SMART NUTRIENT MANAGEMENT WITH NANO UREA ON RABI MAIZE (*Zea mays* L.) UNDER RAINFED SITUATION

A Thesis

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IN

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By

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August, 2023

DEDICATED TO
MY BELOVED WIFE
AND DAUGHTER

ASSAM AGRICULTURAL UNIVERSITY

FACULTY OF AGRICULTURE

CERTIFICATE – I

This is to certify that the thesis entitled **"Smart nutrient management with nano urea on *rabi* Maize (*Zea mays* L.) under rainfed situation"** submitted to the Faculty of Agriculture, Assam Agricultural University, in partial fulfillment for the degree of **Master of Science (Agriculture)** in **Agronomy** is a record of research work carried out by **Mr. Rajib Singh, Roll No. 2021-AMB-10** under my personal supervision and guidance.

All helps received by his have been duly acknowledged.

No part of this thesis has been reproduced elsewhere for any degree.

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CERTIFICATE – II

This is to certify that the thesis entitled **"Smart nutrient management with nano urea on *rabi* Maize (*Zea mays* L.) under rainfed situation"** submitted by **Mr. Rajib Singh, Roll No. 2021-AMB-10** to the faculty of Agriculture, Assam Agricultural University, in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy** has been examined and approved by the Student's Advisory Committee after viva-voce.

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ABSTRACT

A field experiment was carried out during *rabi*, 2022-23 at the experimental plot of the Department of Agronomy, B. N. College of Agriculture, Assam Agricultural University, Biswanath Chariali to assess “Smart nutrient management using nano urea on *rabi* maize (*Zea mays* L.) under rainfed situation” with two objectives *viz.* studying the effect of foliar application of nano-urea on growth and yield of *rabi* maize and to find out the optimum combination of nano-urea and with conventional urea. The experiment consisted of 11 treatments in randomized block design *viz.* T_1: Recommended Dose of Fertilizer (RDF) T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage, T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage, T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage, T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage, T_6: :25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage, T_7: 25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage, T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage, T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage, $T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage, T_{11}: 100% P & K.

The results of the investigation revealed that the treatment T_1 (RDF) resulted in relatively taller plant height (103.20 cm) at knee high stage which is statistically at par with T_8, T_9 and T_{10}. However, the highest plant height during tasseling (245.20 cm) and physiological maturity (243.80 cm) was observed in T_8 (50% of recommended dose of N from conventional urea + spraying Nano urea @ 6 ml l^{-1} at knee high and tasseling stage). T_1 also registered the significantly higher number of green leaves (8.73) plant^{-1}, dry matter accumulation (138.83 g) and leaf area index (1.84) at knee high stage. Conversely, in later stage of growth, effect of nano urea was found to be significant with notably higher value of number of green leaves plant^{-1} (11.67 and 9.60); leaf area index (4.63 and 3.10 plant^{-1}) and dry matter accumulation (214.76 and 645.26 g plant^{-1}) recorded at tasseling and physiological maturity, respectively under T_8. The crops under this treatment also showed the significantly thicker stem (7.53 cm).

Crops receiving 50 % N from conventional urea and 6 ml l^{-1} of nano urea recorded greater crop growth rate (CGR) between knee high and tasseling (209.79 g m^{-2}

day^{-1}) and between tasseling and physiological maturity (638.10 g m^{-2} day^{-1}). In case of, relative growth rate (RGR), higher value (0.32 g g^{-1} d^{-1}) was recorded under T_6 that receiving 25% recommended N from conventional source and 6ml l^{-1} of nano urea in between knee high to tasseling; whereas between tasseling to physiological maturity stage the highest value (0.47 g g^{-1}d^{-1}) was found in T_8. The effect of nano urea was also observed with respect to leaf chlorophyll content and relative water content (RWC) of leaf as the highest being 1.37 mg g^{-1} fw. and 91.23 %, respectively recorded under T_8 .

Effect on yield parameters revealed significantly influence of nano urea with respect to increased length (35.88 cm), weight (368 g) and girth (20.29 cm) of cob together with more number of seeds per cob (615.93) and test weight (247.54 g) which were recorded under T_8. The improvement of these yield parameters was reflected in grain yield (72.25 q ha^{-1}), stover yield (110.67 q ha^{-1}) and harvest index (39.50 %) and production efficiency (120.42 %) as well.

The soil available nitrogen was highest (268.75 kg ha^{-1}) in T_{10} (50 % N + 100% P & K + spray of Nano urea @ 10 ml l^{-1}), however T_1 (RDF), T_8 (50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}) and T_9 (50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1}) showed comparable value and the lowest value (241.19 Kg ha^{-1}) was recorded in T_{11} i.e. 100% P & K.

Among all the treatments, T_1 (RDF) recorded the highest cost of cultivation (₹ 80,650 ha^{-1}) followed by T_8 and, the lowest (₹ 75000 ha^{-1}) was incurred in T_{11} i.e.100% P & K. The highest gross return (Rs. 1,50,569 ha^{-1}), net return (Rs. 72,069 ha^{-1}) and benefit-cost ratio (1.91) was obtained in T_8 whereas, T_{11} *i.e.* 100% P & K recorded the lowest gross return (₹. 86,305 ha^{-1}), net return (₹ 11,305 ha^{-1}) and benefit-cost ratio (1.15).

Results showed that spraying of nano urea @ 6ml/L at knee high and tasseling stage with basal application of 50% of recommended N from conventional urea with 100 % P & K was superior in terms of noticeably enhanced and economically efficient corn yield which was resulted from significantly improved growth and yield parameters. Therefore, it could be inferred that spraying of nano-urea @ 6ml l^{-1} at knee high and tasseling stage coupled with basal application of 50% of recommended N from conventional urea with 100 % P & K could be a promising and smart option as nutrient management strategy to harvest higher and economically efficient *rabi* corn yield under rainfed upland situation in Assam.

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LISTOF ABBREVIATIONS

@	:	At the rate of
%	:	Per cent
g	:	Gram
˚c	:	Degree celsius
et al.	:	Et alia
Etc.	:	Et cetera
m	:	Meter
mm	:	Millimeter
i.e.	:	That is to say
N	:	Nitrogen
P	:	Phosphorus
K	:	Potassium
q	:	Quintal
DAS	:	Days After Sowing
kg	:	Kilogram
Fig.	:	Figure
viz.	:	Videlist ‘namely’
B:C	:	Benefit: Cost ratio
BSSH	:	Bright Sunshine Hours
CD	:	Critical Difference
SEd	:	Standard error of deviation
SV	:	Sources of Variation
df	:	Degrees of freedom
Max.	:	Maximum

Min.	:	Minimum
OC	:	Organic Carbon
pH	:	Potential of hydrogen
No.	:	Number
NS	:	Not Significant
BD	:	Bulk Density
RH	:	Relative Humidity
SMW	:	Standard Meteorological Week
ha^{-1}	:	Per hectare
$Plant^{-1}$	:	Per plant

CHAPTER I
INTRODUCTION

Maize (*Zea mays* L.) is the third most important food grain crop in India next to rice and wheat. The total production of maize in the world is 819 million tonnes (M t), with a productivity of 5.2 tonnes/ha. More than 40% of the maize grain is produced in the USA, followed by China (20.0%), Brazil (6.3%), Mexico (2.5%), Indonesia (2.2%) and India (2.0%). In India, Maize (*Zea mays* L.) is considered as the third most important cereal crop after rice and wheat. It is successfully grown in India under varied agro-ecologies, ranging from sea-level to high altitudes up to 3000 m. It is the main source of cereal for food, forage and processed industrial products and it has the highest yield potential among the cereals hence it is called "Queen of Cereals". The nutritive value of maize is high as it contains 72% starch, 10% protein, 8.5% fibre, 4.8% oil, 3.0% sugar and 1.7% ash. Maize is an efficient converter of absorbed nutrient into food because it is a C_4 plant.

India is the fourth-largest producer of maize in the world and the seventh-largest producer overall, accounting for 2% of global production and 4% of the world's total area under maize. The area cultivated under maize in India is 9.28 million ha in 2019-20 (*Directorate of Economics And Statistics, Ministry of Agriculture, Government of India*). India produced 2.00 million MT of maize in 1949-50 which by 2019-20 the production climbed to 26.74 million MT, nearly a 12 fold increase. While the area virtually tripled from 3.30 million ha to 9.28 million ha, the average production grew by 4.57 times over that time from 630 kg $ha^{-1}$to 2881 kg ha^{-1}. Madhya Pradesh and Karnataka have the highest acreage under maize among Indian states, followed by Maharashtra, Rajasthan, Uttar Pradesh and others. Bihar is the third-highest producer. The state with the highest production of maize is Andhra Pradesh followed by Madhya Pradesh and Karnataka (Anonymous, 2020. A few small enterprises are currently using it increasingly due to the fast growing demand for chicken feeds and fodder in Assam. The crop now occupies a state area of 31000 ha and has a yield of 91000 t (2017-18) with a productivity of about 2911 kg ha^{-1} (Kalita and Bora, 2019). Currently, the developed nations consume more corn than the developing nations, but predictions show that by 2050, the need for corn in developing nations will double due to the explosive expansion of the poultry sector, which is the main factor promoting increase in maize production (Prasanna *et al*., 2014).

In India, there are three growing seasons for maize *viz*., *kharif*, *rabi*, and *summer*. The most significant season is *kharif*, which accounts for around 83% of the total area, followed by *rabi*, which accounts for 17% of the total area under maize in India. In terms of overall output, *kharif* maize was produced on land area of 7.47 million ha, yielding 18.79 million tonnes of grain with an average productivity of 4382 kg ha^{-1}, while *rabi* maize was cultivated on an area of 1.82 million ha, yielding 7.95 million tonnes of grain with an average productivity of 2512 kg ha^{-1} (*Directorate of Economics And Statistics, Ministry of Agriculture, Government of India*). Largest producer states of *rabi* maize include Bihar, Andhra Pradesh, Tamil Nadu and Rajasthan.

Field works during the *kharif* season cannot be completed on time because of irregular distribution of south-west monsoon. In *rabi*, field activities may be planned and carried out whenever it is most convenient because there are no significant environmental obstacles which contribute to achieving higher returns. The response to the application of nitrogen and other fertilizers is better in the *rabi* season than the *kharif* season due to the more favourable growth conditions. The amount of infestation by various diseases and insect-pests is fairly low during the *rabi* season due to low temperature and humidity, leading to increased yields. Due to decreased photorespiration losses from cooler night time temperatures and bigger leaf surface areas for efficient photosynthetic activities, maize plants often exhibit higher levels of productivity during the *rabi* season. Weeds are easier to manage during *rabi* season than in *kharif* because of efficient water management and cooler weather. All these factors contribute largely towards maximising profits from every additional unit of monetary inputs (Singh *et al*., 2012).

The chemical fertilizers has increase the higher production and productivity of a crop which leads to Green revolution in one hand and on the other hand it has caused environmental pollution. Nutrient use efficiency of conventional fertilizers is very low. To overcome all these drawbacks in a better way, nano-technology can be a ray of hope. Nano-fertilizer is an important tool in agriculture to increased crop growth, yield and quality parameters with higher nutrient use efficiency, reduction in wastage of fertilizers and cost of cultivation. Nano-fertilizers are applied either to soil and/ or leaves. Foliar spray operation can be amidst in any situation of the weather and critical soil conditions. On the other hand, it promotes the direct access of nutrients into the plant system and reduces the wastage of fertilizer. Hence, foliar application of nano-fertilizer leads to increased nutrient use efficiency (NUE) and has given a quick effect to the growth of crops. Nano-fertilizers are further reactive and can penetrate through cuticle, ensuring controlled release and targeted delivery. Present review summarizes the mode of action of nano-fertilizers in to the plant system and effect of foliar applied nano-fertilizers on crop growth, yield, quality, NUE and alleviation of abiotic stress and heavy metals toxicity (Mahil *et al.,* 2019).

Nano-urea provides new interdisciplinary venture into agriculture and food sciences by converging science and engineering. It promises significant contribution to agricultural research, which can lead to new avenues for solving numerous agricultural problems. Nano urea have potential applications in agriculture system, *viz.*, less as pollutants, controlled delivery of fertilizers, nutrients can act as nano architects in formation and binding of soil structure. Typically, nitrogen content in a healthy plant ranges from 1.5 to 4%. Foliar application of nano-urea at critical crop growth stages of a plant effectively fulfils its nitrogen requirement and increases the efficiency of fertilizer leads to higher crop productivity and quality in comparison to conventional urea.

Maize is an exhaustible crop that demands high nutrition for their growth and development. The productivity of the crop depends on nutrient management system. Inorganic fertilizers are most widely used all over the world as it gives higher yield and the end result is also much appreciable. Efficient use of nitrogen is important for maize production as it increases the yield and maximizes economic return and minimize NO_3 leaching to ground. An organic fertilizer such as poultry manure, FYM and vermi-compost are free from synthetic compounds and chemicals. The best source of nutrients can be received from the organic manure. It is not harmful to the environment. Bio-fertilizers are also a good source of nutrients as it binds the atmospheric nitrogen which is inaccessible to plants and ammonium ion and is released into the soil. It also improves the fertility of the soil.

In recent times, present agriculture is highly supported by the use of high rates of agrochemicals and fertilizers. Synthetic chemical fertilizers are used for the maximum growth and productivity of crops, but they are not successful to improve plant nutrient use efficiency (NUE) and crop productivity. The NUE values of the three most basic macronutrients *i.e.*, nitrogen, phosphorus and potassium are low at 30-35%, 18-20% and 35-40%, respectively which shows that more than half of the broadcasted fertilizers in the fields are lost and do not reach their targeted sites due to different factors such as photolysis, hydrolysis, leaching and microbial immobilization and degradation (Ganapati *et al.,* 2018). Nano-science and Nano-technology represent a new frontier for the research community. Nano-fertilizer is working with the smallest possible particles which elevate hopes for improving agricultural productivity through encountering problems unsolved conventionally. Nano-technology has its goal in realization of novel materials and devices with features on the nano scale, drawing from fields such as colloidal science, device physics and supramolecular chemistry. In the management aspects, efforts are made to increase the efficiency of applied fertilizer with the help of nano clays and zeolites and restoration of soil fertility by releasing fixed nutrients. It has found potential applications in controlling nutrient release and availability, characterization of soil minerals, weathering of soil minerals and development, nature of soil rhizosphere and nutrient ion transport in soil plant system (Alzreejawi *et al.,* 2021).

Direct application of fertilizers to the soil will results in loss of nutrients in different ways such as photolysis, hydrolysis, leaching and degradation. Hence the applied fertilizer may not able to reach the targeted sites in the plant system and unable to enhance the optimal growth and productivity of crops (Ajit kumar *et al*., 2021). Hence an attempt will be made to increase the efficiency of applied fertilizer in the form of nano-fertilizer through foliar spray to the maize crop.

Keeping in view in the above information and literatures the present investigation entitled "Smart nutrient management using nano urea on *rabi* Maize (*Zea mays* L.) under rainfed situation" has been formulated with the following objectives.

1. Study the effect of foliar application of Nano urea on growth and yield of Rabi Maize.
2. Find out the optimum combination of Nano urea and with conventional urea.

CHAPTER II
REVIEW OF LITERATURE

Literature pertaining to the research topic entitled "Smart Nutrient Management using Nano Urea on Rabi Maize (*Zea mays* L.) under rainfed situation" conducted during the *rabi* season, 2022 at the experimental area of Post graduate experimental plot, Department of Agronomy, Biswanath College of Agriculture, Biswanath Chariali. This chapter critically reviews and presents the study's related literatures. The following sub-headings are used to review the literature.

2.1 Effect of conventional and nano fertilizer on maize

2.2 Effect of nano urea on growth and growth attributes of crops

2.3 Effect of nano urea on yield and yield attributes of crops

2.4 Requirement of levels of nano fertilizer in crops

2.5 Effect of nano urea on production economics of crops

2.1 Effect of Nano fertilizer on the growth and yield of maize

Mohammadi *et al.* (2014) conducted an experiment with six levels of urea (0, 30, 60, 90, 120 and 150 kg ha^{-1}) in corn. The results showed that urea had a significant effect on the number of grain rows, number of grains per row, number of grains per cob, grain weight, grain yield, biological yield and harvest index of the crop. Corn yield and yield components were superior in urea treatment while the minimum was recorded in the control plots. It was recommended to use urea @ 150 kg ha^{-1} to achieve the improved yield parameters and yield.

Rajonee *et al.* (2016) carried out an in vitro incubation for 30 days under field moisture conditions and compared to a standard fertilizer. It was found that even though the release of N was higher for nano fertilizer than conventional fertilizer, both sources' nutrient release patterns showed a markedly declining trend over time. To determine the effectiveness of nano fertilizer in promoting plant development, a pot experiment was also carried out with *Ipomoea aquatica*. They reported that plants fed with nano fertilizer accumulated more nitrogen, while the post effect of nano fertilizer application in soil showed better soil pH, soil moisture content, CEC and available nitrogen under nano fertilizer treatment than the conventional fertilizer at harvest.

Srivani *et al.* (2022) conducted an experiment to investigate the effects of urea and nano urea on growth, yield, and economics in fodder maize (*Zea mays* L.). In terms of growth and yield of fodder maize crop, soil application of urea @33 kg N ha^{-1} each at basal, 20 and 40 DAS recorded significantly at par with basal soil application of urea @33 kg N ha^{-1} + foliar spray of nano urea @3 ml l^{-1} each at 20 and 40 DAS. As a result, nitrogen management with urea and urea + nano urea foliar spray @3 ml l^{-1} may be the best combination among other foliar spray rates for achieving the best use efficiency and sustainability.

Al-Juthery *et al.* (2018) studied the treatments which contained four amounts of nano-fertilizer (25, 50, 75 and 100 g) in potato. They used 400 litres of solution ha^{-1} with 1 kg of required nitrogen fertiliser and 100 L^{-1} water of foliar spray was applied. Results revealed that the applied treatment (SMP+SW+HP) had a considerably better yield of fresh, dried tubers, vegetative yield and biological yield than di and single spray combinations.

Ganapati *et al.* (2018) studied the effect of nitrogen levels and modified urea on growth and yield of pearl millet (*Pennisetum glaucum* L.) under rainfed condition and observed that the modified urea has increased the yield of pearl millet.

Alyasari *et al.* (2019) reported significant results in a field trial with nano fertilizer on maize crop growth that the protikcalbor with 3ml l^{-1}treatment was superior in plant height (152.2 cm) chlorophyll content (33.57). Spadprotikcalbor with 4ml l^{-1} treatment had a higher number of leaves (13.47) than the control, which had the lowest rates for all traits.

Mahil *et al.* (2019) conducted experiments on foliar application of nano fertilizers in agricultural crops and observed that the gradual increase in the growth and development of agricultural crops and found the yield increases then to the conventional fertilizers.

Sahi Al-Saray and Al-Rubaee (2019) conducted an experiment at Iraq and reported that Nano fertilizer is more effective than the conventional fertilizer. It was found that Nano fertilizer has significant role in increasing the yield on the all seasons.

Al-Juthery *et al.* (2020) conducted an experiment at Iraq and studied the indicators on maize plant included chlorophyll content in leaves (SPAD unit), plant height (m), stem diameter(cm), biological yield (ton h^{-1}), grains yield (ton h^{-1}) and harvest index (%). The Results showed the significant superiority of nano NPK (12-12-36) spray in achieving the highest means for all studied indicators. It showed the highest means for leaf chlorophyll content, stem diameter, grains yield and harvest index. It may have sonic beneficial effects on pest and disease problems. It gave higher total production; monetary returns and greater resources use efficiently and increased the land productivity by almost 60 per cent.

Ajithkumar *et al.* (2021) studied effect of nano-fertilizer on growth, grain yield and managing turcicum leaf blight disease in maize. The field experiment was carried out in randomized block design at Main Agricultural Research Station, University of Agricultural Sciences, Raichur during Kharif seasons of 2019 and 2020. The nano-fertilizers such as nano-nitrogen (nano N), nano-copper (nano Cu), nano zinc (nano Zn) and sea weed extract were sprayed to the maize crop in different combinations with recommended dose of fertilizers. The results revealed that treatment T_{11} [50% N, 100% PK, 0% Zinc + 2 sprays of nano N (4ml/l) mixed with Sea weed extract (2ml/l)] produced the tallest height (226 cm), largest leaf area (801.16 cm^2) and girth of stem (6.97 cm) of the maize among all the treatments which was on line with the other treatments and much better than the other treatments (T_8 and T_4), the control (T_1 - 180.67 cm), and the rest of the treatments.

Kumar *et al*. (2021) found that the nitrogen content in a healthy plant ranges from 1.5 to 4%. Foliar application of Nano Urea at critical crop growth stages of a plant effectively fulfils its nitrogen requirement and increases the efficiency of fertilizer leads to higher crop productivity and quality in comparison to conventional urea.

Manikandan *et al.* (2021) investigated the destiny of nitrogen in the soil system and learn more about how nano-fertilizers can increase the production of crops with improved N use efficiency. In two greenhouse trials with two different soil textures (Inceptisol - Periyanayakkan palayam soil series-clay loam and Alfisols-Irugur soil series-sandy loam), the response of maize plants to artificial fertilisers was examined. The grain N content of nano zeo urea treatment showed consistently higher value.

Rajesh *et al.* (2021) conducted a field study in Rabi 2020-2021 with the aim of determining the impact of foliar sprays of nano N and nano Zn on growth and yield of sweet maize crop. A total of thirteen different nutrient treatments, including chemical nano nitrogen, chemical nano zinc, and green nano zinc along with two recommended fertilizer doses, were included in the experiment, which was set up using the Randomised Complete Block Design (RCBD) and replicated three times. The absolute control treatment was also included and plant height (225.7 cm), maximum green leaves per plant (12.60), leaf area (7130 cm^2 $plant^{-1}$), leaf area index (5.94), total accumulation of dry matter (295.2 g $plant^{-1}$), SPAD (61.74) and NDVI (0.80) are all noticeably higher. foliar applications of chemically synthesized nano N at 4 ml/l and chemically synthesised nano Zn at 2 ml/l at 25 and 50 DAS, respectively, were seen at harvest with applications of 75% N, 100% P & K. This treatment was comparable to 100% NPK + 25 kg ha-1 $ZnSO_4$ and 75% RDN + foliar application of chemically synthesised nano N @ 4 ml/l and green synthesised nano Zn @ 2 ml/l.

Safa A. M. Alzreejawi *et al.* (2021) conducted a field experiment at Iraq and stated that Nano-fertilizer of NPK has increased the total yield of Maize then to the conventional fertilizer of NPK.

Sameer Mohapatro *et al.* (2021) reported that the application of 150% RDN resulted in the maximum values of growth attributes, such as plant height, dry matter accumulation, leaf area index, and crop growth rate, as well as yield attributes, such as cob length, cob girth, grains per cob, test weight inclusive of grain yield (6.65 t/ha) and straw yield (8.42 t/ha). Application of 150% RDN demonstrated its superiority for expression of crop growth characteristics, yield attributes and yields; it was followed at various growth stages by 125% RDN and 100% RDN. The crop performance from treatments using precision N management instruments such the Leaf Colour Chart (LCC) and SPAD metre was likewise very similar to that of the 150% RDN, 125% RDN and 100% RDN treatments

Kashyap *et al*. (2022) reported that the T_{12}: Leaf Colour Chart Threshold 5 with Nano Urea Spray @ 6 ml/l observed higher growth, yield attributing characteristics, quality, gross monetary, net monetary return and B: C ratio respectively in rice crop.

Rohit *et al*. (2022) reported the three levels of conventional fertilizer (0% N, 50% N and 100% N) and foliar spray of nano urea fertilizer at three concentrations (0%, 50% and 100%) respectively the results of the application of different levels combination of conventional fertilizer and nano urea increased maize growth, yield and soil chemical properties. The application of conventional fertilizer and nano urea in treatment T_9 (N100, 100%P and K fertilizers + 2 sprays of Nano nitrogen (4ml/l) Available Nitrogen) resulted in a higher available nitrogen (kg ha^{-1}) Available in depths of 247.12 cm (0-15 cm) and 199.2 cm (15-30 cm). Phosphorous (kg ha^{-1}) (kg ha^{-1}) 39.36 in the 0-15 cm range and 31.63 in the 15-30 cm range Available Potassium (kg ha^{-1}) (kg ha^{-1}) Significant values were found to be 4.34 in the 0-15 cm depth and 9.37 in the 15-30 cm depth.

Samui *et al.* (2022) conducted an experiment in the rainfed regions of Southern Odisha, maize is the dominant crop. As a result, nanotechnology must be used to optimise the use of nitrogen-based fertilisers. In this regard, the current study used a randomised block design with 11 treatments and three replications. The study found that using 100% RDN + foliar spray of nano-urea @ 4ml/L, twice at the knee and tasseling stages, was superior in influencing *rabi* maize morphology, yield attributes and yield. However, because the adoption of 75% RDN + foliar spray of nano urea @ 4ml/L at the knee and tasseling stages was significantly comparable to 100% RDN, this may be the best managerial option for achieving sustainability.

Vishvajeet D Jadhav *et al.* (2022) conducted in Randomized Block Design with T_1: Absolute control; T_2: 2% Urea spray; T_3: 100% RDF (125: 60: 30 kg N: P_2O_5: K2O); T_4: SPAD threshold 36-40; T_5: SPAD threshold 36-40; T_6: SPAD threshold 36-40; T_7: SPAD threshold 41-45; T_8: SPAD threshold 41-45; T_9: SPAD threshold 41-45; T_{10}: SPAD threshold 42; T_{11}: SPAD threshold 42; A total of three copies of each of the twelve treatments were used in maize. Findings showed that foliar applications of SPAD threshold 46-50 with nano urea spray at 6 ml/l produced higher growth rates and yield-related traits and qualities with nano urea spray @ 6 ml/l, GMR, NMR and B: C ratio were all significantly higher in the SPAD threshold 46-50.

