory committee on ___/___/2022.

The manuscript has been subjected to plagiarism check by software Urkund. It is certified that as per the check, the similarity index of the content is 7 % and is within permissible limit as per the MPUAT guidelines on checking Plagiarism.

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This is to certify that the thesis entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** submitted by **Mr. Ritesh Patidar** to the Maharana Pratap University of Agriculture & Technology, Udaipur in partial fulfillment of the requirement for the degree of **Master of Science in Agriculture** in the subject of **Agronomy** after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination held on ___/___/2022 was found satisfactory; we therefore, recommend that the thesis be approved.

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This is to certify that **Mr. Ritesh Patidar,** student of M.Sc. (Ag.) of the **Department of Agronomy** has made all the corrections/modifications in the thesis **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** which were suggested by the external examiner and the advisory committee in the oral examination held on ___/____/2022. The final copies of the thesis duly bound and corrected were submitted on ____/____/2022.

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***Date:***
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# CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF APPENDICES

# ACRONYMS & ABBREVIATIONS

| | | | | | |
|---|---|---|---|---|---|
| ANOVA | : | Analysis of variance | kg | : | Kilogram |
| @ | : | At the rate of | Max. | : | Maximum |
| B-C | : | Benefit cost ratio | MSS | : | Mean sum of square |
| cm | : | Centimetre | mg | : | Milligram |
| C.V. | : | Coefficient of variation | mm | : | Millimetre |
| r | : | Correlation coefficient | Min. | : | Minimum |
| CGR | : | Crop growth rate | pH | : | Negative log of H ions activity |
| C.D. | : | Critical difference | N | : | Nitrogen |
| DAS | : | Days after sowing | NS | : | Non-significant |
| °C | : | Degree Celsius | ha$^{-1}$ | : | Per hectare |
| °E | : | Degree East | % | : | Per cent |
| df | : | Degree of freedom | P | : | Phosphorus |
| °N | : | Degree North | K | : | Potassium |
| dSm$^{-1}$ | : | Desi Simon per metre | q | : | Quintal |
| DMA | : | Dry matter accumulation | RBD | : | Randomized block design |
| EC | : | Electrical conductivity | RDN | : | Recommended dose of nitrogen |
| *et al.* | : | (*et alibi*) and elsewhere | RDF | : | Recommended dose of fertilizers |
| Fig. | : | Figure | RGR | : | Relative growth rate |
| g | : | Gram | R.H. | : | Relative humidity |
| HI | : | Harvest index | ₹ | : | Rupees |
| ha | : | Hectare | SEm± | : | Standard error of mean |
| *i.e.* | : | (id est) that is | m$^2$ | : | Square metre |
| CRI | : | Crown root initiation | *viz.* | : | (Videlicet) namely/ that is |
| g g$^{-1}$ day$^{-1}$ | | gram per gram per day | hrs | : | Hours |
| kg ha$^{-1}$ | : | Kilogram per hectare | g m$^{-2}$ day$^{-1}$ | | gram per metre square per day |
| Mg ha$^{-1}$ | : | Mega gram per hectare | L. | : | Linnaeus |
| m | : | Metre | µ | : | Micro |
| m$^{-1}$ | : | Per metre | mg g$^{-1}$ | : | milligram per gram |
| ml | : | milli litre | ml l$^{-1}$ | : | milli litre per litre |
| MOP | : | Muriate of potash | $P_2O_5$ | : | Phosphorus penta oxide |
| No. | : | Number | ppm | : | Parts per million |
| NUE | : | Nitrogen use efficiency | var. | : | Variety |
| SSP | : | Single super phosphate | USWB | : | United states weather bureau |
| WP | : | Wettable powder | ZnO | : | Zinc oxide |
| SPAD | : | Soil plant analysis development | SMP | : | Super micro plus |
| FRR-CR | : | Full recommended rate of conventional fertilizer | FRR-NR | : | Full recommended rate of nano fertilizer |
| NCSF | : | Nano chelated super fertilizer | NAA | : | Nano-amino acid |
| Fe | : | Iron | Zn | : | Zinc |
| NPs | : | Nano particles | NK | : | Nano Potassium |
| L | : | Liquid | G | : | Granular |

# 1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is an edible grain grown under a wide range of climates, soils and best adapted to temperate regions with rainfall between 30 and 90 cm. Currently, about 95% of the wheat grown globally is hexaploid bread wheat (*Triticum aestivum* L.), which is known as common/ bread wheat and valued for bread making and remaining 5% being tetraploid durum wheat.

Globally wheat (*Triticum* spp.) occupies an area of about 216.14 million hectares with an estimated annual production of 763.58 million tonnes with a productivity of 3.53 metric tonnes (USDA, 2020). In the world main wheat producing countries are China, India, Russia, USA, France, Canada, Ukraine, Pakistan, Germany, Argentina and Turkey (FAO, 2019). In India, wheat is farmed on around 31.76 million hectares, yielding 108.75 million tonnes with a productivity of 34.24 quintal hectare$^{-1}$ (Progress report, IIWBR, Karnal, 2021). In Rajasthan, wheat crop covers an area of 34.97 lakh hectares with an annual production of 10.92 million tonnes and an average productivity of 3.5 tonnes ha$^{-1}$ which is slightly higher than national average. Rajasthan state is on fifth position in terms of wheat production after Uttar Pradesh, Punjab, Haryana and Madhya Pradesh (Government of Rajasthan, 2021).

Wheat is mainly grown for human food but about 10 per cent is retained for seed and industry (for production of starch, malt, dextrose, gluten). Wheat grain contains all essential nutrients; kernel contains about 12 per cent moisture, including carbohydrate (60-80% mainly as starch), protein (8-15%) containing adequate amounts of all essential amino acids (except lysine, tryptophan and methionine), fats (1.5-2%), minerals (1.5-2%), vitamins (such as B complex, vitamin E) and 2.2% crude fibers.

According to the Food and Agriculture Organization (FAO) of the United Nations, the world population is expected to increase to almost 10 billion by 2050. Considering the limited land availability, the increased frequency of extreme climate events and the current inefficient utilization of resources (e.g., water, energy and nutrients), meeting the future global food demand sustainably is one of the major challenges that agriculture and the whole food supply chain need to face in the future. The intensive application of conventional agrochemicals has already been demonstrated to result in an unsustainable impact on the environment.

Recent estimates suggest that the usage of fertilizers may contribute around 30 per cent of the total crop yield, while the rest 70 per cent depending on the effective application of other factors and agricultural inputs. Nevertheless, a massive amount of fertilizers that are applied either become fixed in the soil or are lost to the environment due to volatilization, leaching and water runoff. However, 50–70 per cent of nitrogenous fertilizers applied through conventional fertilization are either lost as water-soluble nitrates, gaseous ammonia, nitrogen oxides or they are incorporated as minerals in the soil through the action of microorganisms. Nitrogen is the most crucial nutrient for crop productivity and it also plays the major role in agriculture.

In India, the total consumption, production and import of nitrogen as a fertilizer is 191.01, 136.85 and 51.91 lakh tonnes, respectively (Pocket book of agricultural statistics, 2020). The most common nitrogenous fertilizer used today is urea which accounts for roughly 82 per cent of India's overall fertilizer use and about 55 per cent of the world's total nitrogen fertilizer usage. Due to its high solubility in water, non-polarity, quick leaf absorption and minimal phytotoxicity urea is the most widely utilized nitrogen source (Bondada *et al.*, 2001). The use of urea has been demonstrated to reduce fertilizer efficiency, resulting in higher costs. Ironically, the unbalanced and haphazard use of inorganic fertilizers had a negative effect on availability of nutrients to plants as well as on soil fertility and soil health resulted lowering productivity of crops and caused chronic diseases in human beings.

To overcome all these drawbacks, nanotechnology holds promise and nano fertilizers can go a long way in ensuring sustainable soil health and crop production (Lal, 2008). New approaches are therefore required to improve agricultural yield and quality while reducing the environmental impact of farming. In this situation, nanotechnology-based nano liquid urea is an eco-friendly, smart fertilizer with high nutrient use efficiency and a long-term solution for reducing pollution and global warming as it lowers nitrous oxide emissions, doesn't contaminate soil, air and water bodies and offers great promises for the secure and effective delivery of nutrients.

Fertilizers, nutrients encapsulated inside nano porous materials ($10^{-9}$m size), coated with thin polymer film or delivered as particle or emulsions of nano scales dimensions are known as Nano-fertilizers. The use of nano fertilizers to specifically release nutrients inside the plant can minimize their losses, avoiding rapid changes in their chemical nature. NFs can release their nutrients in 40–50 days, while synthetic fertilizers do the same in 4–10 days. As a result, a synthetic urea fertilizer can rapidly lose more than 70 per cent of its N content after field application through leaching and volatilization, leaving less than 20 per cent to be readily available for plants.

One nano urea particle is roughly 30 nanometers in size (IFFCO, 2021) and has 10,000 times larger surface area to volume than ordinary urea. Furthermore, because of its extreme small size and surface penetrable abilities nano urea is readily grabbed by plants when sprayed on their leaves. These nanoparticles penetrate to the areas of the plant where nitrogen is needed and release nutrients in a controlled way. The site-specific and regulated release of the active ingredient from conventional agri-inputs in nano form helps to reduce excess runoff, avoid eutrophication and eliminate residual contamination.

As nano-fertilizers contain nutrients and growth promoters enclosed in nano scale polymers they deliver the major nutrients to the crop with as needed in a phased manner. Through ensuring improved nutrient use efficiency these nanoscale polymers ensure low and target efficient release for providing nutrients to the crop in a sustained way throughout its life cycle. Therefore, in order to provide farmers with a feasible and financially viable option for maintaining sustainable crop production with improved crop quality and increased resource use efficiency (nutrients) the current study was undertaken to evaluate the response of wheat crop to eco-friendly granular as well as foliar nano-N. The assessment of these environmentally friendly nano-fertilizers might be quite helpful.

Therefore, sustainable efforts are being made to synchronize nutrient availability and improve NUE values in agricultural systems without a further deterioration of surrounding environments. Nano urea has been proposed as a way to increase the overall NUE values of fertilizers through a more controlled and slower nutrient release.

Keeping in mind the optimistic results of nano urea and demand of wheat, an experiment entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** was conducted during *rabi*, 2021-22 at the Instructional Farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan to fulfill following objectives:

1. To assess the effect of nano urea on growth and yield of wheat.
2. To evaluate the effect of nano urea on nutrient content and uptake.
3. To work out the economics of treatments.

# 2. REVIEW OF LITERATURE

The current situation requires a change away from traditional crop production methods to modern technologies like smart fertilizer application which are both environmentally friendly and effective. This is necessary to ensure food security for the growing population, to reduce environmental risks and to ensure long-term sustainability. Numerous studies have shown that using nano fertilizers in conjunction with commercial fertilizers increases crop yields. This chapter is a summary of research findings on the **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions".**

## 2.1 EFFECT OF NANO FERTILIZERS

### 2.1.1 Crop growth

Liu *et al.* (2012) from China conducted research to examine the effects of combined application of nitrogen fertilizer and nano-carbon on nitrogen use of soil and rice yield to a rice cultivar. The research indicates that applying nitrogen fertilizer and nano-carbon together considerably improved dry matter accumulation compared to using inorganic conventional fertilizers. In Iran Jafarzadeh *et al.* (2013), carried out a field experiment on the wheat crop with three levels of potassium soil application (no application, 150 kg $ha^{-1}$ potassium sulfate and 10 kg $ha^{-1}$ nano potassium) as well as four levels of nano potassium foliar application (no application, foliar application at tillering, foliar application at stem elongation and foliar application at tillering and stem elongation) and observed that soil application of nano potassium resulted in significant rise in plant height and tillers $plant^{-1}$.

Adhikari *et al.* (2015) carried out an experiment to determine the characterization of zinc oxide nano particles and their effect on growth of maize. Their experiment gave positive result with higher plant height, root volume, root length and dry matter weight by the application zinc oxide nano particle as compared to the conventional Zn fertilizer ($ZnSO_4$). In South Korea an experiment was conducted to examine the impact of nano fertilizers on rice crop growth and development. They found that applying the full recommended amount of conventional and nano fertilizer treatments augmented plant height by 3.6 per cent over control (Benzon *et al*., 2015).

In order to determine the impact of foliar application of nano chitosan-NPK fertilizer on wheat plants Aziz *et al.* (2016) carried out an experiment in Mansoura (Egypt) and they found that there was a significant upsurge in all growth variables, including plant height (51.32 cm), shoot length (43.56 cm), fresh weight (0.8 g plant$^{-1}$), dry weight (0.3 g plant$^{-1}$) and leaf area (14 cm$^{2}$ plant$^{-1}$), as well as a significant reduction in days taken to 50 per cent ear head stage, days to physiological maturity and days to harvesting than the yield attributes of wheat plants treated with non-fertilized and normal fertilized NPK. Manikandan and Subramanian (2016) carried out and research experiment at Coimbatore (Tamilnadu) to determine the response of maize plants to the zeolite-based nitrogen nano fertilizers and conventional fertilizers in Inceptisols and Alfisols type of soil. They reported significant increase in plant height (152.3 cm, 178.1 cm), root length (65.9 cm, 76.4 cm) and dry matter accumulation (151.4 and 130.1 g) by foliar application nano-zeourea in comparison to application of conventional urea.

Al-Juthery *et al.* (2018) conducted a field experiment at Al-Shafeieyah (Iraq), to study the effect of foliar application of different sources of nano fertilizers on growth and yield of wheat. According to study foliar application of super micro (SMP) plus nano fertilizer followed by the spraying combined of tri (N+P+K), di (N+P), (N+K) and (P+K) nano fertilizer compared to control and traditional (NPK+TE) fertilizer treatments was proved to be efficient. Application of super microplus (SMP) nano fertilizer significantly increased plant height (87.77 cm), spike length (12.22 cm) and chlorophyll (58.22 SPAD). Astaneh *et al.* (2018) carried out an experiment of nano chelated nitrogen and urea fertilizers on wheat plant under normal and drought stress condition at two locations at Khodayan and Nasrabad in Iran. The results revealed that application of urea (110 kg ha$^{-1}$) and nano chelated nitrogen (41 kg ha$^{-1}$) had significant effects on stem weight (1.37 kg m$^{-2}$ and 1.05 kg m$^{-2}$), spike weight, spike length, plant height, number of tillers and stem diameter.

Morsy *et al.* (2018) conducted an experiment during two winter seasons at Abu Simbel (Egypt). The results revealed that foliar application with nano fertilizer (400 ppm) with N-levels (100 kg N fed$^{-1}$) in combination with irrigation (100 %) increased plant height (87.7 and 85.7 cm), spike length (9.1 and 9.1cm), grains spike$^{-1}$ (64.2 and 60.8) and number of tillers m$^{-2}$ (6.68 % and 5.38 %) compared to the control treatment. An experiment was carried out by Rathnayaka *et al.* (2018) at

Sammanthurai (Sri Lanka) involving the use of NPK fertilizers and nano nitrogen fertilizer to test the growth attributes and yield of rice cultivar. The results revealed that plant height (57.9 cm), number of tillers plant$^{-1}$ (6) and plant dry weight (9.9 g) were significantly improved by application of 100 per cent nano nitrogen.

Al-Juthery *et al.* (2019) carried out a field experiment on wheat cultivar at the Al-Shafeieyah, (Iraq). They observed that foliar spray of the combined nano-(Fe + Cu + Zn) application significant increase plant height, length of spike, by 27.47, 28.53, respectively compared to control plot. Al-Juthery *et al.* (2019) conducted a field experiment at Husseiniya (Iraq) to study the effect of foliar nutrition with some of nano fertilizers and nano amino acids on growth and yield of wheat. The results showed that significant response was recorded with foliar nutrition of tri nano mixture of nano chelated super granules (NCSF), nano amino acids (NAA) and nano potassium (NK) treatments in all growth parameters of wheat for plant height (81.66 cm), length of spike (11.88 cm), total chlorophyll (51.99 SPAD) in comparison to control.

Mehta and Bharat (2019) conducted an experiment on use of nano and non-nano fertilizers in wheat (*Triticum aestivum* L.) at Jammu (Jammu & Kashmir) during the *rabi* 2015-2016. The results indicated that among the applied treatments 100 per cent NPK + nano NPK (liquid) recorded significantly greater number of effective tillers (75.19), supreme length of the ear (14.38 cm), highest number of grains ear$^{-1}$ (39.06) and uppermost 1000 grain weight (42.50 g) than control. Rani *et al.* (2019), conducted an experiment to study the effect of chemical and nano nitrogenous fertilizer on yield and yield attributes of sorghum crop (*Sorghum bicolor* L.) a pot culture experiment was carried out at Junagadh (Gujrat). The results revealed that significant increase in plant height (177.67 cm), maximum number of leaves (17.73) and maximum length of spike (25.53) was recorded with the treatment $T_4$ (2.5 times reduction of RDN) through nano fertilizer which was statistically at par with $T_7$ (RDN through nano fertilizer). To examine the effect of IFFCO nano fertilizer on growth and yield attributes of maize an investigation was carried out by Kumar *et al.* (2021) at several locations across India. The results revealed that the application of 50 per cent N, 100 per cent PK, 0 per cent Zinc + 2 sprays of IFFCO nano N (4 ml litre$^{-1}$) in combination with IFFCO Sagarika (2 ml litre$^{-1}$) had greatest influence on plant height (226 cm), maximum leaf area (801.16 cm$^2$) and girth of stem (6.97 cm).

Morsy *et al.* (2021) investigated the impact of the preceding crop, sowing methods, and nano fertilizer on the growth, production and quality of bread wheat at the Abu Simbel (Egypt). The foliar application of nano fertilizer with 500 ml $fed^{-1}$ gave the highest mean values for plant height (90.29 and 89.91cm), number of spike $plant^{-1}$ (5.28 and 5.44), number of leaves $plant^{-1}$ (19.31 and 19.23) and flag leaf area (42.50 and 41.98 $cm^{-2}$) in 2018-19 and 2019- 20 seasons, respectively.

At Bogor, (Indonesia) an experiment was carried out by Rostaman *et al.* (2021) on rice crop. They found that using inorganic nano fertilizer in conjunction with NPK + urea fertilizer is beneficial. When nano inorganic fertilizers with 400 times dilution were combined with NPK + urea fertilizer at a recommended dose of 75 per cent recorded increment in plant height at 30 and 60 DAS by 57.95 and 96.05 cm as compared to the control. The effect of nano ZnO fertilizer and bulk ZnO on the development of commonly grown traditional (Pachchaperumal, Suwandel) and inbred (Bg 94-1) rice varieties was investigated in Sri Lanka. In comparison to the other variety, rice variety Suwandel expressed an upsurge in mean plant height (96.10 cm) when treated with nano-ZnO 60 mg $l^{-1}$. Nano-ZnO-fertilizer concentrations of both 60 and 120 mg $l^{-1}$ shows significant increase in mean biomass and per cent dry weight of Bg 94-1, Pachchaperumal, and Suwandel. (Somaratne *et al*., 2021)

### 2.1.2 Yield attributes and yield

Fan *et al.* (2012) conducted an experiment at Jilin (China) to access the effects of combined nitrogen fertilizer and nano-carbon application on yield and nitrogen use of rice grown on saline-alkali soil. They observed the significant increase in dry matter accumulation and yield of rice in saline- alkali soil with combined application of nitrogen fertilizer and nano-carbon particle. Jafarzadeh *et al.* (2013) conducted a field experiment on the wheat crop in Iran with three levels of soil applied potassium (no application, 150 kg $ha^{-1}$ potassium sulfate and 10 kg $ha^{-1}$ nano potassium), four levels of foliar applied nano potassium foliar application (no application, foliar application at tillering, foliar application at stem elongation and foliar application at tillering and stem elongation) and they testified that soil application of nano potassium had substantial effect on number of tillers $plant^{-1}$, 100 grain weight, economic and biological yield but had not any significant effect were pronounced on spike length and number of seed $spike^{-1}$, whereas foliar application of nano potassium had substantial effect on all yield parameters and biological yield except 100 grain weight.

Armin *et al.* (2014) conducted an experiment at Sabzevar (Iran) to study the effect of different concentrations and different application times of nano-Fe fertilizer on wheat crop. They observed that number of tillers, seeds spike$^{-1}$, grain yield, biological yield and 1000 grain weight were significantly affected by the concentration and timing of the administration of nano fertilizers. They reported that foliar application of nano Fe at tillering + stem elongation and at tillering stage exhibited grain yield increment of 9.17 per cent and 5.19 per cent, respectively as comparison to foliar application of Fe at stem elongation. In South Korea, an experiment was carried out to examine the impact of nano fertilizers on rice crop growth and development and results revealed that the application of full recommended rate of conventional and nano fertilizer boosted the grain yield and yield attributes *viz.*, number of reproductive tillers (9.10 %), spikelets (15.42 %) panicle weight (17.4 %), total grain weight (unpolished-17.5 %, polished - 20.7 %), total shoot dry weight (15.3 %) and harvest index (2.9 %) than treatments in comparison (Benzon *et al.*, 2015).

In Iran, experiment was carried out by Mosanna *et al.* (2015) to study the morpho-physiological response of maize (*Zea mays* L.) to zinc nano chelate foliar and soil application at different growth stages. They observed that 94 per cent more seed yield plant$^{-1}$ was obtained when nano chelate Zn applied to crop through foliar application while, soil + foliar application of nano chelate Zn had 51 per cent more harvest index compared to control. Aziz *et al.* (2016), reported substantial increment in spike length, 100 grain weight (4.64 g), number of grains spike$^{-1}$ (8.66), grain yield plant$^{-1}$ (4.28 g), and straw yield plant$^{-1}$ (0.163 g) of the wheat when it was treated with nano chitosan-NPK 10 % fertilizers as compared to wheat plants treated with normal non-fertilized and normal fertilized NPK.

Manikandan and Subramanian (2016) evaluated the response of maize plants to the zeolite-based nitrogen nano fertilizers and conventional fertilizers in two greenhouse experiments at Coimbatore (Tamilnadu) under two distinct soil textures (Inceptisol and Alfisols). They reported that Zeourea and nano-zeourea fertilized maize plants recorded significantly higher grain yield plant$^{-1}$ (295 g and 254 g) in Inceptisol and Alfisols over conventional urea treatment. At Tehran (Iran), Ghasemi *et al.* (2017) testified that the utmost biological yield (13800 kg ha$^{-1}$), grain yield (6332 kg ha$^{-1}$) and straw yield (7470 kg ha$^{-1}$) were obtained from spraying 20 ppm zinc nano oxide at mid-tillering and panicle initiation.

At Sari (Iran),) rice cultivars (Tarom Mahalli and Tarom Hashemi) chosen as the primary factors and nitrogen rates (34 and 69 kg N ha$^{-1}$ and nitroxin) with nanoparticles (nano potassium, nano silicon and control) serving as sub factors. The results shows that Tarom Hashemi obtained the highest paddy yield (5000 kg ha$^{-1}$) with the application of 34 kg N ha$^{-1}$ and nano potassium treatment, while Tarom Mahalli obtained the highest paddy yield (4657 kg ha$^{-1}$) with nitroxin and nano potassium consumption. While, the highest harvest index was also obtained by application of nitroxin and nano silicon. (Lemraski *et al*., 2017).

Al-Juthery *et al.* (2018) conducted a field experiment at Al-Shafeieyah (Iraq) to examine the effect of foliar application of different sources of nano fertilizers affected wheat growth and yield. In comparison to control and traditional (NPK+TE) fertilizer treatments, foliar application of super micro plus (SMP) nano fertilizer followed by spraying combined of tri (N+P+K), di (N+P), (N+K), and (P+K) nano fertilizer showed superior results. Application of super micro plus (SMP) nano fertilizer noted substantially higher biological yield (13.36 Mg ha$^{-1}$) and grain yield (5.99 Mg ha$^{-1}$), 1000 grain weight (47.88 g) and harvest index (44.96%). Astaneh *et al.* (2018) carried out an experiment of nano chelated nitrogen and urea fertilizers on wheat plant under drought stress condition at two locations *viz*., Firoozabad and Ramhormoz in Iran. Results revealed that nitrogen (urea) and nano chelated nitrogen had significant effects on 1000 seed weight, biological and seed yield and harvest index. At Sammanthurai (Sri Lanka), the number of tillers plant$^{-1}$ (06) and yield (2.8 tonnes ha$^{-1}$) was significantly improved by 100 per cent nano nitrogen application (Rathnayaka *et al.*, 2018).