Adishainesh Aher *et al.* (2023) N1-1 ml/l foliar spray nano urea, N_2-2 ml/l foliar spray nano urea and N_3-3 ml/l foliar spray nano urea are the three levels of nano urea. In contrast, there are three levels of zinc: Z1 is 20 kg ha^{-1}, Z2 is 25 kg ha^{-1} and Z3 is 30 kg ha^{-1}. The results of the experiment suggest that $ZnSO_4$ 30 kg ha^{-1} can ensure the profitable production of baby maize.

2.2 Effect of nano urea on growth and growth attributes of field crops

Kaviani *et al.* (2016) included leaf sprays of 0.00, 1.00, 2.00, 3.00, 4.00 and 5.00g l^{-1} of biologic nano-fertilizer designed specifically for ornamental plants and concentrations of 0.00, 0.60, 1.20, 1.80, 2.40 and 3.0 g per pot. The plants fed with 3.00 g pot^{-1} drench + 2.00 g l^{-1} spray of nano-fertilizer particular for ornamental plants obtained the highest number of nodes (19.33), root length (6.83 cm), leaf number (133.30) and proliferation rate (133.53 cm). In comparison to the numerous other treatments and the control, the root volume (163.00 ml), root number (7.63) and shoot number (8.63) in this treatment were significant.

Yogendra *et al*. (2020) conducted an experiment on nano fertilizers for increasing nutrient use efficiency, yield and economic returns in important winter season crops of Uttar Pradesh and reported that inclusion of nano fertilizers in winter crops like wheat, field pea, lentil, cabbage, cauliflower, mustard, potato, amaranthus, chilli, tomato, garden pea, and garlic has obtained with 50% less nitrogen as compared to the N applied under farmers fertilizer practice (FFP) and applying nano Nitrogen in standing crops gave yields higher than Farmers Fertilizers Practise in most of these crops and found that the above crops yield return is more than the conventional fertilizer applied methods.

Midde *et al.* (2021) conducted a field experiment the “Effect of Nano Nitrogen on Growth and Yield Attributes of Rice (*Oryza sativa* L.)” will be studied in 2021 at Annamalai University in Tamil Nadu. The study's findings showed that the treatment 50% RDN + 50% Nano N (T_7) produced the tallest plant height (104.7 cm) and the greatest number of tillers (348), which were much higher than those of any other treatment. T_6 came in second with 102.6 cm and 331 tillers. Reduced plant height (81.9 cm) and tiller count (185) compared to control (T_1).

Navya *et al*. (2022) studied the foliar application of nano nitrogen in combination with conventional urea on mustard in the Northern Telangana zone. The experiment used a randomised block design with eight treatment combinations and three replications. The application of 100% RDN and 50% RDN as a basal +one nano-N spray before flowering at a rate of 1250 ml ha^{-1} resulted in higher plant height, leaf area index, SPAD, dry matter accumulation and yield attributing characteristics of mustard.

During the *rabi* seasons of 2019-20 and 2020-21, Neogi and Das (2022) conducted a field experiment to ascertain the impact of nitrogen and zinc fertilisers, when used in nano form, on the growth and productivity of potato in inceptisols. The application of nano fertilizers greatly increased potato plant height, dry matter output and leaf area index, according to the results. The treatment T_8 showed a taller plant height (63.4 cm) and the greatest number of shoots per plant (4.80) and it was statistically comparable to the treatments T_9 (application of 50% RDN + 100% RDPK + nano-N and nano-Zn as foliar applications) and T_6 (application of 100% Recommended Dose of NPK + foliar nano-N-sprays at 25 and 45 DAP). Treatment T_1 (control plot) had the smallest plant height (39.8 cm) and fewest number of shoots per plant (2.02).

Rostaman, *et al.* (2022) conducted a field study at Indonesia and stated the main advantage of using of nano inorganic fertilizer application with 400 times dilution on 75% NPK + Urea fertilization recommendation was able to increase the weight of milled dry grain by 11.3% when compared to 100% NPK + Urea fertilization. legumes in intercropping and mixed cropping was found to be the saving of nitrogen Fertilizer in rice crop.

Samanta *et al.* (2022) conducted a field experiment on finger millet during the rabi season to compare the effectiveness of foliar applications of urea and nano-urea. The treatment used in this investigation were 0 kg N ha^{-1} (T_1), 20 kg N ha^{-1} (T_2), 40 kg N ha^{-1} (T_3), 20kg N ha^{-1} + 2 sprays of 1% urea (T_4), 20kg N ha^{-1} + 2 sprays of 2% urea (T_5), 20kg N ha^{-1} +2 sprays of nano urea @ 2ml L^{-1} (T_6), 20kg N ha^{-1} + 2 sprays of nano urea @ 3ml L^{-1} (T_7), 20kg N ha^{-1} + 2 sprays of nano urea @ 4ml L^{-1} (T_8), 40kg N ha^{-1} + 2 sprays of nano urea @ 2ml L^{-1} (T_9), 40kg N ha^{-1} + 2 sprays of nano urea @ 3ml L^{-1} (T_{10}), 40kg N ha^{-1} + 2 sprays of nano urea @ 4ml L^{-1} (T_{11}). The taller plant height (104.9 cm), maximum dry matter (406.2 g/m^2) and LAI (4.8) were recorded by 40 kg N ha^{-1} + 2 sprays of nano urea @ 4ml L^{-1} (T_{11}) which was statistically at par with 40kg N ha^{-1} + 2 sprays of nano urea @ 3ml L^{-1} (T_{10}), 40 kg N ha^{-1} + 2 sprays of nano urea @ 2ml L^{-1} (T_9), 40 kg N ha^{-1} (T_3) and 20kg N ha^{-1} + 2 sprays of nano urea @ 4ml L^{-1} (T_8) applied at tillering and pre flowering stage, respectively applied at tillering and pre flowering stage, respectively. With 0 kg ha^{-1} N, however, dwarf plant height, dry matter and leaf area index were all significantly reduced (T_1).

2.3 Effect of nano urea on yield and yield attributes of field crops

In total, 187 trials were done by Tiwari *et al.* in potato fields owned by farmers in various districts of Uttar Pradesh were treated during Rabi 2019-20 with five different methods, but in this article, the effects of using nano-urea versus non-nano urea was assessed. On the basis of 187 experiments, only two selected treatments-Farmer's Fertiliser Practise (FFP) (T_1) and FFP - 50% N + 2 Spray of Nano Urea (T_2) are being offered. The findings demonstrated that yields were produced using 50% less nitrogen than FFP and that in the majority of these trials, spraying 2 sprays of nano-nitrogen to standing crops resulted in yields that were higher than FFP.

Kumar *et al.* (2020) conducted six hundred on-farm trials with 8 crops namely wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), maize (*Zea mays*), urdbean (*Vigna mungo*), chickpea (*Cicer arientinum*), mustard (*Brassica juncea*), isabgoal (*Plantago ovata*) and rose (*Rosa damascene*) in different districts of Rajasthan during winter season of 2019-20. T_1- Farmer's Fertilizer Practise was the treatment utilised in the experiments. (FFP) T_2-FFP - 50% N + 2 Sprays of Nano nitrogen T_3 -FFP + 2 Sprays of Nano zinc T_4 -FFP + 2 Sprays of Nanocu T_5 - FFP - 50% N + 1 Spray of Nano nitrogen T_6 - FFP - 50% N + 1 Spray of Nano-nitrogen. Nano Zn plus one nano cu spray. The results show that for wheat (4628 kg ha^{-1}), barley (4625 kg ha^{-1}), maize (5250 kg ha^{-1}), urdbean (2063 kg ha^{-1}) and chickpea (2164 kg ha^{-1}), the mean grain yield under T_5 was the highest, followed by T_2, T_3, T_4, and T_5.

In order to assess the impact of nitrogen and zinc nano fertiliser with organic farming practises on cereal and oil seed crops, Kumar *et al.* (2022) conducted a total of 160 field demonstrations at two locations in Haryana, India: Khaliyawas (28.19° N, 76.76° E) and Khatawali (28.22° N, 76.76° E), with a total area of 1225 acres. The following treatments are employed on various crops: 1. Wheat T_1-N:P:K:Zn (kg) (150:60:30:25) T_2-Organic Manure 2.5 MT + Biofertilizer Consortium 1250 ml + 25 kg of granular seaweed extract + 625 ml of liquid seaweed 19 extract + 3 sprays of each Nano Nitrogen and Nano Zinc 2. T_1-N:P:K:Zn (kg) (60:30:0:0) Pearl millet 2.5 MT of T_2-Organic Manure + 250 ml of Biofertilizer Consortium + 25 kg of Granular Seaweed Extract + 625 ml of Liquid Seaweed Extract + 3 sprays of Nano Nitrogen and Nano Zinc 3. T_1-N:P:K:Zn:S (kg) (80:30:20:25:25) mustard T_2-Organic manure 1.25 MT + 1250 ml of the biofertilizer consortia + 25 kg of seaweed extract granules + 625 ml of seaweed extract liquid + 2 sprays of nano nitrogen and nano zinc. It was discovered that the average yield of wheat was 5.35% higher in T_2 than T_1 and the average yield of sesame was 24.24% higher in T_2 than T_1. Similar results were seen with T_2 pearl millet, which yielded 4.2% more than T_1, and T_2 mustard, which yielded 8.4% more than T_1.

In order to increase the productivity and profitability of green gram, Saitheja *et al.* (2022) conducted a field experiment at the wetland farm of the Tamil Nadu Agricultural University, Coimbatore, in the summer of that year. They did this by using a variety of basal nitrogen doses and foliar applications of nano and regular urea at the Flower Initiation (FI) stage and for 15 days after. According to the experiment's findings, 100% RDN and nano urea foliar spray at 4ml per litre of water greatly increased fertility co-efficient (71.2%), pods plant^{-1} (38.5 No.), seeds pod^{-1} (12.7 No.), maximum seed yield (1291 kg ha^{-1}) and haulm yield (3346 kg ha^{-1}). The application of 80% RDN and nano urea foliar spray @ 4 ml litre^{-1} of water, however, recorded a fertility co-efficient of 70.6%, 38.0 pods plant^{-1}, 12.6 seeds pod^{-1}, seed yield of 1289 kg ha^{-1} and haulm yield of 3334 kg ha^{-1}. With N4-Control F4-1% urea (normal) at flower initiation stage and 15 days following, reduced seed production (686 kg ha^{-1}) and haulm yield (1777 kg ha^{-1}) was produced.

Samanta *et al.* (2022) conducted a field experiment in the Rabi season of 2021-2022 to compare the effectiveness of foliar urea and nano-urea applications on finger millet. The maximum grain yield (1351.7 kg ha^{-1}), straw yield (4029.3 kg ha^{-1}) and biological yield (5381.1 kg ha^{-1}) were recorded by 40kg N ha^{-1} + 2 sprays of nano urea @ 4ml L^{-1} (T_{11}) which was statistically at par with 40kg N ha^{-1} + 2 sprays of nano urea @ 3ml L^{-1} (T_{10}), 40kg N ha^{-1} + 2 sprays of nano urea @ 2ml L^{-1} (T_9), 40 kg N ha^{-1} (T_3) and 20 kg N ha^{-1} + 2 sprays of nano urea @ 4ml L^{-1} (T_8) applied at tillering and pre flowering stage, respectively. However, with 0 kg N (T_1), the significantly lowest grain yield (kg ha^{-1}), straw yield (kg ha^{-1}) and biological yield (kg ha^{-1}) were observed.

Samui *et al.* (2022) investigated how the foliar application of urea and nano-urea affected the development and productivity of Rabi maize throughout the Rabi season in 2021-2022. The results showed that 100% RDN+FSNU @ 4 ml L^{-1} at knee height and tasseling was significantly better than 100% RDN without foliar supplementation, all treatments with 75% RDN and control (grain yield, stover yield and biological yield are 2.31, 6.23, 8.5 t ha^{-1}, respectively) in terms of grain yield (6.84 t ha^{-1}), stover yield (10.83 t ha^{-1}), and biological yield (17.7 t ha^{-1}).

2.4 Requirement of levels of Nano fertilizer in field crops

To examine the effects of nano-iron oxide on yield and agronomic features of soybean (cultivar 'L_{17}'), Sheykhbaglou *et al.* (2010) conducted a field experiment on clay soil in Urmia University's Agricultural Research Station, Iran, during the 2009-2010 growing season. A field experiment with three replications was created using a randomised full block design. Five levels of nano iron oxide were used as treatments: 0, 0.25, 0.5, 0.75 and 1 g l^{-1}. The highest grain yield, according to the results, was achieved with 0.5 g l^{-1} of nano-iron oxide, which resulted in a 48% increase in grain production above the control.

Manikandan and Subramanian (2015) conducted an investigation to examine the response of maize (NK-6240) to various fertiliser formulations. The five procedures under consideration are all T_1 urea. T_2 Zeolite and Urea are physically mixed in an exact 1:1 ratio on a w/w 31 basis. T_3 Nano Zeolite and Urea are physically mixed in a 1:1 ratio on a weight-per-weight basis. Intercalated T_4 Zeourea (1:1) T_5 Nano zeourea, intercalated (1:1). According to the findings, the grain N content of nano zeourea on inceptisol and alfisol (Control: 0.48; Treated: 0.76%) was consistently higher.

In order to investigate the effects of nitrogen fertiliser (urea), nano urea, and bio fertilization (*Azotobacter chroococcum*) on the chemical makeup and productivity of sage plant (*Salvia officinalis* L.), Hegab *et al.* (2018) conducted a field experiment at Baloza Research Station of Desert Research Centre, North Sinai. The soil was treated with two types of mineral fertilisers: nano urea, urea and biofertilizer (*A. chroococcum*). Each treatment was reproduced three times in the experiment, which was set up using a split plot design. The treatment that was most successful (Nano 500 ppm with bio N fertiliser) produced the greatest significant values of yield components, which were 64.4, 2.77, 11249, and 4395 for plant height (cm), oil (%), herb fresh and dry weight (kg), respectively.

In this study, the effects of only two selected treatments, Farmer's Fertiliser Practise (FFP) (T_1) and FFP - 50% N + 2 Spray of Nano Urea (T_2), based on 187 trials, are being examined. Tiwari *et al.* (2021) evaluated a total of 187 trials on farmers’ fields with potatoes in different districts of Uttar Pradesh during Rabi 2019-20 with five treatments. Trials with potato crops on farmer fields have shown that the amount of urea sprayed by farmers to deliver nitrogen to the crop can be successfully decreased to half.

During the Rabi seasons of 2019-20 and 2020-21, Neogi and Das (2022) conducted a field experiment to ascertain the impact of nitrogen and zinc fertilisers applied in nano form on the growth and productivity of potato in inceptisols. It has been noted that foliar application of nano-N + nano-Zn combined with 100% RDF of NPK was found to be more effective than application of 100% RDF of NPK with any single application of nano-N or nano-Zn by foliar means in increasing the total tuber yield of potatoes.

2.5 Effect of nano urea on production economics of crops

Kumar *et al.* (2020) conducted six hundred on-farm trials with 8 crops namely Wheat (*Triticum aestivum* L.), Barley (*Hordeum vulgare*), Maize (*Zea mays*), Urdbean (*Vigna mungo*), Chickpea (*Cicer arientinum*), Mustard (*Brassica juncea*), Isabgoal (*Plantago ovata*) and Rose (*Rosa damascene*) in different districts of Rajasthan during winter season of 2019-20.T_1- Farmer’s remedy is the one employed in trials. Fertiliser Practise (FFP) T_2 - FFP - 50% N + 2 Sprays of Nano Nitrogen T_3 - FFP - 50% N + 2 Sprays of Nano Zinc T_4 - FFP - 50% N + 2 Sprays of Nano Copper T_5 - FFP - 50% N + 1 Spray of Nano Copper, Nano N with one spray each of nano Zn and nano Cu. The results show that T_5 for wheat (Rs.5726.88 ha^{-1}), maize (Rs.7920 ha^{-1}), and chickpea (Rs.9506.25 ha^{-1}), followed by T_4, T_3 and T_2 accordingly, had the highest economic return over FFP.

In this paper, the effects of only two selected treatments, Farmer's Fertiliser Practise (FFP) (T_1) and FFP - 50% N + 2 Spray of Nano Urea (T_2) on potato based on 187 trials, are being presented. Tiwari *et al.* (2021) evaluated total 187 trials on farmers' fields with potato in different districts of Uttar Pradesh during Rabi 2019-20 with five treatments. Results showed that FFP-50% N + 2 Sprays of Nano-N (T_2) obtained a higher B:C ratio than FFP, or T_1, obtained from farmer's fertiliser practise (FFP).

During the *rabi* seasons of 2019-20 and 2020-21, Neogi and Das (2022) conducted a field experiment to ascertain the impact of nitrogen and zinc, when administered as nano form fertilisers, on the growth and productivity of potato in inceptisols. The treatment T_8 with the application of 100% RDF of NPK+ foliar nano-N sprays + foliar nano-Zn sprays showed the highest net return (Rs.1,71,466 ha^{-1}) and benefit cost ratio (2.69). Under the treatment T_1 (control), a minimum net return of Rs.16080 ha^{-1} and a benefit cost ratio of 0.80 were noted. It was clear that applying 100% RDF of NPK+2 foliar spraying of nano-N + 2 foliar spraying of nano-Zn boosted the net return by 64.7% over applying 100% RDF of NPK.

In order to increase the productivity and profitability of green gram, Saitheja *et al.* (2022) conducted a field experiment at the wetland farm of the Tamil Nadu Agricultural University, Coimbatore, during the summer season of 2022. They did this by using a variety of basal nitrogen doses and foliar applications of nano and regular urea at the Flower Initiation (FI) stage and for 15 days after. The treatment combination of basal supply of 100% RDN integrated with foliar spray of nano urea @ 4ml $litre^{-1}$ of water at flower initiation stage and 15 days thereafter accounted higher gross returns of Rs.100114 ha^{-1} and Rs.99976 ha^{-1}, respectively. The treatment combination of basal dose of 80% RDN integrated with foliar spray of nano urea @ 4ml $litre^{-1}$ of water at flower initiation stage and 15 days thereafter accounted higher net return of Rs.53549 ha^{-1}. At flower initiation stage and 15 days, Control + 1% urea (Normal) recorded a minimum gross return of Rs. 53199 ha^{-1}, a net return of Rs. 11068 ha^{-1} and a B: C ratio of 1.26.

CHAPTER III
MATERIALS AND METHODS

The present investigation entitled "**Smart Nutrient Management using Nano Urea on Rabi Maize (*Zea mays* L.) under rainfed situation"** was conducted at the Post graduate experimental plot, Department of Agronomy, Biswanath College of Agriculture, Assam Agricultural University, Biswanath Chariali, Assam during the *rabi* season, 2022-23. The methodology followed and materials used in conducting the experiment are described in this chapter.

3.1 Location of the experimental site

The experiment site is situated at 26˚43′32″ N latitude and 93˚7′59″ E longitude with an altitude of 86.70 m above mean sea level with uniformly plain topography. It lies in the North Bank plain Zone of Assam.

3.2 Climatic conditions

The Post graduate experimental plot, Department of Agronomy, Biswanath College of Agriculture, Biswanath Chariali, Assam Agricultural University situated within the North Bank plain Zone of Assam experiences a sub tropical climate. Summer season prevails during May to August and the cold winter from December to January whereas a mild winter is experiences during September to November and February to March. This zone receives the highest intensity of rainfall during monsoon season, which normally begins from first week of June. However, pre-monsoon shower occurs during the month of March to May. The period between January to February experiences scanty rainfall. The station received average annual rainfall of 1998 mm during 1972-2021, while during pre-monsoon (March-May), monsoon (June-September), post monsoon (October-November) and winter (December-February) periods, the average rainfall was 484.2 mm (24.48%), 1276.1 mm (64.51%), 152.4 mm (7.70%), and 65.3 mm (3.30%), respectively.

The weekly data on weather parameters such as rainfall (mm), mean maximum and minimum temperature (°C), relative humidity (%), mean evaporation (mm), wind speed (kmph) and bright sunshine hours (hr) in standard meteorological week (SMW) during the experimental period was recorded at the meteorological observatory of the department of Agricultural Meteorology, Biswanath College of Agriculture, Assam Agricultural University, Biswanath Chariali and presented in Annexure-I and graphically depicted in Fig. 3.1.

The weekly mean maximum temperature during the crop growth period ranged from 21.6° to 33.4°C while the mean minimum temperature ranged from 8.05°C to 16.05°C. The mean relative humidity (RH) ranged from 89.4% to 95% in the morning hours whereas in the evening hours, it ranged from 51.3% to 74.1%. Total rainfall of 185.4 mm was received during crop growth period out of which, the highest amount received was during 8th October to 14th October, 2022 with total rainfall of 68.6 mm which coincide with Knee high stage of the crop. The total number of rainy days was 19 during the entire crop growth period. Variation was also observed in other weather parameters viz., mean bright sunshine hours, wind speed, etc. The mean bright sunshine hours varied from 1.2 to 9.6 hours per day during the crop growth period while the mean evaporation during the crop growth period was 2.11 mm day^{-1} and the average wind speed varied from 0.97 to 1.92 km hr^{-1} during the crop growth period.

3.3 Soil characteristics of the experimental site

The soil samples were analyzed at the soil testing laboratory, department of soil science, Biswanath College of Agriculture, AAU, Biswanath Chariali and the soil testing laboratory of All India Coordinated Research Project for Dryland Agriculture, Biswanath Chariali centre, Assam Agricultural University.

Composite soil samples were drawn at random from a depth of 0-15 cm from the experimental field. The soil was then air dried, powdered and allowed to pass through 2 mm sieve and analyzed for different physio-chemical properties including textural class, available soil moisture, pH, soil organic carbon, available nitrogen, phosphorus and potassium by adopting the standard procedures presented in Table 3.1 and Table 3.2 along with the results. The soil of the experimental site was sandy loam in texture. The soil was acidic in reaction, medium in organic Carbon, available Nitrogen, Phosphorus and Potassium.

3.3 Soil Moisture regime

The effect of different nano-urea application on soil moisture content (%) is 13.79% at sowing, 9.42% at knee high, 12.54% at tasseling and 13.41% at harvest was recorded throughout the crop periods. The highest soil moisture content was seen at sowing time of the crop.

Throughout the period of field investigation soil moisture regime was fluctuated due to the influence of agro-meteorological parameters, more particularly the rainfall which led to rise and fall of soil moisture content.