From Abu Simbel (Egypt), Morsy *et al.* (2018) reported that 100% irrigation level with nano fertilizer @ 400 ppm in combination with N level of 100 kg fed$^{-1}$ significantly higher spike length (9.1 and 9.1 cm),1000 grain weight (47.7 and 47.0 g), grain yield (2617.1 and 2672.0 kg fed$^{-1}$) than other treatment. Al-Juthery *et al.* (2019) carried out a field experiment on wheat cultivar at the Al-Shafeieyah, (Iraq). They recorded that foliar spray of the tri nano fertilizer (Fe + Cu + Zn) gave the highest grain yield (12.30 Mg ha$^{-1}$), biological yield (91.87 Mg ha$^{-1}$), weight of 1000

(53.47 g) and harvest index (18.09 %) as compared to other treatments. At Husseiniya (Iraq), the highest grain yield (7.036 Mg $h^{-1}$), biological yield (15.53 Mg $h^{-1}$), weight of 1000 grains (50.43 g), harvest index (45.59 %) and agronomic productivity was achieved when foliar nutrition of tri nano mixture of NCSF + NAA + NK was applied compared to control (Al-Juthery *et al.*, 2019).

Experiment was investigated on use of nano and non-nano fertilizers on yield and yield attributes of wheat (*Triticum aestivum* L.) during the *rabi* season of 2015-2016 at Jammu (Jammu & Kashmir). Mehta and Bharat (2019) reported that application of 100 per cent NPK + nano NPK (liquid) recorded significantly maximum grain yield (44.45 q $ha^{-1}$) and straw yield (55.99 q $ha^{-1}$) than other treatments. They concluded that integrated use of nano and non-nano fertilizers had significant effect on the grain yield.

Rani *et al.* (2019) conducted a pot experiment on a sorghum crop in Junagadh (Gujrat) to access the effect chemical and nano nitrogenous fertilizer. They recorded that application of $T_4$ (2.5 times reductionof RDN through nano fertilizer) followed by $T_7$ (RDN through nano fertilizer) produced the greatest test weight (28.33 g), seed yield (51.23 g $pot^{-1}$) and straw yield (117.13 g $pot^{-1}$) when compared to conventional RDN treatment through chemical fertilizer. In Uttar Pradesh (India), various field demonstrations conducted on farmers' fields by Kumar *et al.* (2020) to study the effect of nano fertilizers on wheat crop. They showed that the application of 50 per cent conventional nitrogen + 2 nano-N sprays increase yield with 9.76 per cent over traditional nitrogen and this treatment also resulted in the uppermost mean yield from several demonstrations, which was 4,779 kg $ha^{-1}$.

During the winter season of 2019-20, Kumar *et al.* (2020) conducted a wheat study in in several district of Rajasthan. They discovered that yields obtained with 50 per cent less nitrogen + one spray of nano N, Zn, and Cu were the highest (4628 kg $ha^{-1}$) with an extra gain of 297.5 kg $ha^{-1}$ over control and a 6.87 per cent increase over control.

During the winter season of 2019-20, Kumar *et al.* (2020) conducted a barley study in various districts of Rajasthan. They discovered that applying 50 per cent less nitrogen plus one spray of each of nano N, Zn, and Cu resulted in a maximum mean yield (4625 kg ha$^{-1}$) with an additional yield of 395 kg ha$^{-1}$ and a 9.34 per cent increase over farmer fertilizer practise.

An experiment was conducted by Kumar *et al.* (2020) in various locations of Rajasthan (India) to investigate the impact of IFFCO nano urea on maize yield metrics. It was found that yield with 50% less nitrogen and one spray of nano N, Zn, and Cu was maximum mean yield (5250 kg ha$^{-1}$) with an additional yield of 450 kg ha$^{-1}$ over farmers' practice and a 9.38 per cent increase. Kumar *et al*. (2021) investigated the influence of IFFCO nano fertilizer on growth and yield parameters of maize at different parts of India. It was observed that application of 50 per cent N, 100 per cent PK, 0 per cent Zinc + 2 sprays of IFFCO nano N (4 ml litre$^{-1}$) mixed with IFFCO Sagarika (2 ml litre$^{-1}$) showed significant increase in grain yield (58.90 q ha$^{-1}$).

An experiment was set up on a wheat crop in Udaipur (Rajasthan) to assess the impact of foliar spraying nano fertilizers on microbial count and yield. They came to the conclusion that highest wheat grain yield (5565.20 kg ha$^{-1}$) and straw yield (7135.46 kg ha$^{-1}$) were achieved with the application of 100% RDF + 1$^{st}$ spray of nano Zn at 14 DAS + 2$^{nd}$ spray of nano Zn at 28 DAS (Meena *et al.*, 2021).

Morsy *et al*. (2021) studied the impact of the previous crop, sowing methods and nano-fertilizer on the growth, productivity and quality of bread wheat at Abu Simbel (Egypt). In the 2018-19 and 2019-20 seasons, foliar spraying wheat plants with 500 mLfed$^{-1}$ of nano fertilizer resulted in increases in spike length by 32.31 per cent, number of grain spike$^{-1}$ by 10.51 per cent, 1000 grain weight by 9.01 per cent and grain yield by 45.45 per cent when compared to the control treatment in the first season. In the second season, the comparable increases were 30.86 per cent, 10.08 per cent, 10.34 per cent and 40.71 per cent in the same order than the control treatment.

In Indonesia (Bogor), Rostaman *et al*. (2021) conducted an experiment on rice crop. According to the findings, using inorganic nano fertilizers in combination with NPK + urea fertilizer is found effective. When nano inorganic fertilizers with 400 times dilution were combined with NPK + urea fertilizer at a recommended dose of 75 per cent increases weight of milled dry rice grain by 22.6 per cent compared to control.

Valojai *et al.* (2021) carried out an experiment at Amol (Iran), to estimate the influence of conventional and nano fertilizers on grain yield and quality of two rice cultivars (Tarom and Shiroudi). The results showed that application of NPK, nano NPK and its combination (NPK + nano NPK) significantly increased the grain yield by (11.24 -149.78 per cent in Tarom and 16.86-95.85 per cent in Shiroudi cultivars) and milled rice yield (25.33–157.35 per cent in Tarom and 16.05–112.39 per cent in Shiroudi cultivars).

### 2.1.3 Quality parameters

Qiang *et al.* (2008), conducted an experiment to evaluate performance of slow controlled release fertilizer made up of nano materials on quality of winter wheat and summer corn and reported that application of nano fertilizers resulted in insignificant increase in protein content whereas soluble sugar content was found to be decreased insignificantly by use of these fertilizers in comparison with conventional NPK chemical fertilizer. Jian *et al.* (2008) conducted a research experiment to explore the application effect of nano synergism fertilizer on winter wheat and reported that application of nano synergism fertilizer resulted in decreased protein content of the wheat (7.52 %) whereas, the fat content was increased significantly (33 %) upon application of these nano materials.

Ghafari and Razmjoo (2013), conducted an experiment at Isfahan (Iran) to evaluate the effects of foliar application of nano iron oxide (2 and g litre$^{-1}$), iron chelate (4 and 8 g litre$^{-1}$) and iron sulphate (4 and 8 g litre$^{-1}$) on quality of bread wheat (*Triticum aestivum* L.) and reported that significantly higher grain carbohydrate yield besides chlorophyll, grain protein and iron contents were observed with application of 8 g litre$^{-1}$ iron sulphate followed by application of 2 g litre$^{-1}$ of nano iron oxide than control plots in comparison. At Coimbatore (Tamilnadu), two greenhouse experiments of two distinct soil textures, (Inceptisol and Alfisols) was carried out by Manikandan and Subramanian (2016). They evaluated the zeolite-based nitrogen nano fertilizers on maize crop and reported that the crude protein content in maize grain (4.9 and 4.7 %) in Inceptisol and Alfisols, respectively, was significantly higher for nano-zeolite urea treatment in comparison to other treatments.

Al-Juthery *et al.* (2018) conducted a field experiment at Al-Shafeieyah (Iraq), to study the effect of foliar application of different sources of nano fertilizers on growth and yield of wheat. The application of nano super micro plus (SMP) fertilizer recorded highest protein (13.69 %) content of the wheat grains in compared to other treatments. From Astaneh *et al.*, (2018) carried out an experiment at two locations *i.e.*, Firoozabad and Ramhormoz in Iran to study the effect According to research, the maximum means of proline (15.65 and 31.5) and chlorophyll a (2.51 and 2.11) were obtained by 110 kg ha$^{-1}$ urea and 41 kg ha$^{-1}$ nano fertilizer under normal and stressful conditions respectively.

Morsy *et al.* (2018) conducted two winter seasons of research at the experimental at Abu Simbel, Egypt. They observed that 100% irrigation level with nano fertilizer @ 400 ppm in combination with N level of 100 kg fed$^{-1}$ had a significantly higher protein (14.70 %) and ash (2.03 %) content than other treatments. Al-Juthery *et al.* (2019) carried out a field experiment on wheat cultivar at the Al-Shafeieyah, (Iraq). They reported that significantly higher protein content (14.22%) and total chlorophyll SPAD (18.22) was obtained with triple nano (Cu +Zn +Fe) application than other treatments.

Burhan and AL-Hassan (2019) carried out an experiment in Baghdad (Iraq) and investigators reported that spraying wheat plant with the liquid nano NPK fertilizer treatment (20:9:10 per cent) with 15% concentration of the levels 750:90:600 mg litre$^{-1}$ recorded the maximum protein in grain (11.83 %), gluten in grain flour (16.99 %) and carbohydrates in grain (59.27 %). Morsy *et al*. (2021) studied the impact of preceding crops, sowing methods, and nano fertilizer on the growth, yield, and quality of bread wheat over two seasons at the Abu Simbel in Egypt. They reported that the first and second seasons' grain yield from plants sprayed with 250 ml fed$^{-1}$ nano fertilizer had the greatest mean values of protein (12.45 and 12.69%), wet gluten (35.03 and 35.23%) and dry gluten (11.55 and 11.69%), respectively.

#### 2.1.4 Nutrient content and uptake

At Coimbatore (Tamilnadu) a research experiment was conducted by Manikandan and Subramanian (2016) and the research findings showed that in inceptisol and alfisol soil highest nitrogen content in grain (0.78 and 0.76 %) were significantly increased by nano-zeourea fertilization while in shoot observed by zeourea. Al-Juthery *et al.* (2018) conducted a field experiment at Al-Shafeieyah (Iraq), to study the effect of foliar application of different sources of nano fertilizers on growth and yield of wheat. The application of super micro plus (SMP) nano fertilizer recorded maximum N, P (2.88 %, 0.6 %) and K (2.66 %) content in leaves compare with traditional fertilizer. To examine the impact of foliar nutrition with some of nano fertilizers and nano amino acids on growth and yield of wheat a field experiment was conducted at Husseiniya (Iraq). It was found that spraying tri mixture of NK (nano potassium), NAA (nano amino acids) and NCSF (nano chelated super granules) significantly increased N, P, K content in grain (2.53, 0.48 and 2.23%, respectively) compared to all other treatment (Al-Juthery *et al.*, 2019).

Al-Juthery *et al.* (2019) carried out a field experiment on wheat cultivar at the Al-Shafeieyah (Iraq). The results revealed that significant response of the combined nano-(Fe + Cu + Zn) followed by the di and single spraying treatments showed a significant response compared to the control treatment, with increases of 141. 23, 33. 33, and 57. 40 per cent for Cu, Zn, and Fe concentrations, respectively. Burhan and Hassan (2019) reported that foliar application of nano NPK fertilizers increase nitrogen, phosphorus, and potassium content in wheat by 19.37, 44.11, and 12.03 per cent, respectively, in Baghdad (Iraq).

At Udaipur (Rajasthan), Meena *et al.* (2021) reported that application of 100% RDF + 1$^{st}$ spray of nano Zn at 14 DAS + 2$^{nd}$ spray of nano Zn at 28 DAS produces the maximum P, K and Zn uptake by wheat grain and wheat straw, respectively, of 17.58, 28.54, and 330.32 kg ha$^{-1}$ and 14.84, 101.10, 305.88 kg ha$^{-1}$. According to research conducted at Ludhiana (Punjab), the highest Zn content (4.16 mg kg$^{-1}$) was recorded with application of ZnO NPs @20 mg l$^{-1}$ in shoot and root of maize fodder at 60 DAS while, seed priming and coating with ZnO NPs @ 40 mg l$^{-1}$ significantly augment the N (1.25%), P (1.29%), and K (9.20%) content (Tondey *et al*., 2021).

### 2.1.5 Economics

During the winter season of 2019-20, Kumar *et al.* (2020) conducted a wheat study in in several district of Rajasthan. They reported that greatest economic return was obtained with 50 per cent less nitrogen + one spray of nano N, Zn, and Cu. Similar study was conducted in barley, and reported that when compared to farmer fertilizer practise, the highest economic return (Rs. 6023.75 ha$^{-1}$) was also highest with application of 50 per cent less nitrogen + one spray of each of nano N, Zn, and Cu.

An experiment was conducted by Kumar *et al.* (2020) in various locations of Rajasthan (India) to investigate the impact of IFFCO nano urea on maize yield metrics. It was found that with 50% less nitrogen and one spray of each of nano N, Zn, and Cu, the economic return (Rs.7920 $ha^{-1}$) was highest.

# 3. MATERIALS AND METHODS

The present investigation entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** was conducted at the Instructional Farm, Agronomy, Rajasthan College of Agriculture, Udaipur (Rajasthan) during the *rabi* season of 2021-22. The details of the materials used, experimental procedures followed and techniques adopted during the course of investigation have been presented in this chapter.

## 3.1 EXPERIMENTAL SITE

During *rabi* 2021-22, the experimental trial was set up in the Rajasthan College of Agriculture's Instructional Farm (Agronomy), Udaipur, which is located in the southern-eastern region of Rajasthan at 24° 35' N latitude, 73° 42' E longitude, and an altitude of 581.13 metres above mean sea level. This area is part of Rajasthan's agro-climatic zone IV a (Sub-Humid Southern Plain and Aravalli Hills).

## 3.2 CLIMATE AND WEATHER CONDITIONS

This zone's climate is characteristic of the subtropics with mild winters and moderate summers, as well as high relative humidity from July to September. Udaipur receives 600.7 mm of annual rainfall on average, with a range of 373-1140 mm, with the majority of this occurring from the South-West monsoon from July to October.

Table 3.1 and Fig. 3.1 show the mean weekly meteorological parameters obtained at the RCA's agrometeorological observatory in Udaipur during the crop growing season. The maximum and minimum temperatures, according to the data, were 38.0$^{o}$C and 3.2$^{o}$C, respectively. Throughout the crop growing season, both maximum and minimum temperatures altered greatly. The maximum temperature decreased from the time of sowing to the month of January and afterward, with increasing trends up to harvest of crop. The maximum and minimum relative humidity during the experimental period were 96.0 and 14.8 per cent, respectively. During the crop growing season, there was a total of 209.1 mm of rain. The evaporation from USWB Class-A pan evaporimeter during the crop season ranged from 0.57 to 6.26 mm day$^{-1}$.

**Table 3.1 Mean weekly meteorology observations during crop period (*Rabi*, 2021-22)**

| Standard met weeks | Duration | Temperature ($^oC$) | | Relative Humidity (%) | | Sunshine (hrs $day^{-1}$) | Rainfall (mm) | Evaporation (mm $day^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | | Max. | Min. | I | II | | | |
| 45 | 5 Nov-11 Nov | 29.5 | 8.5 | 87.8 | 52.8 | 8.0 | 0.0 | 3.80 |
| 46 | 12 Nov-18 Nov | 27.4 | 7.3 | 93.2 | 62.7 | 6.4 | 0.0 | 3.09 |
| 47 | 19 Nov-25 Nov | 24.8 | 12.4 | 94.8 | 58.7 | 5.0 | 12.0 | 1.88 |
| 48 | 26 Nov-2 Dec | 26.9 | 10.2 | 95.1 | 57.5 | 6.5 | 170.8 | 2.79 |
| 49 | 3 Dec-9 Dec | 23.6 | 9.4 | 95.0 | 59.5 | 4.6 | 0.0 | 1.43 |
| 50 | 10 Dec-16 Dec | 25.0 | 6.4 | 95.8 | 55.2 | 6.1 | 0.0 | 1.50 |
| 51 | 17 Dec-23 Dec | 23.6 | 3.3 | 92.2 | 51.1 | 7.7 | 0.0 | 1.06 |
| 52 | 24 Dec-31Dec | 23.5 | 7.8 | 94.3 | 59.3 | 6.9 | 0.0 | 1.46 |
| 1 | 1 Jan - 7Jan | 23.3 | 8.9 | 94.4 | 69.0 | 5.9 | 18.0 | 1.13 |
| 2 | 8 Jan -14 Jan | 20.8 | 3.8 | 95.7 | 53.1 | 8.8 | 4.8 | 0.79 |
| 3 | 15 Jan - 21 Jan | 23.5 | 3.8 | 96.0 | 61.8 | 8.2 | 0.0 | 0.57 |
| 4 | 22 Jan - 28 Jan | 21.5 | 3.2 | 92.5 | 64.0 | 8.8 | 0.0 | 0.93 |
| 5 | 29 Jan - 4 Feb | 27.0 | 4.2 | 89.2 | 59.7 | 8.5 | 0.0 | 1.07 |
| 6 | 5 Feb -11 Feb | 25.8 | 5.0 | 92.0 | 69.1 | 8.8 | 0.0 | 1.03 |
| 7 | 12 Feb - 18 Feb | 26.6 | 5.1 | 95.2 | 66.7 | 8.7 | 0.0 | 1.10 |
| 8 | 19 Feb -25 Feb | 30.0 | 7.5 | 86.1 | 57.8 | 9.4 | 0.0 | 3.43 |
| 9 | 26 Feb - 4 Mar | 30.0 | 8.9 | 90.4 | 70.5 | 8.2 | 0.0 | 3.90 |
| 10 | 5 Mar -11 Mar | 31.4 | 12.3 | 82.7 | 48.0 | 7.5 | 0.0 | 4.31 |
| 11 | 12 Mar - 18 Mar | 36.2 | 12.3 | 59.2 | 17.1 | 8.3 | 3.5 | 5.86 |
| 12 | 19 Mar - 25 Mar | 37.7 | 13.1 | 48.8 | 19.8 | 7.3 | 0.0 | 6.24 |
| 13 | 26 Mar - 1 Apr | 38.0 | 11.9 | 45.5 | 14.8 | 8.4 | 0.0 | 6.26 |

**Source:** Agrometeorological observatory, Instructional Farm Rajasthan College of Agriculture, MPUAT, Udaipur

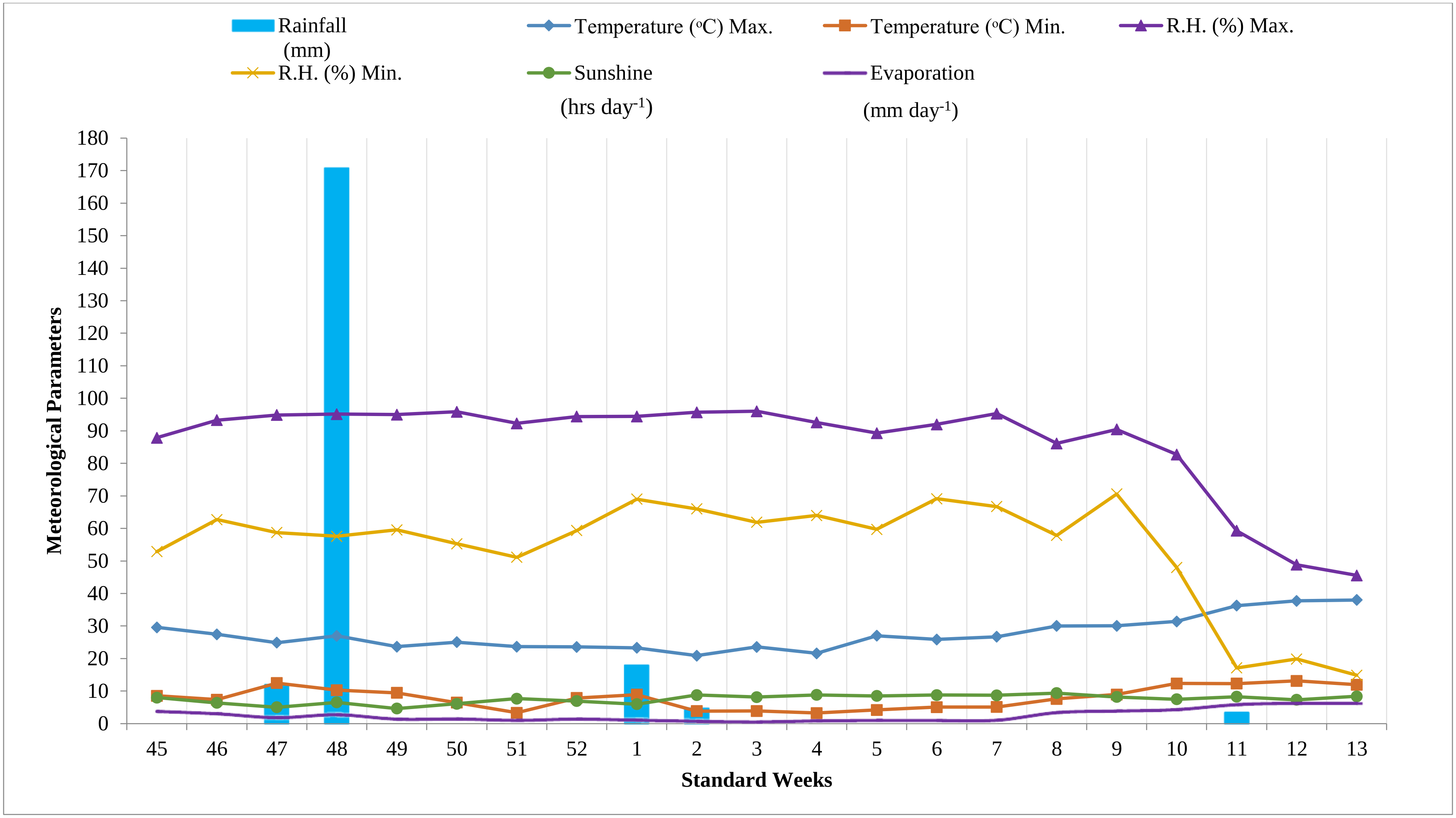



**Figure 3.1 Mean weekly weather parameters during the crop growth period (*Rabi,* 2021-22)**

## 3.3 PHYSICO-CHEMICAL PROPERTIES OF SOIL

Before the set-up of experiment, random samples were gathered from five spots of the experimental field up to a depth of 15.0 cm. The samples were then pooled to generate a composite sample than sample was left in oven for drying at 105°C for 72 hours than after sieving that was used to determine the various physio-chemical characteristics of soil. Table 3.2 lists the findings of the soil sample analysis.

**Table 3.2 Physical, chemical and biological properties of the soils of the experimental field before the sowing of the crop**

| Characteristics | Content | Method of analysis | Reference |
|---|---|---|---|
| **Mechanical composition** | | | |
| Sand (%) | 35.10 | International pipette method | Piper (1950) |
| Silt (%) | 29.70 | | |
| Clay (%) | 35.00 | | |
| Texture | Clay loam | Texture triangle | Triangular diagram (Brady, 1983) |
| **Physical properties** | | | |
| Bulk density (g $cc^{-1}$) | 1.35 | Core sampler method | Black (1965) |
| Particle density (g $cc^{-1}$) | 2.58 | | Black (1965) |
| Porosity (%) | 47.28 | | Black (1965) |
| **Chemical properties** | | | |
| Organic carbon (%) | 0.66 | Rapid titration method | Walkley and Black (1934) |
| Available nitrogen (kg $ha^{-1}$) | 286.50 | Alkaline $KMnO_4$ method | Subbiah and Asija (1956) |
| Available phosphorus (kg $ha^{-1}$) | 21.60 | Olsen's method | Olsen *et al.* (1954) |
| Available potassium (kg $ha^{-1}$) | 369.70 | Flame photometer | Richards (1968) |
| Electrical conductivity ($dSm^{-1}$ at 25°C) | 0.892 | Conductivity bridge | Richard (1968) |
| pH (1:2.5 soil water ratio) | 7.75 | pH meter | Richard (1968) |

From the above-mentioned Table 3.2 it is noticeable that the soil texture of the experimental unit was clay loam and the pH was 7.75 depicting the slightly alkaline reaction. The bulk density of the soil is optimum (1.35 g $cc^{-1}$). The nutrient status of the soil showed organic carbon content (0.66%), available nitrogen content (286.50 kg $ha^{-1}$), available phosphorus content (21.60 kg $ha^{-1}$) and available potassium content (369.70 kg $ha^{-1}$) depicting overall medium nutrient status of the soil.