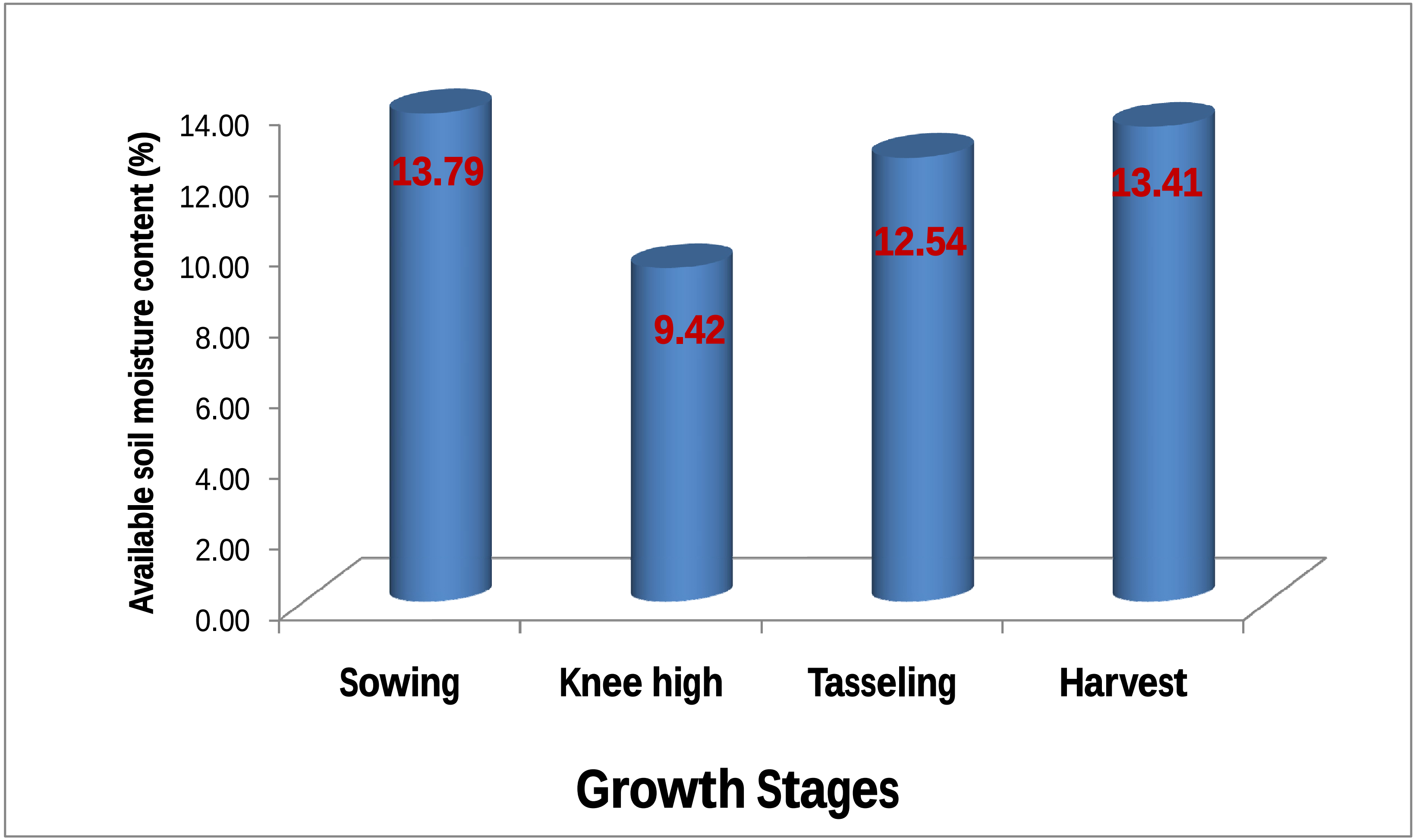


Fig. 3.1: Available soil moisture content throughout the growing period

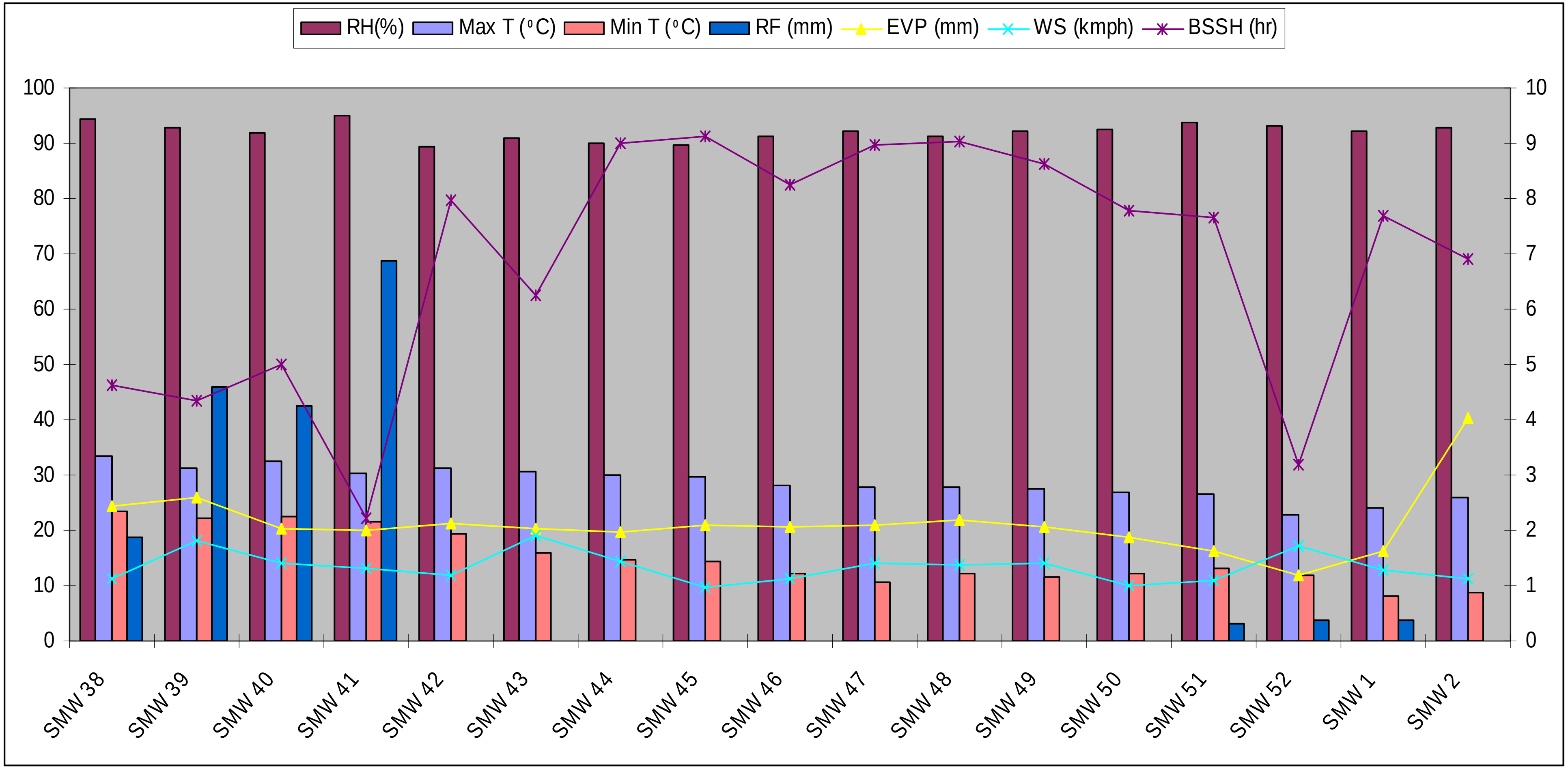


Fig.3.2: Meteorological observations during crop growing period

Table 3.1: Soil physical characteristics of the experimental site

Sl. No.	Particulars	Value obtained	Method
i	Sand (%)	56.92	Hydrometer method (Kaddah, 1974)
ii	Silt (%)	22.90	
iii	Clay (%)	20.17	
iv	Textural class	Sandy loam	
v	Soil Moisture (%)	13.05	Digital soil moisture meter (Model HH2)

Table 3.2: Soil chemical properties of the experimental site

Sl. No.	Particulars	Value obtained	Range	Method
i	pH	4.86	Acidic	Glass electrode method (Jackson, 1973)
ii	Organic carbon (%)	0.60	medium	Rapid titration method (Walkley and Black, 1934)
iii	Available N (kg ha^{-1})	265.86	medium	Modified Kjeldahl’s method (Jackson, 1973)
iv	Available P_2O_5 (kg ha^{-1})	20.70	medium	Bray-1 Method (Jackson, 1973)
v	Available K_2O (kg ha^{-1})	206.85	medium	Flame Photometry (Jackson, 1973)

3.5 Experimental details:

3.5.1 Experimental techniques and design

The experiment was laid out in a Randomized Block Design (RBD) with 11 treatments replicated thrice. The treatments were allocated randomly using a random number table in each replication. The plan of layout of the experiment is showed in Fig.3.2.

Experimental design	: Randomized Block Design (RBD)
Number of replication	: 3
Number of plot in each replication	: 11
Total number of plots	: 33
Size of plot	: 5 m x 4 m
Net Area	: 660 m^2
Gross Area	: 972 m^2

3.5.2 Treatment details

The details of the treatment have been mentioned below along with their notations.

T_1: Recommended Dose of Fertilizer (RDF)
T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage
T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage
T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage
T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage
T_6: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage
T_7 : 25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage
T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage
T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage
T_{11}: 100% P & K

3.5.3 Details of the variety, seed rate and fertilizer doses:

Crop	Variety	Seed rate	Fertilizer Dose
Maize	Hybrid Maize JKMH-4152	22.5 kg ha^{-1}	60:40:40 $N:P_2O_5:K_2O$ Kg ha^{-1}

3.6. Land preparation

The experimental land was ploughed thoroughly twice with the help of tractor drawn disc plough followed by rotavator to obtain a fine tilth. Weeds and other stubbles were removed from the field at the time of final land preparation. The land was uniformly leveled, smoothened with a wooden plank. Then the experimental plots were laid out as per the layout plan and drainage paths were formed between plots to discharge excess water.

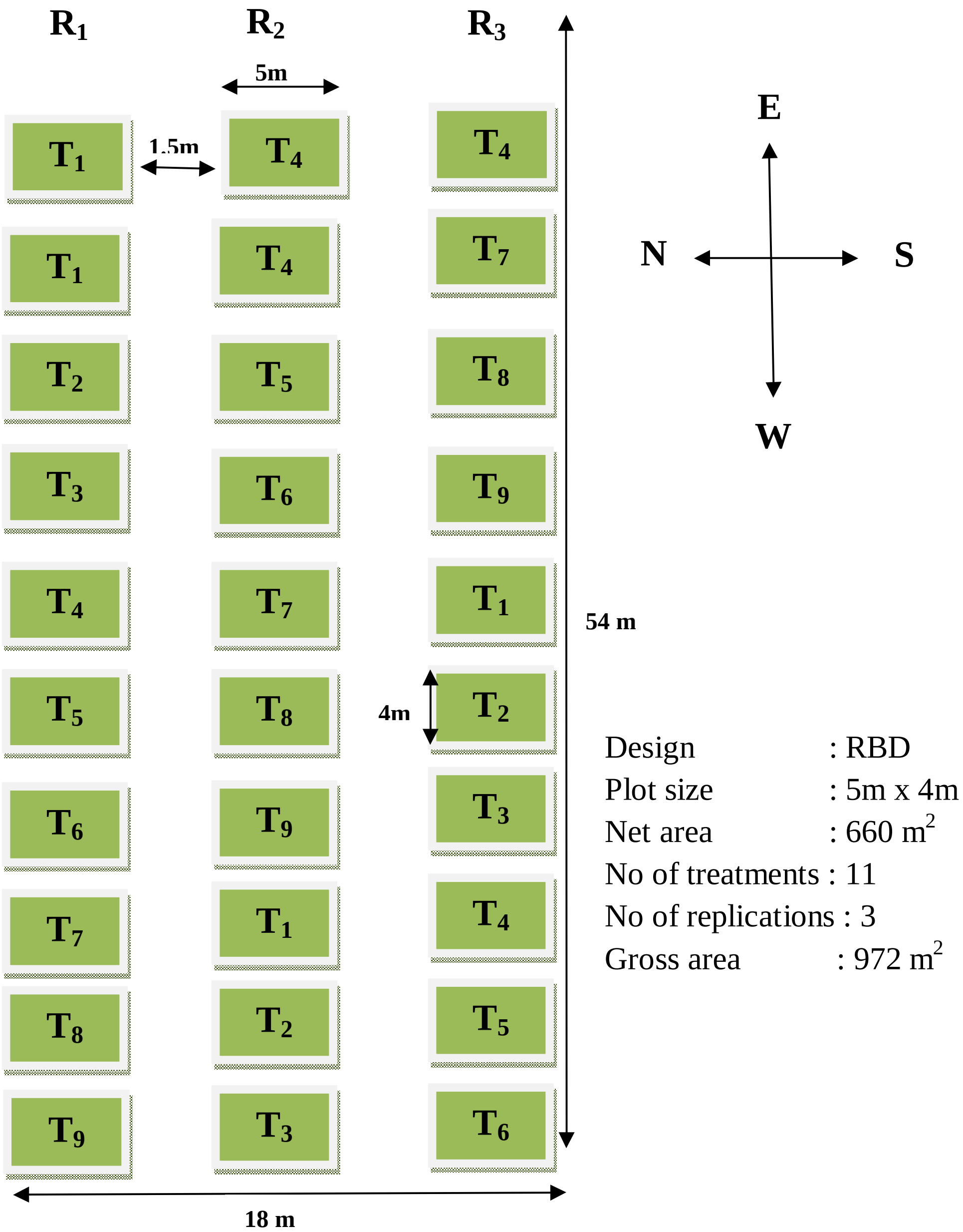
3.7. Inorganic Nutrients

In the experiment conducted, a dose of 60:40:40 $N:P_2O_5:K_2O$ Kg ha^{-1} was applied in the experiment. Full dose of phosphorus and potassium and respective treatment doses of Nano-urea were applied in the before sowing of the maize crop.

3.8. Agronomic practices

The crop schedule in field operations carried out during the experiment conducted in the Table 3.3 Crop Calendar.

Sl. No.	Activity	Tentative time
1	Site selection	2nd September, 2022
2.	Initial soil sampling	5th September, 2022
3.	Land preparation	12th September, 2022
4.	Lay out of the experiment, Seedbed and application of Fertilizer	18th September, 2022
5.	Sowing of seeds	20th September, 2022
6.	Intercultural operations	16.10.2022 to 21.10.2022
7.	Nano urea foliar application	23.10.2022 and 05.12.2022
8.	Harvesting of maize	19.01.2023
9.	Soil and plant sampling	25.01.2023



T_1 : RDF
T_2 : 100% P&K + Nano urea @ 6ml/l at KH and TS
T_3 : 100% P&K + Nano urea @ 8ml/I at KH and TS
T_4 : 100% P&K + Nano urea @ 10ml/l at KH and TS
T_5 : 25% N + 100% P&K + Nano urea @ 6ml/l at KH and TS
T_6 : 25% N + 100% P&K + Nano urea @ 8ml/l at KH and TS
T_7 : 25% N + 100% P&K + Nano urea @ 10ml/l at KH and TS
T_8 : 50% N + 100% P&K + Nano urea @ 6ml/l at KH and TS
T_9 : 50% N + 100% P&K + Nano urea @ 8ml/l at KH and TS
T_{10} : 50% N + 100% P&K + Nano urea @ 10ml/l at KH and TS
T_{11} : 100% P&K

Fig. 3.3: Plan of the experimental layout

3.9 Sowing of seeds

Before sowing, healthy and matured seeds of maize crops were treated with fungicide Bavistin @ 2.2 g kg^{-1} seed to protect the crop from seed borne diseases. The crops were all sown following the package of practices of *rabi* crops of Assam, 2021. The depth of sowing was maintained at about 3-5cm and seeds were covered with soil. The seed rate, row to row and plant to plant spacing of the crop maintained in the experiment are given in Table 3.4

Table 3.4: Seed rate and spacing of Maize crops

Crops	Seed rate	Spacing
Maize	22.5 kg ha^{-1}	Sole : 60 cm x 30 cm

3.10 Intercultural operation

Manual weeding was done twice at 25 and 50 days after sowing and subsequent weeding by light hoeing was given when necessary in all the treatments to keep the plots weed free throughout the crop growth period. No chemical weeding was undertaken. Earthing up was done subsequently after weeding.

3.11 Plant protection measures- The maize plant showed slight infestation by stem borer prior to tasseling stage, which was immediately controlled by application of 'Lambda' (Cyhalothrin 25 EC) @ 1.5 ml in 1 lit of water.

3.12 Foliar application of nitrogen

The Foliar application of nano urea was done at knee high stage 30 days after sowing and another at tasseling stage 60 days after sowing according to the respective treatments.

3.12 Harvesting

Harvesting was done when 75-80% of the cob husk turned pale yellow in color and the grains were hard enough having less than 30% moisture and shelled after sufficient sun drying.

3.13 Observation on Morphological parameters

i) Plant height: Five plants were selected randomly in each plot and height of the plants was measured from base of the plant to the base of the fully opened top leaf until tassel emergence (At knee high, tasseling and harvesting stages). The plant height was measured from the base of the plant to the collar of flag leaf. The average was calculated and expressed as cm plant^{-1}

ii) Number of leaves plant^{-1}: The number of leaves plant^{-1} was recorded by counting the number of fully opened leaves of randomly selected five plants at different stages of knee high, tasseling and at harvest and then the average was calculated.

iii) Plant Population: From each plot, the numbers of plants were recorded and the average of the recorded data was taken for statistical analysis.

iv) Girth of stem: The ground level, Knee high level and breast level were recorded for girth of stem at harvesting stage and then the average was calculated and expressed as cm plant^{-1}

3.14 Observation on Physiological parameters

i) Leaf area index (LAI) plant^{-1}: LAI plant^{-1} was calculated by dividing the leaf area per plant by the land area occupied by single plant at different interval of 30 DAS, 60 DAS and at harvest and then the average was worked out.

Leaf area index was worked out using the formula given by Sestak *et al.* (1971), as indicated below.

$$LAI = \frac{\text{leaf area per plant}}{\text{ground area occupied by plant}}$$

ii) Total Dry matter accumulation plant^{-1}: Five plants from each plot were randomly selected to record the dry matter production. The sampled plants were separated into roots, shoot parts and cob. The harvested samples were sun dried and then dried in oven at 60-70°C till constant weight. Dry weight was recorded separately to assess dry matter accumulation in different parts of plant. The calculated averaged weight was expressed in g plant^{-1}.

iii) Relative leaf water content (RLWC): Three plants from each plot were randomly selected at the time of tasseling and harvest stage to record the relative leaf water content. Accordingly leaf fresh weight, oven dried weight (at 60-70°C) and turgid/saturated weight was recorded to calculate the RLWC (%) using the following formula as suggested by González and González-Vilar (2001) and the average was worked out.

$$\text{RLWC (\%)} = \frac{\text{fresh weight} - \text{dry weight}}{\text{saturated weight} - \text{dry weight}} \times 100$$

iv) Crop growth rate (CGR): Crop growth rate for the period from 0 to 30 DAS, 30 to 60 DAS and 60 DAS to harvest were calculated using the mathematical formula given by Watson (1958) and expressed in g m^{-2} day^{-1}.

$$\text{CGR} = \frac{W_2 - W_1}{A(T_2 - T_1)} \text{ g m}^{-2} \text{ day}^{-1}$$

Where,

W_1 and W_2 = Plant dry weight recorded at T_1 and T_2 days, respectively

T_2-T_1 = Time interval in days

A = Ground area in which W_1 and W_2 were estimated

v) Relative growth rate (RGR): Relative growth rate for the period from 0 to 30 DAS, 30 to 60 DAS and 60 DAS to harvest were calculated using the mathematical formula given by Watson (1958) and expressed in g m^{-2} day^{-1}.

$$\text{RGR} = \frac{\log W_2 - \log W_1}{(T_2 - T_1)} \text{ g g}^{-1} \text{ day}^{-1}$$

Where,

W_1 and W_2 = Plant dry weight recorded at T_1 and T_2 days, respectively

T_2-T_1 = Time interval in days

A = Ground area in which W_1 and W_2 were estimated

vi) Total Chlorophyll Content (mg g^{-1}fw):

Dried leaf samples were collected. Small sections of dried leaves were cut out while avoiding the big and mid ribs. To evaluate the chlorophyll content, 0.1g of dried leaves was weighed in an electric weighing balance. The measured sample was then immersed in a test tube filled with 5 ml of Dimethyl sulfoxide (DMSO), covered with aluminium foil, and kept in a dark place overnight. The following day, the leaf sections were taken out and 10 ml of volume makeup was done.

The samples were placed in the cell for observation through spectrophotometer. The Optical Density (OD) of the sample was recorded on PC based double beam spectrophotometer 2202 using 663 and 645 nm wave length.

Total chlorophyll content in the dried as well as fresh leaves was calculated and expressed in mg/g.

Total Chlorophyll = $[20.2(A_{645}) + 8.02(A_{663})] \times V / (1000 \times W)$ mg g^{-1} fw

Where,

A645 and A663= Optical Density value at 645nm and 663nm wavelength of light respectively

V = Final volume of chlorophyll extract in DMSO (ml)

W = Fresh/Dried weight of leaf sample (g)

3.15 Observation on yield and yield attributing parameters

i) Number of Seed per cobs: Five cobs were selected randomly in each plot and number of seeds per cobs were counted and recorded per cob. Their average was expressed in seeds per cobs.

ii) Length and Girth of cob^{-1}: Five cobs from each plot were selected randomly and were measured in cm individually. The average was calculated and measured in cm of lenth and girth of cob^{-1}.

iii) Test weight: One hundred (100) healthy well dried seeds were counted from the bulk of seeds harvested from each plot and their weights were recorded in gram and expressed as test weight.

iv) Cob weight: Five cobs from each plot were selected randomly and their weight along with husk was recorded individually. Then the average was calculated out and expressed in g cob^{-1}.

v) Grain yield: At maturity, cobs from each plot were harvested separately, then sun dried and cleaned. The grains were shelled from the dried cobs manually and grain yield of the individual net plot was recorded and converted in q ha^{-1}.

vi) Stover yield: Stover yield was recorded from each plot after complete sun drying the remaining plant residue after harvest and expressed in q ha^{-1}.

vii) Harvest index (HI): Harvest index is defined as the ratio of economic yield to total biological yield (Donald and Hamblin 1976) and expressed in percentage.

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

Economic yield = Grain yield (q ha^{-1})

Biological yield = Grain yield + stover yield (q ha^{-1})

3.16 Soil analysis

3.16.1 Collection of soil samples: During the field experiment composite soil samples were collected from each plot before sowing and also after harvest of the maize crop. The collected soil samples were dried under shade, powdered and then passed through 2 mm sieve and preserved for analysis. For organic carbon analysis, the 2 mm sieved soil samples were subjected for further grinding and passed through 0.2 mm sieve.

3.16.2 Soil physical and chemical parameters

i) Determination of soil texture and p^H: The relative proportion of sand, silt and clay i.e. soil texture was determined using Hydrometer method developed by Kaddah (1974) whereas soil PH was determined in 1:2.5 (soil:water) suspension using the glass electrode method as narrated by Jackson (1973).

ii) Determination of moisture content: From each plot, five randomly selected spots were tested for soil moisture content in % separately using Digital soil moisture meter (Model HH2). The readings were duly recorded at different time intervals and their averages were worked out

iii) Available nitrogen: Available nitrogen (kg ha^{-1}) in soil was estimated Modified Kjeldahl method as described by Jackson (1973).

iv) Available phosphorus: Available phosphorous (kg ha^{-1}) in soil was estimated by Brays-1 method Method as described by Jackson (1973).

v) Available potassium: Available phosphorous (kg ha^{-1}) in soil was estimated by flame photometry method as described by Jackson (1973).

vi) Organic carbon: Organic carbon (%) in the soil was estimated by rapid titration method as suggested by Walkley and Black (1934).

3.17 Economic indices

Recommendation and adoption of any practice by the cultivars depend upon its economics indices. Therefore, it becomes essential to work out economics of the treatments tested for judging the best treatment under study, for getting higher net profit per hectare. Economics was calculated on the basis of the prevailing market prices of the commodities during the study.

i) Cost of cultivation: Cost of cultivation was calculated for each treatment based on the prevailing market prices of the different inputs.

ii) Gross return: Gross return was estimated considering the monetary value of the produced in different treatments based on the market prices of different produce.

iii) Net return: The net return was calculated by subtracting the cost of cultivation from the gross return.

iv) Benefit:Cost ratio: Benefit: cost ratio was computed dividing gross return by cost of cultivation.

$$\text{B:C ratio} = \frac{\text{Gross return(Rs. ha}^{-1}\text{)}}{\text{cost of cultivation(Rs. ha}^{-1}\text{)}}$$

vii) Economic Efficiency: Efficiency can be expressed as a ratio by using the following formula.

$$\text{Economic Efficiency} = \frac{\text{Output (Rs. ha}^{-1}\text{)}}{\text{Input (Rs. ha}^{-1}\text{)}}$$

It is express efficiency as a percentage by multiplying the ratio by 100.

3.18 Efficiency

i) Production Efficiency: Production efficiency is an economic concept that indicates the maximum level of output a manufacturer can produce without lowering the output of another product. These theory was given by Debreu-Farrell 1951.

$$\text{Production Efficiency} = \frac{\text{Actual Output}}{\text{Standard Output}}\ X\ 100$$

ii) Agronomic efficiency: Agronomic efficiency (AE) is the efficiency of applied nutrients in increasing grain or biomass yield. It is calculated as the increase in yield per unit of nutrient applied.

$$\text{Agronomic Efficiency} = \frac{\text{Yield of Fertilizer treatment} - \text{Yield of non fertilizer treatment}}{\text{Fertilizer N content}}$$

iii) Rain Water Use Efficiency (RWUE): The Rain Use Efficiency (RUE) factor is the quotient of annual primary production by annual rainfall, i.e. the number of kilograms aerial dry matter phytomass produced over 1 ha in 1 year per millimetre of total rain fallen. It is calculated as WUE (kg yield per mm rainwater) = Yield (kg ha^{-1}) divided by cumulative rainfall (mm) from sowing to harvest

3.19 Statistical Analysis

The collected data was analysed statistically by the method described by Gomez and Gomez (1984). Significance of the variance due to the treatment effect was determined by calculating the respective ‘F’ values. Whenever variance ratio (F) was significant, the critical difference was worked at 5% level otherwise only S.Ed was calculated. Data on individual crops were interpreted using mean value wherever statistical analysis was not applicable.

PLATE 1: LAND PREPARATION

PLATE 2: FERTILIZER AND SOWING

PLATE 3: GERMINATION

PLATE 4: 30 DAYS AFTER PLANTING

PLATE 5: MIXING OF NANO-UREA FERTILZER

PLATE 6: SPRAYING OF NANO-UREA FERTILIZER

CHAPTER IV
EXPERIMENTAL FINDINGS

The experimental findings of the study entitled "Smart Nutrient Management using Nano Urea on Rabi Maize (*Zea mays* L.) under rainfed situation" carried out during the *rabi* season of 2022-23 at the Post graduate experimental plot, Department of Agronomy, Biswanath College of Agriculture, Assam Agricultural University, Biswanath Chariali, Assam are presented in this chapter along with tables and diagrams. Observations were recorded on growth parameters, physiological parameters, yield attributing and yield parameters, efficiency, physico-chemical properties of soil and economics during the investigation.

4.1 Growth parameters of maize

4.1.1 Plant height

The data pertaining to plant height at different time intervals (knee high, tasseling and physiological maturity stages) as influenced by varied levels of nano-urea and conventional urea are presented in the Table 4.1.

The effect of different nano-urea application on plant height among treatments measured at knee high, tasseling and physiological maturity stages were found to be significant. At knee high stage, the maximum plant height (103.20 cm) was recorded in T_1 *i.e.* recommended dose of fertilizer which was statistically at par with T_7 *i.e.* 25 % N + 100% P & K + spray of nano-urea @ 10 ml l^{-1}, T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} , T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 8 ml l^{-1} and T_{10} *i.e.* 50% N + 100% P & K + spray of nano-urea @ 10 ml l^{-1}. Maximum plant height (245.20 cm at tasseling and 243.80 cm) was recorded in T_8 which statistically significant. The lowest plant height (70.13 cm at knee height, 194.13 cm at tasseling and 200.13 cm at physiological maturity respectively) was recorded in T_{11} *i.e.* 100% P & K.

4.1.2 Number of leaves plant^{-1}

The data pertaining to number of leaves at different growth stages (knee high, tasseling and physiological maturity stages) as influenced by varied levels of nano-urea and conventional urea are presented in the Table 4.2.

The effect of different nano-urea application on number of leaves among treatments measured at knee high, tasseling and physiological maturity stages were found to be significant. The highest numbers of leaves (8.73 nos.) was recorded in T_1 *i.e.* rrecommended dose of fertilizer which was statistically at par with T_8 *i.e.* 50 % N + 100% P & K + spray of nano- urea @ 6 ml l^{-1} at knee high stage. Maximum number of leaves (11.67 nos. at tasseling) was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was found at par with T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 8 ml l^{-1} while at physiological maturity, increased number of leaves (9.60 nos.) was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was comparable with T_9 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1}. The lowest number of leaves recorded to be 8.20 nos. at knee height, 9.00 nos. at tasseling and 9.00 nos. at physiological maturity respectively in T_{11} (100% P & K).

4.1.3 Girth of the stem

The data on girth of the stem at physiological harvest as influenced by varied levels of nano-urea and conventional urea effects are presented in the Table 4.3.

Significant effect of nano-urea application was found to with respect to girth of the stem. The maximum girth of the stem (7.53 cm) was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was, however comparable to T_9 (50% N + 100% P & K + spray of nano urea @ 8 ml l^{-1}) and T_{10} (50% N + 100% P & K + spray of nano urea @ 10 ml l^{-1}). The T_{11} *i.e.* 100% P & K registered the lowest girth of 5.34 cm.

4.2 Physiological parameters of maize

4.2.1 Leaf area index

Leaf area index per plant at different time intervals like knee high, tasseling and physiological maturity stages differed significantly among treatments due to varied levels of nano-urea and conventional urea. The data are presented in the Table 4.4.

The greatest value of leaf area index (1.84) was recorded in T_1 *i.e.* recommended dose of fertilizer at knee high stage which was found at par with T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 10 ml l^{-1}. On the other hand, the increased leaf area index of 4.63 at tasseling was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was significantly highest among all the treatments, whereas at physiological maturity maximum leaf area index (3.10) was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was comparable with T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 8 ml l^{-1} and T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 10 ml l^{-1} . The lowest leaf area index plant^{-1} (1.17 at knee high, 2.78 at tasseling and 1.78 at physiological maturity stages) respectively was recorded in T_{11} *i.e.* 100% P & K.

Table 4.1: Plant Height (cm) at various growth stages as influenced by varied levels of nano urea and conventional urea

Treatment	Plant Height (cm)		
	Knee high	Tasseling	Physiological maturity
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	103.20	213.87	217.53
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	84.15	194.93	202.00
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	89.20	194.47	208.20
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	91.40	200.80	214.90
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	92.80	206.40	215.17
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	94.93	209.53	218.67
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	100.67	220.73	226.27
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	101.07	245.20	243.80
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	102.53	244.93	232.40
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling sta	101.13	226.93	226.87
T_{11}: 100% P & K	70.13	194.13	200.13
S.Ed±	1.95	4.49	1.88
CD(P=0.05)	3.96	9.15	3.83

Table 4.2: Number of green leaves plant^{-1} at various growth stages as influenced by varied levels of nano urea and conventional urea

Treatment	Green leaves per plant (Nos.)		
	Knee high	Tasseling	Physiological maturity
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	8.73	10.33	9.38
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	8.27	9.67	9.20
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	8.33	10.00	9.25
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	8.38	10.10	9.26
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	8.49	10.20	9.34
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	8.46	10.20	9.53
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	8.47	10.33	9.53
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	8.57	11.67	9.60
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	8.51	11.53	9.57
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	8.50	10.40	9.40
T_{11}: 100% P & K	8.20	9.00	9.00
S.Ed±	0.10	0.14	0.16
CD(P=0.05)	0.21	0.30	0.33

Table 4.3: Girth of stem (cm) at physiological maturity as influenced by varied levels of Nano urea and conventional urea

Treatment	Girth of Stem (cm)
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	5.96
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	5.75
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	5.82
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	5.92
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	7.13
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	7.23
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	7.37
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	7.53
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	7.47
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	7.46
T_{11}: 100% P & K	5.34
S.Ed±	0.17
CD(P=0.05)	0.34

4.2.2 Total dry matter accumulation

Total dry matter accumulation per plant at different crop growth stages expressed as g plant^{-1} showing significant difference among treatments due to varied levels of nano-urea and conventional urea are presented in the Table 4.5.

At knee high stage, maximum accumulation of total dry matter (138.83 g) was recorded in T_1 *i.e.* recommended dose of fertilizer (RDF). The maximum total dry matter accumulation (214.76 g at tasseling and 645.26 g at physiological maturity) was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was statistically significant over rest of the treatment while the lowest (80.81 g at knee high stage, 113.59 g at tasseling and 269.43 g at physiological maturity) were recorded in T_{11} *i.e.* 100% P & K.

4.2.3 Crop growth rate plant^{-1}

Crop growth rate per plant (g m^{-2}day^{-1}) at different time intervals (between knee high and tasseling and between tasseling and physiological maturity stages) differed significantly among treatments due to varied levels of nano-urea and conventional urea are stated in the Table 4.6.

Significantly highest crop growth rate *i.e.* 209.79 g m^{-2} day^{-1} was registered in between knee high and tasseling under T_8 *i.e.* 100% P & K + spray of nano urea @ 6 ml l^{-1} which is statistically significant. Similarly, maximum crop growth rate of. 638.10 g m $^{-2}$ day^{-1} was recorded in between tasseling and physiological maturity in the same treatment *i.e.* T_8.

The lowest value of 110.89 and 265.64 g m^{-2} day^{-1} was recorded in between knee high and tasseling and in between tasseling and physiological maturity stages, respectively, in T_{11} *i.e.* 100% P & K.

4.2.4 Relative growth rate

Relative growth rate (g g^{-1} day $^{-1}$) at different time intervals (between knee high and tasseling and between tasseling and physiological maturity stages) differed significantly among treatments due to varied levels of nano-urea and conventional urea (Table 4.7).

Significantly increased relative growth rate per plant *i.e.* 0.32 g g^{-1} day^{-1} in between knee high and tasseling was recorded in T_6 *i.e.* 25% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which is, however at par with T_1 *i.e.* rrecommended dose of fertilizer (RDF) and T_7 *i.e.* 25% N + 100% P & K + spray of nano urea @ 8 ml l^{-1}. Between tasseling and physiological maturity, increased relative growth rate of 0.47 g g^{-1} day^{-1} was recorded in T_8 i.e. 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was found to be at par with T_9 and T_{10} (*i.e.* 100% P & K + spray of nano urea @ 6 ml l^{-1} and *i.e.* 50 % N + 100% P & K + spray of nano urea @ 10 ml l^{-1}).

The T_{11} *i.e.* 100% P & K recorded the lowest relative crop growth rate of 0.15 g g^{-1} day^{-1} between knee high and tasseling and 0.38 g $g^{-1}$$day^{-1}$ in between tasseling and physiological maturity stages respectively.

4.2.5 Total leaf chlorophyll

The data pertaining to total leaf chlorophyll measured at tasseling and expressed in µmol m^{-2} presented in the Table 4.8 showed significant effect owing to varied levels of nano-urea and conventional urea.

The treatment T_8 (50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1}) was found to have the significant maximum value of total leaf chlorophyll (1.37 µmol m^{-2}) while the lowest total leaf chlorophyll (0.73 µmol m^{-2}) was recorded in T_{11} *i.e.* 100% P & K.

4.2.6 Relative leaf water content

The data pertaining to relative leaf water content (%) measured at tasseling are presented in the Table 4.9.

The effect of different levels of application of nano-urea and conventional urea on relative leaf water content of the crop at tasseling stage was found to be significant. The greater magnitude (91.23 %) was recorded in T_8 *i.e.* 25% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was, however found comparable with T_9 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 10 ml l^{-1}. Further, the lowest value (70.30 %) was recorded in T_{11} *i.e.* 100% P & K.

Table 4.4: Leaf area index (LAI) at various growth stages as influenced by varied levels of nano urea and conventional urea

Treatment	Leaf area index(LAI)		
	Knee high	Tasseling	Physiological maturity
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	1.84	4.14	2.64
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	1.36	3.32	1.99
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	1.44	3.48	2.32
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	1.58	3.57	2.57
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	1.60	3.58	2.58
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	1.66	3.59	2.58
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	1.66	3.72	2.59
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	1.67	4.63	3.10
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	1.68	4.43	2.94
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	1.79	4.29	2.79
T_{11}: 100% P & K	1.17	2.78	1.78
S.Ed±	0.03	0.06	0.22
CD(P=0.05)	0.06	0.12	0.45

Table 4.5: Total dry matter accumulation (g plant^{-1}) at various growth stages as influenced by varied levels of nano urea and conventional urea

Parameters	Knee high	Tasseling	Physiological maturity
T_{1}: Recommended Dose of Fertilizer (RDF)	138.83	180.20	480.93
T_{2}: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	82.71	141.20	371.71
T_{3}: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	87.82	144.83	394.95
T_{4}: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	85.82	146.06	395.63
T_{5}: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	96.86	156.21	410.39
T_{6}: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	80.44	167.96	413.40
T_{7} :25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage	105.60	168.45	437.27
T_{8}: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	121.33	214.76	645.26
T_{9}: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	120.23	201.54	586.53
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	123.48	181.73	514.82
T_{11}: 100% P & K	80.81	113.59	269.43
S.Ed(±)	4.03	3.50	3.26
CD (p=0.05)	8.20	7.12	6.64

Table 4.6: Crop Growth Rate plant^{-1} (g m^{-2} day^{-1}) in between knee high & tasseling and tasseling & physiological maturity stages as influenced by varied levels of nano urea and conventional urea

Treatment	Crop growth rate (g m^{-2} day $^{-1}$)	
	Between Knee High & Tasseling stage	Between Tasseling & Harvesting stage
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	176.65	474.92
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	138.67	367.00
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	141.90	390.12
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	142.86	390.76
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	152.98	405.18
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	165.27	407.80
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	164.93	431.65
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	209.79	638.10
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	197.53	579.81
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stag	177.84	508.76
T_{11}: 100% P & K	110.89	265.64
S.Ed±	2.28	4.03
CD(P=0.05)	4.63	8.21

Table 4.7: Relative Growth Rate plant^{-1} (g g^{-1} day^{-1}) in between knee high and tasseling stages and tasseling and physiological maturity stage as influenced by varied levels of nano urea and conventional urea

Treatment	Relative growth rate (g g^{-1} day^{-1})	
	Between knee high & tasseling stage	Between tasseling & harvesting stage
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	0.23	0.43
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	0.27	0.43
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	0.22	0.43
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	0.18	0.43
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	0.21	0.42
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	0.32	0.39
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	0.2	0.42
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	0.16	0.47
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	0.22	0.46
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	0.19	0.46
T_{11}: 100% P & K	0.15	0.38
S.Ed±	0.04	0.01
CD(P=0.05)	0.09	0.03

Table 4.8: Chlorophyll a, Chlorophyll b and Total Chlorophyll (mg g^{-1} fw.) at knee high, tasseling and physiological maturity stages as influenced by varied levels of nano urea and conventional urea

Parameters	Chlorophyll a (mg g^{-1} fw.)	Chlorophyll b (mg g^{-1} fw.)	Total Leaf Chlorophyll (mg g^{-1} fw.)
T_1: Recommended Dose of Fertilizer (RDF)	0.95	0.36	1.31
T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	0.71	0.24	0.95
T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	0.70	0.26	0.96
T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	0.74	0.24	0.98
T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	0.74	0.24	0.98
T_6: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	0.83	0.30	1.13
T_7 :25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage	0.88	0.28	1.16
T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	1.02	0.34	1.37
T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	0.97	0.32	1.30
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	0.97	0.31	1.28
T_{11}: 100% P & K	0.54	0.19	0.73
S.Ed(±)	0.003	0.001	0.006
CD (p=0.05)	0.007	0.003	0.012

Table 4.9: Relative leaf water content (%) at tasseling stage as influenced by varied levels of nano urea and conventional urea

Treatment	Relative leaf water content (%)
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	75.57
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	72.01
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	72.92
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	73.76
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	78.80
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	78.90
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	79.10
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	91.23
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	90.72
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	85.61
T_{11}: 100% P & K	70.30
S.Ed±	0.30
CD(P=0.05)	0.66

4.3 Yield parameters of maize

4.3.1 Length of cob

Length of cob was found to be significantly influenced by varied levels of nano and conventional urea (Table 4.10).

The greatest cob length (35.88 cm) was recorded in T_8 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which is statistically at par with T_9 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1}. Lowest value (25.61 cm) was recorded in T_{11} *i.e.* 100% P & K.

4.3.2 Girth of Cob

The crop responded significantly towards varied levels of nano and conventional urea with respect to girth of cob (Table 4.10).

Thicker cob of 20.29 cm girth was recorded in T_8 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was, however comparable with T_9 and T_{10} *i.e.* 50 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1} and 50% N + 100% P & K + spray of nano urea @ 10 ml l^{-1} , respectively. The lowest cob girth (15.69 cm) was recorded with T_{11} (100% P & K).

4.3.3 Weight of Cob

The cob weight as influenced by varied levels of nano-urea and conventional urea are presented in the Table 4.10 which showed significant effect.

Significantly highest cob weight (368.00 g) was recorded in T_8 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1} while the lowest value (191.67 g) was recorded under T_{11}.

4.3.4 Number of seeds cob^{-1}

Crop response towards varied levels of nano-urea and conventional urea was found significant in term of number of seeds cob^{-1} which is mentioned in Table 4.11.

The crop receiving treatment T_8 (50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1}) recorded significantly maximum number of seeds cob^{-1} (615.93) while the lowest number of seeds cob^{-1} (375.07) was recorded in T_{11}.

4.3.5 Test weight (g)

Data enumerated in Table 4.11 depicted that the test weight (g) was significantly influenced by varied levels of nano-urea and conventional urea.

The greatest value of test weight (247.54 g) was recorded in T_8 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was, however statistically at par with T_9 and T_{10} *i.e.* 50 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1} and 50% N + 100% P & K + spray of nano urea @ 10 ml l^{-1}, respectively. Lowest test weight (175.26 g) was recorded T_{11} *i.e.* 100% P & K.

4.3.6 Stover yield

The data pertaining to stover yield (q ha^{-1}) as influenced by varied levels of nano-urea and conventional urea are presented in the Table 4.12.

The crops grown under T_9 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1} registered significantly increased stover yield (112.33 q ha^{-1}) which was, however comparable with T_8 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1}. The lowest value of 75.33 q ha^{-1} was recorded under T_{11} *i.e.* 100% P & K.

4.3.7 Grain yield

The data pertaining to grain yield (q ha^{-1}) influenced by varied levels of nano-urea and conventional urea effects are presented in the Table 4.12.

Highest grain yield (72.25 q ha^{-1}) was recorded in T_8 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was statistically at par with T_9 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1}. The lowest grain yield (42.10 q ha^{-1}) was recorded in T_{11} *i.e.* 100% P & K.

4.3.8 Harvest index (%)

The data pertaining to harvest index (%) as influenced by varied levels of nano and conventional urea effects are presented in the Table 4.12.

The highest magnitude of harvest index (%) (39.50 %) was recorded in T_8 i.e. 50 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was however, comparable with T_1 *i.e.* recommended dose of fertilizer, T_3 *i.e.* 100% P & K + spray of nano urea @ 8 ml l^{-1}, T_5 *i.e.* 25 % N + 100% P & K + spray of nano urea @ 6 ml l^{-1}, T_6 *i.e.* 25 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1}, T_7 *i.e.* 25 % N + 100% P & K + spray of nano urea @ 10 ml l^{-1}, T_9 *i.e.* 50 % N + 100% P & K + spray of nano urea @ 8 ml l^{-1} and T_{10} *i.e.* 50 % N + 100% P & K + spray of nano urea @ 10 ml l^{-1}. Lowest harvest index (%) (35.85 %) was recorded T_{11} *i.e.* 100% P & K.

Table 4.10: Length (cm), girth (cm) and weight (g) of cob as influenced by varied levels of nano-urea & conventional urea

Parameters	Length of cob (cm)	Girth of cob (cm)	Weight of cob (gm)
$\mathbf{T_1}$: Recommended Dose of Fertilizer (RDF)	30.55	18.66	340.00
$\mathbf{T_2}$: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	27.20	15.96	256.67
$\mathbf{T_3}$: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	27.65	16.71	268.33
$\mathbf{T_4}$: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	28.33	16.93	270.33
$\mathbf{T_5}$: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	28.36	17.17	280.00
$\mathbf{T_6}$: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	29.90	18.12	290.00
$\mathbf{T_7}$ **:** 25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage	30.95	18.21	297.00
$\mathbf{T_8}$: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	35.88	20.29	368.00
$\mathbf{T_9}$: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	32.56	18.77	345.00
$\mathbf{T_{10}}$: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	31.97	18.23	310.67
$\mathbf{T_{11}}$: 100% P & K	25.61	15.69	191.67
S.Ed(±)	2.14	1.09	5.80
CD (p=0.05)	3.36	2.23	11.84

Table 4.11: No of seeds cob^{-1} & Test weight (gm) as influenced by varied levels of nano-urea & conventional urea

Parameters	No. of seeds cob^{-1}	Test weight (g)
T_1: Recommended Dose of Fertilizer (RDF)	522.60	243.58
T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	454.00	222.36
T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	460.53	227.55
T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	467.87	231.70
T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	472.33	241.65
T_6: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	477.07	242.76
T_7 :25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage	517.67	243.85
T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	615.93	247.54
T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	595.13	244.99
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	531.73	242.31
T_{11}: 100% P & K	375.07	175.26
S.Ed(±)	5.68	2.80
CD (p=0.05)	11.57	5.92

Table 4.12: Grain yield (q ha^{-1}), Stover yield (q ha^{-1}) and Harvest Index (%) as influenced by varied levels of nano-urea & conventional urea

Parameters	**Grain yield (q ha^{-1})**	**Stover yield (q ha^{-1})**	**Harvest Index (%)**
T_1: Recommended Dose of Fertilizer (RDF)	60.46	97.33	38.32
T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	51.41	88.00	36.88
T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	53.1	88.75	37.43
T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	54.03	90.50	37.38
T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	57.03	95.00	37.51
T_6: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	61.22	101.33	37.66
T_7 :25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage	65.06	106.67	37.89
T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	72.25	110.67	39.50
T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	69.70	112.33	38.29
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	65.13	105.67	38.13
T_{11}: 100% P & K	42.10	75.33	35.85
S.Ed(±)	2.40	1.44	1.02
CD (p=0.05)	3.12	2.93	2.07

4.4 Efficiency parameters

4.4.1 Production efficiency

Production efficiency (%) was found to be differed significantly among treatments due to varied levels of nano and conventional urea (Table 4.13).

The highest magnitude of 120.42% was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was statistically at par with T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 8 ml l^{-1}. The lowest production efficiency (70.17%) was recorded T_{11} *i.e.* 100% P & K.

4.4.2 Agronomic efficiency

The varied levels of nano-urea and conventional urea significantly influenced the agronomic efficiency (kg kg^{-1}) of the crop (Table 4.13).

The greatest value of agronomic efficiency (3879.16 kg kg^{-1}) was recorded in T_2 *i.e.* 100% P & K + spray of nano urea @ 6 ml l^{-1}. While the lowest (30.60 kg kg^{-1}) was recorded T_1 *i.e.* recommended dose of fertilizer.

4.4.3 Rain water use efficiency

The data pertaining to rain water use efficiency (kg ha^{-1} mm^{-1}) calculated at harvest as influenced by varied levels of nano and conventional urea are presented in the Table 4.14.

The effect of different nano-urea application on rain water use efficiency at harvesting was found to be significant. The maximum rain water use efficiency (40.32 kg ha^{-1} mm^{-1}) was recorded in T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} which was found statistically at par with T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 8 ml l^{-1} while the lowest value (23.49 kg ha^{-1} mm^{-1}) was recorded in T_{11} *i.e.* 100% P & K.

4.5 Physico-chemical properties of soil

4.5.1 Soil p^H, soil organic carbon content and soil electrical conductivity

The varied levels of nano-urea and conventional urea failed to show any significant variation in with respect to soil p^H, soil organic carbon content (%) as well as soil electrical conductivity (%) at harvest (Table 4.15).

4.5.2 Available Nitrogen, Phosphorus and Potassium at harvest

The available Nitrogen (N), Phosphorus (P_2O_5) and Potassium (K_2O) at harvest differed significantly among treatments owing to different levels of nano and conventional urea (Table 4.16).

The Table 4.16 showed that the available nitrogen (268.75 kg ha^{-1}) was recorded in T_{10} *i.e.* 50% N + 100% P & K + spray of nano urea @ 10 ml l^{-1} which was statistically at par with T_1 *i.e* recommended dose of fertilizer, T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1} and T_9 *i.e.* 50% N + 100% P & K + spray of nano urea @ 10 ml l^{-1}. The lowest value (241.19 kg ha^{-1}) was recorded in T_{11} *i.e.* 100% P & K.

No significant variation in available phosphorus was found due to varied levels of nano-urea and conventional urea (Table 4.16).

Likewise, the available potassium at harvest did not differ significantly (Table 4.16).

4.5.3 Soil moisture content

The data pertaining to soil moisture content (%) as influenced by varied levels of nano-urea and conventional urea at different crop growing stages *viz.* sowing, knee high, tasseling and physiological maturity stages are enumerated in the Fig. 3.1

The effect of different nano-urea application on soil moisture content (%) is 13.79% at sowing, 9.42% at knee high, 12.54% at tasseling and 13.41% at harvest was recorded through out the crop periods. The highest soil moisture content was seen at sowing time of the crop.

4.6 Economics

The data pertaining on economics of maize crop as influenced by varied levels of nano-urea and conventional urea effects are presented in the Table 4.17.

Among all the treatments, T_1 *i.e.* recommended dose of fertilizer (RDF) recorded the highest cost of cultivation (Rs. 80650 ha^{-1}) followed by T_8 *i.e.* 50% N + 100% P & K + spray of nano urea @ 6 ml l^{-1}. The lowest cost of cultivation (Rs. 75000 ha^{-1}) was incurred in T_{11} *i.e.*100% P & K.

The highest gross return (Rs. 150569 ha^{-1}), net return (Rs. 72069 ha^{-1}), Benefit-cost ratio (1.91) and economic efficiency (191.80%) was obtained in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} whereas, T_{11} *i.e.* 100% P & K recorded the lowest gross return (Rs. 86305 ha^{-1}), net return (Rs. 11305 ha^{-1}), Benefit-cost ratio (1.15) and economic efficiency (115.07 %).

Table 4.13: Production efficiency (%) and Agronomic efficiency (kg kg^{-1}) as influenced by varied levels of nano-urea & conventional urea

Parameters	Production efficiency (%)	Agronomic efficiency (kg kg^{-1})
T_1: Recommended Dose of Fertilizer (RDF)	100.77	30.60
T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	85.68	3879.16
T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	88.50	3437.5
T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	90.05	2982.5
T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	95.05	414.72
T_6: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	102.03	398.33
T_7 :25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage	108.43	382.66
T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	120.42	418.75
T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	116.17	287.5
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	108.55	191.91
T_{11}: 100% P & K	70.17	0
S.Ed(±)	5.72	
CD (p=0.05)	11.64	

Table 4.14: Rain water use efficiency (kg ha^{-1} mm^{-1}) at harvest as influenced by varied levels of nano urea and conventional urea

Treatment	Rain water use efficiency (kg ha^{-1} mm^{-1})
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	33.74
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	28.69
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	29.63
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	30.15
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	31.82
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	34.16
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	36.31
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	40.32
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	38.90
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	36.34
T_{11}: 100% P & K	23.49
S.Ed±	1.91
CD(P=0.05)	3.88

Table 4.15: pH, Organic Carbon (OC) and Electrical conductivity (EC) content of soil after harvest of the crop as influenced by varied levels of nano-urea & conventional urea

Treatment	Soil p^H	Soil organic carbon	Electrical conductivity (%)
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	4.84	0.45	0.05
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	4.66	0.47	0.04
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	4.72	0.51	0.06
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	4.88	0.50	0.07
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	4.81	0.50	0.06
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	4.80	0.48	0.07
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	4.88	0.51	0.05
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	4.89	0.53	0.06
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	4.90	0.51	0.07
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	4.91	0.52	0.06
T_{11}: 100% P & K	4.76	0.50	0.05
S.Ed±	0.01	0.01	0.01
CD(P=0.05)	NS	NS	NS

Table 4.16: Available Nitrogen (N), Phosphorus (P_2O_5) and potassium (K_2O) content of soil after harvest of the crop as influenced by varied levels of nano-urea & conventional urea

Treatment	N kg ha^{-1}	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}
$T_{1:}$ Recommended Dose of Fertilizer (RDF)	267.79	18.30	165.56
$T_{2:}$ 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	249.43	19.50	164.19
$T_{3:}$ 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	251.95	19.10	174.67
$T_{4:}$ 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	252.99	18.90	156.34
$T_{5:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	258.12	18.70	163.02
$T_{6:}$ 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	259.18	18.60	159.01
$T_{7:}$ 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	261.33	18.50	186.45
$T_{8:}$ 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	268.05	17.90	179.59
$T_{9:}$ 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	268.27	17.80	151.25
$T_{10:}$ 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling sta	268.75	17.80	159.48
T_{11}: 100% P & K	241.19	19.70	144.26
S.Ed±	0.40	0.04	2.07
CD(P=0.05)	0.82	NS	NS

Table 4.17: Economics Analysis as influenced by varied levels of nano-urea & conventional urea

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross Return (Rs. ha^{-1})	Net Return (Rs. ha^{-1})	B:C ratio	Economic efficiency
T_1: Recommended Dose of Fertilizer (RDF)	80650	123943	43293	1.53	153.68
T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	77500	105391	27891	1.35	135.98
T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	77500	108855	31355	1.40	140.45
T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	77500	110762	33262	1.42	142.91
T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	78500	116912	38412	1.48	148.93
T_6: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	78500	125501	47001	1.59	159.87
T_7: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	78500	133373	54873	1.69	169.90
T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	78500	150569	72069	1.91	191.80
T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	78500	142885	64385	1.82	182.01
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	78500	133517	55017	1.70	170.08
T_{11}: 100% P & K	75000	86305	11305	1.15	115.07

PLATE 7: FINAL VIEW OF PLOT

PLATE 8: LEAF CHLOROPHYLL ESTIMATION

PLATE 9: DRY MATTER ESTIMATION

PLATE 10 : SOIL MOISTURE ESTIMATION

PLATE 11: GERMINATION TEST

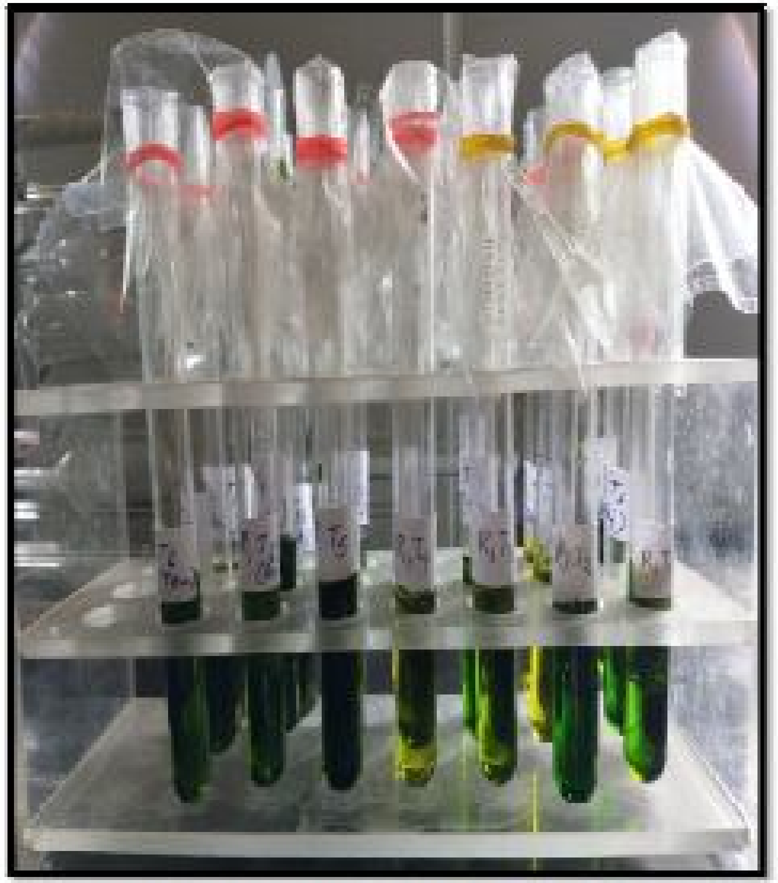


PLATE 12: CHLOROPHYLL ESTIMATION

PLATE 13: RLW CONTENT ESTIMATION

PLATE 14: OVERALL LAYOUT OF EXPERIMENT

PLATE 15: VISIT TO MY EXPERIMENTAL PLOT BY ASSOCIATE DEAN SIR AND ADVISORY COMMITTEE MEMBERS

PLATE 16: VISIT TO MY EXPERIMENTAL PLOT BY ADVISORY COMMITTEE MEMBERS

CHAPTER V
DISCUSSION

The results of the field experiment entitled “Smart Nutrient Management using Nano Urea on Rabi Maize (*Zea mays* L.) under rainfed situation ” during the *rabi* season of 2022-23 at Biswanath College of Agriculture, Assam Agricultural University, Biswanath Chariali, Assam are critically discussed in this chapter with possible scientific reasoning and references to findings reported by earlier investigations under the following subheadings.