## 3.4 CROPPING HISTORY

Before the current experiment in *rabi* 2021-22, the experimental field had been following a maize-wheat crop rotation for a number of previous years.

## 3.5 EXPERIMENTAL DETAILS

### 3.5.1 Treatment details and layout

Field experiment was conducted during 2021-2022. The experiment was comprised of 9 treatments which were laid out in a Randomized block Design with 3 replications. Details of the treatments are given in Table 3.3 and plan of layout is given in Figure 3.2.

**Table 3.3: Treatment details along with their designated symbol**

| S. No. | Symbol | | Treatments |
|---|---|---|---|
| 1 | $N_1$ | : | One spray nano urea at tillering (40-45 DAS) |
| 2 | $N_2$ | : | Two spray nano urea at tillering (40-45DAS) and jointing (60-65 DAS) |
| 3 | $N_3$ | : | RDN (1/3$^{rd}$ basal, 2/3$^{rd}$ CRI-Rec. N) |
| 4 | $N_4$ | : | RDN+ one spray of nano urea at tillering |
| 5 | $N_5$ | : | RDN+ two spray of nano urea at tillering and jointing |
| 6 | $N_6$ | : | RDN+ one spray of urea (5%) at tillering |
| 7 | $N_7$ | : | RDN+ two spray of urea (5%) at tillering and jointing |
| 8 | $N_8$ | : | RDN+ one spray of urea (5%) + nano urea at tillering |
| 9 | $N_9$ | : | Absolute control (No nitrogen) |

### 3.5.2 Other experimental details

| | | | |
|---|---|---|---|
| 1. | Season | : | *Rabi* 2021-22 |
| 2. | Test crop | : | Wheat (Raj 4079) |
| 3. | Design | : | RBD |
| 4. | Total number of treatments | : | 09 |
| 5. | Number of replications | : | 03 |
| 6. | Total number of plots | : | 27 |

| | | | |
|---|---|---|---|
| 7. | Plot size | : | |
| | Gross | | 1.80 m × 8.0 m = 14.40 $m^2$ |
| | Net | | 1.40 m × 7.0 m = 9.80 $m^2$ |
| 8. | Row spacing | : | 20 cm |
| 9. | Seed rate | : | 100 kg $ha^{-1}$ |
| 10. | Weed management | : | Sulfosulfuron 75% WP (32.5 g) + Metsulfuron 20% WP (20 g) |

## 3.6 DETAILS OF AGRONOMIC OPERATIONS

Table 3.5 lists the details of all pre and post-sowing procedures carried out in the experimental field throughout the cropping season *rabi*, 2021-22 in chronological order and with full explanation mentioned below.

### 3.6.1 Field preparation

The field was prepared with tractor-drawn equipment after the harvested of last crop. The experimental field was cross-harrowed and levelled properly after one deep ploughing to break up clods and bring the soil to the desired tilth for proper wheat germination and crop growth. Individual plots were levelled with a rake after all bunds and irrigation channels were prepared. As per layout (Fig 3.2) plots were drawn along with irrigation channels.

### 3.6.2 Nutrient management

Urea, SSP and MOP are commercial fertilizers that used to deliver the recommended dose of nutrients *i.e.,* 80, 40 and 20 NPK kg $ha^{-1}$. As a basal dose, the full doses of phosphorus and potassium were applied in each plot while, recommended nitrogen was applied in desired quantity as per treatment.

**Application of nano urea**

Nano urea was applied in each plot as per the treatments during the crop growth with the help of sprayer. Because one bottle of nano urea (500 ml) is equal to one bag of urea, a total of 1250 ml nano urea is required per hectare for wheat crops. The first nano urea spray was applied at the tillering stage (45 DAS) and the second was applied during the jointing stage (65 DAS).

**Table 3.4: Detailed information of treatment application plot$^{-1}$ given below**

| Treatments | Treatment dose plot$^{-1}$ |
|---|---|
| $N_1$ | 1.8 ml nano urea plot$^{-1}$ litre$^{-1}$ water |
| $N_2$ | 1.8 ml nano urea plot$^{-1}$ litre$^{-1}$ water+ 1.8 ml nano urea plot$^{-1}$ litre$^{-1}$ water |
| $N_3$ | 249.9 g plot$^{-1}$ |
| $N_4$ | 249.9 g plot$^{-1}$ + 1.8 ml nano urea plot$^{-1}$ litre$^{-1}$ water |
| $N_5$ | 249.9 g plot$^{-1}$ + 1.8 ml nano urea plot$^{-1}$ litre$^{-1}$ water+ 1.8 ml nano urea plot$^{-1}$ litre$^{-1}$ water |
| $N_6$ | 249.9 g plot$^{-1}$ litre$^{-1}$ water + 50.4 mg urea plot$^{-1}$ litre$^{-1}$ water |
| $N_7$ | 249.9 g plot$^{-1}$ litre$^{-1}$ water + 50.4 mg urea plot$^{-1}$ litre$^{-1}$ water + 50.4 mg urea plot$^{-1}$ litre$^{-1}$ water |
| $N_8$ | 249.9 g plot$^{-1}$ litre$^{-1}$ water + 50.4 mg urea plot$^{-1}$ litre$^{-1}$ water + 1.8 ml nano urea plot$^{-1}$ litre$^{-1}$ water |
| $N_9$ | No nitrogen |

### 3.6.3 Seed rate and sowing

The wheat variety Raj 4079 was used as test crop. Seeds were manually sown in all the plots on 11th November, 2021. Sowing at 3.0 cm depth by opening furrows in lines at a distance of 20.0 cm row to row spacing keeping the total number of rows in each plot 9. Seeds were sown at the rate of 100 kg ha$^{-1}$. The seeds in all the plots were covered with thin layer of soil thereafter.

**Raj 4079: -** Wheat variety Raj 4079 is highly heat tolerant and recommended for warmer areas. It is dwarf with good spikes. Due to its height, it resolves lodging problem. It matures in 137 days. This variety was released in year 2010.

### 3.6.4 Water management

Prior to sowing the crop, a pre-sowing irrigation was given to the field. Then, various irrigations were applied to the field at CRI (21 DAS), late jointing (63 DAS) and milking (105 DAS) stage of the crop.

### 3.6.5 Weed management

For effective weed control Sulfosulfuron 75% WP (32.5 g) + Metsulfuron 20% WP (20 g) was sprayed with the help of knapsack sprayer fitted with flat fan T-jet nozzle using a spray volume of 500 litres hectare$^{-1}$ at 32 days after sowing.

### 3.6.6 Harvesting

The crop was harvested after 137 days from sowing on 27$^{th}$ March, 2022. The crop was harvested manually with sickles at maturity. Two rows from each side of the plots of individual plots were harvested separately to eliminate the border effects. The crop plants after cutting from the ground level were allowed for sun drying for 2-3 days. After drying, the harvested produce of net plot size was tied separately into bundles, tagged and the bundle weight was recorded with the help of spring balance.

### 3.6.7 Threshing and winnowing

The sun-dried produce of the crops from each plot was threshed manually by mini power operated thresher which separated the grain out from the straw. The grain of wheat from the individual plots were collected, weighed and kept in the bags and weight of grain was recorded on pan balance.

**Chronological record of crop management**

The test crop (wheat) was raised as per the package and practices of the wheat crop. Agronomic operations that were carried out in the experimental field are stated below in chronological order in Table 3.5.

**Table 3.5: Schedule of crop raising activities**

| S. No. | Detail of operations | Date of operation |
|---|---|---|
| 1. | Field preparation with plough and rotavator | 28.10. 2022 |
| 2. | Preparation of layout | 04.11. 2022 |
| 3. | Sowing and basal fertilizer application | 11.11. 2022 |
| 4. | Irrigation for germination | 11.11. 2022 |
| 5. | First irrigation | 02.12. 2022 |
| 6. | Herbicide spray at 32 DAS | 12.12. 2022 |

| S. No. | Detail of operations | Date of operation |
|---|---|---|
| 7. | 1st nano urea spray | 26.12. 2022 |
| 8. | 1st urea (5%) solution spray | 26.12. 2022 |
| 8. | Second irrigation | 11.01. 2022 |
| 9. | 2nd nano urea spray | 13.01. 2022 |
| 10. | Third irrigation | 25.02.2022 |
| 11. | Harvesting and tagging | 27.03.2022 |
| 12. | Threshing and winnowing | 31.03.2022 |

## 3.7 OBSERVATIONS RECORDED

Following observations were noted and analyzed to test the effect of different treatments on soil as well as the crop.

### 3.7.1 Growth characters

Initially the growth parameters were recorded at 15 days after sowing and subsequent observations were taken at different stages.

#### 3.7.1.1 Plant population

The number of plants was counted from three randomly selected 0.5 m row length of each plot at 15 DAS. These were averaged and expressed as numbers of plant at 0.5 m row length.

#### 3.7.1.2 Plant height

Five plants selected randomly from each plot and the height of wheat plant was measured with the help of metre scale from the base of the plant to the top of the last fully developed leaf at 50, 75 and 100 days and at harvest. Plant height at harvest was measured from the ground level to the topmost portion of the ear head and mean values are presented in centimetres (cm). Average of all the five plants was taken for statistical analysis.

#### 3.7.1.3 Dry matter accumulation

Plant samples for dry matter accumulation were taken from 0.5 m row length from the border row at different growth stages at 50, 75, 100 DAS and at harvest. The plants were cut from the ground level and the sample plants were put into punched paper bags. These samples were subjected to sun drying and thereafter shifted in the oven to dry at a temperature of 65±5°C till a constant weight was achieved. Then, the samples were weighed for estimating total dry matter accumulation (g) under each treatment.

### 3.7.1.4 Number of tillers plant$^{-1}$

The numbers of tillers plant$^{-1}$ were calculated at harvest from randomly selected five plants in each plot. Average of these counts was taken for statistical analysis.

### 3.7.1.5 Crop growth rate

The increase in dry weight unit$^{-1}$ land area at unit$^{-1}$ time.

cumulative crop growth rate (CGR) was calculated at 50-75 and 75-100 DAS and 100-harvest as per the formula given by Radford (1967) and was expressed as g m$^{-2}$ day$^{-1}$:

$$\mathrm{CGR} = \frac{1}{\mathrm{P}} \times \frac{\mathrm{W}_2 - \mathrm{W}_1}{\mathrm{T}_2 - \mathrm{T}_1}$$

P = Land area, $W_1$= Dry matter at $T_1$ time and $W_2$= Dry matter at $T_2$ time

### 3.7.1.6 Relative growth rate

The relative growth rate (RGR) defines the dry weight increase in time interval in relation to the initial weight. It was calculated at 50-75 and 75-100 DAS and 100-harvest and expressed as g g$^{-1}$ day$^{-1}$. The was calculated by following formula:

$$\mathrm{RGR} = \frac{(\log_e \mathrm{W}_2 - \log_e \mathrm{W}_1)}{\mathrm{T}_2 - \mathrm{T}_1}$$

$W_1$= Dry matter at $T_1$ time and $W_2$= Dry matter at $T_2$ time

### 3.7.1.7. Total tillers

The total number of tillers 0.5 m$^{-1}$ row length was recorded from the two sampling rows of outer side. Mean of both the counts was taken for statistical analysis.

## 3.7.2 Yield attributes and yield

### 3.7.2.1 Number of effective tillers plant$^{-1}$

Tillers which bear ears were counted from randomly selected five plants of each plot at crop maturity. Average of these counts was taken for statistical analysis.

#### 3.7.2.2 Number of grains ear$^{-1}$

Randomly selected five productive ears from each plot at harvest and threshed discretely then recorded the number of grains ear$^{-1}$ and it was expressed as average number of grains ear$^{-1}$.

#### 3.7.2.3 Weight of grains ear$^{-1}$

The five randomly selected ears from each plot were threshed separately, weighed and expressed in gram. Average of these used for statistical analysis.

#### 3.7.2.4 Test weight

1000 grains from produce of each net plot were taken, weighed and expressed as gram.

#### 3.7.2.5 Grain yield

After the threshing and winnowing process of each plot the grain yield from each plot was recorded and expressed in kg ha$^{-1}$.

#### 3.7.2.6 Straw yield

Straw yield was calculated by subtracting the economic yield from biological yield of treatment and expressed in kg ha$^{-1}$.

#### 3.7.2.7 Harvest index

Harvest index was calculated by dividing the economic yield (grain yield) to the biological yield and expressed in percentage as suggested by Donald and Hamblin (1976).

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

### 3.7.3 Quality parameter

#### 3.7.3.1 Chlorophyll content

A chlorophyll meter (SPAD-502, Minolta, Japan) was used to obtain readings estimating leaf chlorophyll concentration (SPAD value). Five plants per treatment were selected randomly and SPAD values were recorded from the fully matured leaves counted from the top of the plants, the youngest fully expanded leaf. As such data were recorded at 60 DAS. Three SPAD readings were taken plant$^{-1}$ and thus each SPAD value represents a mean of 15 readings per treatments.

**3.7.3.2 Proline estimation**

Free proline content in leaves (µmol g$^{-1}$) was extracted at 65 DAS and determined by the method of Bates *et al*. (1973). 100 mg fresh leaf sample was standardized in 5 ml of 3 per cent aqueous sulphosalicylic acid and the supernatant was collected after centrifugation at 5000 rpm for 5 min. The volume of supernatant was made to 10 ml with the sulphosalicylic acid. The sample extract of 2 ml was taken in one test tube and at the same time in a series of test tubes 0.2, 0.4, 0.6, 0.8 and 1.0 ml of proline solutions were prepared by dissolving 10 mg of proline in 100 ml of 3 per cent sulphosalicylic acid. In each test tube, the volume was made to 2 ml with 3 % sulphosalicylic acid. A tube with 2 ml of sulphosalicylic acid was served as a control.

In all test tubes, 2 ml ninhydrine reagent (1.25 g ninhydrine in 20 ml of 6 N orthophosphoric acid) and 2 ml glacial acetic acid were added and kept in boiling water bath at 100°C for 10 minute and then cooled in ice bucket. Then, 4 ml toluene was added and mixed thoroughly by vortex mixer for 10 seconds. Optical density was measured at 520 nm against a reagent blank using spectrophotometer. The quantity of free proline in the 100 mg of leaf was then calculated using the standard curve. Its amount was calculated on fresh weight basis using the following formula:

µmoles of proline g$^{-1}$ fresh leaf tissue =

$$\frac{(\mu\text{g proline/ml} \times \text{ml toluene})/115.5\ \mu\text{g}/\mu\text{ mole}}{\text{g sample}/5}$$

**3.7.3.3 Protein content**

Protein content of seeds were computed Lowry *et al*. (1951) method. Protein content expressed as percentage**.**

**3.7.4 Plant analysis**

Following chemical analysis were carried out in plant samples (seed and haulm) to evaluate the effect of each treatment of experimental trial.

**3.7.4.1. N, P and K (%) content in grain and straw at harvest**

Five plants were selected at random after harvest and grain were collected from these plants. The collected samples were oven dried at 65°C till constant weight is obtained. Then, samples were grounded to produce fine powder and passed through 60 mesh sieves to obtain final sample for the nutrient analysis. Table 3.6 represents the methods that were adopted to carry out the analysis.

**Table 3.6 Methods of chemical analysis of grain and straw**

| S. No. | Parameters | Method of analysis | References |
|---|---|---|---|
| 1. | Nitrogen content | N was estimated by using spectrophotometer after developing colour with Nessler's reagent | Linder (1959) |
| 2. | Phosphorus Content | P was estimated by using spectrophotometer after developing colour with vanado-molybdo phosphoric yellow colour method | Richards (1968) |
| 3. | Potassium Content | Flame photometer | Jackson (1973) |

#### 3.7.4.2 Nutrient uptake

The total uptake of nitrogen, phosphorus and potassium by grain and straw at harvest were analyzed by multiplying per cent nutrient content with their corresponding dry matter accumulation using the following formula:

Formula:

$$\text{Nutrient uptake } (\text{kg ha}^{-1}) = \frac{\text{Nutrient content (\%) x dry matter accumulation (kg ha}^{-1})}{100}$$

### 3.7.5 Soil studies

#### 3.7.5.1 Nitrogen, phosphorus and potassium content

For estimation of N, P and K content in soil, soil sample were collected after harvest from each plot with the help of khurpi. Then after samples were grinded (by mortar and pestle), sieved and dried for laboratory analysis. Then the nutrient status of the soil is estimated by methods presented in the Table 3.2.

#### 3.7.5.2 Nitrogen use efficiency

The nitrogen use efficiency of crop were calculated by subtracting yield of no nitrogen treated plot from the yield of nitrogen treated plot and its result was divided by amount of nitrogen applied. It is expressed as kg $kg^{-1}$.

Formula:

$$\text{Nitrogen use efficiency } (\text{kg kg}^{-1}) = \frac{\text{Yield N (kg) - Yield C (kg)}}{\text{Quantity of nitrogen applied (kg)}}$$

Where: -

Yield N = Yield of treated plot (kg)

Yield C = Yield of control plot (kg)

### 3.8 Economics

For interpreting any experimental trial, the most important criterion is to check the economic feasibility of the treatments by evaluating and calculating the economics, net return (₹ $ha^{-1}$) and benefit-cost ratio (B-C ratio). Cost of production and the produce was calculated with the help of average market price of the inputs and the output so obtained.

#### 3.8.1 Net return

Gross return was calculated by multiplying the grain yield and straw yield with their respective selling prices in the market. Later by deducting the cost of the cultivation from the gross return, net return was calculated.

Net return (₹ $ha^{-1}$) = Gross return (₹ $ha^{-1}$) – Cost of cultivation (₹ $ha^{-1}$)

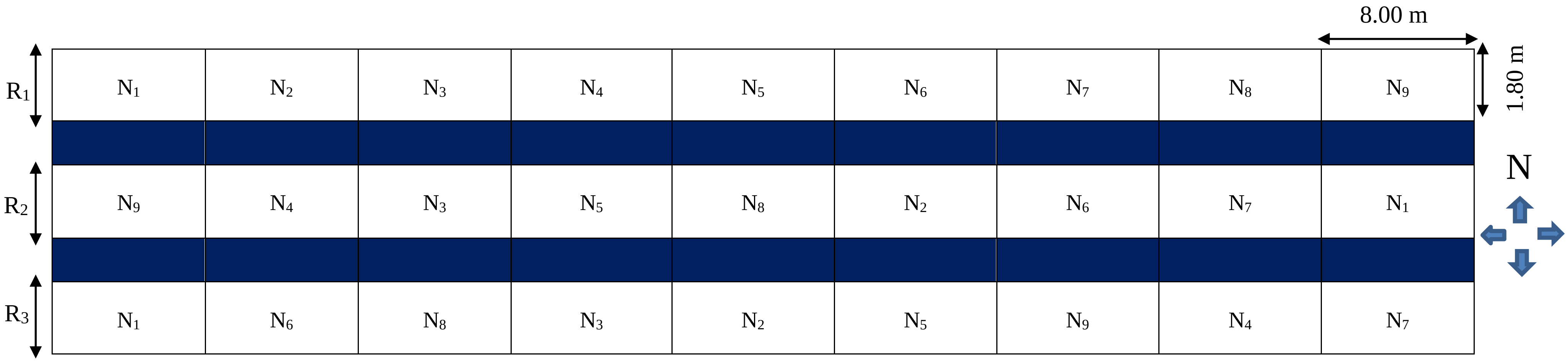
#### 3.8.2 Benefit-cost ratio

Treatment-wise benefit-cost ratio was calculated to analyze and determine the economic viability of the treatments by using the formula:

$$\text{B-C ratio} = \frac{\text{Net return (₹ ha}^{-1}\text{)}}{\text{Total cost (₹ ha}^{-1}\text{)}}$$

### 3.8.3 Statistical analysis

All the data were subjected to statistical analysis by adopting suitable method of analysis of variance for testing the significance of variation in experimental result. Wherever, the F value was found significant at 5% level of significance, the critical difference (CD) value was calculated for making comparison between the treatment means. Moreover, regression equations and coefficient of correlation were calculated among selected characters in order to establish cause and effect relationship. These calculations were all completed using the usual statistical method recommended by Panse and Sukhatme in 1989.




**Treatment Details**

| | | | | | | |
|---|---|---|---|---|---|---|
| **(A) Integrated nutrient supply (09)** | | | | | | |
| $N_1$ | : | One spray nano urea at tillering (40-45 DAS) | | $N_6$ | : | Rec. N + one spray of urea (5%) at tillering |
| $N_2$ | : | Two spray nano urea at tillering (40-45 DAS) and jointing (60-65 DAS) | | $N_7$ | : | Rec. N + two spray of urea (5%) at tillering and jointing |
| $N_3$ | : | Recommended N (1/3$^{rd}$ basal, 2/3$^{rd}$ CRI-Rec. N) | | $N_8$ | : | Rec. N + one spray of urea (5%) + nano urea at tillering |
| $N_4$ | : | Rec. N + one spray of nano urea at tillering | | $N_9$ | : | Absolute control (No nitrogen) |
| $N_5$ | : | Rec. N + two spray of nano urea at tillering and jointing | | | | |

**Experiment Details**

| | | | | | | |
|---|---|---|---|---|---|---|
| Design | : | RBD | | Plot size | : | |
| Total number of treatments | : | 09 | | Gross | | 1.80 m x 8.00 m =14.40 m$^2$ |
| Number of replications | : | 03 | | Net | | 1.40 m x 7.00 m = 9.80 m$^2$ |
| Total number of plots | : | 27 | | RDN (kg ha$^{-1}$) | : | 80+ 40 +20 kg NPK |
| Row spacing | : | 20 cm | | | | |

**Figure 3.2 Plan of Layout**

# 4. EXPERIMENTAL RESULTS

This chapter presents the findings of field experiment entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** conducted at Instructional Farm Agronomy, Rajasthan College of Agriculture, Udaipur (Rajasthan) during *rabi* 2021-22.

## 4.1 GROWTH CHARACTERS

### 4.1.1 Plant Population at 15 DAS

Application of different sources of nitrogen did not cause any substantial variation on plant population (0.5 m row length) at 15 DAS (Table 4.1).

### 4.1.2 Plant height

**50 DAS**

An analysis of data from Table 4.2 indicates that application of various sources of nitrogen cause significant variation in plant height at 50 DAS. The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded the maximum plant height (57.56 cm) which was statistically at par with all treatment combinations except control ($N_9$). Data further indicated that the maximum plant height obtained under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically higher by means of 16.07 per cent over control (49.59 cm).

**75 DAS**

Data (Table 4.2) indicates that the highest plant height (77.80 cm) at 75 DAS was found under the application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was in proportionate with other remaining treatments except control ($N_9$). The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded an increase of 22.19 per cent over control (63.67 cm).

**100 DAS**

Results revealed that the application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) stage had recorded the maximal plant height (94.20 cm) at 100 DAS and it was comparable with all treatments *i.e.*, $N_1$ (One spray nano urea at tillering), $N_2$ (Two spray nano urea at tillering and jointing) , $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5

%) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, remain significantly superior over control. The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) increased plant height with the magnitude of 25.38 per cent over control (Table 4.2).

**At harvest**

Data explicate from Table 4.2 show that the highest plant height (95.00 cm) was found under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) and this was statistically comparable to all nitrogen sources used under investigation but it was statistically higher over control. Data further indicates that the application of RDN + two spray of nano urea at tillering and jointing ($N_5$) shows increase in respect of plant height by 23.90 per cent over control (76.67 cm).

### 4.1.3 Dry matter accumulation

**50 DAS**

The results revealed that the application of RDN + two spray of nano urea at tillering and jointing ($N_5$) growth stages of wheat crop recorded significantly higher dry matter accumulation (23.0 g) and it was statistically at par with $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) but significantly superior over other sources of nitrogen. Data further depicted that dry matter accumulation under $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded maximum and it was significantly higher over control by means of 55.09 per cent (Table 4.3).

**75 DAS**

A reference of data (Table 4.3) indicates that different sources of nitrogen influenced the dry matter accumulation at 75 DAS in wheat crop. The maximum dry matter accumulation (61.15 g) was recorded under the application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically at par with $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) but statistically higher over other applied nitrogen sources. The magnitude of increase in dry matter accumulation with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) was 27.39 per cent over control (48.0 g).

**100 DAS**

A perusal of data shows that the loftier dry matter accumulation (184.67 g) at 100 DAS was recorded under $N_5$ (RDN + two spray of nano urea at tillering and jointing) and this finding was statistically at par with $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) however, this was statistically superior over control with the magnitude of 18.12 per cent (Table 4.3).

**At harvest**

Data depicted in Table 4.3 indicate that the highest dry matter accumulation (196.53 g) was recorded under $N_5$ (RDN + two spray of nano urea at tillering and jointing). Data further analysed and indicates that the maximal dry matter accumulation obtained under treatment $N_5$ however, it was statistically at par with $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) but it was statistically higher over other remaining treatments. The magnitude of increase in dry matter accumulation at harvest by $N_5$ (RDN + two spray of nano urea at tillering and jointing) over control was 19.83 per cent.

### 4.1.4 Number of tillers plant$^{-1}$

Results revealed that among the different sources of nitrogen under study, the highest number of tillers plant$^{-1}$ (7.56) was recorded under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) and it was statistically at par with several treatments *i.e.*, $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly greater over remaining treatments. The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) significantly increased number of tillers plant$^{-1}$ by 44.82 per cent control (Table 4.4).

### 4.1.5 Crop Growth Rate

An appraisal of data (Table 4.4) indicates that various sources of nitrogen did not affect the crop growth rate (g m$^{-2}$ day$^{-1}$) of wheat crop at various growth stages *i.e.*, between 50-75 DAS, 75 -100 DAS and 100 DAS to at harvest.

### 4.1.6 Relative Growth Rate

It is clear from data (Table 4.5) that the significant difference in relative growth rate (g $g^{-1}$ $day^{-1}$) was not established due to different sources of nitrogen used under study.

### 4.1.7 Total tillers

Data presented in Table 4.5 indicates that diverse application of nitrogen sources produced significant variation on total number of tillers in wheat. The maximum number of total tillers (41.50) was recorded under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) and it was comparable with several treatments *i.e.,* $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, it was significantly superior over rest of the applied nitrogen sources. Data further depicted that application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) significantly increased total number of tillers by 22.05 per cent over control.

## 4.2 YIELD ATTRIBUTES AND YIELD

### 4.2.1 Number of effective tillers

A perusal of data (Table 4.6) shows that the highest number of effective tillers (39.55) measured from 0.5 m row length was obtained under $N_5$ (RDN + two spray of nano urea at tillering and jointing) and it was statistically at par with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but higher over rest of the treatments. The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) increased number of effective tillers by 27.17 per cent over control (31.10).

### 4.2.2 Number of grains $ear^{-1}$

It is noted from data given in Table 4.6 shows that premier number of grain $ear^{-1}$ (42.70) was found under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically congruent with various applied treatments *i.e.,* $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %)

at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly greater over other treatments. Application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) increased number of grains ear$^{-1}$ by the tune of 24.23 per cent over control.

### 4.2.3 Weight of grains ear$^{-1}$

A close examination of data (Table 4.6) indicates that under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) the maximum weight of grain ear$^{-1}$ (2.20) was obtained and this result was statistically at par with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, superior over rest of the treatments. Application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) represented an increase in weight of grains ear$^{-1}$ by 4.76 per cent over control.

### 4.2.4 Test weight

Data (Table 4.6) indicates that the utmost test weight (49 g) was obtained with the application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) and this was statistically analogous with $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but it was significantly higher over control (42.37 g). The magnitude of increase in test weight with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) was 15.64 per cent over control.

### 4.2.5 Grain yield

A perusal of data from Table 4.7 shows that application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) improved grain yield. Data further indicates that $N_5$ (RDN + two spray of nano urea at tillering and jointing) had the maximum grain yield (50.01 q ha$^{-1}$) which was statistically at par with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but it was significantly superior over $N_1$ (One spray nano urea at tillering) , $N_2$ (Two spray nano urea at tillering and jointing) and control (33.49 q ha$^{-1}$). The magnitudes of increase of grain yield with application of RDN + two spray of nano urea at tillering and jointing were 27.35 over $N_1$, 21.86 over $N_2$ and 49.32 per cent over control.

### 4.2.6 Straw yield

The data from Table 4.7 indicates that application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) improve straw yield. Data further indicates that $N_5$ (RDN + two spray of nano urea at tillering and jointing) had maximum straw yield (144.50 q $ha^{-1}$) which was statistically at par with $N_4$ (RDN + one spray of nano urea at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly higher over other treatments. The magnitudes of rise in straw yield with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) were 49.86 per cent over control.

### 4.2.7 Harvest index

Application of different sources of nitrogen did not cause any significant variation on harvest index (Table 4.7).

## 4.3 QUALITY PARAMETERS

### 4.3.1 Chlorophyll content in leaves at 60 DAS

The maximum chlorophyll content (42.50 SPAD) was recorded with $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically at par with $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but higher over other treatment combination. The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) enhanced the chlorophyll content with magnitude of 19.6 per cent over control (Table 4.8).

### 4.3.2 Proline content in leaves at 65 DAS

Different sources of nitrogen used under experiment did not cause any significant variation on proline content at 65 DAS (Table 4.8).

### 4.3.3 Protein content in grain

A reference of data (Table 4.8) shows that application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded the maximum protein content (11.92 %) in grain which was found statistically at par with various treatments *i.e.,* $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly higher over rest of applied sources of nitrogen. Data further indicated that application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded 5.86 per cent increment in protein content over control.

## 4.4 PLANT ANALYSIS

### 4.4.1 N, P and K content (%) in grain and straw at harvest

#### 4.4.1.1 Grain

##### 4.4.1.1.1 Nitrogen

The higher value of nitrogen content (1.907 %) in grain was found under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) that was statistically at par with $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but statistically superior over $N_1$ (One spray nano urea at tillering) and control. The magnitude of increase in nitrogen content with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) was 5.88 per cent over control (Table 4.9).

##### 4..4.1.1.2 Phosphorus

An analysis of data (Table 4.9) shows that application of various sources of nitrogen did not cause any significant variation for phosphorus content in grain.

##### 4.4.1.1.3 Potassium

It is clear from data (Table 4.9) that the significant difference for potassium content in grain was not established due to different sources of nitrogen application.

#### 4.4.1.2 Straw

##### 4.4.1.2.1 Nitrogen

An assessment of data presented in Table 4.9 indicates that maximum nitrogen content (0.490 %) in straw was recorded under $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically at par with $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, it was statistically higher over $N_1$ (One spray nano urea at tillering) and control by means of 4.03 and 6.06 per cent respectively.

##### 4.4.1.2.2 Phosphorus

According to Table 4.9, phosphorus content in straw was determined to be non-significant for the several sources of nitrogen studied under experiment.

##### 4.4.1.2.3 Potassium

Data persuaded in Table 4.9 did not notice any significant variation for potassium content in straw under the various applied sources of nitrogen.

### 4.4.2 N, P and K uptake in grain and straw at harvest

#### 4.4.2.1 Nitrogen uptake

##### 4.4.2.1.1 Grain

It is evident from data (Table 4.10) shows that the maximum uptake of nitrogen (95.38 kg ha$^{-1}$) was obtained with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) that was significantly comparable with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but statistically higher over control by means of 58.17 per cent.

##### 4.4.2.1.2 Straw

It is clear from data (Table 4.10) that the maximum nitrogen uptake (30.73 kg ha$^{-1}$) was observed under $N_5$ (RDN + two spray of nano urea at tillering and jointing) application, such result was statistically at par with $N_4$ (RDN + one spray of nano urea at tillering) and $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) however, superior over control by 58.89 per cent.

#### 4.4.2.1.3 Total

The Table 4.10 clearly shows that the highest total uptake of nitrogen (126.10 kg $ha^{-1}$) was recorded under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) and which was statistically analogous with various treatment *i.e.*, $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + Nano urea at tillering) but higher over control. Application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) observed significantly higher total uptake of nitrogen by 58.33 per cent over control (79.64 kg $ha^{-1}$).

### 4.4.2.2 Phosphorus uptake

#### 4.4.2.2.1 Grain

The maximum phosphorus uptake (22.53 kg $ha^{-1}$) by grain was recorded when crop was treated with $N_5$ (RDN + two spray of nano urea at tillering and jointing) and it was statistically at par with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly greater over remaining sources of nitrogen *i.e.*, $N_1$ (One spray nano urea at tillering), $N_2$ (Two spray nano urea at tillering and jointing) and control with the tune of 33.78, 26.78 and 59.11 per cent (Table 4.10)

#### 4.4.2.2.2 Straw

Data (Table 4.10) shows that the greatest phosphorous content (10.23 kg $ha^{-1}$) was attained with the application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) and it was statistically at par with $N_4$ (RDN + one spray of nano urea at tillering) and $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) but statistically greater over remaining sources nitrogen. The magnitude of increase in phosphorus content with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) was 59.84 per cent over control

**4.4.2.2.3 Total**

The results revealed that the maximum total uptake of phosphorus (32.76 kg ha$^{-1}$) was recorded when crop was treated with $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically proportionate with $N_4$ (RDN + one spray of nano urea at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly higher as compare to other treatment combinations. Application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) increase total phosphorus uptake over control by 59.33 per cent (Table 4.10).

**4.4.2.3 Potassium uptake**

**4.4.2.3.1 Grain**

Table 4.10 illustrates that treatment $N_5$ *i.e.*, RDN + two sprays of nano urea at tillering and jointing) had recorded the highest potassium uptake (18.49 kg ha$^{-1}$) by grain, which was statistically comparable to $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly superior over control with the tune of 58.71 per cent.

**4.4.2.3.2 Straw**

A close examination of data given in Table 4.10 indicates that the maximum potassium uptake (105.21 kg ha$^{-1}$) by straw was found under $N_5$ (RDN + two spray of nano urea at tillering and jointing) that was statistically at par with $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering) and $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) but higher over remaining treatments. The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) represented an increased potassium uptake by 55.31 per cent over control.

**4.4.2.3.3 Total**

The maximum total potassium uptake (123.71 kg ha$^{-1}$) by straw was recorded with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically at par with $N_4$ (RDN + one spray of nano urea at tillering) and $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) but significant superior over remaining nitrogen sources. The magnitude of increase in total potassium uptake with application $N_5$ (RDN + two spray of nano urea at tillering and jointing) was 55.82 per cent over control (Table 4.10).

## 4.4 SOIL STUDIES

### 4.4.1 N, P and K content in soil after harvest

#### 4.4.1.1 N content

Data presented in Table 4.11 did not notice any significant variation for nitrogen content in soil under the various applied sources of nitrogen.

#### 4.4.1.2 P content

There was no significant result was observed in respect to phosphorus content in soil after harvest of the wheat crop (Table 4.11).

#### 4.4.1.3 K content

Table 4.11 represented that non-significant result was observed in regard to potassium content in soil after harvest of wheat crop.

### 4.4.2 Nitrogen use efficiency

It is clear from Table 4.10 that the peak nitrogen use efficiency (15.41 kg $kg^{-1}$) was gained under treatment $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) that was statistically at par with $N_1$ (One spray nano urea at tillering), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering) and $N_6$ (RDN + one spray of urea (5 %) at tillering) but significantly higher over lasting treatments.

## 4.5 ECONOMICS

### 4.5.1 Net return

According to the data (Table 4.12), the highest net return (119937 ₹ $ha^{-1}$) was obtained using $N_5$ (RDN + two sprays of nano urea at tillering and jointing) which was statistically comparable to $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) and higher over rest of the treatments. The increase of net return with application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) was 75.71 per cent over control.

### 4.5.2 B-C ratio

It is clear from data (Table 4.11) that application with $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded the maximum B-C ratio (2.81) which was statistically at par with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, significantly greater over $N_1$ (One spray nano urea at tillering), $N_2$ (Two spray nano urea at tillering and jointing) and control. Data further indicates that the application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) increase in B-C ratio with magnitudes of 67.26 per cent over control.

**Table 4.1 Effect of nitrogen sources on plant population of wheat**

| **Treatments** | **Plant population at 15 DAS (0.5 m row)** |
|---|---|
| $N_1$ | 12.83 |
| $N_2$ | 13.17 |
| $N_3$ | 13.50 |
| $N_4$ | 13.50 |
| $N_5$ | 13.33 |
| $N_6$ | 12.92 |
| $N_7$ | 13.33 |
| $N_8$ | 13.08 |
| $N_9$ | 13.25 |
| **SEm±** | 0.50 |
| **CD (P= 0. 05)** | NS |

**Table 4.2 Effect of nitrogen sources on plant height of wheat**

| Treatments | Plant height (cm) | | | |
|---|---|---|---|---|
| | 50 DAS | 75 DAS | 100 DAS | At harvest |
| $N_1$ | 55.67 | 72.40 | 90.42 | 90.73 |
| $N_2$ | 53.89 | 71.77 | 89.47 | 90.63 |
| $N_3$ | 55.33 | 72.13 | 90.00 | 90.67 |
| $N_4$ | 55.78 | 73.07 | 91.80 | 92.33 |
| $N_5$ | 56.89 | 73.93 | 92.95 | 93.33 |
| $N_6$ | 56.00 | 73.40 | 92.87 | 93.00 |
| $N_7$ | 57.56 | 77.80 | 94.20 | 95.00 |
| $N_8$ | 54.56 | 72.00 | 89.73 | 90.67 |
| $N_9$ | 49.59 | 63.67 | 75.13 | 76.67 |
| **SEm±** | 1.42 | 2.24 | 3.22 | 3.29 |
| **CD (P= 0. 05)** | 4.27 | 6.72 | 9.66 | 9.87 |

**Table 4.3 Effect of nitrogen on dry matter accumulation of wheat**

| Treatments | Dry matter accumulation (g) 0.5 m row length | | | |
|---|---|---|---|---|
| | **50 DAS** | **75 DAS** | **100 DAS** | **At harvest** |
| $N_1$ | 17.00 | 48.67 | 158.00 | 168.50 |
| $N_2$ | 17.33 | 50.33 | 158.67 | 171.17 |
| $N_3$ | 17.67 | 50.33 | 162.00 | 172.33 |
| $N_4$ | 18.33 | 52.83 | 163.33 | 176.50 |
| $N_5$ | 23.00 | 61.15 | 184.67 | 196.53 |
| $N_6$ | 20.17 | 53.00 | 168.67 | 179.33 |
| $N_7$ | 21.33 | 54.17 | 170.33 | 180.67 |
| $N_8$ | 18.17 | 50.83 | 162.67 | 173.33 |
| $N_9$ | 14.83 | 48.00 | 156.33 | 164.00 |
| **SEm±** | 0.90 | 2.38 | 5.24 | 5.35 |
| **CD (P= 0.05)** | 2.68 | 7.12 | 15.72 | 16.05 |

**Table 4.4 Effect of nitrogen sources on number of tillers plant$^{-1}$ and CGR of wheat**

| Treatments | Tillers plant$^{-1}$ | CGR (g m$^{-2}$ day$^{-1}$) | | |
|---|---|---|---|---|
| | | Between 50-75 DAS | Between 75-100 DAS | Between 100 DAS-At harvest |
| $N_1$ | 5.33 | 8.44 | 29.16 | 2.80 |
| $N_2$ | 5.78 | 8.80 | 28.89 | 3.33 |
| $N_3$ | 6.89 | 8.71 | 29.78 | 2.76 |
| $N_4$ | 6.56 | 9.20 | 29.47 | 3.51 |
| $N_5$ | 7.56 | 10.17 | 32.94 | 3.16 |
| $N_6$ | 6.89 | 8.76 | 30.84 | 2.84 |
| $N_7$ | 7.44 | 8.76 | 30.98 | 2.76 |
| $N_8$ | 6.56 | 8.71 | 29.82 | 2.84 |
| $N_9$ | 5.22 | 8.84 | 28.89 | 2.04 |
| **SEm±** | 0.36 | 0.65 | 1.55 | 1.42 |
| **CD (P = 0.05)** | 1.09 | NS | NS | NS |

**Table 4.5 Effect of nitrogen sources on total tillers and RGR of wheat**

| Treatments | RGR (g $g^{-1}$ $day^{-1}$) | | | Total tillers (0.5 m row length) |
|---|---|---|---|---|
| | Between 50-75 DAS | Between 75-100 DAS | Between 100 DAS- At harvest | |
| $N_1$ | 0.0421 | 0.0470 | 0.0026 | 36.17 |
| $N_2$ | 0.0427 | 0.0461 | 0.0030 | 38.00 |
| $N_3$ | 0.0420 | 0.0468 | 0.0025 | 39.50 |
| $N_4$ | 0.0423 | 0.0453 | 0.0031 | 40.33 |
| $N_5$ | 0.0392 | 0.0441 | 0.0025 | 41.50 |
| $N_6$ | 0.0385 | 0.0465 | 0.0024 | 40.83 |
| $N_7$ | 0.0372 | 0.0459 | 0.0024 | 41.00 |
| $N_8$ | 0.0412 | 0.0465 | 0.0025 | 39.67 |
| $N_9$ | 0.0471 | 0.0473 | 0.0019 | 34.00 |
| **SEm±** | 0.0025 | 0.0023 | 0.0012 | 1.07 |
| **CD (P = 0. 05)** | NS | NS | NS | 3.21 |

**Table 4.6 Effect of nitrogen sources on yield attributes of wheat**

| Treatments | Yield attributes | | | |
|---|---|---|---|---|
| | Effective tillers (0.5 m row length) | Grains ear$^{-1}$ | Weight of grain ear$^{-1}$ (g) | Test weight (g) |
| $N_1$ | 33.88 | 38.00 | 1.60 | 38.76 |
| $N_2$ | 35.00 | 40.30 | 1.68 | 39.43 |
| $N_3$ | 35.55 | 40.03 | 2.07 | 45.70 |
| $N_4$ | 37.90 | 42.33 | 2.13 | 48.53 |
| $N_5$ | 39.55 | 42.70 | 2.20 | 49.00 |
| $N_6$ | 36.83 | 41.93 | 2.08 | 48.31 |
| $N_7$ | 37.67 | 42.03 | 2.10 | 48.23 |
| $N_8$ | 36.33 | 41.20 | 2.10 | 47.39 |
| $N_9$ | 31.10 | 34.37 | 2.02 | 42.37 |
| **SEm±** | 1.35 | 0.86 | 0.06 | 0.67 |
| **CD (P = 0.05)** | 4.07 | 2.57 | 0.17 | 2.02 |

**Table 4.7 Effect of nitrogen sources on yield and harvest index of wheat**

| Treatments | Yield (q $ha^{-1}$) | | Harvest Index (%) |
|---|---|---|---|
| | Grain | Straw | |
| $N_1$ | 39.27 | 49.06 | 44.42 |
| $N_2$ | 41.04 | 51.70 | 44.26 |
| $N_3$ | 44.74 | 56.03 | 44.57 |
| $N_4$ | 47.19 | 58.98 | 44.44 |
| $N_5$ | 50.01 | 62.75 | 44.17 |
| $N_6$ | 45.05 | 56.22 | 44.32 |
| $N_7$ | 45.80 | 57.12 | 44.41 |
| $N_8$ | 44.91 | 55.13 | 44.84 |
| $N_9$ | 33.49 | 41.87 | 44.41 |
| **SEm±** | 2.60 | 2.09 | 1.47 |
| **CD (P = 0.0 5)** | 7.80 | 6.27 | NS |

**Table 4.8 Effect of nitrogen sources on quality parameters of wheat**

| Treatments | Quality parameters | | |
|---|---|---|---|
| | Chlorophyll (SPAD) at 60 DAS | Proline (µ mol $g^{-1}$) at 65 DAS | Protein (%) |
| $N_1$ | 39.07 | 0.784 | 11.62 |
| $N_2$ | 39.83 | 0.767 | 11.65 |
| $N_3$ | 40.43 | 0.772 | 11.66 |
| $N_4$ | 41.63 | 0.765 | 11.74 |
| $N_5$ | 42.50 | 0.733 | 11.92 |
| $N_6$ | 42.27 | 0.762 | 11.73 |
| $N_7$ | 39.37 | 0.777 | 11.78 |
| $N_8$ | 40.60 | 0.775 | 11.82 |
| $N_9$ | 35.53 | 0.799 | 11.26 |
| **SEm±** | 1.06 | 0.011 | 0.09 |
| **CD (P = 0.05)** | 3.17 | NS | 0.27 |

**Table 4.9 Effect of nitrogen sources on nutrient content in grain and straw of wheat**

| Treatments | Nutrient content (%) | | | | | |
|---|---|---|---|---|---|---|
| | Grain | | | Straw | | |
| | **N** | **P** | **K** | **N** | **P** | **K** |
| $N_1$ | 1.860 | 0.429 | 0.352 | 0.471 | 0.153 | 1.636 |
| $N_2$ | 1.863 | 0.433 | 0.357 | 0.475 | 0.155 | 1.646 |
| $N_3$ | 1.865 | 0.427 | 0.351 | 0.476 | 0.154 | 1.627 |
| $N_4$ | 1.879 | 0.438 | 0.364 | 0.482 | 0.156 | 1.657 |
| $N_5$ | 1.907 | 0.451 | 0.371 | 0.490 | 0.163 | 1.677 |
| $N_6$ | 1.876 | 0.435 | 0.362 | 0.479 | 0.156 | 1.653 |
| $N_7$ | 1.884 | 0.441 | 0.366 | 0.485 | 0.158 | 1.661 |
| $N_8$ | 1.891 | 0.445 | 0.369 | 0.488 | 0.160 | 1.668 |
| $N_9$ | 1.801 | 0.423 | 0.348 | 0.462 | 0.153 | 1.618 |
| **SEm±** | 0.014 | 0.006 | 0.005 | 0.005 | 0.002 | 0.026 |
| **CD (P = 0.0 5)** | 0.044 | NS | NS | 0.015 | NS | NS |

**Table 4.10 Effect of nitrogen sources on nutrient uptake by grain, straw and total**

| Treatments | Nutrient uptake (kg ha$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen | | | Phosphorus | | | Potassium | | |
| | Grain | Straw | Total | Grain | Straw | Total | Grain | Straw | Total |
| $N_1$ | 73.04 | 23.11 | 96.15 | 16.84 | 7.50 | 24.34 | 13.84 | 80.23 | 94.07 |
| $N_2$ | 76.46 | 24.55 | 101.01 | 17.77 | 8.01 | 25.79 | 14.66 | 85.14 | 99.79 |
| $N_3$ | 83.48 | 26.66 | 110.14 | 19.11 | 8.68 | 27.79 | 15.70 | 91.46 | 107.16 |
| $N_4$ | 88.67 | 28.43 | 117.10 | 20.69 | 9.20 | 29.89 | 17.19 | 97.74 | 114.93 |
| $N_5$ | 95.38 | 30.73 | 126.10 | 22.53 | 10.23 | 32.76 | 18.49 | 105.21 | 123.71 |
| $N_6$ | 84.51 | 26.93 | 111.45 | 19.63 | 8.78 | 28.41 | 16.27 | 92.91 | 109.19 |
| $N_7$ | 86.14 | 27.70 | 113.84 | 20.19 | 9.03 | 29.22 | 16.75 | 94.94 | 111.70 |
| $N_8$ | 84.94 | 26.91 | 111.85 | 20.00 | 8.82 | 28.82 | 16.58 | 91.96 | 108.53 |
| $N_9$ | 60.30 | 19.34 | 79.64 | 14.16 | 6.40 | 20.56 | 11.65 | 67.74 | 79.39 |
| **SEm±** | 4.84 | 1.02 | 5.18 | 1.22 | 0.42 | 1.36 | 0.92 | 4.20 | 4.46 |
| **CD (P = 0.05)** | 14.53 | 3.06 | 15.53 | 3.65 | 1.25 | 4.08 | 2.75 | 12.58 | 13.38 |

**Table 4.11 Effect of nitrogen sources on nutrient content of soil and nitrogen use efficiency**

| Treatments | Nutrient content (kg ha$^{-1}$) | | | Nitrogen use efficiency (kg kg$^{-1}$) |
|---|---|---|---|---|
| | N | P | K | |
| $N_1$ | 275.29 | 21.40 | 351.16 | 10.05 |
| $N_2$ | 277.19 | 21.61 | 353.09 | 6.56 |
| $N_3$ | 279.05 | 21.96 | 359.30 | 14.10 |
| $N_4$ | 281.74 | 21.89 | 361.02 | 9.98 |
| $N_5$ | 285.53 | 22.08 | 364.81 | 8.48 |
| $N_6$ | 283.09 | 22.01 | 359.73 | 14.48 |
| $N_7$ | 284.83 | 22.54 | 363.39 | 15.41 |
| $N_8$ | 283.83 | 22.24 | 362.19 | 8.32 |
| $N_9$ | 265.86 | 21.38 | 347.59 | 0.00 |
| **SEm±** | 4.46 | 0.39 | 6.28 | 2.15 |
| **CD (P = 0.05)** | NS | NS | NS | 6.45 |