5.1 Effect on nano-urea on growth parameters

Taller plants were recorded in crops treated with recommended dose of fertilizer at knee high stage which was found at par with T_7 (25% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1}), T_8 (50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}), T_9 (50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1}) and T_{10} (50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1}). However, in tasseling and physiological maturity, T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} resulted in increased plant height which was statistically at par with T_9 *i.e*. 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} (Fig 5.1). This might be attributed to enhanced availability of nitrogen owing to foliar spray of nano-urea resulting in more cell growth. This result corroborates the findings of Samui *et al.* (2022). Similar trend was also observed in the case of number of green leaves plant^{-1} (Table 4.2 and Fig 5.2). Increased height and leaf numbers of the crop might be due to rapid cell division and cell elongation because of increased availability of nitrogenous fertilizer in plant system. Many findings documented similar results (Kashyap and Bainade, 2022 and Kaviani *et al.*, 2016). The result also showed thicker stem under varied doses of nano-urea application along with 50% N from conventional urea (Fig 5.3) which might attribute to efficient utilization of nitrogen from foliar application of nano-urea resulting in increased plant metabolism and thereby improving the overall morphology and physical characteristics of plant. Similar results were revealed by Mahil and Kumar, 2019 and Singh and Singh, 2019.

5.2 Effect on nano-urea on physiological parameters

Crop response towards varied levels and forms of fertilizer nitrogen was vividly observed with respect to different physiological parameters throughout the crop growing period. At knee high stage, crops receiving recommended dose of fertilizer showed higher value of LAI and dry matter production, whereas in later stages, effect of nano-urea was found to significant as the greater value were recorded in T_8 and T_9 which received 50% of recommended N from conventional source and 6 and 8 ml l^{-1} of nano-urea, respectively (Fig 5.4 and 5.5). This might attribute to better vegetative growth due to prompt availability of nitrogen from foliar application of nano urea that enhanced the plant height with more number of leaves, which ultimately resulted in higher leaf area as well as dry matter of the plant in the later stages *i.e.* tasseling and physiological maturity. Similar findings were also recorded by Kaviani *et al.* (2016) and Satdev *et al.* (2020). Increased nitrogen availability imparting boost in cell growth as were reported by various researchers (Movahhedi Dehnavi, 2015 and Samui, *et al.*, 2022)

Influence of nano-urea on achieving greater magnitude of CGR was clearly evident (Fig. 5.6). The crop nourished with T_8, T_9 and T_{10} which received 50% N from conventional urea and 6, 8 and 10 ml l^{-1} of nano urea, respectively recorded greater CGR between knee high and tasseling and between tasseling and physiological maturity, as well. In the case of RGR, higher value was recorded under T_6 receiving 25% recommended N from conventional source and 6ml l^{-1} of nano urea which was followed by T_2 that received only 6 ml l^{-1} of nano urea in between knee high and tasseling stage. This might attributed to abrupt availability following effective utilization of more N due to application of nano urea on the foliage resulting in a big fillip in plant biomass of these initially deprived plants. Contrary to this, from tasseling to physiological maturity, greater RGR was observed in treatment receiving 50% of recommended N from conventional urea along with 6, 8 and 10 ml l^{-1} of nano urea (Fig 5.7).

The superior crop growth rate and relative growth rate is due to the fact that nano nutrients supplied through foliage has mobilized more efficiently by the plant resulting in enhanced growth attributes and ultimately enhanced the crop growth rate and relative growth rate. Additionally, the increase in dry matter production with foliar applications of nano-N resulted in the readily nutrients at critical period of crop nutrient demand. The above results were found in conformity with the findings of Egli, 2019 and Alimamy *et al.* 2022.

Pronounced effect of nano urea was seen with respect to leaf chlorophyll content, the highest being recorded in T_8 where 50% of recommended N was applied as urea along with spraying of nano urea @ 6 ml l^{-1} (Fig.5.8). This might attribute to utilization of relatively more readily available N from nano urea in production of photosynthetic pigment. Jadhav *et al.* 2022 reported that N play key role in constituent of Chlorophyll, ATP-ADP, enzymes and amino acids in plant. Improvement of photosynthetic pigment due to increased availability of N was also reported by Abdel *et al.* 2019 and Kashyap and Bainade, 2022. The T_8 treatment also registered significantly higher value of RWC which was followed by a lower but comparable value in T_9 while the others irrespective of receiving more N (T_{10}) or less or completely no N showed lower RWC. This is probably because of sufficient availability and optimum utilization of N in plant inducing relatively more osmotic regulation with less cell wall elasticity of tissue (Ritchie *et al.*, 1990). Greater sensitivity of RWC toward higher level of N content was also revealed by Lu, *et al.* 2004. Contribution of N and K in enhancing water content of leaf tissue through improved osmolyte synthesis under normal and drought conditions was reported by Ahanger *et al.*, 2021).

5.3 Effect on nano-urea on yield parameters

Relatively improved yield parameters such as thicker, longer and heavier cob; higher number of seeds cob^{-1} with more test weight was recorded in the treatment having 50% of recommended N from conventional source coupled with spraying of nano urea @ 6 ml l^{-1} (T_8). The improvement of these yield parameters was reflected in grain yield, straw yield and harvest index as well (Fig. 5.11, 5.12 and 5.13). The efficient N supply due to foliar application of nano urea might have enhanced the yield parameters that ultimately increased the yield. Singh *et al.* 2000 opined that being the fundamental part of proteins, the improved N supply might lead to better utilization of other resources resulting in improved yield attributes and yield. The improved yield contributing parameters might be due to favorable effect of nitrogen on physiological processes that led to enhanced photosynthetic efficiency and better translocation of assimilates to the sink (Kumar *et al.*, 2004). These results were agreement with the findings of Bindhani *et al.* (2007), Sepat and Kumar (2007), Sujatha *et al.* (2008) and Kumar (2009).

5.4 Effect on nano-urea on efficiency parameters

Highest production efficiency (kg $day^{-1}ha^{-1}$) (120.42 kg $day^{-1}ha^{-1}$) was recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} which was statistically at par with with T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1}. The above results were found in conformity with the findings of Merghany *et al.* 2019 and Mandal 2021.

Results showed that with the increase of doses of nano urea and conventional urea, agronomic efficiency was decreasing and the lowest value was recorded in T_1 which received 100% recommended dose of N from conventional urea. The greatest agronomic efficiency was recorded in T_2 which received only nano urea @ 6 ml l^{-1} as a source of N and which was followed by T_3 , T_4 , T_5, T_6, T_7, T_8, T_9, and T_{10}. In spite of no or lesser level of basal application of conventional urea, nano urea sprayed at knee high and tasseling at various rates was able to bring substantial yield increase that ultimately resulted in higher agronomic efficiency. The underlying reason may be the easy accessibility of nano-N particles through the cell wall and reaching the plasma membrane while the larger particles *i.e.* 20-50 nm can enter through stomata. Increased mobility of nano-N inside the plant system facilitates binding with carrier proteins through aquaporin, ion channels and via endocytosis and metabolized inside the plant cell (Preetha and Balakrishnan, 2017 and Lahari *et al*., 2021).

On the other hand, relatively higher grain yield in T_8 resulted in greater rainwater use efficiency. The treatments receiving nano urea and 50% recommended N from conventional urea produced more grain yield as compared to others. Production of increased grain yield coupled with maintenance of greater RWC of leaf with relatively lower volume of rainwater might result in increased rain water use efficiency. This observation corroborates with the findings of Chander *et al.* 2014.

5.5 Effect on nano-urea on soil nutrient status at harvest

Results showed that varied level of conventional and nano urea significantly influence on phyto-available N in soil at harvest while no significant effect was noticed in terms of phyto-available P_2O_5 and K_2O. The comparatively higher status of available N was found in those treatments receiving 50% recommended N from conventional source along with relatively higher doses of nano urea *i.e.* T_{10} which was followed by those treated with comparatively lesser doses of N *viz.* T_9 , followed by T_8, T_1, T_7, T_6, T_5, T_4, T_3, T_2 and lastly by T_{11}. Many researchers reported that nano-fertilizers enable swift nutrient transport and delivery through nano-sized (50-60nm) channels on plasmodesmata (Mahanta *et al.*, 2020). Further these smart fertilizers possess large surface area facilitating enhanced sorption and regulated release kinetics to specific sites (Rameshaiah *et al.*, 2015). Therefore, easy accessibility of foliar applied nano-N for plant metabolic processes might be the probable reason for negligible changes in soil available -N status at harvest. Upadhya, *et al.* (2023) also opined possibility of non-occurrence of nutrient mining as a result of application of nano urea and reported that 75% of recommended N should be applied in a nitrogen deficient soil to avoid nutrient mining.

5.6 Economics of production

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.

Among all the treatments, T_1 *i.e.* recommended dose of fertilizer (RDF) recorded the highest cost of cultivation (Rs. 80,650 ha^{-1}) followed by T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}. The lowest cost of cultivation (Rs.75000 ha^{-1}) was incurred in T_{11} *i.e.* 100% P & K.

The highest gross return (Rs. 1,50,569 ha^{-1}), net return (Rs.72,069 ha^{-1}), Benefit-cost ratio (1.91) and Economic efficiency (191.80 %) was obtained in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} whereas, T_{11} *i.e.* 100% P & K recorded the lowest gross return (Rs.86,305 ha^{-1}), net return (Rs.11,305 ha^{-1}), Benefit-cost ratio (1.15) and Economic efficiency (115.07%) as shown in (Fig. 5.18).

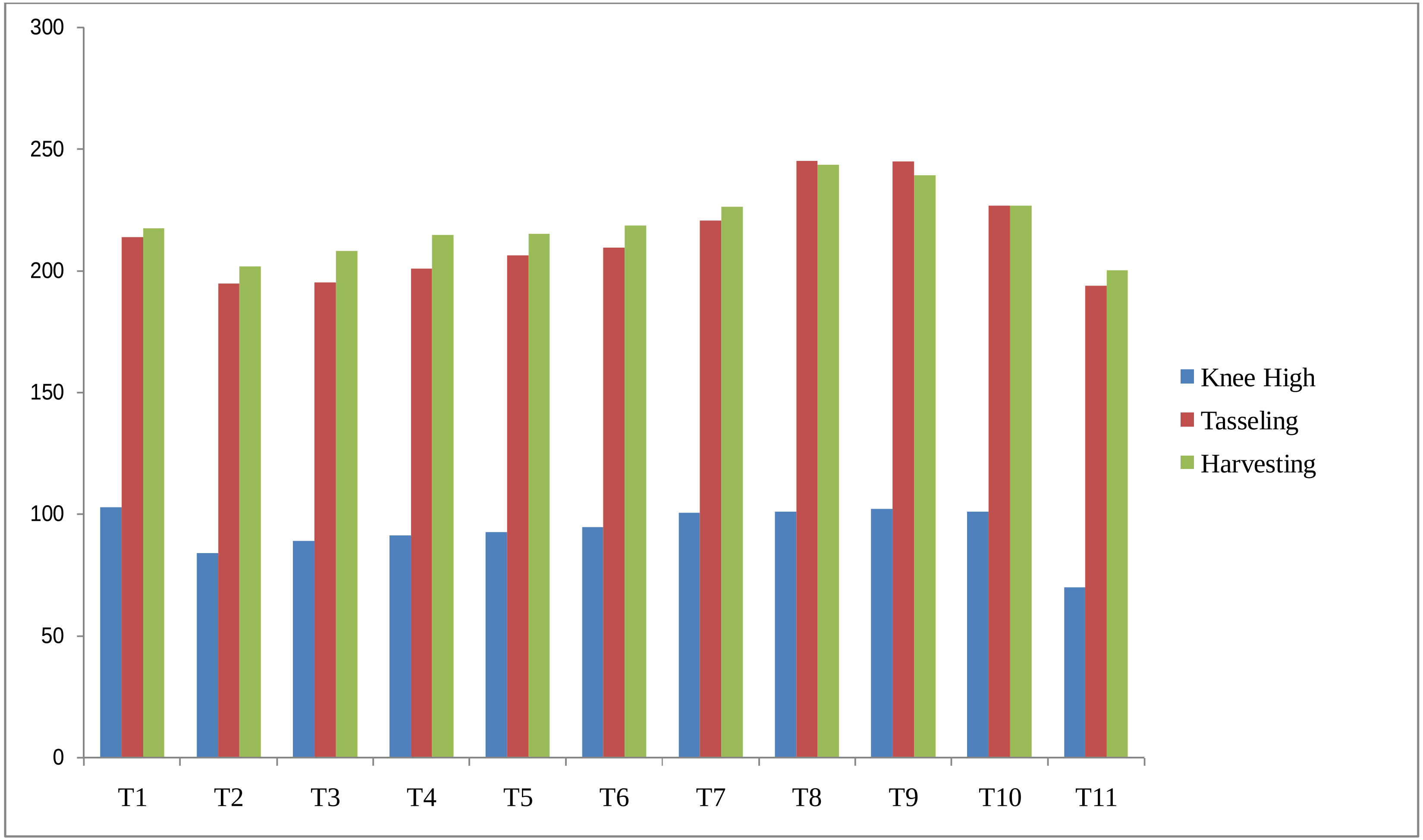


Fig. 5.1: Plant height (cm) at various growth stages as influenced by varied levels of nano urea and conventional urea

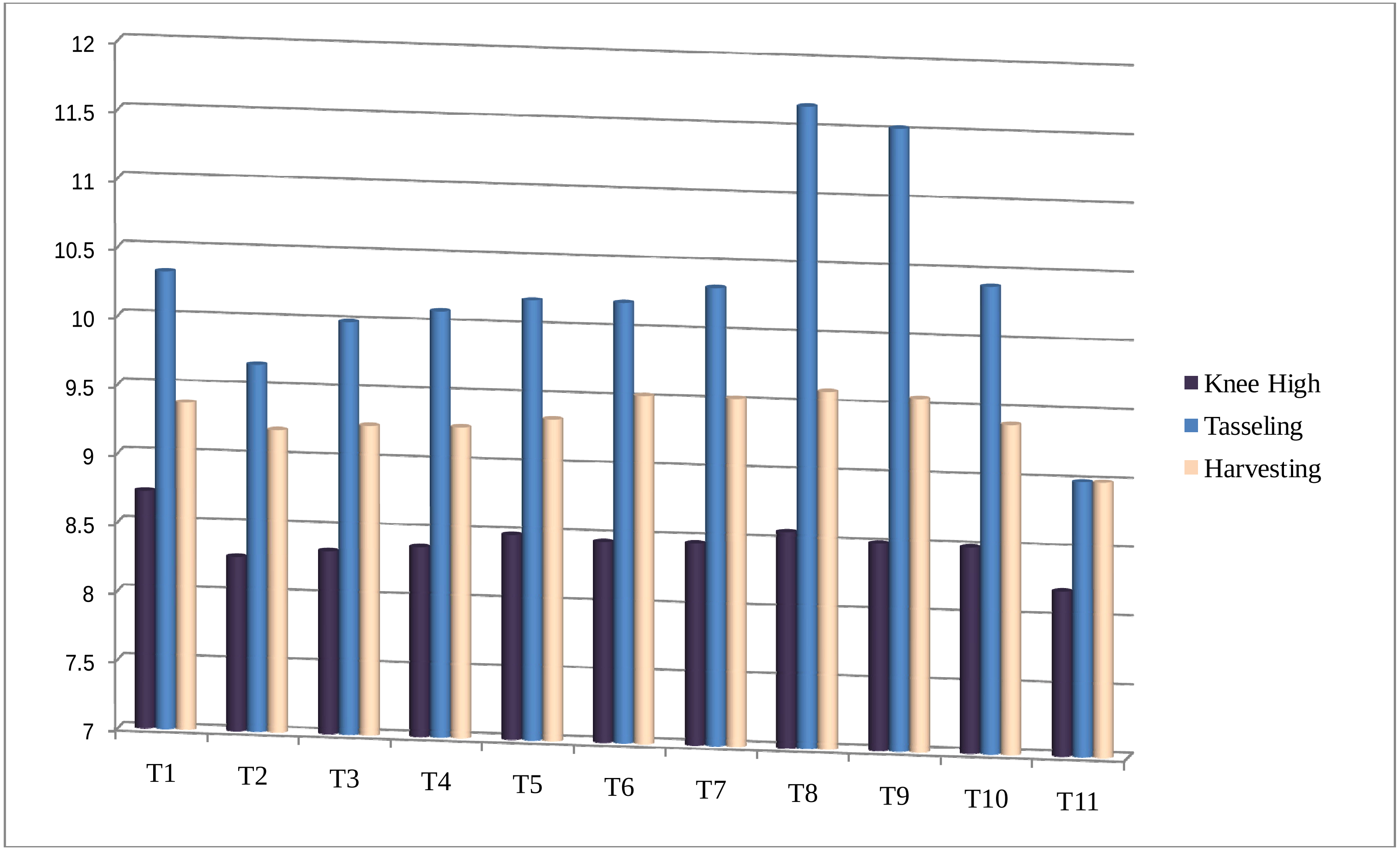


Fig. 5.2: Number of green leaves plant^{-1} at various growth stages as influenced by varied levels of nano urea and conventional urea

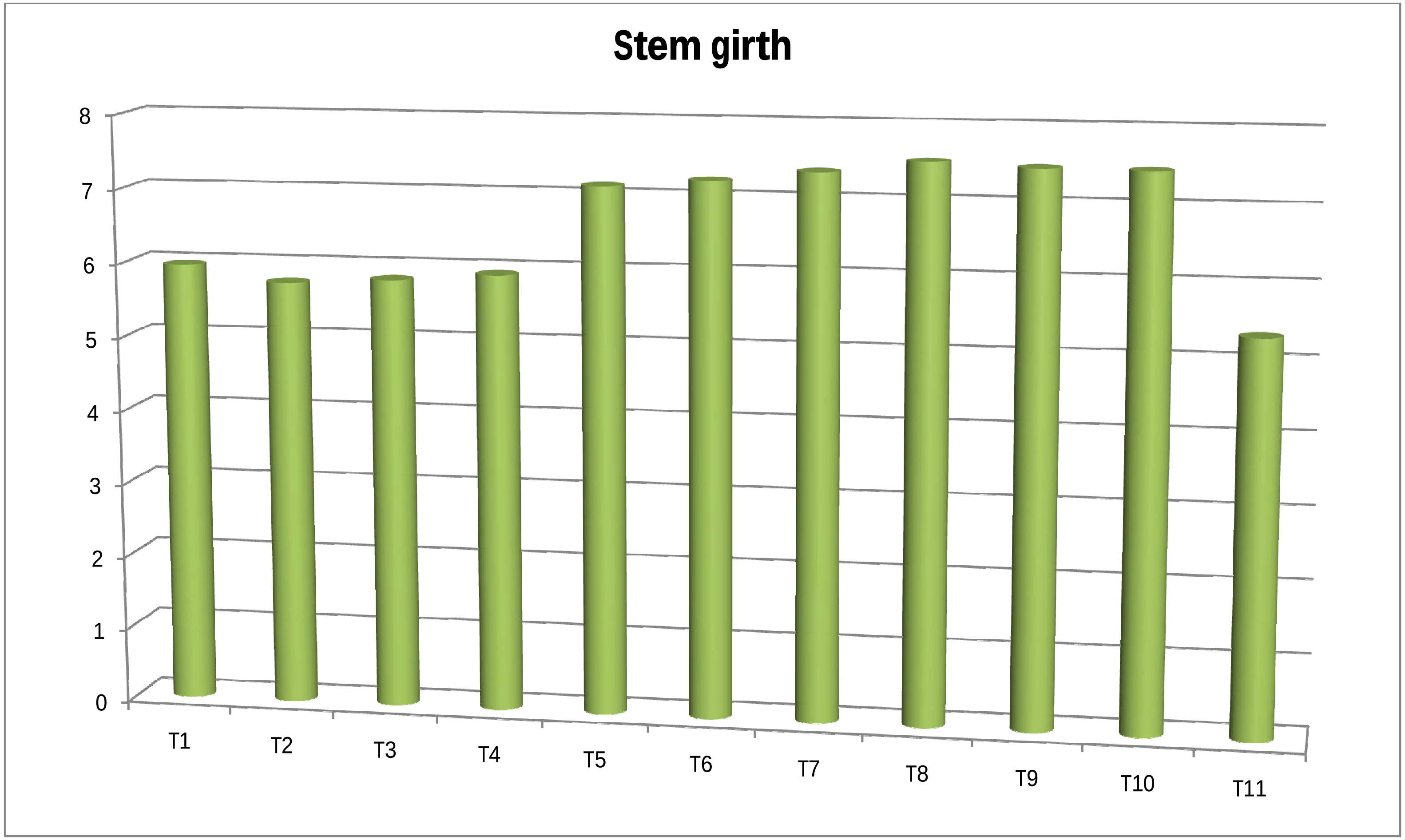


Fig. 5.3: Stem girth (cm) at Physiological maturity as influenced by varied levels of nano urea and conventional urea