**Table 4.12 Effect of nitrogen sources on economics of wheat**

| Treatments | Economics | |
|---|---|---|
| | **Net return (₹ ha$^{-1}$)** | **B-C ratio** |
| $N_1$ | 86423 | 2.10 |
| $N_2$ | 91825 | 2.20 |
| $N_3$ | 103931 | 2.50 |
| $N_4$ | 111226 | 2.64 |
| $N_5$ | 119937 | 2.81 |
| $N_6$ | 104814 | 2.52 |
| $N_7$ | 107222 | 2.58 |
| $N_8$ | 103217 | 2.45 |
| $N_9$ | 68255 | 1.68 |
| **SEm±** | 6939 | 0.16 |
| **CD (P = 0.05)** | 20802 | 0.50 |

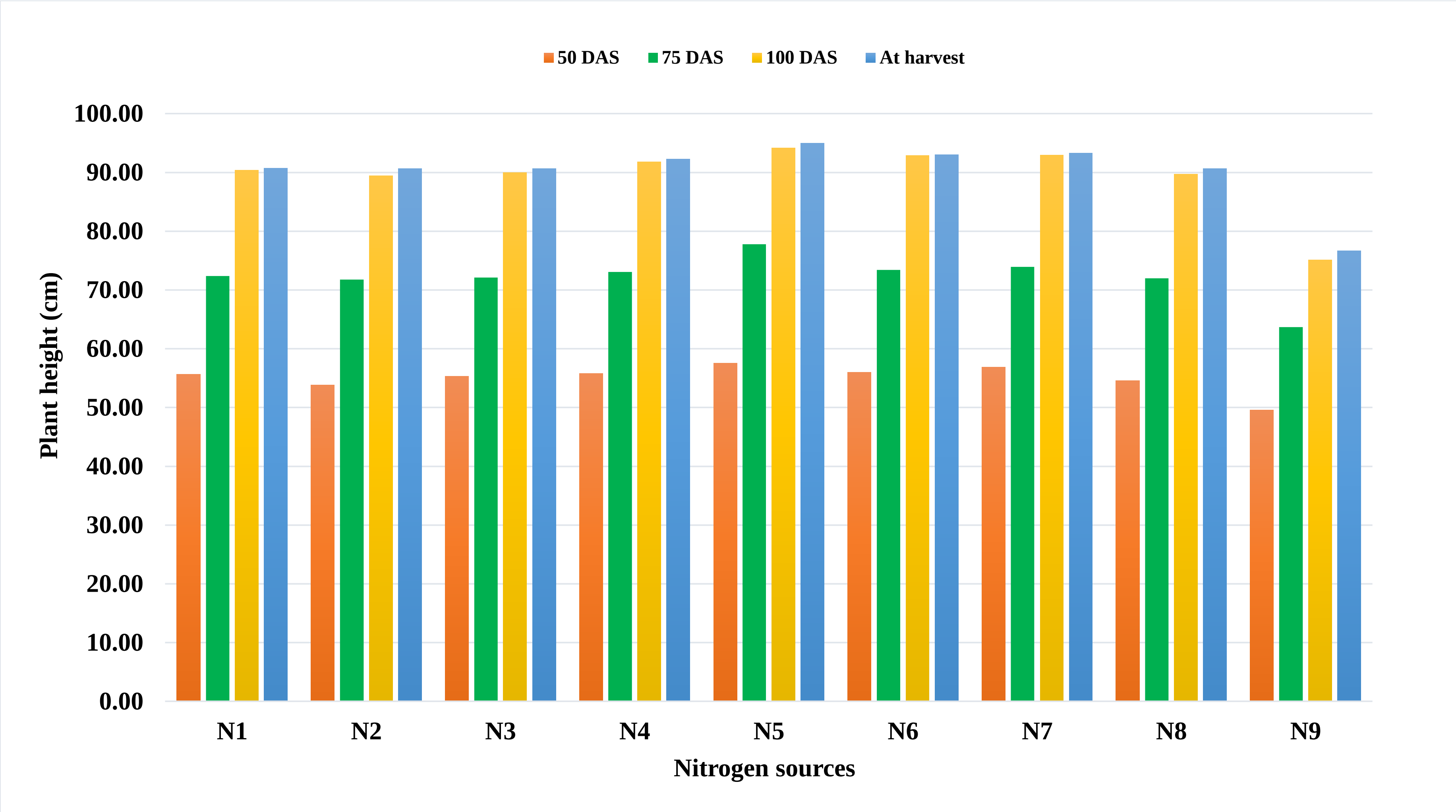



**Figure 4.1 Effect of nitrogen sources on plant height (cm)**

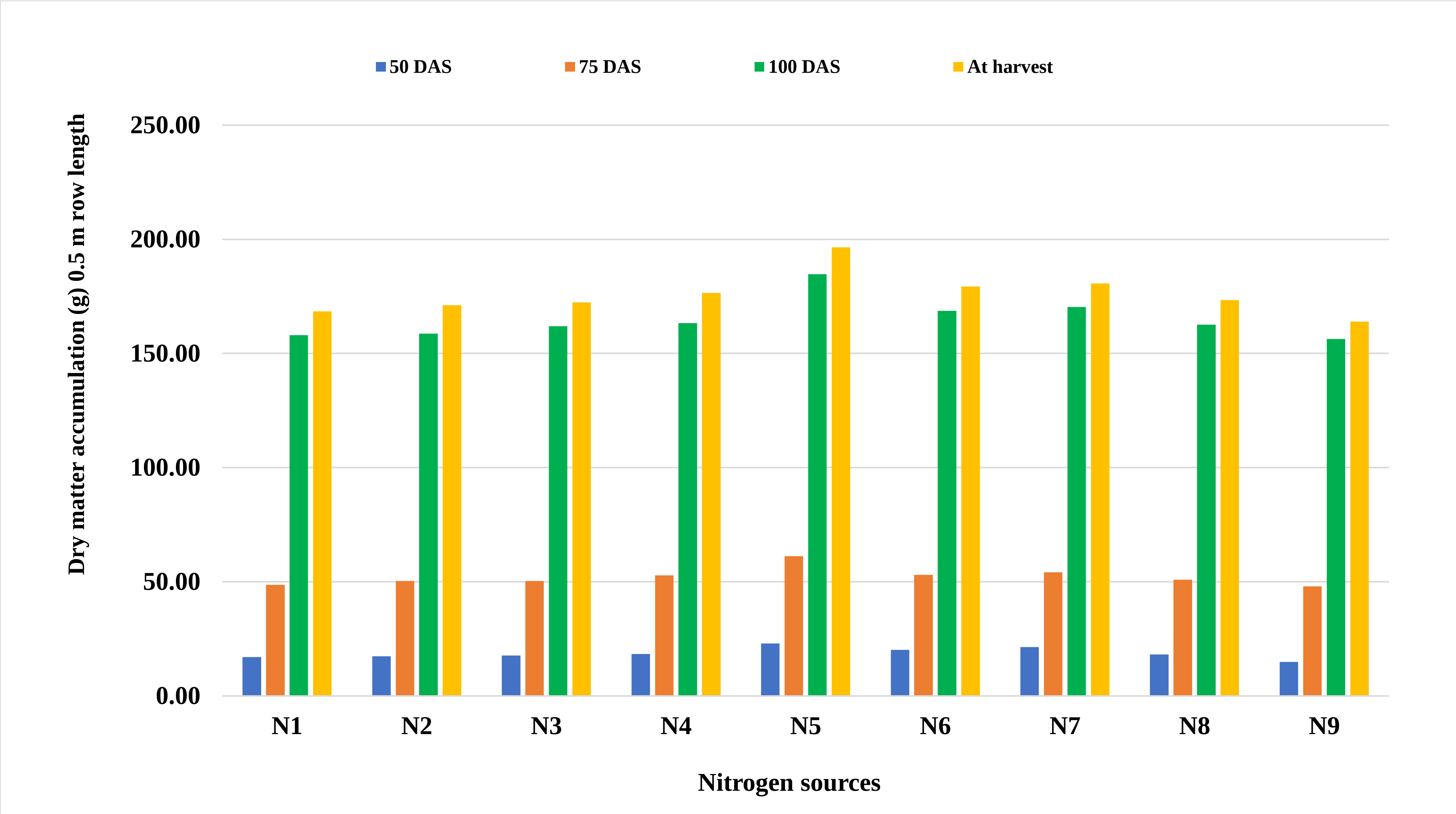



**Figure 4.2 Effect nitrogen sources on dry matter accumulation (g) 0.5 m row length**

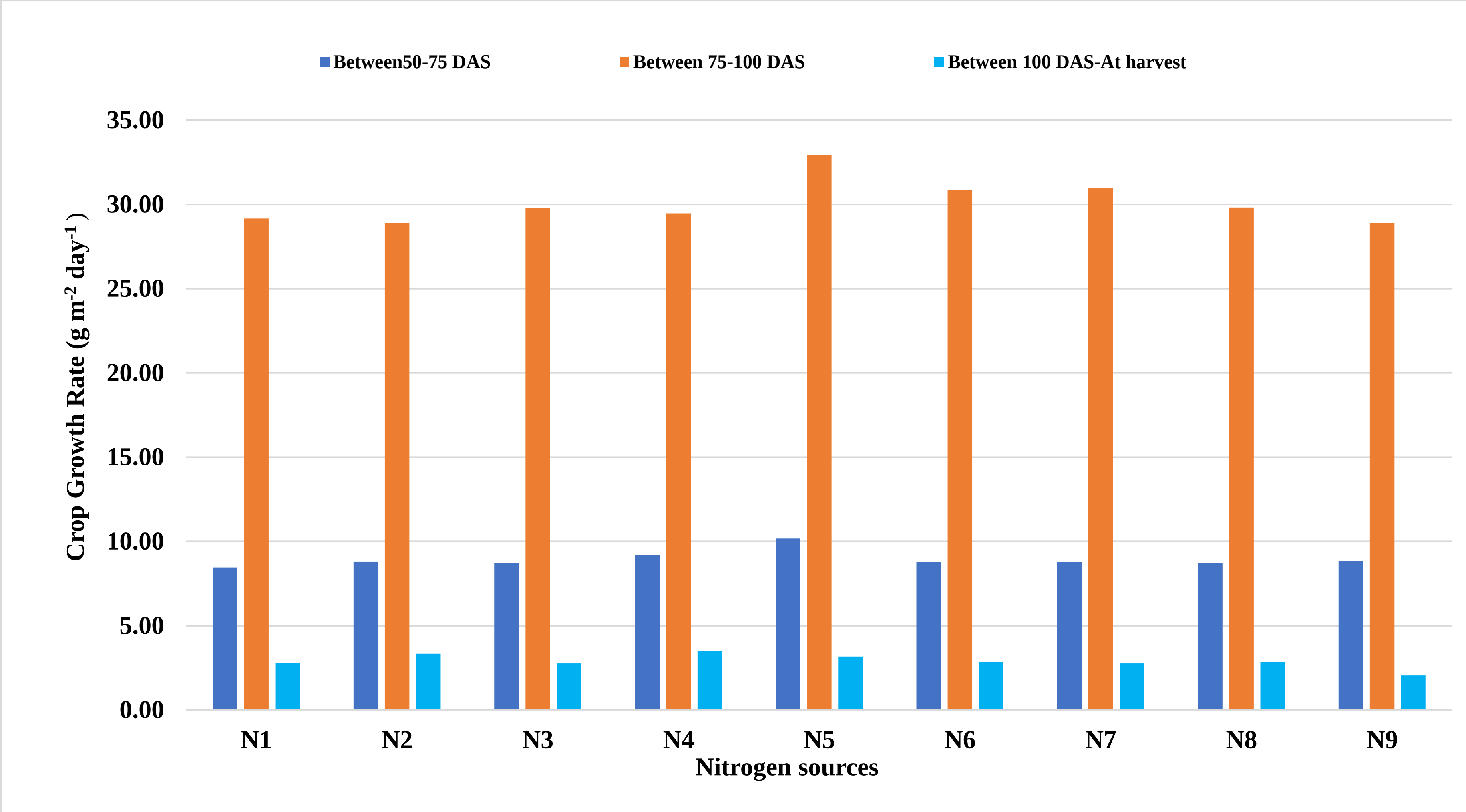



**Figure 4.3 Effect of nitrogen sources on crop growth rate (g $m^{-2}$ $day^{-1}$)**

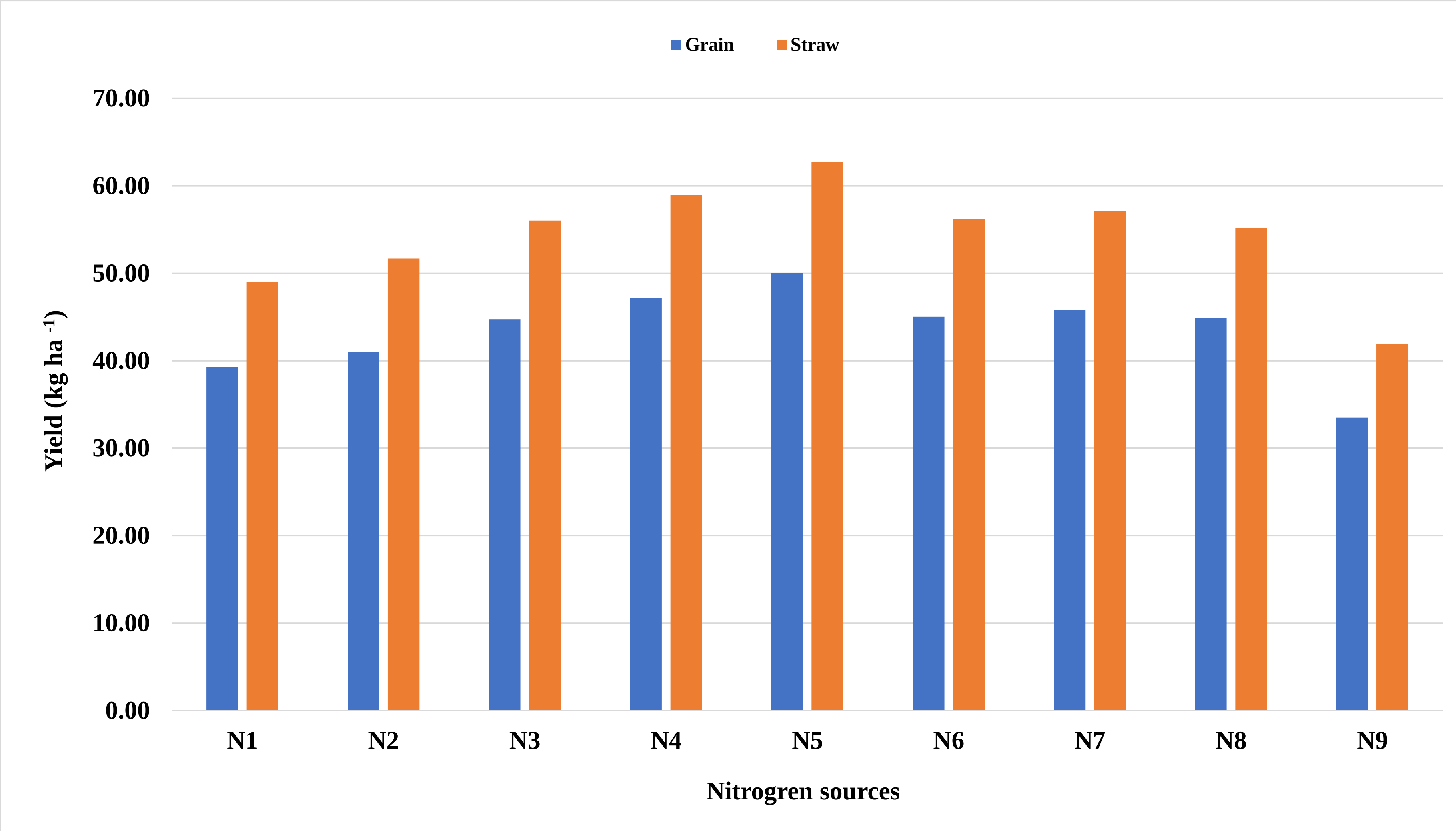



Figure 4.4 Effect of nitrogen sources on yield (kg ha$^{-1}$)

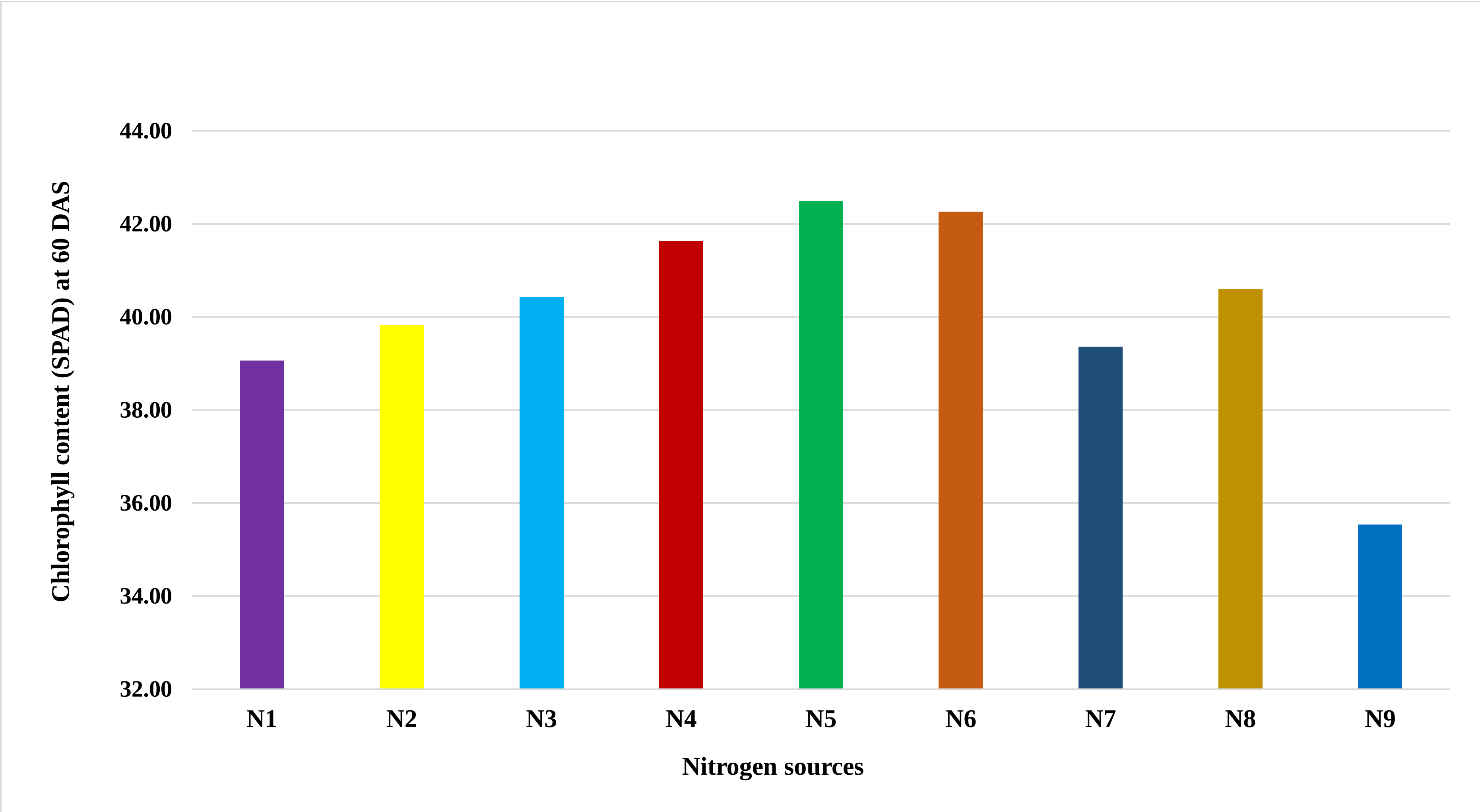



**Figure 4.5 Effect of nitrogen sources on chlorophyll content (SPAD)**

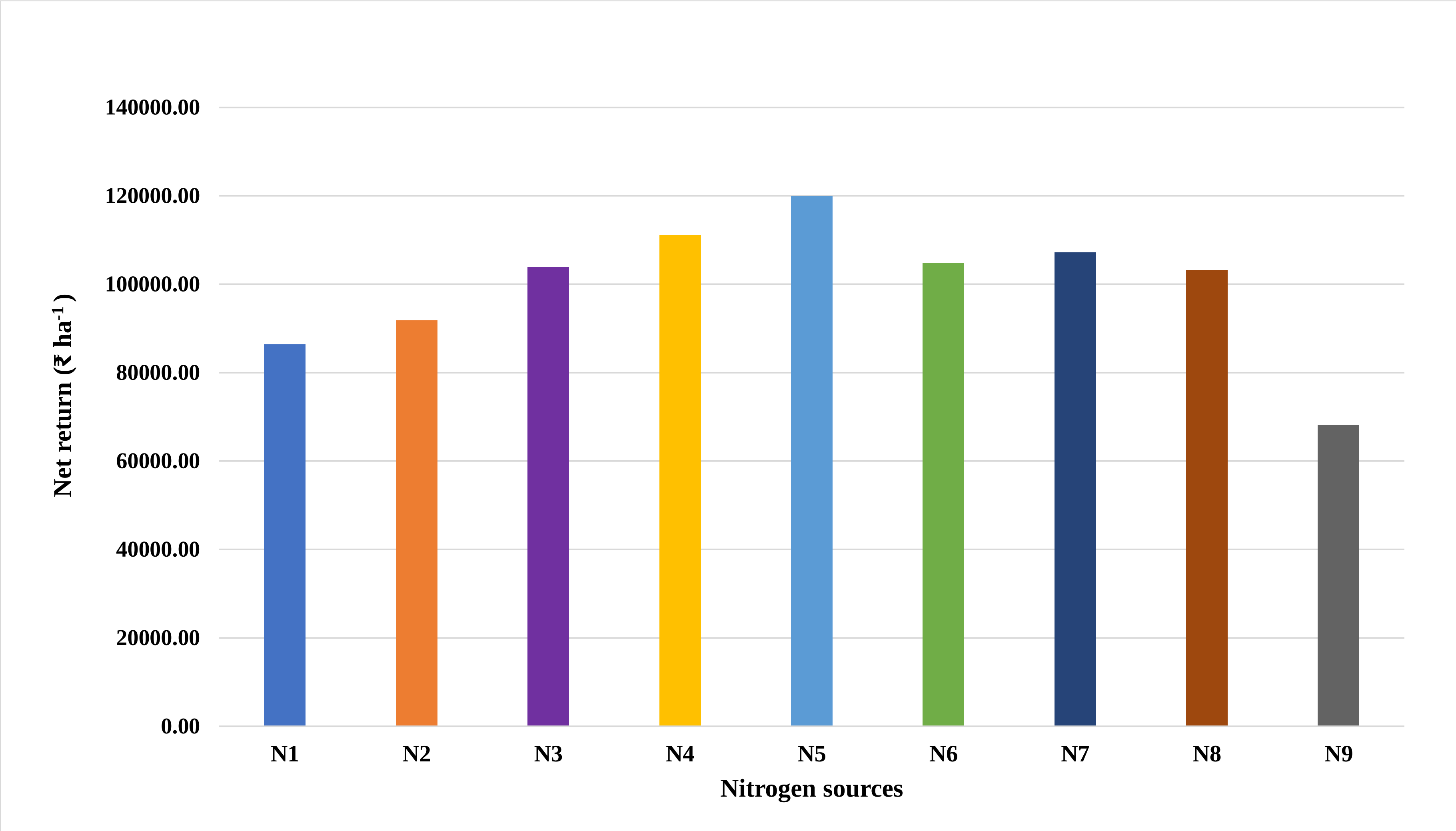



**Figure 4.6 Effect of nitrogen sources on net return (₹ $ha^{-1}$)**

# 5. DISCUSSION

The consequences of the present experimental investigation entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** executed at Instructional Farm Agronomy, Rajasthan College of Agriculture, MPUAT, Udaipur (Rajasthan) during the *rabi* season of 2021-22 have been described in detail in the previous chapter. The most appropriate experimental findings are discussed below along with conceivable explanations and evidences supported by relevant findings where it was deemed important to separate the information into categories of practical values and to evaluate the cause and effect relationship between various treatments with regard to the many researched features.

The yield potentiality of a variety is undoubtedly influenced by the genotype from which it was developed but it can also be influenced by adopting appropriate agronomic practices especially nutrient management taking precedence.

## 5.1 EFFECT OF NITROGEN SOURCES

### 5.1.1 Growth parameters

The statistical analysis of Table 4.2 indicates that the maximal plant height (57.56, 77.80, 94.20 and 95.00 cm) at 50, 75, 100 DAS and at harvest was obtained under the application of treatment $N_5$ (RDN + two sprays of nano urea at tillering and jointing). This behaviour could be explained by the fact that the impact of nano urea on wheat crop growth and development was evident, as shown by the significance of nitrogen in plants as a primary component of amino acids, proteins, vitamins, hormones and enzymes all of which have an immediate effect in promoting cell division and enlargement both longitudinally and transversely and increased meristematic activities leads to an increase in internodal length resulting in an increased plant height. Furthermore, plant height was increased even at lower application rates when nano fertilizer was combined with traditional fertilizers. The findings of experiment corroborate with results of Hanafey *et al*. (2014), Benzon *et al*. (2015), Hamoda *et al*. (2016), Manikandan and Subramanian (2016), Kandil and Eman (2017), Singh *et al*. (2017), Burhan and AL-Hassan (2019), Abd El-Aal and Rania (2018), Mahil and Kumar (2019) and Kumar *et al*. (2020).

It is evident from the data presented in Table 4.4 and 4.5 that the uppermost dry matter accumulation (23.00, 61.15, 184.67 and 196.53 g) at 50, 75, 100 DAS, at harvest and number of tillers attained from RDN + two sprays of nano urea at tillering and jointing ($N_5$) treated wheat plants. This behaviour of rise in dry matter accumulation might be due to that nitrogen is required for chlorophyll synthesis and photosynthetic activity both of which enhance vegetative growth and this enhancement was largely determined by the quantity and efficiency of photosynthetic active radiation intercepted by the crop. Additionally, the application of nano NPK has a significant effect on the growth of wheat crops because the tiny size of nano fertilizers results in better absorption of nano nutrients which affects plant growth mechanisms. It is also perceived that the activity of water was boosted after introducing nanomaterials and N, P and K and these were absorbed into the plants with the absorption of water resulting in an enhanced in dry matter production. In the same way the conceivable reason behind increased number of tillers was that nano fertilizers enhance the activity of chloroplast, antioxidant enzyme system and nitrate reductase which are potential mechanisms that enhanced growth and resulted in a higher number of tillers. The research findings showed a positive and significant relationship between the amount of dry matter accumulated at harvest and wheat crop growth characteristics *i.e.*, plant height at 50 DAS (r = 0.752**), plant height at 75 DAS (r = 0.835**), plant height at 100 DAS (r = 0.679**), plant height at harvest (r = 0.692**), tillers plant-1 (r= 0.836**), total number of tillers (r = 0.801**) and number of effective tillers (r = 0.885**) and test weight (r = 0.680**) (Table 5.1). This is also substantiated through regression studies which revealed that a unit increase in aforementioned characters increased the dry matter accumulation by 3.032, 2.110, 1.118, 1.210, 9.166, 2.992, 3.328 and 1.566 g. Similar findings were recorded by Changmei *et al*. (2002), Hong *et al*. (2005), Moore (2006), Liu *et al*. (2008), Navarro *et al*. (2008), Eichert and Goldbach (2008), Ma *et al*. (2009), Fernandez and Eichert (2009), Nekrasova *et al*. (2011), Junejo *et al*. (2012), Dhoke *et al*. (2013), Mahmoodzadeh *et al*. (2013), Xin *et al*. (2014), Aziz *et al*. (2016), Manikandan and Subramanian (2016), Ali and Al Juthery (2017), Rathnayaka *et al*. (2018), Morsy *et al*. (2018), Asibi *et al*. (2019) and Kumar *et al*. (2020).

### 5.1.2 Yield attributes and yield

Data obtainable in Table 4.6 revealed that application of various sources of nitrogen had significant effect on number of effective tillers of wheat crop. Among the different treatment of nitrogen sources that the determined number of effective tillers was noted under treatment $N_5$ *i.e*., RDN + two sprays of nano urea during tillering and jointing. it may be due that the use of conventional fertilizer in conjunction with nano fertilizer had a substantial impact on the number of effective tillers. The reason behind that nano fertilizer has a harmonious effect on the practicality of conventional fertilizer for enhanced nutrient fascination by plant cells resultant in optimal growth of plant parts and metabolic processes such as photosynthesis which translates to higher photosynthates accumulation and translocation to the economically important plant parts resulting in increased number of reproductive tillers. The correlation studies validate that positive and significant relation between effective tillers and growth and yield parameters such as number of total tillers (r = 0.959**) and crop dry matter accumulation at harvest (r = 0.801**) (Table 5.1). These findings were similar with results of Benzon *et al*. (2015).

As shown in Table 4.6 the maximum number of grains ear$^{-1}$ (42.70) was recorded under application of $N_5$ (RDN + two sprays of nano urea during tillering and jointing). The increase in the number of grains ear$^{-1}$ in nano urea applied treatment may be due to that the nano nitrogen plays a pivotal role in increasing height and leaf area of the plant including obtaining a high carbon representation and transfer its products to the downstream (grain) and the nano fertilizer also cause an increase in biological reactions, enzymatic reactions and the regularity of hormones which has created a new opportunity for plant to accumulate the required dry material for the pollination and fertilization process and it also diminishes the proportion of ovarian abortion and thus increased pollination and fertilization which leads to increase the number of grains ear$^{-1}$. In addition to their nutritional role the readiness of the nitrogen element produces a regulation in the hormones and control the auxin at top of the ear. The cytokinin acts to prevent the transfer of auxin from old to new grain and then increase the grain set in an ear, which is reflected in the increase of the number of grains ear$^{-1}$. These results are in line with Sharifi and Taghizadeh (2009), Grover *et al*. (2012), Moosapoor *et al*. (2013), Hassan *et al*. (2015), Aziz *et al*. (2016), Khospeyak *et al*. (2016) and Rani *et al*. (2019).

Results from Table 4.6 revealed that the maximum weight of grain ear$^{-1}$ and test weight was recorded under the application of RDN + two sprays of nano urea during tillering and jointing ($N_5$). The enhancement in grain weight is directly proportional to plant growth which related genetically to the synthetic and all the factors that affect the growth, where the development and fullness of seeds is an important indicators of plant yield. The probable reason behind an increase in grain weight with the nano fertilizers is that nano fertilizer provides major nutrients in a balanced manner which results an increase in leaf area, sustained vitality in carbon representation and formation of carbohydrates and proteins and thus increased the grain weight. Such types of the beneficial effect of nano fertilizer were observed by Jabouri and Anwar (2008), Benzon *et al*. (2015), Sharifi and Namvar (2016), Hasaneen *et al*. (2016), Kaviani *et al*. (2016) and Rani *et al*. (2019).

The results of Table 4.7 revealed significant differences between the different nitrogen treatments in respect to grain yield. The treatment of $N_5$ (RDN + two sprays of nano urea during tillering and jointing) gave the highest grain yield (50.01 q ha$^{-1}$) and straw yield. As, grain yield was influenced by the genotype, environmental factors and other agronomic practices, including fertilization which depends on the carbon representation rate and the efficiency of transfer its outputs to grain. Increasing the yield of wheat crop with nano fertilizer application might be due to that nanoparticle induced enhancement in photosynthesis and nutrient use efficiency leading to more production of grain yield. Furthermore, nanoparticles may also expand leaf duration, improve leaf area index and slow down leaf senescence all of these increase grain output. Another potential explanation for the higher grain yield is that nano fertilizer increased nutrient uptake by the plant resulting in ideal growth of the plant parts, as well as metabolic processes like photosynthesis which resulted in the maximum accumulation and translocation of photosynthates to the economic parts of the plant ensuring the higher yield that may be related to increased source (leaves) and sink (economic part) strength. Frequent rainfall during the crop growth period provides sufficient moisture and favorable temperature during the crop growth period up to early march might be the potential reason for higher grain yield. Likewise, the increase in straw production with the foliar spray of nano nitrogen fertilizers might be credited to nano fertilizers because of the rapid fascination of nano fertilizers by the plant and ease of translocation which assisted in a quicker rate of photosynthesis and more dry matter accumulation, resulting in a loftier straw yield. It was also noticed that the addition of nano nitrogen increases the absorption area which contributes to increasing the accumulation of dry material in the unit area and improving plant growth in general. The correlation studies stated positive and substantial relation among grain yield and yield components of the wheat crop *viz*. crop dry matter accumulation at 100 DAS (r = 0.774**), dry matter accumulation at harvest (r = 0.839**), plant height at 100 DAS (r = 0.902**), plant height at harvest (r = 0.869**), total number of tillers (r = 0.966**) and number of effective tillers (r = 0.982**), grain $ear^{-1}$ (r = 0.955**), grain weight $ear^{-1}$ (r = 0.572*) and test weight (r = 0.769) (Table 5.1). This is also corroborated through regression studies which shows that a unit increase in the aforementioned characters increased the grain yield by 0.434, 0.439, 1.193, 0.749, 1.890, 1.933, 1.751, 13.392 and 0.926 q $ha^{-1}$. Similar findings were reported by Corredor *et al*. (2009), Ma *et al*. (2009), Sharifi and Taghizaden (2009), Liu *et al*. (2009), Al abode and Hamoud (2010), Valadkhan *et al*. (2015), Razzaq *et al*. (2016), Kandil and Eman (2017), Singh *et al*. (2017), Nadi *et al.* (2013), Tarafdar *et al*. (2014), Benzon *et al*. (2015), Drostkar *et al*. (2016), Gommaa *et al*. (2017), Kandil and Eman (2017), Morsy *et al*. (2018), Rani *et al*. (2019), Al-Juthery *et al.* (2019), Burhan and AL-Hassan (2019), Choudhary *et al*. (2019), Kumar *et al*. (2020), Meena *et al*. (2021), Morsy *et al*. (2021) and Somaratne *et al*. (2021).

### 5.1.3 Quality

Data presented in Table 4.8 shows that the maximum chlorophyll content (42.50 SPAD) was found under the application of $N_5$ (RDN + two sprays of nano urea during tillering and jointing) treatment it may be because of the higher contribution of N content, which might have increased leaf-area duration and thus increased chlorophyll content in wheat. It may also be possible that nitrogen plays a role in many physiological functions of plant growth and development. These functions include the synthesis of chlorophyll and the development of thylakoid and chloroplasts thus leading to higher chlorophyll content. A positive and significant correlation was observed between straw yield and chlorophyll content (r = 0.906**) at 60 DAS. This evidence was supported by the findings of Bayu *et al*. (2005), Saeid and Maryam (2011) and Masoud *et al*. (2012).

The data presented in Table 4.8 reveals that the different treatments of nano and chemical nitrogen fertilizer had significant effect on protein content (%) of wheat crop.

The significantly highest protein content (11.92 %) was observed with the application of $N_5$ (RDN + two sprays of nano urea during tillering and jointing) treatment. The logical explanation for this phenomenon is that nano fertilizer increases the crop plant's surface area and nutrient availability, both of which contribute to the rise of plant quality metrics (such as protein and sugar content) by quickening the rate of response or synthesis processes. It might be also possible that the control and steady release property of nano fertilizer balance the increased nitrogen content and uptake by plant which resulted in improved protein content in plants. The correlation studies expressed positive and substantial relationship between protein content and nitrogen content in grain of wheat crop. The positive correlation observed between protein content in grain and nitrogen (r = 1.000**) content in grain. This result of increment in protein percentage was in accordance with the finding of Masoud *et al.* (2012), Amirnia *et al.* (2014), Celsia and Mala (2014), Havlin *et al.* (2014), Dimkpa *et al.* (2015), Hasaneen *et al.* (2016), Khanday *et al.* (2017), Morsy *et al.* (2018), Qureshi *et al.* (2018), Mahil and Kumar (2019), Burhan and AL-Hassan (2019), Hasan and Saad (2020).

### 5.1.4 Nutrient Content and Uptake and NUE

As shown in Table 4.9 the nano-fertilizer treatment in combination with RDN has significant effect on grain and straw nitrogen content. In present study, the maximum nitrogen content in grain (1.907 %) and straw (0.49 %) was perceived under treatment $N_5$ (RDN + two sprays of nano urea during tillering and jointing). This may be because of nano fertilizers have larger surface area and particle size less than the pore size (5 to 50 nm) of leaves of the plant which can enhance penetration into the plant tissues from applied surface and augment content and uptake of the nutrients. The optimistic and weighty correlation observed between grain yield and nitrogen (r = 0.937**), phosphorous (r = 0.808**) and potassium (r = 0.815**) content in grain, similarly between straw yield and nitrogen (r = 0.902**), phosphorous (r = 0.744**) and potassium (r = 0.799**) content in straw and also in case of test weight positive and significant relation with nitrogen (r =0.856**) content in grain. The results are agreed with results of Junrungrean *et al.* (2002), Aljabri *et al.* (2010) and Junejo *et al.* (2012).

Data from Table 4.10 indicates that significant rise shown in nitrogen uptake in grain (99.88 kg $ha^{-1}$) and straw (30.73 kg $ha^{-1}$) of wheat with the application of $N_5$ treatment *i.e.*, RDN + two sprays of nano urea during tillering and jointing. This may be due to fertilizer particles coated with nano membranes facilitate slow and steady release of nutrients. Coating and cementing of nano and sub nano-composites are capable of regulating the release of nutrients from the fertilizer capsule and nano particles having both positive and negative charged binding site that adsorbed available nitrogen in soil to minimize different type losses resulted in increased uptake of nitrogen by crop. Similarly, significant increase in phosphorus and potassium uptake in wheat grain (22.53 and 10.23 kg $ha^{-1}$, respectively) and straw (18.49 and 105.21 kg $ha^{-1}$, respectively) was also recorded under $N_5$ treatment (RDN + two sprays of nano urea during tillering and jointing). This could be because nanoparticles triggering metabolic activities in plants resulting in increased exudation and acidity. Subsequently, desorption of $PO_4^{3-}$ may occurs as a result of a ligand exchange reaction triggered by plant root exudation, potentially disrupting the adsorption-desorption equilibrium and releasing phosphorus into the soil solution where it is easily available for uptake. While, the better uptake of potassium from nano fertilizer than conventional fertilizer may be due to the application of nano fertilizer may expose the plant nutrient (NPK) to more surface area that can augment the fixation of plant nutrient of nanoparticle which leads to minimize the losses and it will release on later stage of crop growth when plant need it. The positive correlation observed between grain yield and nitrogen (r =0.999**), phosphorous (r = 0.994**) and potassium (r =0.995**) uptake by grain, likewise positive and substantial correlation observed between straw yield and nitrogen (r =0.997**), phosphorous (r = 0.992**) and potassium (r =0.998**) uptake by straw. These results are in conformity with Buerkert *et al*. (1998), Kumar *et al*. (2014), Dimkpa *et al*. (2015), Guru *et al*. (2015), Hussien *et al*. (2015), Kaviani *et al*. (2016), Soliman *et al*. (2016), Singh *et al*. (2017), Shrivastava *et al*. (2017), Togas *et al*. (2017), Al Juthery *et al*. (2018), Dhasil *et al*. (2018) and Qureshi *et al*. (2018).

Data (Table 4.11) the peak nitrogen use efficiency was observed under treatment $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing). This might be due to that the amount of nitrogen applied in $N_7$ treatment is lower as compared other treatments that results in higher nitrogen utilization and reduces the risks of nitrogen losses *i.e*., leaching, denitrification and volatilization. It is also noticed that addition of phosphorus and potassium on top of nitrogen fertilizer played important role in improving nitrogen use efficiency (NUE). The correlation studies show positive and substantial interrelationship between NUE (r =0.644*) and grain yield of wheat This result is in mark with results of Fofana *et al*. (2005) and Duan *et al*. (2014).

### 5.1.5 Economics

Among the several applied treatments under experiment application of treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) attained the highest net return and benefit- cost ratio among which was statistically comparable with various treatments *i.e.*, $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) whereas, the lowermost net returns and B-C ratio were recorded under absolute control ($N_9$).

Nano fertilizers may boost crop development and yield characteristics as well as make active photosynthetic activities and source-sink relationships which directly affect yield. Reduced urea treatment and efficient foliar nano fertilizer application led to lower cultivation costs, which in turn increased grain and straw yield and ultimately net return. These results were consistent with the results of Mehta and Bharat (2017), Manikandan and Subramanian (2016) and Kumar *et al*. (2020).

**Table 5.1 Correlation coefficient and regression equation showing relationship between (X) and (Y) variable of nitrogen sources**

| S.No. | Dependent variable (Y) | Independent variable (X) | Correlation coefficient (r) | Regression equation (Y = a+ b x) |
|---|---|---|---|---|
| 1 | Effective tillers | Total tillers | 0.959** | Y= -1.178+0.952 |
| 2 | Crop DMA at Harvest (g) | Plant height (cm) at 50 DAS | 0.752** | Y= 8.961+3.032 |
| 3 | Crop DMA at Harvest (g) | Plant height (cm) at 75 DAS | 0.835** | Y= 23.373+2.110 |
| 4 | Crop DMA at Harvest (g) | Plant height (cm) at 100 DAS | 0.679* | Y= 75.654+1.118 |
| 5 | Crop DMA at Harvest (g) | Plant height at harvest (cm) | 0.692* | Y= 66.551+1.210 |
| 6 | Crop DMA at Harvest (g) | Total tillers plant$^{-1}$ at harvest | 0.836** | Y= 116.521+9.166 |
| 7 | Crop DMA at Harvest (g) | Total number of tillers at harvest | 0.801** | Y= 59.143+2.992 |
| 8 | Crop DMA at Harvest (g) | Number of effective tillers | 0.885** | Y= 56.059+3.328 |
| 9 | Crop DMA at Harvest (g) | Test weight | 0.680* | Y= 104.892+1.566 |
| 10 | Grain yield (kg ha$^{-1}$) | Crop DMA at 100 DAS | 0.774** | Y= -28.103+0.434 |
| 11 | Grain yield (kg ha$^{-1}$) | Crop DMA at harvest | 0.839** | Y= -33.736+0.439 |
| 12 | Grain yield (kg ha$^{-1}$) | Plant height (cm) at 100 DAS | 0.902** | Y= -42.686+1.193 |
| 13 | Grain yield (kg ha$^{-1}$) | Plant height at harvest (cm) | 0.869** | Y= -23.606+0.749 |
| 14 | Grain yield (kg ha$^{-1}$) | Total number of tillers at harvest | 0.966** | Y= -30.207+1.890 |
| 15 | Grain yield (kg ha$^{-1}$) | Number of effective tillers | 0.982** | Y= -26.048+1.933 |
| 16 | Grain yield (kg ha$^{-1}$) | Grains ear$^{-1}$ | 0.955** | Y= -27.117+1.751 |
| 17 | Grain yield (kg ha$^{-1}$) | Grain weight ear$^{-1}$ | 0.572* | Y= 16.741+13.392 |
| 18 | Grain yield (kg ha$^{-1}$) | Test weight | 0.769** | Y= 1.548+0.926 |
| 19 | Grain yield (kg ha$^{-1}$) | N (%) in grain | 0.937** | Y= -246.35+155.04 |

| S.No. | Dependent variable (Y) | Independent variable (X) | Correlation coefficient (r) | Regression equation (Y = a+ b x) |
|---|---|---|---|---|
| 20 | Grain yield (kg $ha^{-1}$) | P (%) in grain | 0.808** | Y= -148.598+440.820 |
| 21 | Grain yield (kg $ha^{-1}$) | K (%) in grain | 0.815** | Y= -128.850+478.752 |
| 22 | Grain yield (kg $ha^{-1}$) | N uptake (kg $ha^{-1}$) by grain | 0.999** | Y= 4.578+0.478 |
| 23 | Grain yield (kg $ha^{-1}$) | P uptake (kg $ha^{-1}$) by grain | 0.994** | Y= 5.664+1.992 |
| 24 | Grain yield (kg $ha^{-1}$) | K uptake (kg $ha^{-1}$) by grain | 0.995** | Y= 5.624+1.377 |
| 25 | Straw yield (kg $ha^{-1}$) | Plant height (cm) at harvest | 0.882** | Y= -36.464+1.005 |
| 26 | Straw yield (kg $ha^{-1}$) | Crop DMA at 75 DAS | 0.817** | Y= -11.679+1.266 |
| 27 | Straw yield (kg $ha^{-1}$) | Crop DMA at 100 DAS | 0.784** | Y= -36.032+0.548 |
| 28 | Straw yield (kg $ha^{-1}$) | Crop DMA at harvest | 0.850** | Y= -43.291+0.555 |
| 29 | Straw yield (kg $ha^{-1}$) | Total number of tillers at harvest | 0.962** | Y= -37.163+2.346 |
| 30 | Straw yield (kg $ha^{-1}$) | Chlorophyll content at 60 DAS | 0.906** | Y= -50.752+2.618 |
| 31 | Straw yield (kg $ha^{-1}$) | N (%) in straw | 0.902** | Y= -243.524+622.275 |
| 32 | Straw yield (kg $ha^{-1}$) | P (%) in straw | 0.744** | Y= -158.831+1362.158 |
| 33 | Straw yield (kg $ha^{-1}$) | K (%) in straw | 0.799** | Y= -361.629+252.207 |
| 34 | Straw yield (kg $ha^{-1}$) | N uptake (kg $ha^{-1}$) by straw | 0.997** | Y= 6.562+1.834 |
| 35 | Straw yield (kg $ha^{-1}$) | P uptake (kg $ha^{-1}$) by straw | 0.992** | Y= 7.238+5.527 |
| 36 | Straw yield (kg $ha^{-1}$) | K uptake (kg $ha^{-1}$) by straw | 0.998** | Y= 4.049+0.560 |
| 37 | Protein content (%) in grain | Nitrogen content in grain (%) | 1.000** | Y= 0.000+6.250 |
| 38 | Nitrogen use efficiency (kg $kg^{-1}$) | Grain yield (kg $ha^{-1}$) | 0.644* | Y= 3708.7+ 66.07 |

* and ** Significant at 5 and 1% level of significance, respectively

# 6. SUMMARY

This section summarises the findings of a field experiment named **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** done during the *rabi* 2021-22 at the Instructional Agronomy Farm, Rajasthan College of Agriculture, MPUAT, Udaipur.

## 6.1 EFFECT OF NITROGEN SOURCES

- Non-significant result was found in respect of plant population at 15 DAS under various sources of nitrogen used under the study.
- The maximum plant height at 50, 75, 100 DAS and at harvest was recorded under treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically at par with $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing).
- The highest dry matter accumulation at 50, 75, 100 DAS and at harvest was recorded under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) and it was statistically at par with $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) but higher over remaining treatments.
- The determined number of tillers plant$^{-1}$ was obtained with application of treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically at par with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but superior over rest of the treatments.
- Crop growth rate between 50 to 75 DAS, 75 to 100 DAS and between 100 DAS to at harvest found non stimulus by application of different nitrogen sources.
- The application of various nitrogen sources did not cause any weighty impact on relative growth rate between 50 to 75 DAS, 75 to 100 DAS and 100 DAS to at harvest.
- Application of treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) had recorded the maximum number of tillers at 0.5 m row length

(41.50) that was found statistically comparable with several treatment combinations *i.e.*, $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but superior over other nitrogen sources.

- The application of various sources of nitrogen significantly influences yield attributing traits *viz*, effective tillers, grains ear$^{-1}$, weight of grains ear$^{-1}$ and test weight. The maximum value of yield attributing characters had recorded under application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) which was statistically at par with $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, effective tillers and weight of grains ear$^{-1}$ was found at par with one extra treatment *i.e.*, $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI) but statistically higher over remaining treatments.

- The significantly higher values of grain and straw yield (50.01 and 62.75 q ha$^{-1}$) was recorded under treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing). Here, the grain yield was found statistically comparable with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5%) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but straw yield was found statistically at par with $N_4$ (RDN + one spray of nano urea at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering). In case of harvest index, it was found non-significant in respect to various applied treatment of nitrogen under experiment.

- The maximum total chlorophyll content at 60 DAS was found with $N_5$ (RDN + two spray of nano urea at tillering and jointing) and this was statistically at par with $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but significantly higher over rest of the treatments.

- Various sources of nitrogen used under study did not cause any significant variation on proline content at 65 DAS of wheat crop.

- The application of treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded the maximum values of protein content which was statistically at par with several treatments *i.e.*, $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) but higher over other treatments.

- Treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded maximum nitrogen content in grain and straw of wheat, which was statistically comparable with $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering). While, phosphorous and potassium content in grain and straw was found non-significant.