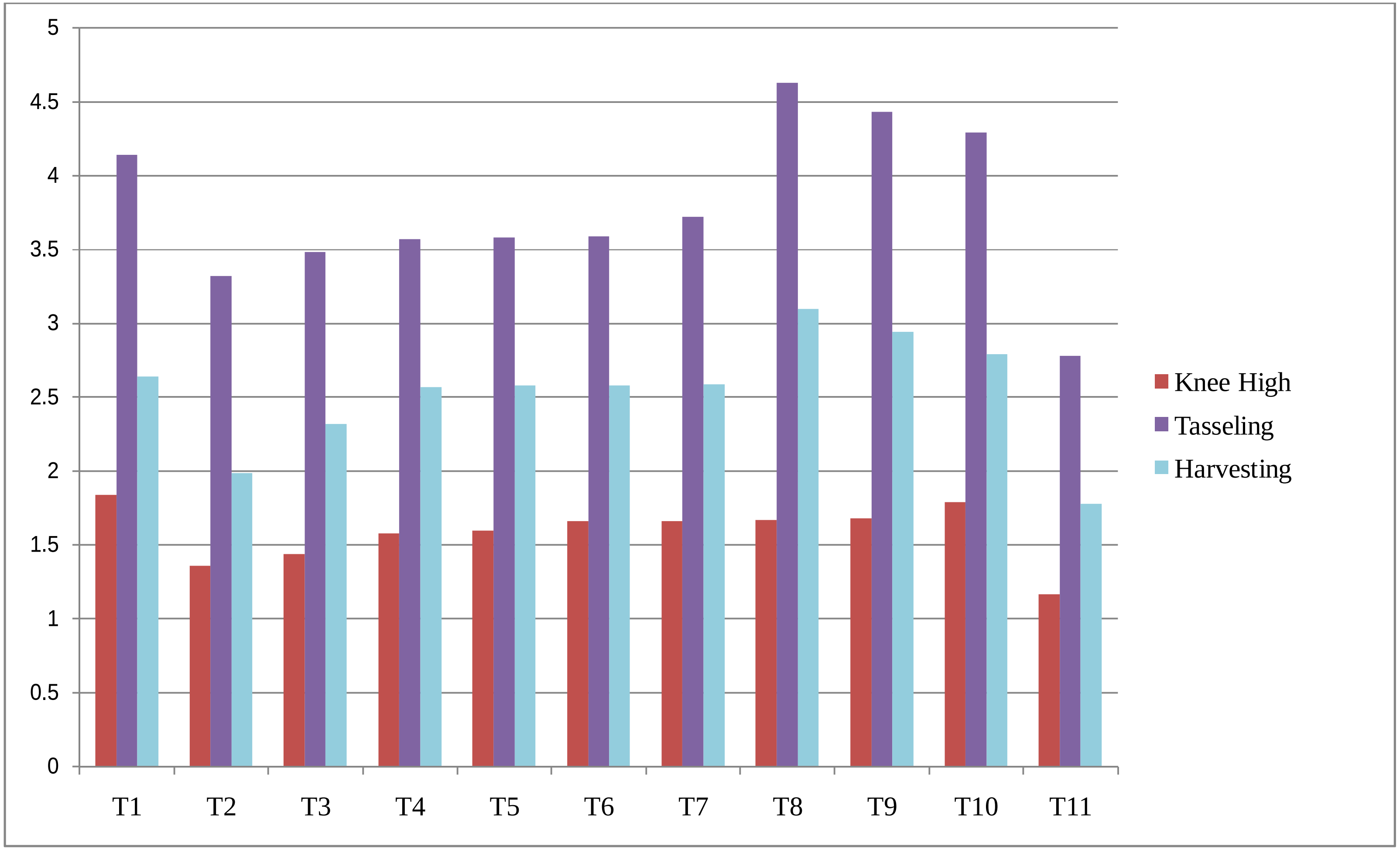


Fig. 5.4: Leaf area index (LAI) plant^{-1} various growth stages as influenced by varied levels of nano urea and conventional urea

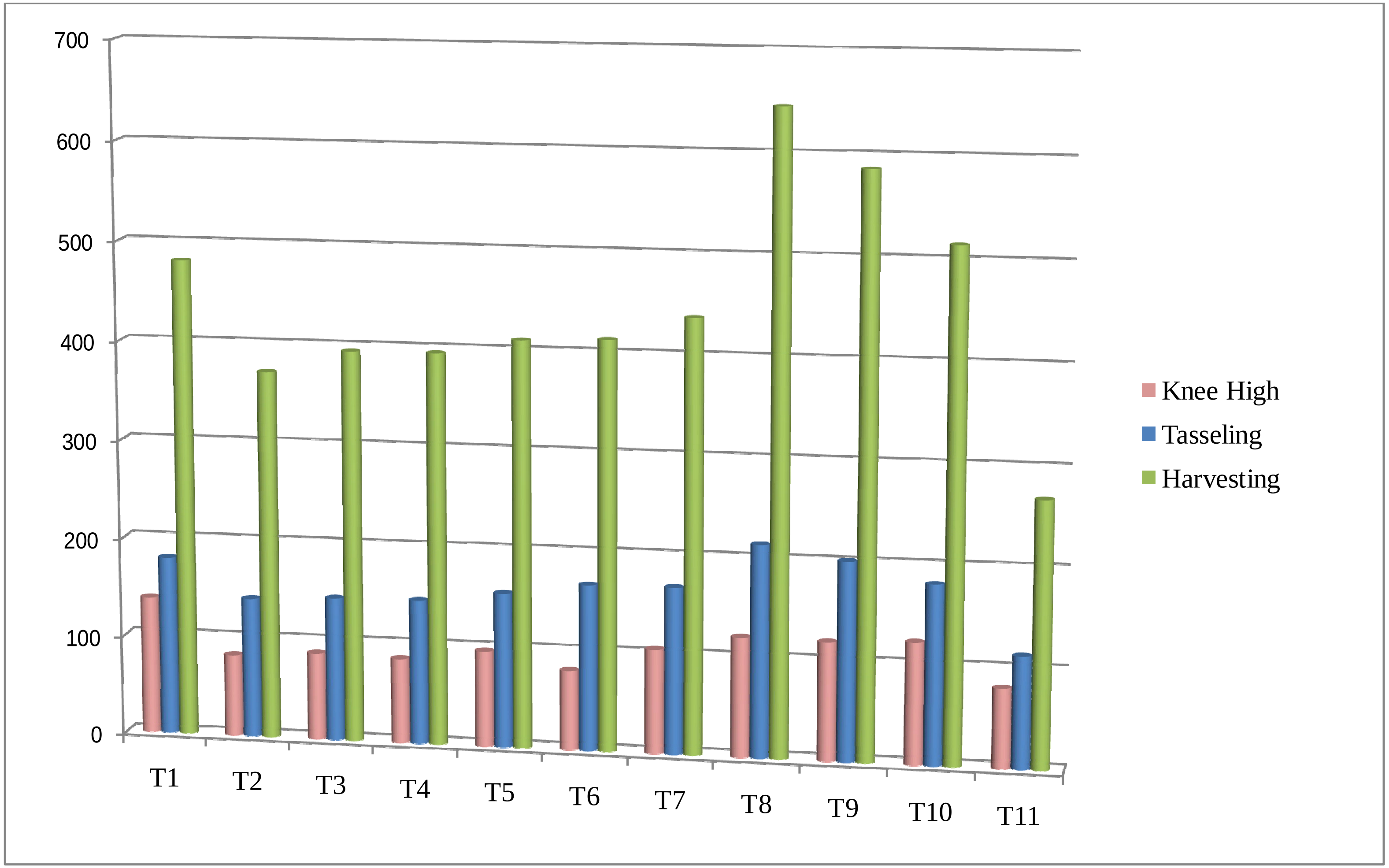


Fig. 5.5: Total dry matter accumulation (g plant-1) at various growth stages as influenced by varied levels of nano urea and conventional urea

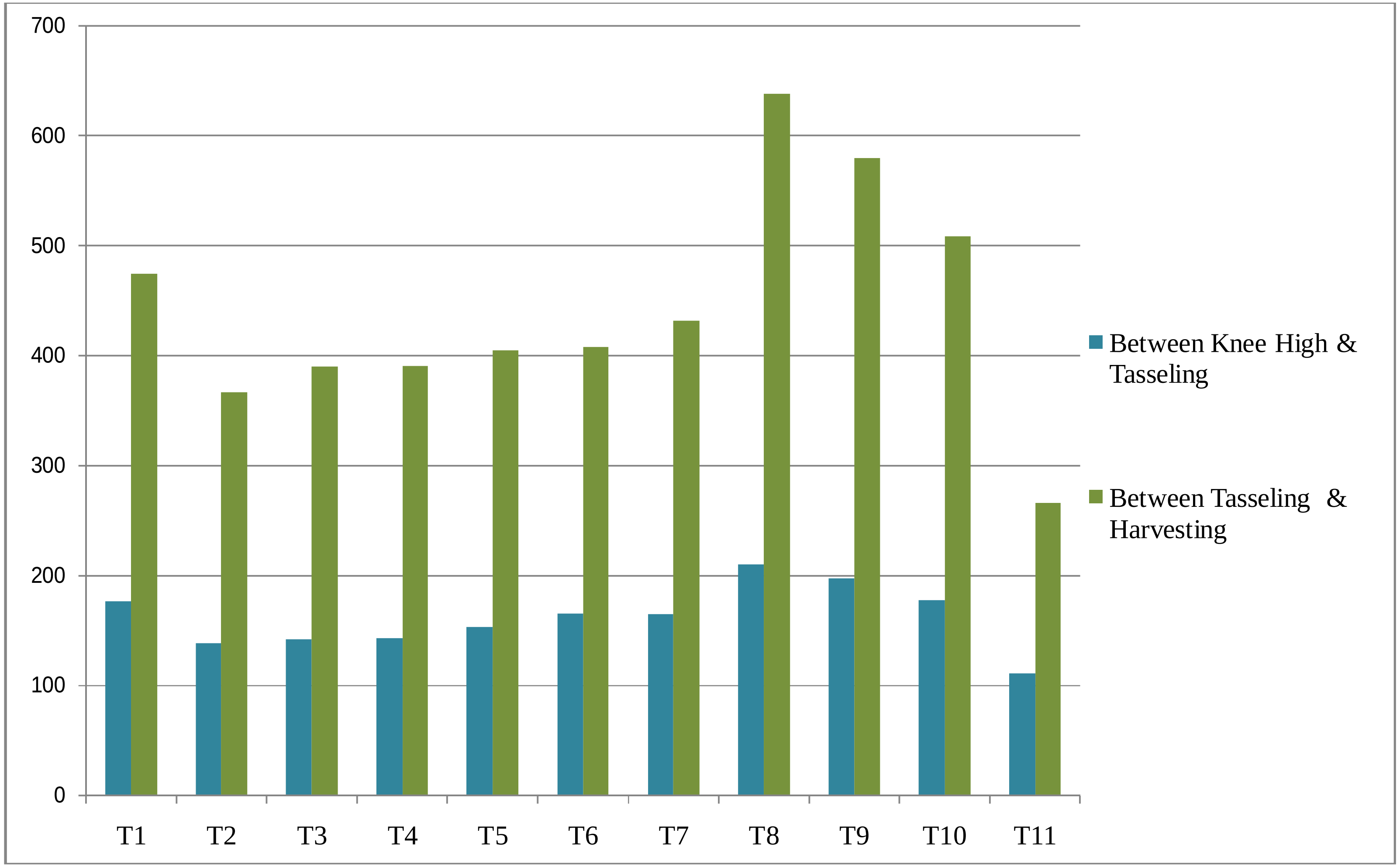


Fig. 5.6: Crop growth rate plant^{-1} (g m^{-2}day^{-1}) in between Knee high and Tasseling stages and Tasseling and Physiological maturity stages of maize

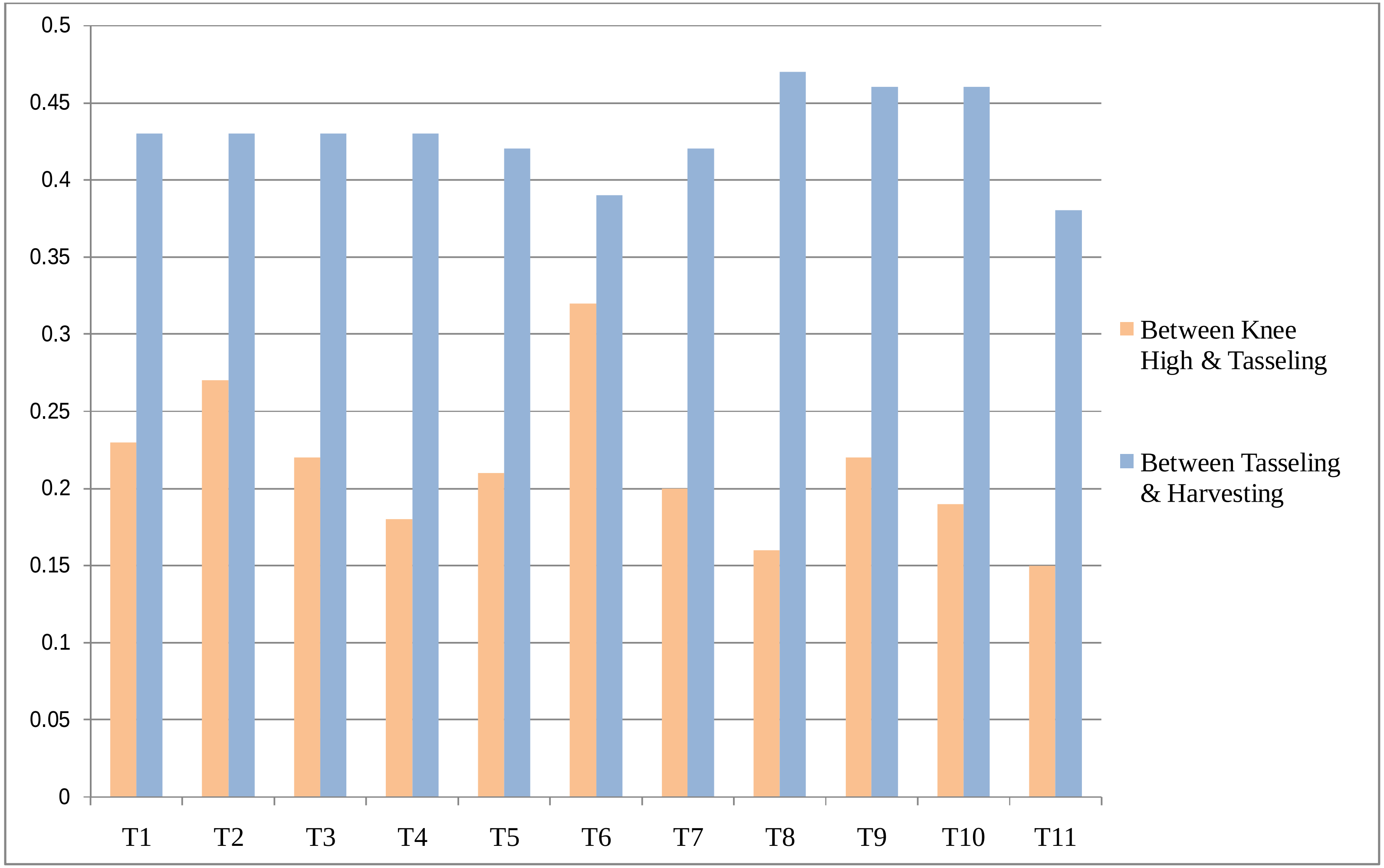


Fig. 5.7: Relative growth rate plant^{-1} (g day^{-1}day^{-1}) in between Knee high and Tasseling stages and Tasseling and Physiological maturity stages of maize

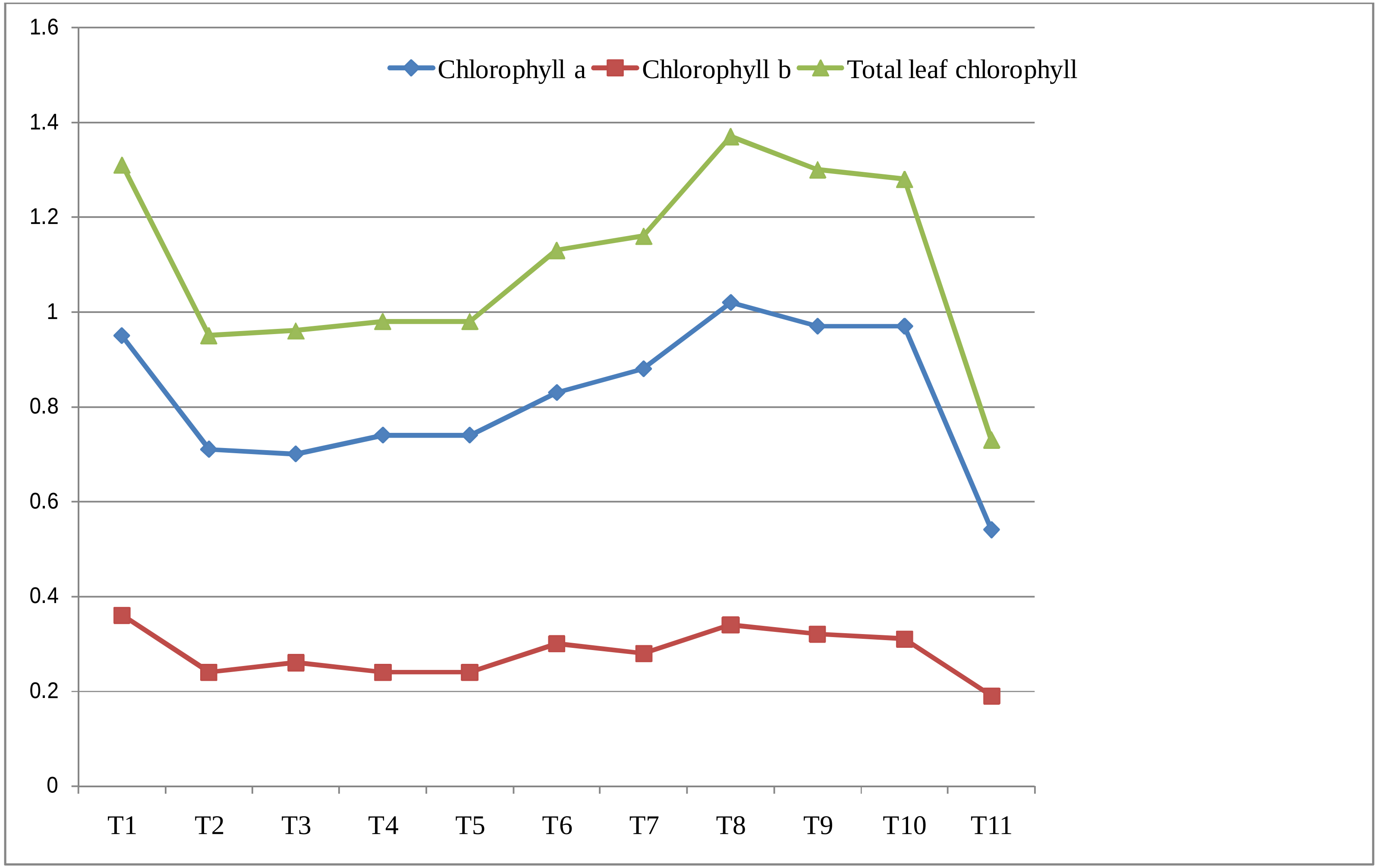


Fig. 5.8: Chlorophyll a, Chlorophyll b and Total chlorophyll (mg/g fr.wt.) as influenced by varied levels of nano urea and conventional urea at tasseling stage

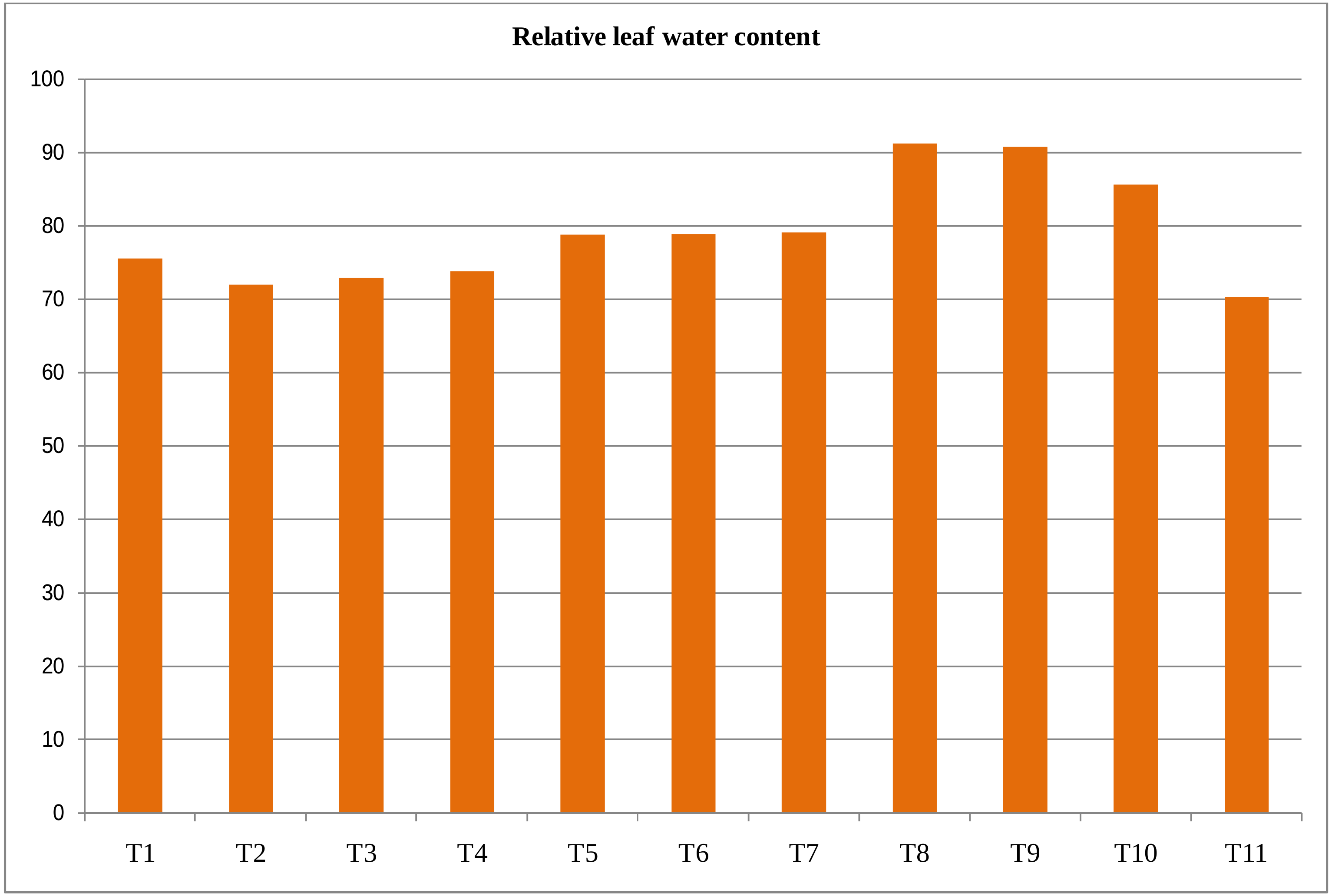


Fig. 5.9: Relative leaf water content (%) at Tasseling stages as influenced by varied levels of nano urea and conventional urea

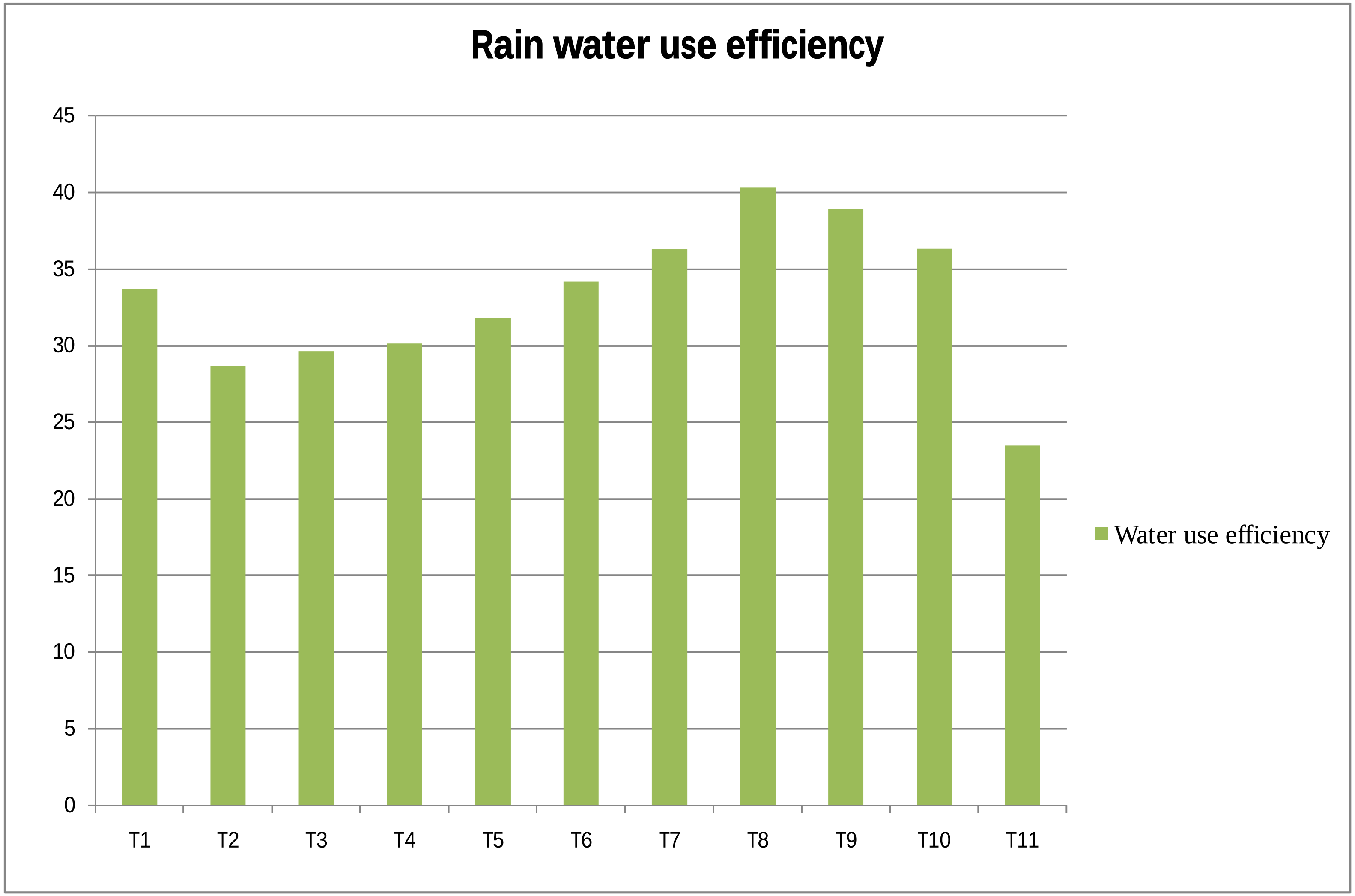


Fig. 5.10: Rain water use efficiency (kg ha^{-1}mm^{-1}) at Physiological maturity stages as influenced by varied levels of nano urea and conventional urea