- The maximum nitrogen, phosphorous and potassium uptake by grain, straw and total was recorded under $N_5$ (RDN + two spray of nano urea at tillering and jointing). The N, P and K uptake by grain was statistically at par with $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, N and P uptake by grain were also analogous to treatment $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI). While, in case of straw N, P and K uptake by straw was at par with $N_4$ (RDN + one spray of nano urea at tillering) and $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) however, P uptake by straw was also analogous to treatment $N_6$ (RDN + one spray of urea (5 %) at tillering). Similarly, total uptake of N, P and K were comparable with $N_4$ (RDN + one spray of nano urea at tillering) and $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) however, total N and P uptake were also analogous treatment $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering).

- Non-significant results were found in respect to nitrogen, phosphorus and potassium content in soil after harvest of crop under several sources of nitrogen used under experiment. While, the peak nitrogen use efficiency was accomplished under treatment $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) which was comparable to $N_1$ (One spray nano urea at tillering), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering) and $N_6$ (RDN + one spray of urea (5 %) at tillering).
- When wheat crop was treated with treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) recorded the maximum net return (₹ 119937 ha$^{-1}$) and B-C ratio (2.81) which was statistically at par with $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea at tillering), $N_6$ (RDN + one spray of urea (5 %) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing) and $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) however, significantly greater over $N_1$ (One spray nano urea at tillering), $N_2$ (Two spray nano urea at tillering and jointing) and control.

# 7. CONCLUSION

On the basis of one year experimentation results during rabi 2021-22, it is concluded that under restricted irrigation wheat crop should be fertilized with recommended dose of nitrogen *i.e.*, 80 kg $ha^{-1}$ along with two foliar sprays of nano urea at tillering and jointing stage to achieve higher nitrogen use efficiency and productivity in prevailing agro climatic conditions of zone IV a (Sub-Humid Southern Plain and Aravalli Hills) of Rajasthan.

# LITERATURE CITED


Abd El-Aal, M.M. and Rania S.M.E. 2018. Effect of foliar spray with lithovit and amino acids on growth, bio constituents, anatomical and yield features of soybean plant. 4th International Conference on Biotechnology Applications in Agriculture (ICBAA), Benha University, Moshtohor and Hurghada, 4-7 April 2018, Egypt.

Adhikari, T., Kundu, S., Biswas, A.K., Tarafdar, J.C. and Subba Rao, A. 2015. Characterization of zinc oxide nano particles and their effect on growth of maize (*Zea mays* L.) plant. *Journal of Plant Nutrition* **38**:1505-1515.

Al abode and Hammoud, J.A. 2010. The performance of the yellow maize in mutual irrigation and the depth of agriculture. Master Thesis. Department of Field Crops Faculty of Agriculture - University of Baghdad.

Ali, N.S. and Al-Juthery, H.W.A. 2017. The application of nanotechnology for micronutrient in agricultural production. *The Iraqi Journal of Agricultural Sciences* **9**(48): 489-441.

Aljabri, M. 2010. Nano technology of zeolite mineral for slow-release nitrogen of urea fertilizer on vertisols paddy soil. Proceeding of the International Conference on Materials Science and Technology (Indonesia). pp -205-210.

Al-Juthery, H.W.A., Habeeb K.H., Altaee F.J.K., AL-Taey K.A. and Al-Tawaha, A.R.M. 2018. Effect of foliar application of different sources of nano fertilizers on growth and yield of wheat. *Bioscience Research* **15**(4):3988-3997.

Al-Juthery, H.W.A., Hardan, H M., Al-Swedi, F G. A., Obaid, M. H. and Al-Shami, Q. M. N. 2019. Effect of foliar nutrition of nano fertilizers and amino acids on growth and yield of wheat. *Earth and Environmental Science* **388**(1):1755-1315.

Al-Juthery, H.W.A., Hassan A.H., Kareem F.K., Musa, R.F. and Khaeim H.M. 2019. The response of wheat to foliar application of nano-micro nutrients. *Plant Archives* **19**(2): 827- 831.

Amirnia, R., Bayat, M. and Tajbakhsh, M. 2014. Effects of nano fertilizer application and maternal corm weight on flowering of some saffron (*Crocus sativus* L.) ecotypes. *Turkish Journal of Field Crops* **19**(2): 158-168.

Armin, M., Akbari, S. and Mashhadi, S. 2014. Effect of time and concentration of nano Fe foliar application on yield and yield components of wheat. *International Journal of Biosciences* **4**(9):69-75.

Asibi, A.E., Chai, Q. and Coulter, J.A. 2019. Mechanisms of nitrogen use in maize. *Agronomy* **9**(775): 1-16.

Astaneh N., Bazrafshan F., Zare M., Amiri B. and Bahrini A. 2018. Effect of nano chelated nitrogen and urea fertilizers on wheat plant under drought stress condition. *Nativa Sinop* **6**(6):587-593.

Aziz, H.M.A., Hasaneen, M.N. and Omer, A.M. 2016. Nano chitosan-NPK fertilizer enhances the growth and productivity of wheat plants grown in sandy soil. *Spanish Journal of Agricultural Research* **14**(1): 17.

Bates, L.S., Waldren, R.P. and Teare, I.D. 1973. Rapid determination of free proline for water stress studies. *Plant and Soil* **39** (1): 205-207.

Bayu, W. G., Rethman, P. S., Hammes and Alemu, G. 2005. Effects of farmyard manure and inorganic fertilizer on sorghum growth, yield and nitrogen use in a semi-arid area of Ethiopia. *Journal of Plant Nutrition* **29**(2): 391-407.

Benzon, L.H.R., Rubenecia, M.R.U., Ultra, V.U. and Lee. 2015. Nano fertilizer affects the growth, development, and chemical properties of rice. *International Journal of Agronomy and Agricultural Research* **7**(1):105-117.

Black, C.A. 1965. Method of soil analysis, Part II, *American Society of Agronomy*, Madison, Wisconsin, United States of America.

Bondada, B.R., Syvertsen, J.P. and Albrigo, L.G. 2001. Urea nitrogen uptake by citrus leaves. *Horticulture Science* **36**(6):1061–1065.

Brady, N.C. 1983. The nature and properties of soils. Macmillan publishing company, New York and Collier Macmillan Publisher, London, pp-750.

Buerkert, A., Haake, C., Ruckwied, M. and Marschner, H. 1998. Phosphorus application affects the nutritional quality of millet grain in the Sahel. *Field Crops Research* **57**: 223-235.

Burhan, M.G. and AL-Hassan, S.A. 2019. Impact of nano NPK fertilizers to correlation between productivity, quality and flag leaf of some bread wheat varieties. *Iraqi Journal of Agricultural Sciences* **1029**(50): 1-7.

Celsia, A.S.R. and Mala, R. 2014. Fabrication of nano structured slow-release fertilizer system and its influence on germination and biochemical characteristics of *Vigna raidata*. *International Journal of Chem Tech Research* **6**(10): 4497-4503.

Changmei, L., Chaoying, Z., Junqiang, W., Guorong, W. and Mingxuan, T. 2002. Research of the effect of nanometre materials on germination and growth enhancement of *Glycine max* and its mechanism. *Soybean Science* **21**(3): 168-171.

Choudhary, R.C., Kumaraswamy, R.V., Kumari, S., Sharma, S.S., Pal, A., Raliya, R., Biswas, P and Saharan, V. 2019. Zinc encapsulated chitosan nanoparticle to promote maize crop yield. *International Journal of Biological Macromolecules* **127**: 126-135.

Corredor, E., Testillano, P.S., Coronado, M.J., González-Melendi, P., Fernández-Pacheco, R., Marquina, C., Ibarra, M.R., de la Fuente, J.M., Rubiales, D., Pérez-de-Luque, A., Risueño, M.C. 2009. Nanoparticle penetration and transport in living pumpkin plants: in situ subcellular identification. *BMC Plant Biology* **9**: 1-11.

Dhansil, A., Zalawadia, N.M., Prajapat, B.S. and Yadav, K. 2018. Effect of nano phosphatic fertilizer on nutrient content and uptake by pearl millet (*Pennisetum glaucum* L.) crop. *International Journal of Current Microbiology and Applied Science* **7**(12): 2327-2337.

Dhoke, S.K., Mahajan, P., Kamble, R. and Khanna, A. 2013. Effect of nanoparticles suspension on the growth of mung (*Vigna radiata*) seedlings by foliar spray method. *Nanotechnology Development* **3**:1-5.

Dimkpa, C.O., McLean, J.E., Britt, D.W. and Anderson, A.J. 2015. Nano-Cu and interaction with nano-ZnO or soil bacterium provide evidence for the interference of nanoparticles in metal nutrition of plants. *Ecotoxicology* **24**: 119-129.

Donald, C.M. and Hamblin, J. 1976. The biological yield and harvest index of cereals as agronomist and plant breeding criteria. *Advances in Agronomy* **28**: 361-404.

Drostkar, E., Talebi, R. and Kanouni, H. 2016. Foliar application of Fe, Zn and NPK nano fertilizers on seed yield and morphological traits in chickpea under rainfed condition. *Journal of Research in Ecology* **4**(2): 221-228.

Duan Y.H., Shi X.J., Li S.L., Sun X.F. and He X.H. 2014. Nitrogen use efficiency as affected by phosphorus and potassium in long term rice and wheat experiments. *Journal of Integrative Agriculture* **13**(3): 588-596.

Eichert, T. and Goldbach, H. E. 2008. Equivalent pore radii of hydrophilic foliar uptake routes in stomatous and astomatous leaf surfaces, further evidence for a stomatal pathway. *Physiologia Plantarum* **132**: 491-502.

Fan, L., Wang, W., Shao, X., Geng, Y., Wang, Z., Ma, Y and Liu, J. 2012. Effects of combined nitrogen fertilizer and nano-carbon application on yield and nitrogen use of rice grown on saline-alkali soil. *Journal of Food, Agricultural and Environment* **10**(1):558-562.

FAO. 2019. *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction.* Rome. (Website: https://doi.org/10.4060/CA6030EN retrieved on dated 09-09-202).

Fernández, V. and Eichert, T. 2009. Uptake of hydrophilic solutes through plant leaves: current state of knowledge and perspectives of foliar fertilization. *Critical Reviews in Plant Sciences* **28**: 36-68.

Fofana B., Tamelokpo A., Wopereis M.C.S., Breman H., Dzotsi K. and Carsky R.J. 2005. Nitrogen use efficiency by maize as affected by a mucuna short fallow and P application in the coastal savanna of West Africa. *Nutrient Cycling in Agroecosystems* **71**: 227-237.

Ghafari, H. and Razmjoo, J. 2013. Effect of foliar application of nano iron oxidase, iron chelate and iron sulphate rates on yield and quality of wheat. *International Journal of Agronomy and Plant Production* **4**(11): 2997-3003.

Ghasemi, M., Ghorban, Noormohammadi, Madani, H., Mobasser, H. R. and Nouri, M. Z. 2014. Effect of foliar application of zinc nano oxide on agronomic traits of two varieties of rice (*Oryza sativa* L.). *Crop Research* **52** (6):195-201.

Gommaa, M.A., Radwan, F.L., Kandil, E.E. and AL-Challabi, D.H.H. 2017. Comparison of some new maize hybrids response to mineral fertilization and some nano fertilizers. *Elexandria Science Exchange Journal* **38**(3): 506-514.

Government of Rajasthan, Department of Agriculture. 2021. Statement showing area sown during *rabi* season, crop wise sowing area 2020-2021 (Website: rajasthan.gov.in retrieved on dated 09-09-2021).

Grover, M., Singh, S. and Teswarlu, B. 2012. Nano technology: scope and limitations in agriculture. *International Journal Nanotechnology Application* **2**(1): 10-38.

Guru, T., Veronica, N., Thatikunta, N. and Reddy, S. 2015. Crop nutrition management with nano fertilizers. *International Journal of Environment Science Technology* **1**(1): 4-6.

Hamoda, S.A.F., Attia, A.N.E., El-Hendi, M.H. and El Sayed, S.O.S. 2016. Effect of nano fertilizer (lithovit) and potassium on growth, fruiting and yield of egyptian cotton under different planting dates. *International Journal of Advance Research in Biological Science* **3**(12): 29-49.

Hanafey F. M. and Lamyaa A. Abd El Rahman. 2014. Inducing salinity tolerance in wheat plants by hydrogen peroxide and lithovit "a nano-$CaCO_3$ fertilizer". *Journal of Agricultural Research* **40** (4): 693-716.

Hasan, B.K. and Saad, T.M. 2020. Effect of nano biological and mineral fertilizers on NPK uptake in wheat (*Triticum aestivum* L.). *Indian Journal of Ecology* **47**(12): 126-130.

Hasaneen, M.N.A.G., Abdel-aziz, H. M. M. and Omer, A. M. 2016. Effect of foliar application of engineered nanomaterials: carbon nanotubes NPK and chitosan nanoparticles NPK fertilizer on the growth of french bean plant. *Biochemistry Biotechnology Research* **4**(4): 68-76.

Hassan, I.A.H., Mahmoud, K.A. and Abdol, M.S.R. 2015. A study of six genotypes of maize (*Zea mays* L.) in Sulaymaniyah. *Diyala Journal of Agricultural Sciences* **7**(2): 195-190.

Havlin, J.L. 2014. Soil fertility and nutrient management. *Upper Saddle River, New Jersey*, pp-460-469.

Hong, F., Zhou, J., Liu, C., Yang, F., Wu, C., mal, L. and Yang, P. 2005. Effect of nano $TiO_2$ on photochemical reaction of chloroplasts of spinach. *Biological Trace Element Research* **105**(1): 269-279.

Hussien, M.M., Soad, M.E.A. and Haggag, W.M. 2015. Response of mineral status to nano fertilizer and moisture stress during different growth stages of cotton plants. *International Journal Chem Tech Research* **8**(12): 643 - 650.

IFFCO, 2021. Environment friendly IFFCO nano Urea (liquid) fertilizer for precision and sustainable agriculture. (Website: https://iffco.in/index.php/ourproducts/ index/nano-urea retrieved on dated 07-09-2021).

IIWBR, 2021. Indian Institute of Wheat and Barley Research, Karnal. (Website: https://iiwbr.icar.gov.in retrieved on dated 09-09-2021).

Jackson, M.L. 1973. Soil chemical analysis. Prentice Hall of India Pvt. Ltd. New Delhi.

Jafarzadeh, R., Jami, M. and Hokmabadi, M. 2013. Response of yield and yield components in wheat to soil and foliar application of nano potassium fertilizer. *Journal of Crop Production Research and Environmental Stresses in Plant Sciences* **5**(2):189-197.

Jian., L., Zhang, Y. D. and Zhang, Z. M. 2008. Study on application of nanometre biotechnology on the yield and quality of winter wheat. *Journal of Anhui Agricultural Sciences* **36**: 15578-15580.

Jubouri, S.M.I. and Anwar, M.W. 2008. Effect of different levels and dates of addition of nitrogen fertilizer in grain yield and quality of two maize varieties (*Zea mays* L.). *Journal of Mesopotamia* **36**(1): 73-56.

Junejo N., Khanif, M.Y., Dharejo, K.A., Hamid, H.A., Abdu, A. 2012. Evaluation of coated urea for ammonia volatilization loss, nitrogen mineralization and microsite pH in selected soil series. *African Journal of Biotechnology* **11**(2):366-378.

Junrungrean, S.P., K. Limtong, K. Wattanaprapat, and T. Patsarayeangyong. 2002. Effect of zeolite and chemical fertilizer on the change of physical and chemical properties latya soil series for sugarcane. $17^{th}$ WCSS,14–21 August, Thailand, pp-1–7.

Kandil, E.E. and Eman, A.O.M. 2017. Response of some wheat cultivars to nano mineral fertilizers and amino acids foliar application. *Alexandria Science Exchange Journal* **38**(1):53-68.

Kaviani, B., Ghaziani, M.V.F. and Negandar, N. 2016. Effect of application methods and different concentrations of biologic nano fertilizer especial for ornamental plants on some morphological, physiological and proliferation traits and enhancing the quality of *buxus hyrcana pojark*. *International Journal of Advance Science and Engineering Technology* **2**: 206 -212.

Khanday, M.U.D., Ram, D., Ali, T., Mehra, S., Wani, S. A, Jan, R., Bhat, M.A. and Bhat, S.J.A. 2017.Strategy for optimization of higher productivity and quality in field crops through micronutrients. *Economic Affairs* **62**(1): 139-147.

Khospeyak, S., Haghi, R.S., Ahmadiyan, A. 2016. The effect of application of nano organic fertilizer and nitrogen fertilizer on yield, yield components and essential oil content of fennel. *Iranian Journal of Field Crops Research* **14**(4): 775-787.

Kumar, Y., Tiwari, K.N., Nayak, R.K., Rai, A., Singh, S.P., Singh, A.N., Kumar, Y., Tomar, H., Singh, T. and Raliya, R. 2020. Nano fertilizers for increasing nutrient use efficiency, yield and economic return in important winter season crops of Uttar Pradesh. *Indian Journal of Fertilizers* **16** (8): 772-786.

Kumar, Y., Tiwari, K.N., Tarunendu, S., Naveen, K.S., Sri, L., Ramesh, V., Girish, C.S., Ramesh, R. 2020. Nano fertilizers for enhancing nutrient use efficiency, crop productivity and economic return in winter season crops of Rajasthan. *Annals of Plant and Soil Research* **22**(4): 324-335.

Kumar, K.A., Kumar, Y., Savitha, A.S., Ajayakumar M.Y., Narayanaswamy, C., Raliya, R., Krupashankar, M.R. and Bhat S.N. 2021. Effect of IFFCO nano fertilizer on growth, grain yield and managing turcicum leaf blight disease in maize. *International Journal of Plant & Soil Science* **33**(16): 19-28.

Kumar, P., Singh, R., Singh, A., Paliwal, D. and Kumar, S. 2014. Integrated nutrient management in pearl millet (*Pennisetum glaucum*) and wheat (*Triticum aestivum*) cropping sequence in semi-arid condition of India. *International Journal of Agriculture Science* **10**(1): 96 - 101.

Lemraski, M.G., Normohamadi, G., Madani, H., Abad, H.H.S. and Mobasser, H.R. 2017. Two Iranian rice cultivars response to nitrogen and nano fertilizer. *Open Journal of Ecology* **7**(10):591-603.

Lal, R. 2008. Promise and limitations of soils to minimize climate change. Journal of Soil Water Conservation **63**(4): 113-118.

Linder, R.C. 1944. Rapid analytical method for some of the more common substances of plant and soil. *Plant Physiology* **19**(1): 76-84.

Liu, J., Wang, Y., Shao, X., Geng, Y., Wang, Z., Ma, Y. and Fan, L. 2012. Effects of combined nitrogen fertilizer and nano-carbon application on yield and nitrogen use of rice grown on saline-alkali soil. *Journal of Food, Agriculture & Environment* **10**(1): 558-562.

Liu, J., Zhang, Y. and Zhang, Z. 2009. The application research on nano biotechnology to promote increasing vegetable production. *Hubei Agricultural Sciences* **1**: 20-25.

Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randar, R.J. 1951. Protein measurement with the folin phenol reagent. *Journal of Biological Chemistry* **193**(3): 265-275.

Ma, J., Liu, J., and Zhang, Z.M. 2009. Application study of carbon nano fertilizer on growth of winter wheat. *Humic Acid* **2**: 14-20.

Mahil, E.I.T. and Kumar, B.N.A. 2019. Foliar application of nano fertilizers in agricultural crops. *Journal of Farm Sciences* **32**(3): 239-249.

Mahmoodzadeh, H., Aghili, R. and Nabavi, M. 2013. Physiological effects of $TiO_2$ nanoparticles on wheat (*Triticum aestivum* L.). *Technological Journal of Engineering and Applied Science* **3**: 1365-1370.

Manikandan, A. and Subramanian, K.S. 2016. Evaluation of zeolite-based nitrogen nano fertilizers on maize growth, yield and quality on inceptisols and alfisols. *International Journal of Plant and Soil Science* **9**(4): 1-9.

Masoud, B., Abdolshahi, R., Nejad, G.M., Yousefi, K. and Tabatabaie, S.M. 2012. Effect of different microelement treatment on wheat (*Triticum aestivum* L.) growth and yield. *International Research Journal of Applied Basic Science* **3**(1): 219-223.

Meena, R.H., Jat, G. and Jain, D. 2021. Impact of foliar application of different nano fertilizers on soil microbial properties and yield of wheat. *Journal of Environmental Biology* **42**: 302-308.

Mehta, S. and Bharat, R. 2019. Effect of integrated use of nano and non-nano fertilizers on yield and yield attributes of wheat (*Triticum aestivum* L.). *International Journal of Current Microbiology and Applied Sciences* **8**(12): 598-606.

Moore, M.N. 2006. Do nanoparticles present ecotoxicological risks for the health of the aquatic environment. *Environment International* **32**(8): 967-976.

Moosapoor, N., Sadeghi, S.M. and Bidarigh, S. 2013. Effect of boher nano fertilizer and chelated iron on the yield of peanut in province guilan. *Indian Journal of Fundamental and Applied Sciences* **3**: 2231-6345

Morsy, A.S.M., Awadalla A. and Sherif, M.M. 2018. Effect of irrigation, foliar spray with nano fertilizer (lithovit) and N-levels on productivity and quality of durum wheat under toshka conditions. *Assiut Journal Agriculture Science* **49**(3): 1-26.

Morsy, A.S.M., Awadalla, A., Hussein, M.M., El-Dek, S. 2021. Impact of preceding crop, sowing methods and nano fertilizer (amino mineral) on bread wheat production and quality in toshka region, Egypt. *Egyptian Journal of Agronomy* **43**(1): 133- 147.

Mosanna, R., Khalilv, E. and Behrozyar. 2015. Morpho-physiological response of maize (*Zea mays* L.) to zinc nano-chelate foliar and soil application at different growth stages. *Journal on New Biological Reports* **4**(1):46 - 50.

Nadi, E., Aynehband, A. and Mojaddam, M. 2013. Effect of nano iron chelate fertilizer on grain yield, protein percent and chlorophyll content of faba bean (*Vicia faba* L.). *International Journal of Bioscience* **3**(9): 267-272.

Navarro, E., Baun, A., Behra, R., Hartmann, N.B., Filser, J., Miao, A.J., Quigg, A., Santschi, P.H. and Sigg, L. 2008. Environmental behaviour and ecotoxicity of engineered nanoparticles to algae, plants and fungi. *Ecotoxicology* **17**(5): 372-386.

Nekrasova, G.F., Ushakova, O.S., Ermakov, A.E., Uimin, M.A. and Byzov, I.V. 2011. Effects of copper ions and copper oxide nanoparticles on elodea densa planch. *Russian Journal of Ecology* **42**(6): 458-463.

Olsen, S.R., Cole, C.V., Wantnable, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soil by extraction with HNO. United States Department of Agriculture Handbook No. 60.

Panse, V.G. and Sukhatme, P.V. 1989. Statistical methods for agricultural workers. Indian Council of Agricultural Research, New Delhi.

Piper, C.S. 1950. Soil and plant analysis. Inter science Publisher, New York, USA.

Pocket book of agricultural statistics. 2020. Government of India Ministry of Agriculture and farmers Welfare Department of Agriculture, Cooperation and Farmers Welfare Directorate of Economics & Statistics. (Website: http://eands.dacnet.nic.in retrieved on dated 09-09-2021).

Qiang, X., Fu-dao, Z., Yu-jun, W., Jian-feng, Z. and Shu-qing, Z. 2008. Effects of slow/controlled release fertilizers felted and coated by nanomaterials on crop yield and quality. *Journal of Plant Nutrition and Fertilizer Science* **14**: 951–955.

Qureshi, A., Singh, D.K. and Dwivedi, S. 2018. Nano fertilizers: a novel way for enhancing nutrient use efficiency and crop productivity. *International Journal of Current Microbiology and Applied Science* **7**(2): 3325-3335.

Radford, P.J. 1967. Growth analysis formulae; their use and abuse . *Crop Science* **7**(3): 171-175.

Rani, B., Nirali, B., Zalawadia, N.M. and Rushang, K. 2019. Effect of different levels of chemical and nano nitrogenous fertilizers on yield and yield attributes of sorghum crop (*Sorghum bicolor* L.) cv. Gundri. *International Journal of Current Microbiology and Applied Sciences* **8**(8):2878-2884.

Rathnayaka, R.M.N.N., Iqbal, Y.B. and Rifnas, L.M. 2018. Influence of urea and nano nitrogen fertilizers on the growth and yield of rice (*Oryza sativa* L.) cultivar ‘Bg 250’. *International Journal of Research Publications* **5**(2): 1-7.

Razzaq, A., Ammara, R., Jhanzab, H.M., Mahmood, T., Hafeez, A. and Hussain, S. 2016. A novel nanomaterial to enhance growth and yield of wheat. *Journal of Nanoscience & Technology* **2**(1):55-58.