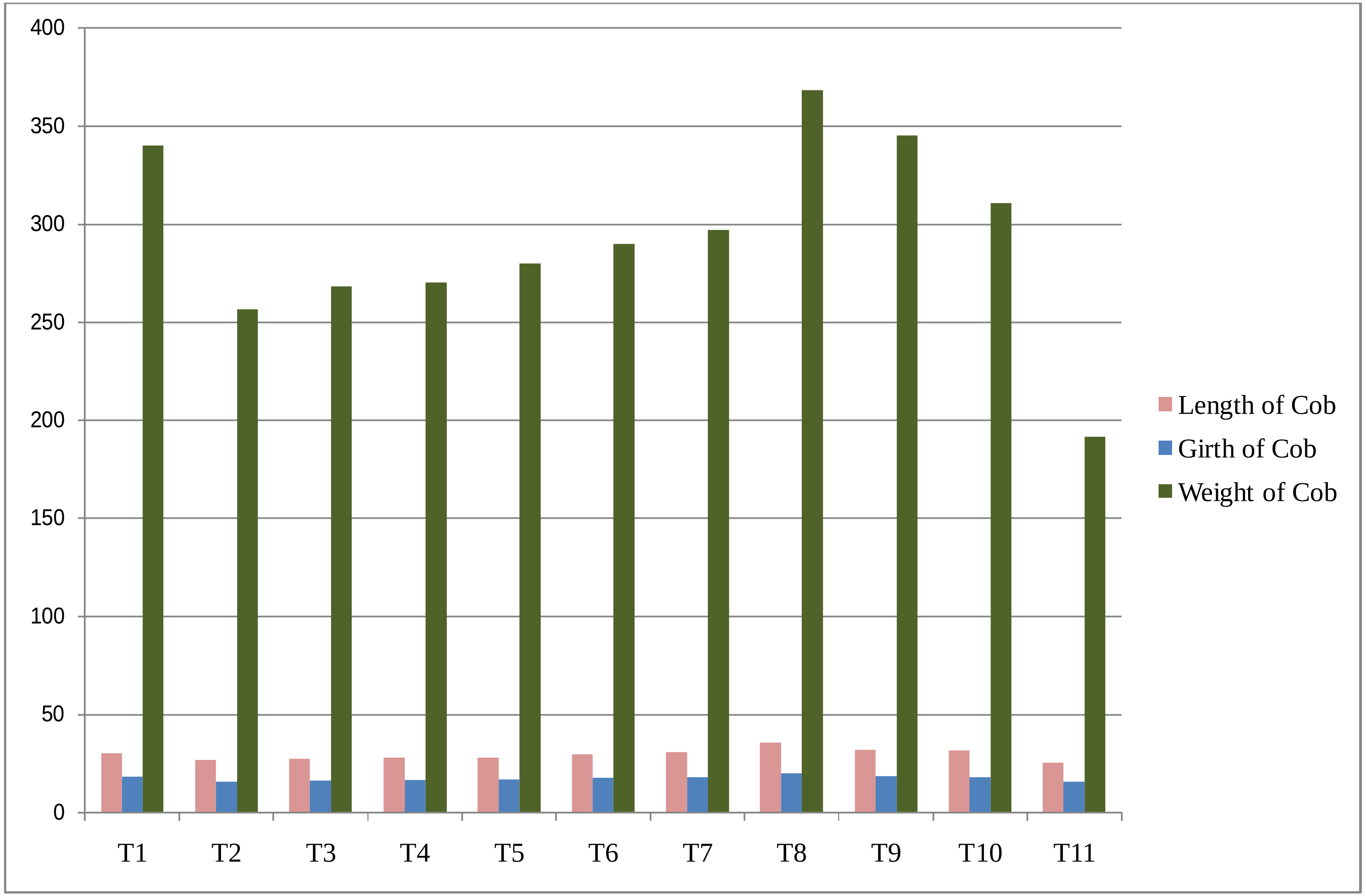


Fig. 5.11: Length (cm), girth (cm) and weight (g) of cob as influenced by varied levels of nano-urea & conventional urea

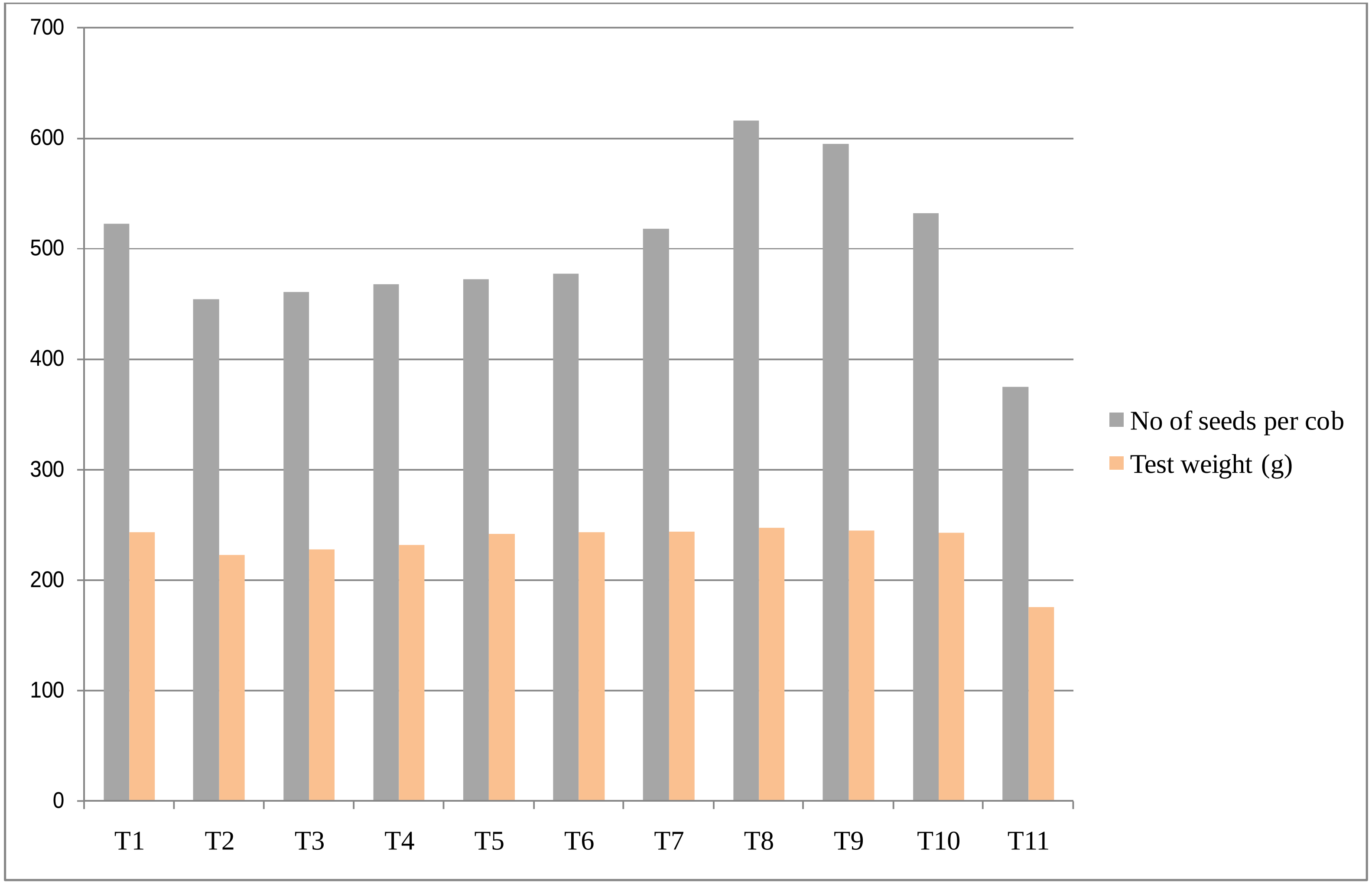


Fig. 5.12: No of seeds cob^{-1} & Test weight (gm) as influenced by varied levels of nano-urea & conventional urea

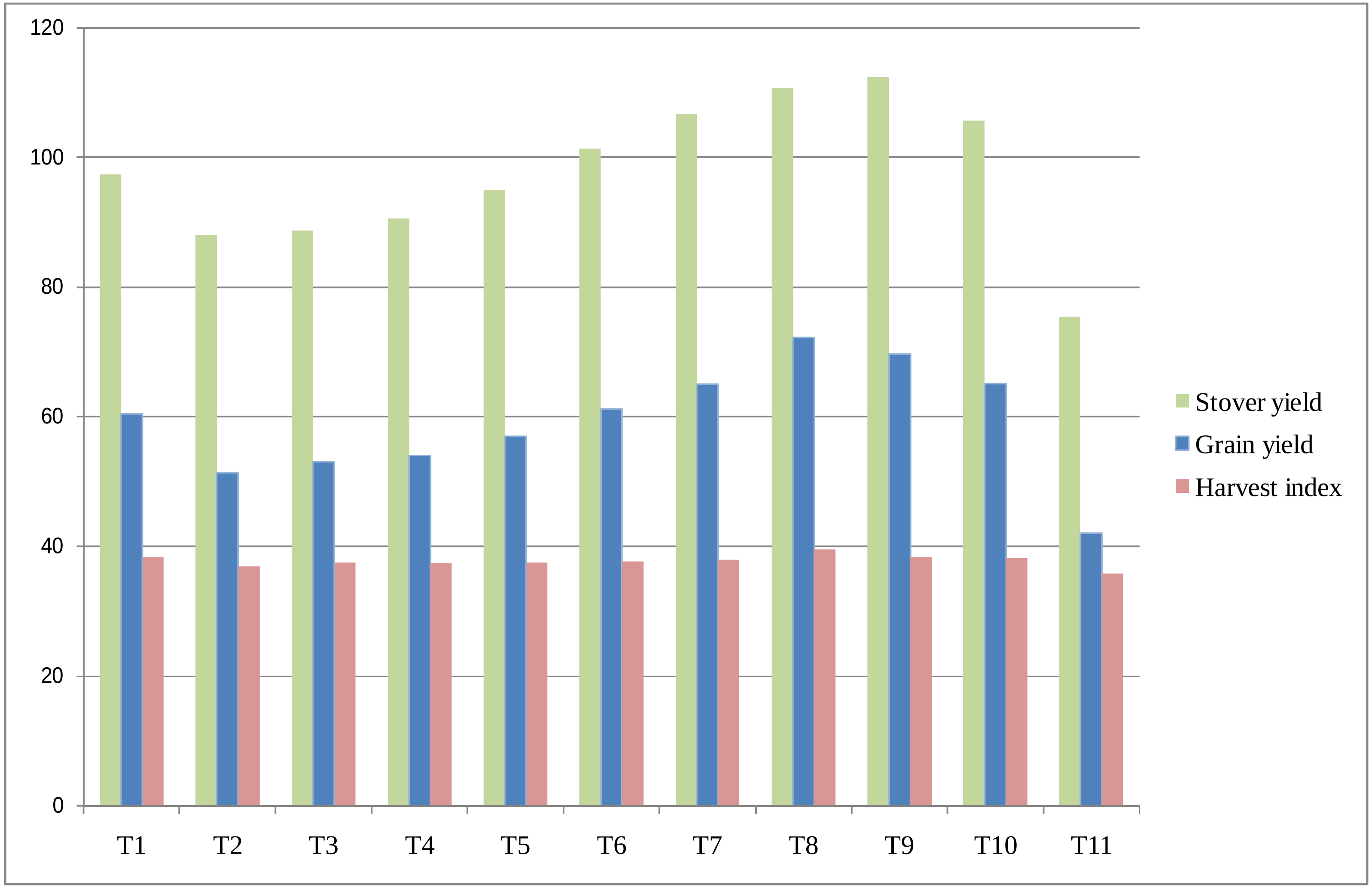


Fig. 5.13: Stover yield (q ha^{-1}), Grain yield (q ha^{-1}) and Harvest index (%) as influenced by varied levels of nano-urea & conventional urea

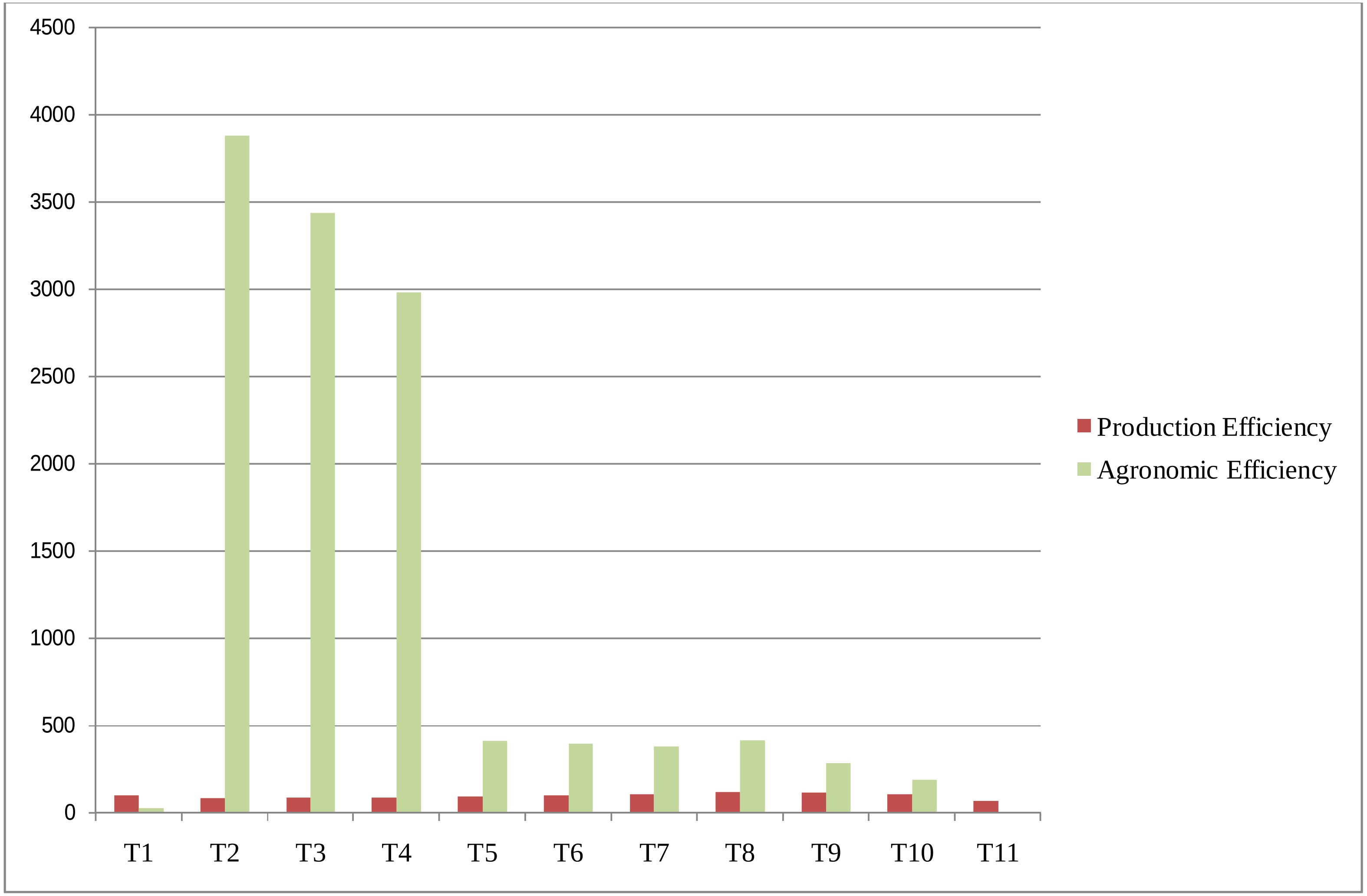


Fig. 5.14: Production efficiency (%) and Agronomic efficiency (kg kg^{-1}) as influenced by varied levels of nano-urea & conventional urea

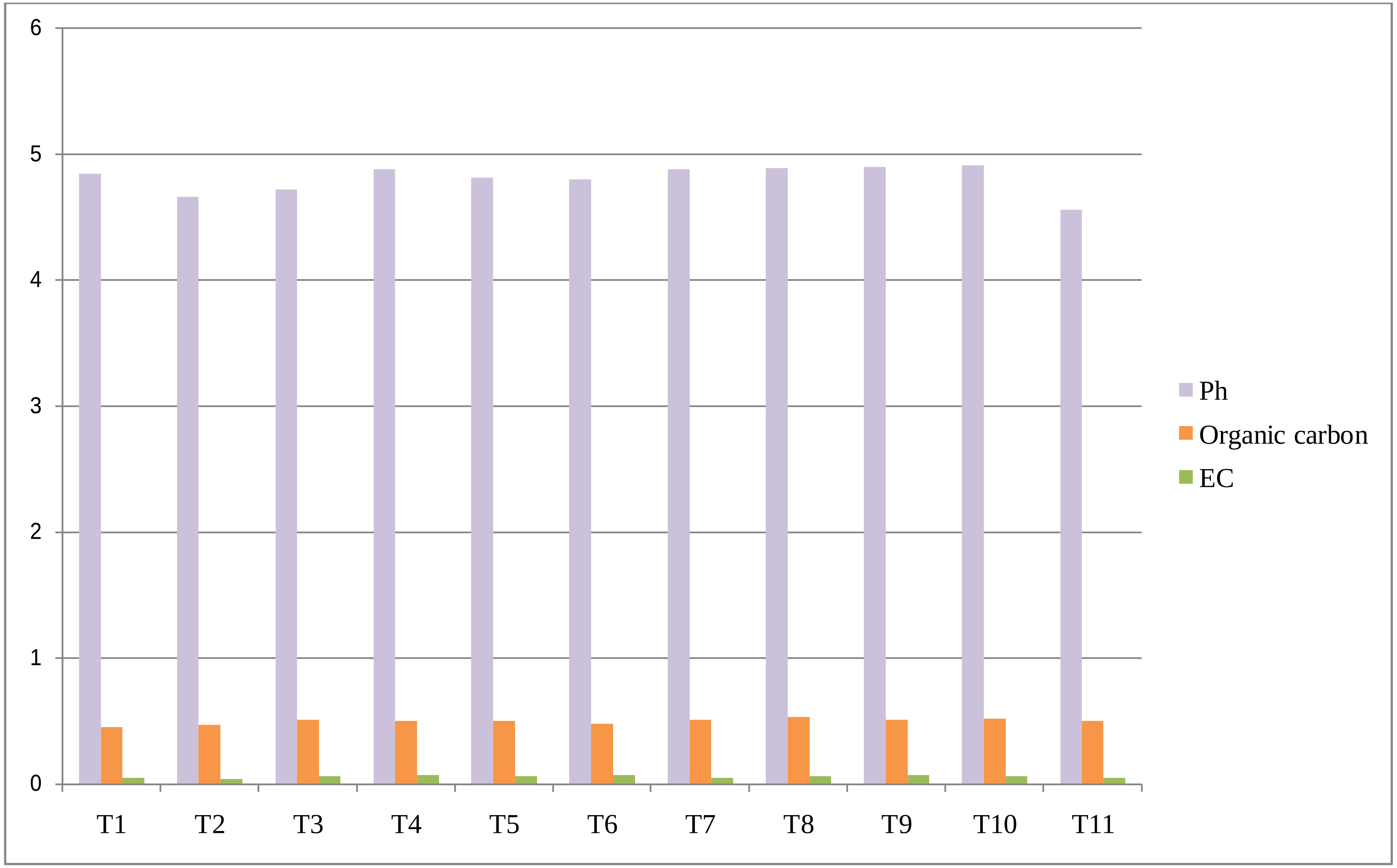


Fig. 5.15: pH, Organic carbon (OC) and Electrical conductivity (EC) content of soil after harvest of the crop as influenced by varied levels of nano-urea & conventional urea

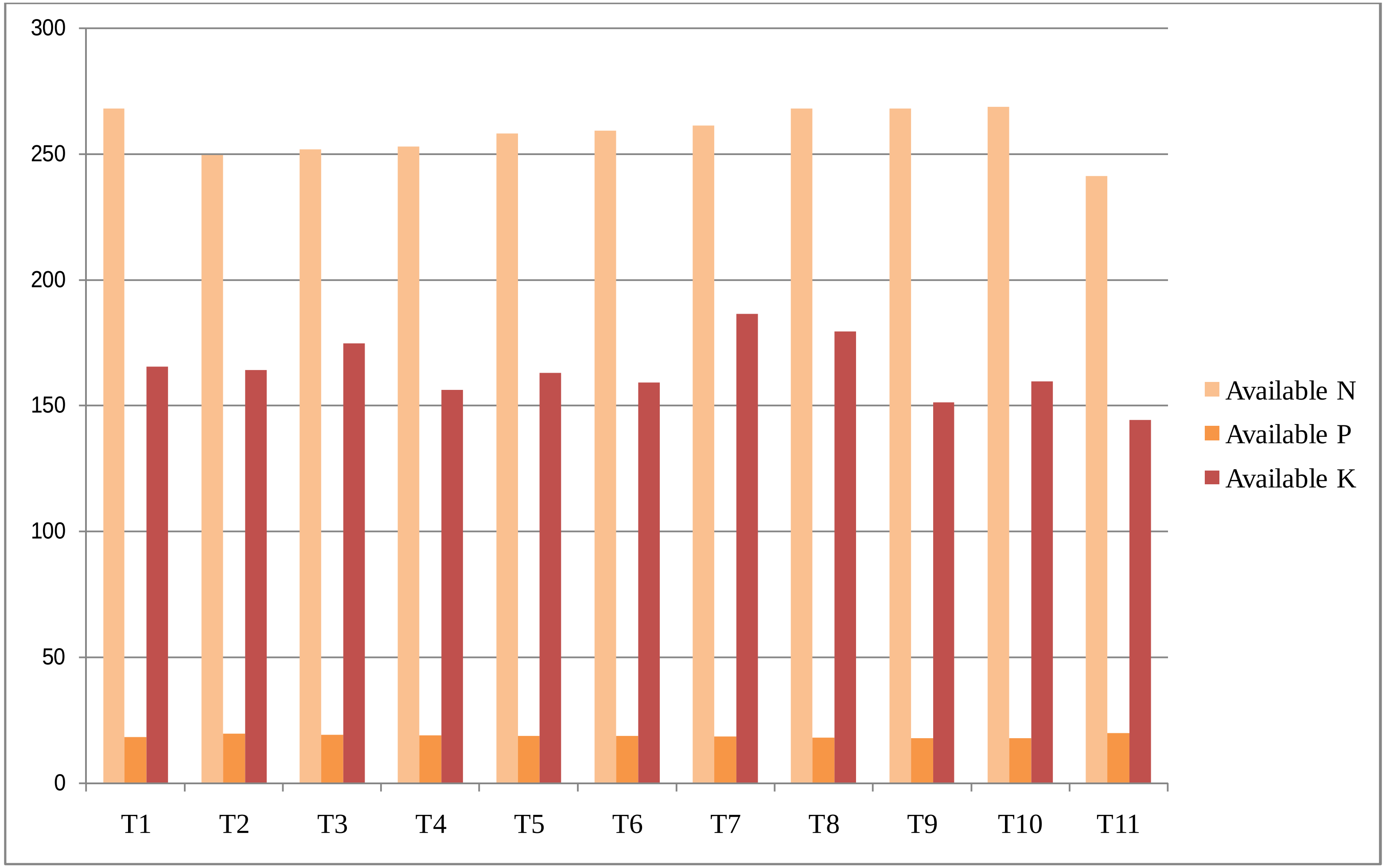


Fig. 5.16: Available Nitrogen (N), Phosphorus (P) and potassium (K) content of soil after harvest of the crop as influenced by varied levels of nano-urea & conventional urea

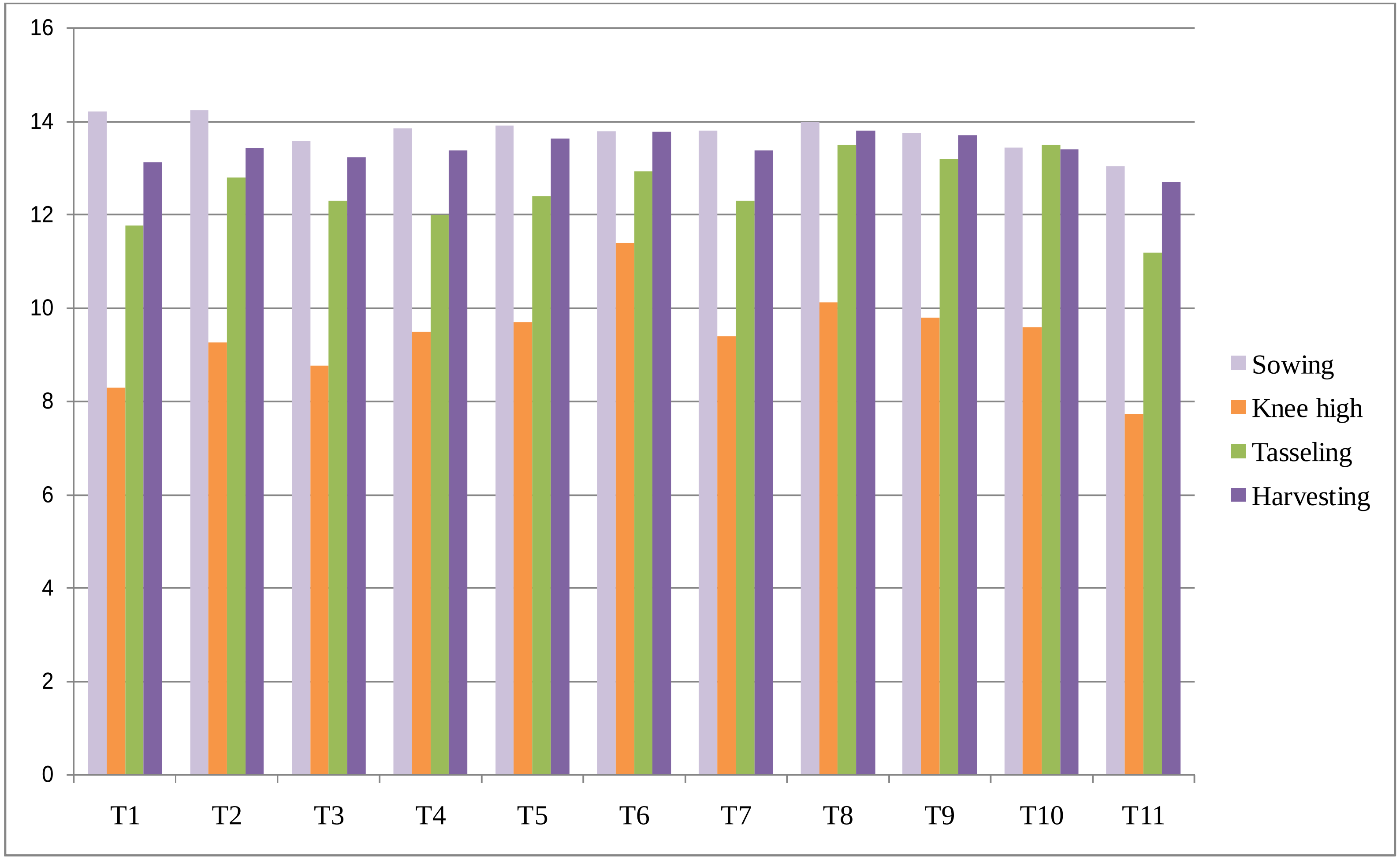


Fig. 5.17: Soil moisture at Sowing, Knee high, Tasseling and Physiological maturity as influenced by varied levels of nano urea and conventional urea

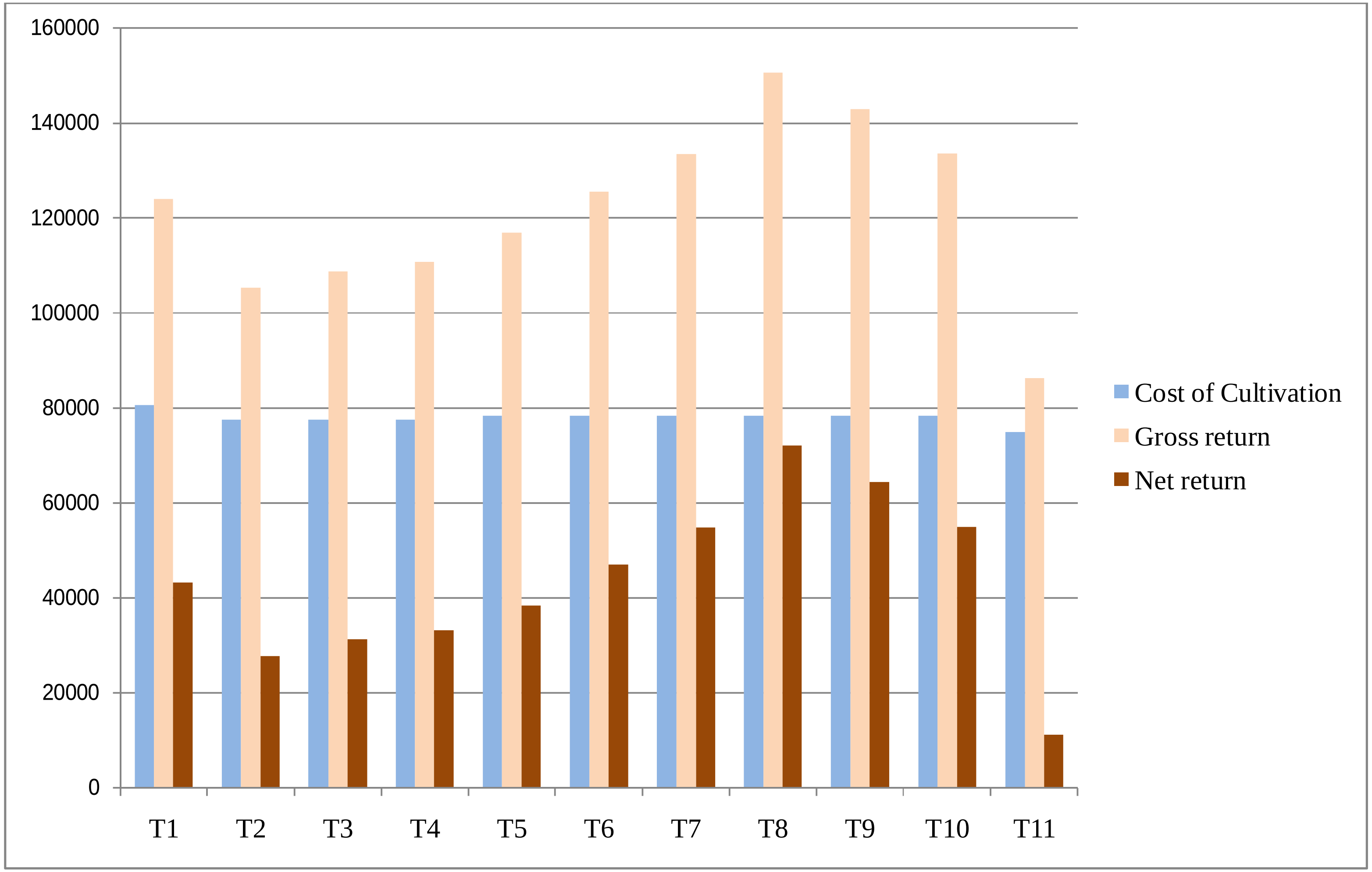


Fig. 5.18: Economics analysis as influenced by varied levels of nano-urea & conventional urea

CHAPTER VI
SUMMARY AND CONCLUSION

Maize (*Zea mays* L.) is one of the most versatile emerging crops shaving wider adaptability under varied agro-climate conditions. Globally, maize is known as the queen of cereals because it has the highest genetic yield potential among the cereals. It is cultivated on nearly 190 m ha in about 165 countries having wider diversity of soil, climate, biodiversity and management practices that contributes to 39% of the global grain production. In India, Maize is grown throughout the year. It is predominantly a kharif crop with 85% of the area under cultivation during the season. Maize is the 3rd most important cereal crops in India after rice and wheat. It accounts for around 10 % of total food grain production in the country. India is also the 5th largest producer of maize in 2020 as per FAO data and India's share in world production accounted to be 2.59% in the same year.

A field experiment was conducted at Biswanath College of Agriculture, Assam Agricultural University, Biswanath Chariali, Assam during *rabi* season of 2022-23 to study the "Smart Nutrient Management using Nano Urea on Rabi Maize (*Zea mays* L.) under rainfed situation". The experiment consisted of 11 treatments in randomized block design *viz*. $T_{1:}$ Recommended Dose of Fertilizer (RDF) T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage, T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage, T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage, T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage, T_6: :25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage, T_7: 25% N + 100% P & K + Spray of Nano urea @ 10ml l^{-1} at knee high and tasseling stage, T_8: 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage, T_9: 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage, T_{10}: 50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage, T_{11}: 100% P & K.

The experiment was conducted in the Post graduate experimental plot, Department of Agronomy, Biswanath College of Agriculture, Biswanath Chariali, Assam Agricultural University situated within the North Bank plain Zone of Assam which experiences a sub tropical climate with sandy loam soil.

The weekly mean maximum temperature during the crop growth period ranged from 21.6° to 33.4°C while the mean minimum temperature ranged from 8.05°C to 16.05°C. The mean relative humidity (RH) ranged from 89.4% to 95% in the morning hours whereas in the evening hours, it ranged from 51.3% to 74.1%. Total rainfall of 185.4 mm was received during crop growth period out of which, the highest amount received was during 8th October to 14th October, 2022 with total rainfall of 68.6 mm which coincide with Knee high stage of the crop. The total number of rainy days was 19 during the entire crop growth period. Variation was also observed in other weather parameters *viz.*, mean bright sunshine hours, wind speed, etc. The mean bright sunshine hours varied from 1.2 to 9.6 hours per day during the crop growth period while the mean evaporation during the crop growth period was 2.11 mm day^{-1} and the average wind speed varied from 0.97 to 1.92 km hr^{-1} during the crop growth period.

The soil of the experimental site was sandy loam in texture. The soil was acidic in reaction, medium in organic Carbon, available Nitrogen, Phosphorus and Potassium. The average soil moisture content at the time of sowing was 13.79% which was reduced to 9.42% during knee high stage; however it increases afterwards 12.54 and 13.41% at tasseling and harvest, respectively.

The field investigation has been undertaken with a view to enhance the productivity of maize in sustainable manner with efficiency utilization of nitrogen. Therefore, the objectives of the experiement were -

1. Study the effect of foliar application of nano urea on growth and yield of *rabi* maize
2. Find out the optimum combination of nano urea and with conventional urea

In the present investigation, various treatment effects were observed in the form of plant height, leaf area, dry matter production, phenological study, CGR, RGR and LAI at different growth stages. Yield parameters and yield were recorded at the time of harvest. During the crop season, microclimatic parameters such as chlorophyll content and relative water content were documented. Moreover, the economics of various treatment combinations were also calculated out.

The salient research findings that were generated to meet the objectives of the present study are mentioned below:

- The maximum plant height (103.20 cm) was recorded in T_1 *i.e.* Recommended Dose of Fertilizer which was statistically at par with T_7 *i.e.* 25% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-}1, T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}, T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} and T_{10} *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high stage. In both tasseling and physiological maturity increased plant height of 245.20 and 243.80 cm, respectively were recorded in T_8 (50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}). The lowest magnitudes plant height (70.13 cm at knee height, 194.13 cm at tasseling and 200.13 cm at physiological maturity respectively) were recorded in T_{11} *i.e.* 100% P & K.
- At knee high stage relatively more number of leaves (8.73) was recorded in T_1 *i.e.* RDF which was statistically at par with T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}. Contrary to this, at tasseling stage and physiological maturity, increased number of leaves (11.67 and 9.60) were recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}. Throughout the crop growing stage, T_{11} *i.e.* 100% P & K registered the lowest number of leaves (8.20 at knee height, 9.00 at tasseling and 9.00 at physiological maturity respectively).
- Significantly thick stem girth (7.53 cm) was recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} which value was comparable with T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} and T_{10} *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1}. The lowest girth of the stem (5.34 cm) was recorded in T_{11} *i.e.* 100% P & K.
- Maximum LAI was recorded at in T_1 *i.e.* RDF for knee high stage (1.84). At tasseling and physiological maturity, greater LAI (4.63 and 3.10, respectively) were recorded under T_8 (50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}) which was, however at par with T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1}.

- Significantly highest total dry matter accumulation (138.83 g) was found under T_1 *i.e* RDF at knee high stage whereas at tasseling and physiological maturity, higher magnitude (214.76 and 645.26 g) were recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} which was followed by T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1}.
- Relatively higher CGR (209.79 g $m^{-2}d^{-1}$) in between knee high and tasseling was recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} followed by T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1}. Similarly, maximum crop growth rate of. 638.10 g m^{-2} day^{-1} was recorded in between tasseling and physiological maturity in the same treatment *i.e.* T_8. The lowest value (110.89 and 265.64 g $m^{-2}d^{-1}$) were recorded in between knee high and tasseling and in between tasseling and physiological maturity stages, respectively, in T_{11} *i.e.* 100% P & K.
- In between knee high and tasseling, T_6 *i.e.* 25% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} registered significantly increased RGR (0.32 g $g^{-1}d^{-1}$) while the maximum RGR of 0.47 g $g^{-1}d^{-1}$ between tasseling and physiological maturity was recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} which was at par with T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} and T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1}.
- Maximum total leaf chlorophyll (1.37 µmol m^{-2}) was recorded in T_8 *i.e.* 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} which was, however at par with T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1}.
- Relatively greater magnitude of RWC (91.23%) was recorded in T_8 *i.e.* 25% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} which was, however found comparable with T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1}. Further, the lowest value (70.30%) was recorded in T_{11} *i.e.* 100% P & K.
- Significantly higher grain yield (72.25 q ha^{-1}), highest test weight (247.54 g), highest number of seeds cob^{-1} (615.93), highest cob weight $plant^{-1}$ (368 g), highest cob girth $plant^{-1}$ (20.29 cm), highest cob length $plant^{-1}$ (35.88 cm) and highest harvest index (%) (39.50%) was recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}.

- Highest stover yield (112. 33 q ha^{-1}) was recorded in T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} which was statistically at par with T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}.
- Highest production efficiency (120.42 kg day^{-1} ha^{-1}) was recorded in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} which was statistically at par with with T_9 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1}.
- The greatest value of agronomic efficiency (3879.16 $kg^{-1}kg$) was recorded in T_2 *i.e.* 100% P & K + Spray of Nano urea @ 6 ml l^{-1}. While the lowest (30.60 kg/kg) was recorded T_1 *i.e.* RDF.
- The highest amount of soil available-N (268.75 kg ha^{-1}) was recorded in T10 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} which was statistically at par with T_1 (RDF), T_8 (50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}) and T_9 (50% N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1}). The lowest value (241.19 kg ha^{-1}) was recorded in T11 *i.e.* 100% P & K. however, no significant variation with respect to soil available phosphorus and potash was observed due to varied levels of nano-urea and conventional urea
- Among all the treatments, T_1 receiving RDF recorded the highest cost of cultivation (Rs. 80650 ha^{-1}) followed by T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1}. The lowest cost of cultivation (Rs. 75000 ha^{-1}) was incurred in T_{11} *i.e.*100% P & K.
- The highest gross return (Rs. 1,23,943 ha^{-1}), net return (Rs. 43,293 ha^{-1}), benefit-cost ratio (1.91) and Economic efficiency (191.80) was obtained in T_8 *i.e.* 50% N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} whereas, T_{11} *i.e.* 100% P & K recorded the lowest gross return (Rs. 86,305 ha^{-1}), net return (Rs. 11,305 ha^{-1}), Benefit-cost ratio (1.15) and Economic efficiency (115.07).

On the basis of the experimental results, the following may be summarized:

❖ Application of 50% of recommended dose of N from conventional urea + 100% P & K with spraying of nano-urea @ 6ml l^{-1} at knee high and tasseling stage of maize significantly increased plant height, number of green leaves per plant and girth of stem.

- ❖ Physiological parameters such as leaf chlorophyll content, relative water content of leaf, dry matter accumulation, leaf area index, CGR, RGR are also found to be superior under the treatment that received 50% of recommended dose of N from conventional urea + 100% P & K with spraying of nano-urea @ 6ml l^{-1} at knee high and tasseling stage.
- ❖ Further, significantly increased number of seeds per cob; length, girth and weight of cob; test weight; grain and stover yield; and harvest index over control (100% P+K) was recorded under 50% of recommended dose of N from conventional urea + 100% P&K with spraying of nano-urea @ 6ml l^{-1} at knee high and tasseling stage; which also showed superiority over other treatments, however, it was at par with similar combination of conventional fertilizer with spraying of 8 ml l^{-1} of nano-urea at knee high and tasseling stage.
- ❖ Application of 50% of recommended dose of N from conventional urea + 100% P&K with spraying of nano-urea @ 6ml l^{-1} at knee high and tasseling stage enhanced the grain yield (72.25 q ha^{-1}) which was found to be superior over rest of the treatments; however, comparable yield was noted under spraying of nano-urea @ 8 ml l^{-1} along with 50% of recommended dose of N from conventional fertilizer and 100% P & K. The per cent yield increase was recorded to be 19.50 and 71.62 over RDF and control (no N with 100% P & K), respectively.
- ❖ Significant highest productivity efficiency was found when the crop was supplied with 50 % of recommended dose of N from conventional fertilizer and 100% P & K with 6 ml l^{-1} of nano-urea at knee high and tasseling stage; which was, however, at par with spraying of nano-urea @ 8ml l^{-1} coupled with same combination of conventional fertilizer. On the other hand, higher magnitude of Agronomic efficiency was noted when only nano-urea was applied as a source of N, the highest being recorded with the treatment receiving application of 100% P & K + nano-urea @ 6 ml l^{-1} at knee high and tasseling stage
- ❖ Reduced soil (basal) application of N showed lower soil available-N at harvest, the lowest being recorded under control. Significantly higher soil available -N was found when the crop was treated with 50% of recommended N from conventional fertilizer along with 10 ml l^{-1} of nano-urea at knee high and tasseling stage, which was found to be at par with 6 & 8 ml l^{-1} of nano-urea as

well as recommended dose of conventional fertilizer-N. However, the P_2O_5 and K_2O status of soil did not show any significant effect.

- The treatment receiving 50% of recommended N from conventional fertilizer along with 6 ml l^{-1} of nano-urea at knee high and tasseling stage was found superior over rest of the treatment in terms of gross return (Rs. 150569 ha^{-1}), net return (Rs. 72069 ha^{-1}), B:C (1.91) and economic efficiency (191.80%). The said treatment was found 38.12 and 76.73% more economically efficient over application of recommended dose of N and of no N application, respectively.

CONCLUSION

The following conclusions could be drawn:

- Spraying of nano urea @ 6 ml l^{-1} at knee high and tasseling stage with basal application of 50% of recommended N from conventional urea along with 100% P_2O_5 (single super phosphate) and K_2O (Muriate of potash) was found to be superior in terms of noticeably enhanced and economically efficient corn yield which was resulted from proficient utilization of readily-available and highly-mobilized nano-N particles in the plant system that led to significant improvement in crop growth and, eventually the yield parameters.
- Therefore, it could be concluded that spraying of nano-urea @ 6ml l^{-1} at knee high and tasseling stage coupled with basal application of 50% of recommended N from conventional urea along with 100% P_2O_5 (single super phosphate) and K_2O (Muriate of potash) could be a promising and smart option as nutrient management strategy to reap better *rabi* corn yield with appreciable economic efficiency under rainfed upland situation in Assam

FUTURE PROSPECTS

- The study may be repeated at least for two years for confirming the present experimental results. Since, these findings are generated only from the one year of experiment; further investigations for more years are required to derive a valid conclusion before putting these findings forward for next level required for recommendations to the farming community.

- It is also felt that nutrient uptake and partitioning pattern need to be studied to have a better perspective of the effect of nano-fertilizer alone or in combination with conventional fertilizer.
- Long term effect of nano fertilizer to be investigated to have its continuous effect on food, crop productivity, soil fertility, crop ecosystem etc.

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ANNEXURE-I

METEOROLOGICAL DATA DURING THE PERIOD OF EXPERIMENTATION USING NANO UREA ON RABI MAIZE UNDER RAINFED SITUATION

SMW	Date	Rainfall	Evaporation (mm)	Relative Humidity (%)	Temperature		Wind speed (Kmph)	BSSH (hr)
					Maximum	Minimum		
38	17 Sep - 23 Sep 2022	18.8	2.44	94.42	33.41	23.51	1.14	4.61
39	24 Sep - 30 Sep 2022	45.8	2.58	92.85	31.12	22.3	1.8	4.34
40	1 Oct - 7 Oct 2022	42.4	2.04	91.85	32.41	22.65	1.41	5
41	8 Oct - 14 Oct 2022	68.6	2	95.00	30.38	21.68	1.32	2.22
42	15 Oct - 21 Oct 2022	0	2.14	89.42	31.37	19.32	1.2	7.96
43	22 Oct - 28 Oct 2022	0	2.02	90.85	30.74	16.08	1.92	6.26
44	29 Oct - 4 Nov 2022	0	1.97	90	30.11	14.62	1.44	9
45	5 Nov - 11 Nov 2022	0	2.08	89.57	29.65	14.27	0.97	9.13
46	12 Nov - 18 Nov 2022	0	2.05	91.28	28.02	12.25	1.14	8.25
47	19 Nov - 25 Nov 2022	0	2.1	92.28	27.68	10.64	1.41	8.98
48	26 Nov - 2 Dec 2022	0	2.18	91.14	27.8	12.07	1.38	9.03
49	3 Dec - 9 Dec 2022	0	2.07	92.14	27.6	11.52	1.42	8.63
50	10 Dec -16 Dec 2022	0	1.88	92.57	26.82	12.14	1	7.78
51	17 Dec - 23 Dec 2022	3	1.64	93.85	26.47	12.98	1.1	7.65
52	24 Dec- 31 Dec 2022	3.6	1.18	93.25	22.67	11.95	1.72	3.19
1	1 Jan - 7 Jan 2023	3.6	1.64	92.28	24.17	8.05	1.28	7.7
2	8 Jan - 14 Jan 2023	0	4.02	92.85	25.91	8.88	1.14	6.91
TOTAL		185.8	1565.6					
MEAN			92.09	28.60765	14.99471	2.11	1.340588	6.861176

Source: Department of Agricultural Meteorology, BNCA, AAU, Biswanath Chariali

ANNEXURE-II

COST OF CULTIVATION

(AREA: 1ha)

Particulars	Unit	Maize		
		Quantity	Rate	Amount
POL	Lt.	50	90	4500
Seed	Kg	25	120	3000
Urea	Kg	180	15	2700
SSP	Kg	250	20	5000
MOP	Kg	65	30	1950
Nano Urea 1L	Lt.	3.5	500	1750
Land preparation and layout	MD	15	338	7098
Fertilizer application and Line sowing	MD	21	338	7098
Gap filling	MD	5	338	4394
Intercultural operation	MD	30	338	11830
Earthling up	MD	20	338	7774
Spraying	MD	4	338	2028
Harvesting of Maize	MD	25	338	9464
Shelling	MD	17	338	6422
			Total	75008

ANNEXURE-III

SCHEDULE OF OPERATION THROUGHOUT THE EXPERIMENT

Sl. No.	Particulars of operation	Time of operation
1	Ploughing	01.09.2022
2	Harrowing	08.09.2022
3	Layout of the experiment	17.09.2022
4	Fertilizer application	18.09.2022
5	Seed sowing	20.09.2022
6	Thinning	28.09.2022
7	Weeding	17.10.2022
8	Earthing up	18.10.2022
9	Nano fertilizer application 1st spray	25.10.2022
10	Nano fertilizer application 2nd spray	30.11.2022
11	Harvesting and picking	02.01.2023
12	Shelling	06.01.2023

APPENDIX-I

Analysis of variance for plant height (cm) at different growth stages of maize

Sources of variance	df	Mean sums of squares		
		Knee high	Tasseling	Harvesting
Replication	10	306.16	1049.17	511.16
Treatment	2	0.78	78.39	1.38
Error	20	5.67	30.25	5.30

- **Significant at 5% level of probability**

APPENDIX-II

Analysis of variance for number of leaves at different growth stages of maize

Sources of variance	df	Mean sums of squares		
		Knee high	Tasseling	Harvesting
Replication	10	0.09	1.72	0.10
Treatment	2	0.02	0.04	0.10
Error	20	0.02	0.03	0.04

- **Significant at 5% level of probability**

APPENDIX-III

Analysis of variance for leaf area index (%) at different growth stages of maize

Sources of variance	df	Mean sums of squares		
		Knee high	Tasseling	Harvesting
Replication	10	0.11	0.89	0.44
Treatment	2	0.001	0.01	0.06
Error	20	0.002	0.01	0.07

- **Significant at 5% level of probability**

APPENDIX-IV

Analysis of variance for dry matter (g) at different growth stages of maize

Sources of variance	**df**	**Mean sums of squares**		
		Knee high	Tasseling	Harvesting
Replication	10	36.74	35.89	859.55
Treatment	2	0.87	4.49	27.68
Error	20	24.31	3.46	15.96

- **Significant at 5% level of probability**

APPENDIX-V

Analysis of variance for yield parameters at different growth stages of maize

Sources of variance	df	Mean sums of squares			
		Length of cob	Girth of cob	Weight of cob	Number of seeds
Replication	10	24.68	5.22	10077.91	12910.61
Treatment	2	18.65	1.74	2459.30	66.65
Error	20	137.68	1.80	74.12	968.71

- **Significant at 5% level of probability**

APPENDIX-VI

Analysis of variance for yield parameters at different growth stages of maize

Sources of variance	df	Mean sums of squares			
		Test weight	Grain yield	Stover Yield	Harvesting index
Replication	10	2699.29	224.22	1123.49	70.21
Treatment	2	0.49	0.80	204.89	4.17
Error	20	1.11	8.07	3.10	1.29

- **Significant at 5% level of probability**

APPENDIX-VII

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross Return (Rs. ha^{-1})	Net Return (Rs. ha^{-1})	B:C ratio	Economic efficiency
T_1: Recommended Dose of Fertilizer (RDF)	80650	123943	43293	1.53	153.68
T_2: 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	77500	105391	27891	1.35	135.98
T_3: 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	77500	108855	31355	1.40	140.45
T_4: 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	77500	110762	33262	1.42	142.91
T_5: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	78500	116912	38412	1.48	148.93
T_6: 25% N + 100% P & K + Spray of Nano urea @ 6ml l^{-1} at knee high and tasseling stage	78500	125501	47001	1.59	159.87
T_7: 25% N + 100% P & K + Spray of Nano urea @ 8ml l^{-1} at knee high and tasseling stage	78500	133373	54873	1.69	169.90
T_8: 50 % N + 100% P & K + Spray of Nano urea @ 6 ml l^{-1} at knee high and tasseling stage	78500	150569	72069	1.91	191.80
T_9: 50 % N + 100% P & K + Spray of Nano urea @ 8 ml l^{-1} at knee high and tasseling stage	78500	142885	64385	1.82	182.01
T_{10}: 50 % N + 100% P & K + Spray of Nano urea @ 10 ml l^{-1} at knee high and tasseling stage	78500	133517	55017	1.70	170.08
T_{11}: 100% P & K	75000	86305	11305	1.15	115.07