Richards, L.A. 1968. Diagnosis and improvement of saline and alkaline soils. United States, Department of Agriculture, Handbook No. 60, pp-432.

Rostaman, T., Wibowo, H., and Nurjaya. 2021. The effects of nano inorganic fertilizer application on rice (*Oryza sativa* L.) productivity. *Earth and Environmental Science* **648**(1):1315-1755.

Saeid, H. and Maryam, H. D. 2011. Effects of nitrogen fertilizer on chlorophyll content and other leaf indicate in three cultivars of maize (*Zea mays* L.). *World Applied Sciences Journal* **15**(12): 1780-1785.

Sharifi, R.S. and Namvar, A. 2016. Effects of time and rate of nitrogen application on phenology and some agronomical traits of maize (*Zea mays* L.). *Journal Biological* **62**(1): 35-45.

Sharifi, R.S. and Taghizadeh. 2009. Response of maize (*Zea mays* L.) cultivars to different levels of nitrogen fertilizer. *Journal of Food and Agriculture Environment* **7**(3-4): 518-521.

Shrivastava, S., Tomar, P.S., Arya, V. and Verma, S.K. 2017. Effect of integrated application of inorganic and organic sources on soil properties, yield and nutrient uptake by pearl millet. *International Journal of Life Science* **12**(1): 609-614

Singh M.D., Gautam, C., Patidar, O.P., Meena, H.M., Prakasha, G. and Vishwajith. 2017. Nano fertilizers is a new way to increase nutrients use efficiency in crop production. *International Journal of Agriculture Sciences* **9**(7): 3831-3833.

Soliman, A.S., Hassan, M., Elella, F.A., Ahmed, A.H.H. and Feky, S.A.E. 2016. Effect of nano and molecular phosphorus fertilizers on growth and chemical composition of baobab (*Adansonia digitata* L.). *Journal of Plant Science* **11**(4): 52-60.

Somaratne, S., Weerakoon, S.R., Karthikeyan, N. and Munasinghe, D.S.P. 2021. The impact of nano-ZnO foliar fertilizer on growth and yield of cultivated rice (*Oryza sativa* L.) varieties in Sri Lanka. *Ceylon Journal of Science* **50**(2): 109–119.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for available nitrogen in soil. *Current Science* **25**(8): 259-260.

Tarafdar, J.C., Raliya, R., Mahawar, H. and Rathore, I. 2014. Development of zinc nano fertilizer to enhance crop production in pearl millet (*Pennisetum americanum*). *Agricultural Research* **3**: 257-262.

Togas, R., Yadav, L.R., Choudhary, S.L. and Shisuvinahalli, G.V. 2017. Effect of integrated use of fertilizer and manures on growth, yield and quality of pearl millet. *International Journal of Current Microbiology and Applied Science* **6**(8): 2510-2516.

Tondey, M., Kalia, A., Singh, A., Singh Dheri, G., Taggar, M.S., Nepovimova, E., Krejcar, O. and Kuca, K. 2021. Seed priming and coating by nano scale zinc oxide particles improved vegetative growth, yield and quality of fodder maize (*Zea mays* L.). *Agronomy* **11**: 2-16.

USDA, 2020. US Department of Agriculture. (Website: https://www.fas.usda.gov/ retrieved on dated 11-09-2021).

Valadkhan, M., Mohammadi, K.H. and Karimi, N.M.T. 2015. Effect of priming and foliar application of nanoparticles on agronomic traits of chickpea. *Biological Forum* **7**(2): 599-602.

Valojai, Seyed, T.S., Niknejad Y., Amoli H.F. and Tari D.B. 2021. Response of rice yield and quality to nano fertilizers in comparison with conventional fertilizers. *Journal of Plant Nutrition* **44**(13):1971-1981.

Walkley, A. and Black, I.A. 1934. An examination of digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**(1): 29-37.

Xin, C., Qing-wei, Y., Jia-lin, S., Shuang, X., Fu-chun, X. and Ya-jun, C. 2014. Research progress on nitrogen use and plant growth. *Journal of North East Agricultural University* **21**(2): 68-74.

# Performance of Wheat (*Triticum aestivum* L.) under various sources of nitrogen and Restricted Irrigation

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# ABSTRACT

During the *rabi* 2021-2022, a field experiment entitled **"Effect of Nano urea on NUE and Productivity of Wheat (*Triticum aestivum* L.) under Restricted Irrigation Conditions"** was conducted at Instructional Farm, Agronomy, Rajasthan College of Agriculture (MPUAT), Udaipur (Rajasthan).

The experiment was conducted in randomised block design with nine different sources of nitrogen *i.e.*, $N_1$ (One spray of nano urea at tillering stage), $N_2$ (Two spray nano urea at tillering and jointing), $N_3$ (RDN 1/3$^{rd}$ basal, 2/3$^{rd}$ CRI), $N_4$ (RDN + one spray of nano urea (5 %) at tillering), $N_5$ (RDN + two spray of nano urea at tillering and jointing), $N_6$ (RDN + one spray of urea ( 5%) at tillering), $N_7$ (RDN + two spray of urea (5 %) at tillering and jointing), $N_8$ (RDN + one spray of urea (5 %) + nano urea at tillering) and $N_9$ (absolute control). Wheat variety "Raj 4079" was used under the experiment.

The result show that in comparison to other nitrogen treatments, the highest crop growth parameters (plant height, dry matter accumulation, tillers plant$^{-1}$ and number of total tillers) and yield attributes (effective tillers, grains ear$^{-1}$, weight of grains ear$^{-1}$, and test weight) were recorded under treatment $N_5$ *i.e.*, RDN + two spray of nano urea at tillering and jointing. While, the crop growth rate and relative growth rate found non-significant. The application of $N_5$ (RDN + two spray of nano urea at tillering and jointing) resulted considerable increase in the yield traits *i.e.*, grain yield, straw yield except harvest index. Superior performance of quality parameters (chlorophyll content and protein content) was also measured under treatment $N_5$ (RDN + two spray of nano urea at tillering and jointing) whereas, proline content was measured as non-significant. Similarly, the maximum nitrogen content in grain and straw of wheat was obtained under treatment $N_5$ (RDN + two spray of nano urea at

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tillering and jointing) however, phosphorus and potassium content found non-significant. Likewise, the maximum uptake of nitrogen, phosphorus and potassium in grain, straw and total were recorded under application of RDN + two spray of nano urea at tillering and jointing ($N_5$). Correspondingly, when crop was treated with $N_5$ (RDN + two spray of nano urea at tillering and jointing) the supreme net return (₹ 119937 $ha^{-1}$) and B-C ratio (2.81) were obtained.

# प्रतिबंधित सिंचाई स्थितियों के तहत गेहूँ (*ट्रिटिकम एस्टिवम* एल.) की नत्रजन उपयोग क्षमता (एनयूई) और उत्पादकता पर नैनो यूरिया का प्रभाव

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## अनुक्षेपण

रबी ऋतु 2021–22 के दौरान **''प्रतिबंधित सिंचाई स्थितियों के तहत गेहूँ (*ट्रिटिकम एस्टिवम* एल.) की नत्रजन उपयोग क्षमता (एनयूई) और उत्पादकता पर नैनो यूरिया का प्रभाव''** नामक एक प्रक्षेप प्रयोग निर्देशात्मक फार्म, सस्य विज्ञान विभाग, राजस्थान कृषि महाविद्यालय (एमपीयूएटी), उदयपुर पर आयोजित किया गया।

यह प्रयोग यादृश्चिक खण्ड़ अभिकल्पना में नत्रजन के नौ विभिन्न स्त्रोतों के साथ किया गया। जो इस प्रकार है– एन$_1$ (कल्ले फुटान अवस्था पर नैनो यूरिया का एक छिड़काव), एन$_2$ (कल्ले फुटान और गाँठ निर्माण अवस्था नेनौ युरिया के दो छिड़काव), एन$_3$ (आर डी एन 1/3 भाग आधार, 2/3 भाग शीर्ष जड़ फूटान), एन$_4$ (आर डी एन + कल्ले फुटान पर युरिया (5%) का एक छिड़काव), एन$_5$ (आर डी एन + कल्ले फुटान एव गाँठ निर्माण अवस्था पर नैनो युरिया के दो छिड़काव), एन$_6$ (आर डी एन + कल्ले फुटान अवस्था पर युरिया (5%) का एक छिड़काव), एन$_7$ (आर डी एन + कल्ले फुटान एंव गाँठ निर्माण अवस्था पर युरिया (5%) के दो छिड़काव), एन$_8$ (आर डी एन + कल्ले फुटान अवस्था पर युरिया (5%) का एक छिड़ाकाव + नैनो यूरिया का एक छिड़काव) और एन$_9$ (सम्पूर्ण नियंत्रण)।

परिणामों से यह पता चला की अन्य नत्रजन उपचारो की तुलना में एन$_5$ (आर डी एन + कल्ले फुटान एव गाँठ निर्माण अवस्था पर नेनौ युरिया के दो छिड़काव) के अन्तर्गत फसल वृद्धि मापदण्ड़ो (पौधे की ऊँचाई, शुष्क पदार्थ संचयन, कुल फुटान की संख्या, फुटान संख्या प्रति पौध) एवं उपज घटक (प्रभावी फुटान संख्या, दाने की संख्या प्रति बाली, दानों का वजन प्रति बाली एवं परीक्षण भार) अधिकतम प्राप्त हुए। जबकि फसल वृद्धि दर और सापेक्ष वृद्धि दर लागू विभिन्न नत्रजन स्त्रोतों के संबंध में गैर महत्वपूर्ण पाए गए। एन$_5$ (आर डी एन + कल्ले फुटान एव गाँठ निर्माण अवस्था पर नैनो युरिया के दो छिड़काव) के उपयोग से दाना एवं भूसा उपज में उल्लेखनीय वृद्धि हुई। गुणवत्ता मापदण्ड़ो (पर्णहरित मात्रा, प्रोटीन मात्रा) का बेहतर प्रदर्शन उपचार एन$_5$ (आर डी एन + कल्ले फुटान एंव गाँठ निर्माण अवस्था पर नैनो युरिया के दो

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छिड़काव) के तहत् प्राप्त हुआ, जबकि प्रोलीन मात्रा को गैर महत्वपूर्ण मापा गया। इसी तरह दाना व भूसा उपज में अधिकतम नत्रजन मात्रा उपचार एन$_5$ (आर डी एन + कल्ले फुटान एव गाँठ निर्माण अवस्था पर नैनो युरिया के दो छिड़काव) के तहत् प्राप्त की गई जबकि फॉस्फेरस एवं पोटेशियम मात्रा सार्थक नही पाई गई। इसी तरह एन$_5$ (आर डी एन + कल्ले फुटान एव गाँठ निर्माण अवस्था पर नैनो युरिया के दो छिड़काव) के उपयोग के तहत् दाना एवं भूसा में नत्रजन, फॉस्फोरस एवं पोटेशियम का अधिकतम उदग्रहण प्राप्त हुआ। एन$_5$ (आर डी एन + कल्ले फुटान एव गाँठ निर्माण अवस्था पर नैनो युरिया के दो छिड़काव) के उपयोग के तहत् अधिकतम शुद्ध लाभ (रू 119937/हेक्टेयर) एवं लाभ लागत अनुपात (2.81) दर्ज किया गया।

## APPENDIX I

**Analysis of variance for plant population at 15 DAS**

| **Source of variation** | **d. f.** | **MSS**<br>**Plant population at 15 DAS (0.5 m row length)** |
|---|---|---|
| Replication | 2 | 1.641 |
| Treatment | 8 | 0.167 |
| Error | 16 | 0.740 |
| CV (%) | | 6.51 |

## APPENDIX II

**Analysis of variance for plant height (cm) at 50, 75, 100 DAS and at harvest**

| **Source of variation** | **d. f.** | **MSS**<br>**Plant height (cm)** | | | |
|---|---|---|---|---|---|
| | | **50 DAS** | **75 DAS** | **100 DAS** | **At harvest** |
| Replication | 2 | 6.370 | 0.811 | 3.102 | 22.278 |
| Treatment | 8 | 16.121* | 41.111* | 96.764* | 85.927* |
| Error | 16 | 6.088 | 15.081 | 31.141 | 32.501 |
| CV (%) | | 4.48 | 5.38 | 6.23 | 6.31 |

* Significant at 5 % level of significance

## APPENDIX III

**Analysis of variance for dry matter accumulation at 50, 75, 100 DAS and at harvest**

| Source of variation | d. f. | MSS | | | |
|---|---|---|---|---|---|
| | | Dry matter accumulation (g) 0.5 m row length | | | |
| | | 50 DAS | 75 DAS | 100 DAS | At harvest |
| Replication | 2 | 3.343 | 11.639 | 54.481 | 11.678 |
| Treatment | 8 | 18.280** | 46.480* | 228.787* | 261.985* |
| Error | 16 | 2.405 | 16.935 | 82.481 | 85.961 |
| CV (%) | | 8.32 | 7.89 | 5.51 | 5.27 |

* Significant at 5 % level of significance ** Significant at 1 % level of significance

## APPENDIX IV

**Analysis of variance for tillers plant$^{-1}$, crop growth rate and relative growth rate**

| Source of variation | d. f. | MSS | | | |
|---|---|---|---|---|---|
| | | Tillers plant$^{-1}$ | CGR (g m$^{-2}$ day$^{-1}$) | | |
| | | | 50 - 75 DAS | 75-100 DAS | 100-At harvest |
| Replication | 2 | 0.016 | 0.339 | 8.274 | 8.052 |
| Treatment | 8 | 2.182** | 0.763 | 5.169 | 0.533 |
| Error | 16 | 0.396 | 1.280 | 7.215 | 6.034 |
| CV (%) | | 9.73 | 12.66 | 8.93 | 18.85 |

** Significant at 1 % level of significance

## APPENDIX V

**Analysis of variance for relative growth rate and total tillers**

| Source of variation | d. f. | MSS | | | |
|---|---|---|---|---|---|
| | | RGR (g $g^{-1}$ $day^{-1}$) | | | Total tillers (0.5m row length) |
| | | 50-75 DAS | 75-100 DAS | 100-At harvest | |
| Replication | 2 | 0.00000573 | 0.00002146 | 0.00000682 | 1.083 |
| Treatment | 8 | 0.00002460 | 0.00000294 | 0.00000035 | 18.792** |
| Error | 16 | 0.00001805 | 0.00001546 | 0.00000444 | 3.438 |
| CV (%) | | 10.27 | 8.51 | 18.53 | 4.75 |

** Significant at 1 % level of significance

## APPENDIX VI

**Analysis of variance for yield attributes**

| Source of variation | d. f. | MSS | | | |
|---|---|---|---|---|---|
| | | Yield attributes | | | |
| | | Effective tillers (0.5 m row length) | Grains $ear^{-1}$ | Weight of grains $ear^{-1}$ | Test weight (g) |
| Replication | 2 | 3.541 | 0.111 | 0.001 | 2.299 |
| Treatment | 8 | 18.546* | 21.352** | 0.131** | 49.539** |
| Error | 16 | 5.539 | 2.202 | 0.010 | 1.358 |
| CV (%) | | 6.54 | 3.68 | 5.04 | 2.57 |

* Significant at 5 % level of significance ** Significant at 1 % level of significance

**APPENDIX VII**

**Analysis of variance for yield and harvest index**

| Source of variation | d. f. | MSS | | |
|---|---|---|---|---|
| | | Yield (q ha$^{-1}$) | | Harvest index (%) |
| | | Grain | Straw | |
| Replication | 2 | 34.819 | 4.372 | 18.554 |
| Treatment | 8 | 71.793* | 111.505** | 0.112 |
| Error | 16 | 20.283 | 13.110 | 6.498 |
| CV (%) | | 10.35 | 6.67 | 5.74 |

* Significant at 5 % level of significance ** Significant at 1 % level of significance

**APPENDIX VIII**

**Analysis of variance for quality parameters**

| Source of variation | d. f. | MSS | | |
|---|---|---|---|---|
| | | Chlorophyll content | Proline content | Protein content |
| Replication | 2 | 3.485 | 0.000124 | 0.0038 |
| Treatment | 8 | 13.382** | 0.000958 | 0.1026** |
| Error | 16 | 3.355 | 0.000383 | 0.0250 |
| CV (%) | | 2.54 | 1.35 | 4.56 |

** Significant at 1 % level of significance

## APPENDIX IX

**Analysis of variance for nutrient content in grain and straw of wheat**

| Source of variation | d. f. | MSS | | | | | |
|---|---|---|---|---|---|---|---|
| | | Nutrient content (%) | | | | | |
| | | Grain | | | Straw | | |
| | | N | P | K | N | P | K |
| Replication | 2 | 0.000099 | 0.000011 | 0.000019 | 0.00004113 | 0.0000014 | 0.000235 |
| Treatment | 8 | 0.002628** | 0.000241 | 0.000208 | 0.00023463* | 0.0000333 | 0.001122 |
| Error | 16 | 0.000640 | 0.000111 | 0.000090 | 0.00007572 | 0.0000152 | 0.002036 |
| CV (%) | | 1.35 | 2.42 | 2.63 | 1.81 | 2.49 | 2.73 |

* Significant at 5 % level of significance ** Significant at 1 % level of significance

## APPENDIX X

**Analysis of variance for nutrient uptake by grain, straw and total**

| Source of variation | d. f. | MSS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Nutrient uptake (kg ha$^{-1}$) | | | | | | | | |
| | | Nitrogen | | | Phosphorus | | | Potassium | | |
| | | Grain | Straw | Total | Grain | Straw | Total | Grain | Straw | Total |
| Replication | 2 | 113.434 | 1.20 | 92.246 | 5.900 | 0.0725 | 4.783 | 3.539 | 16.352 | 5.992 |
| Treatment | 8 | 313.806** | 33.02** | 550.146** | 17.900** | 3.597** | 37.496** | 12.448** | 354.018** | 498.484** |
| Error | 16 | 70.511 | 3.13 | 80.489 | 4.446 | 0.525 | 5.552 | 2.526 | 52.857 | 59.793 |
| CV (%) | | 10.31 | 6.79 | 8.35 | 11.10 | 8.50 | 8.57 | 10.13 | 8.10 | 7.34 |

** Significant at 1 % level of significance

## APPENDIX XI

**Analysis of variance for nutrient content in soil and nitrogen use efficiency**

| Source of variation | d. f. | MSS | | | |
|---|---|---|---|---|---|
| | | Nutrient content of soil (kg ha$^{-1}$) | | | Nitrogen use efficiency (kg kg$^{-1}$) |
| | | N | P | K | |
| Replication | 2 | 93.355 | 0.799 | 125.641 | 41.952 |
| Treatment | 8 | 116.473 | 0.440 | 107.262 | 68.362** |
| Error | 16 | 59.886 | 0.457 | 118.566 | 13.890 |
| CV (%) | | 2.77 | 3.09 | 3.04 | 6.45 |

** Significant at 1 % level of significance

## APPENDIX XII

**Analysis of variance for economics**

| Source of variation | d. f. | MSS | |
|---|---|---|---|
| | | Economics | |
| | | Net return (₹) | B-C ratio |
| Replication | 2 | 189258874.65 | 0.11 |
| Treatment | 8 | 705918469.44** | 0.35** |
| Error | 16 | 144438991.66 | 0.08 |
| CV (%) | | 12.06 | 11.99 |

** Significant at 1 % level of significance

## APPENDIX-XIII

**Treatment wise cost of cultivation, yield and economic returns**

| Treatment | Yield (q ha$^{-1}$) | | | Economics | | | |
|---|---|---|---|---|---|---|---|
| | Grain | Straw | Biological | Cost of cultivation | Gross return | Net return | B-C ratio |
| $N_1$ | 39.27 | 49.06 | 88.33 | 41190 | 127613 | 86423 | 2.10 |
| $N_2$ | 41.04 | 51.70 | 92.74 | 41790 | 133615 | 91825 | 2.20 |
| $N_3$ | 44.74 | 56.03 | 100.77 | 41545 | 145476 | 103931 | 2.50 |
| $N_4$ | 47.19 | 58.98 | 106.18 | 42145 | 153370 | 111226 | 2.64 |
| $N_5$ | 50.01 | 62.75 | 112.76 | 42745 | 162682 | 119937 | 2.81 |
| $N_6$ | 45.05 | 56.22 | 101.27 | 41545 | 146359 | 104814 | 2.52 |
| $N_7$ | 45.80 | 57.12 | 102.92 | 41545 | 148767 | 107222 | 2.58 |
| $N_8$ | 44.91 | 55.13 | 100.04 | 42145 | 145362 | 103217 | 2.45 |
| $N_9$ | 33.49 | 41.87 | 75.36 | 40590 | 108845 | 68255 | 1.68 |

## APPENDIX- XIV

## COST OF CULTIVATION AND PRICES USED TO COMPUTE ECONOMICS WHEAT

### Common Cost of Cultivation

| S No. | Particulars | Cost (₹) | |
|---|---|---|---|
| | | **Unit cost** | **Cost ha$^{-1}$** |
| **A.** | **Common cost of cultivation** | | |
| 1. | Field preparation (12 hrs. through 2 ploughings) | ₹ 600 h$^{-1}$ | 7200.00 |
| 2. | Layout and opening of furrows (6-man days) | ₹ 300 man$^{-1}$ day$^{-1}$ | 1800.00 |
| 3. | Fertilizer application and sowing (2.5 hrs.) | ₹ 800 h$^{-1}$ | 2000.00 |
| 4. | Fertilizer (kg ha$^{-1}$): SSP: 250 kg, MOP: 33.3 kg ha$^{-1}$ | SSP: ₹ 7.24 kg$^{-1}$<br>MOP: ₹ 17.40 kg$^{-1}$ | 1810.00<br>580.00 |
| | | | **2390.00** |
| 5. | Seed (100 kg ha$^{-1}$) | ₹ 32 kg$^{-1}$ | 3200.00 |
| 6. | Irrigation (03) | ₹ 1600 irrigation$^{-1}$ | 4800 |
| 7. | Sulfosulfuron 75% WP (32.5 g) + Metsulfuron 20% WP (20 g) | ₹ 2500 kg$^{-1}$ | 2500.00 |
| 8. | Herbicide spray (2-man days) | ₹ 300 man$^{-1}$ day$^{-1}$ | 600.00 |
| 9. | Spray of nano urea twice (2-man days) | ₹ 300 man$^{-1}$ day$^{-1}$ | 600.00 |
| 10. | Harvesting (30-man days) | ₹ 300 man$^{-1}$ day$^{-1}$ | 9000.00 |
| 11. | Threshing and winnowing (5 hours) | ₹ 1200 hours$^{-1}$ | 6000.00 |
| 12. | Miscellaneous | | 500.00 |
| | | **Total (₹)** | **40590.00** |

**Treatment Cost**

| (B) | Common cost of treatment | | Cost (₹) | |
|---|---|---|---|---|
| | | | Unit cost (₹) | Cost ha$^{-1}$ (₹ ha$^{-1}$) |
| 1. | $N_1$ | 1250 ml nano urea | ₹ 240/500 ml | 600 |
| 2. | $N_2$ | 1250 ml nano urea + 1250 ml nano urea | ₹ 240/500 ml + ₹ 240/500 ml | 1200 |
| 3. | $N_3$ | 173.6 kg urea | ₹ 5.50 kg$^{-1}$ | 954.8 |
| 4. | $N_4$ | 173.6 kg urea + 1250 ml nano urea | ₹5.50 kg$^{-1}$ + ₹ 240/500 ml | 1554.8 |
| 5. | $N_5$ | 173.6 kg urea + 1250 ml nano urea + 1250 ml nano urea | ₹ 5.50 kg$^{-1}$ + ₹240/500 ml+ ₹ 240/500 ml | 2154.8 |
| 6. | $N_6$ | 173.6 kg urea + 5 g per 100 ml | ₹ 5.50 kg$^{-1}$ | 955 |
| 7. | $N_7$ | 173.6 kg urea + 5 g per 100 ml + 5 g per 100 ml | ₹ 5.50 kg$^{-1}$ | 955.18 |
| 8. | $N_8$ | 173.6 kg urea + 5 g per 100 ml + 1250 ml nano urea | ₹ 5.50 kg$^{-1}$ + ₹ 5.50 kg$^{-1}$ + ₹ 240/500 ml | 1555 |
| 9. | $N_9$ | No nitrogen | 0 | 0 |
| | **Selling price of Wheat** | | | |
| | 1. Grain kg$^{-1}$ (₹) | | 25.00 | |
| | 2. Straw kg$^{-1}$ (₹) | | 06.00 | |

**Plagiarism Report**

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