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Research Article

Effect of Nano-urea on Productivity and Soil Quality of Dual-purpose Oat (*Avena sativa* l.) under New Gangetic Alluvial Zone

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ABSTRACT

Dual-purpose crops can alleviate the feed gap to integrate crop and livestock systems when the forage deficit is severe. However, there is limited information about the type of dual-purpose management and cereal species that would be most optimal for both forage and grain production. Therefore, an experimental study was conducted to assess the effect of nano-urea on the productivity and quality of dual-purpose oat (*Avena sativa* L.) in the new Gangetic alluvial zone. The experiment was laid out in a randomized complete block design(RCBD) with ten different treatments with comprising of different levels (T1 =Control (Without any fertilizer), T_2 =RDF (N, P_2O_5, K_2O: 80, 40, 40 kg/ha), T_3=75% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water, T_4=50% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water, T_5=75% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water, T_6= 50% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water, T_7 = 75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water, T_8 = 50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water, T_9 = 75% of RDN along with Full dose of P & K + Urea (2% spray), T_{10}= 50% of RDN along with Full dose of P & K + Urea (2% spray). From the above said experiment, it is observed that application of75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water recorded the highest green fodder yield (272.83 q/ha) and other forage quality attributes, *i.e.,* dry matter yield (61.50 q/ha), crude protein (14.24%) and crude fibre(47.33%). The same result was recorded in yield and yield-attributing characters, such as grain yield (17.83 q/ha), no. of grains per panicle, no. of effective tillers per plant, as well as growth characters of dual-purpose oat.

Key words: Dual Purpose, Green forage yield, Dry matter yield, Crude protein, Crude fibre, Nano-urea

Introduction

Green fodder is grown in India on 8.4 million hectares, accounting for 5.23% of the country's total area. The area has been essentially steady for the last two decades (Koli and Bhardwaj, 2018; Jana *et al.,* 2022). Not only that, but the country accounts for around 15% of the world's total livestock population on 2.29% of the global land area (Sarkar *et al*., 2023; Kumar *et al*., 2023). According to the Union Ministry of Fisheries, Animal Husbandry, and Dairy, the Government of India's ICAR-Indian Grassland and Fodder Research Institute (IGFRI) in Jhansi estimates deficits of 11.24%, 23.4%, and 28.9% in green fodder, dry fodder, and concentrates, respectively. The shortfall may expand at a rate of 1.23% per year due to the growing cattle population and current feed production. Oat (*Avena sativa* L.) is an important dual-purpose crop that produces high-quality fodder and grain for livestock. It is highly prized for its rapid regeneration capabilities and

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exceptional palatability, making it an ideal source of green fodder. Oats have grown in popularity in India's northern and north-western regions due to their rapid regrowth capability and better palatability. Improving the production of oats and quality is critical for meeting rising market demand, providing significant economic benefits to farmers, and promoting sustainable agricultural development (Cui *et al.* 2023). Foliar application of major and micronutrients aids in the quick transfer of nutrients when compared to soil application, which is critical in alleviating stress in plant (Sarkar *et al.*, 2021; Sarkar *et al.*, 2022). The use of nano urea as a foliar spray liquid at critical crop growth stages effectively fulfils the plant's nitrogen requirement and leads to higher crop productivity and quality compared to conventional urea. The nitrogen-holding capacity of nano urea refers to how much nitrogen can be stored in the particles. According to Babo Prem *et al.* (2021), these nutrients are slowly released and provide a consistent source for plant growth. Therefore, the present investigation was carried out to assess the effect of nano urea on growth, yield attributes and forage quality of the oat variety, Kent under the Gangetic alluvial soil of West Bengal.

Materials and Methods

A field experiment named "Effect of Nano-urea on productivity and soil quality of dual-purpose oat (*Avena sativa* L.)" was conducted during the rabi season of 2021-22 and 2022-23 at the Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya, Gayeshpur, Nadia, West Bengal. The experimental field was designed to simulate a humid, subtropical environment and typical medium land in West Bengal's New Alluvial Zone. The research station is approximately 9.75 meters above mean sea level and is situated at 230N latitude and 890E longitude. The soil had a sandy clay loam texture, was classified as an inceptisols, and had a pH range of 6.9 to 7.1. The area's topography is average. In this experiment, oats seeds were sown with a 25 cm row-to-row spacing and a 5 cm plant-to-plant spacing (continuous sowing), using high-quality Kent seeds at a seed rate of 100 kg/ha. The general suggested dose of N, P_2O_5, and K_2O was 80, 40, and 40 kg ha^{-1}, respectively. Urea, single super phosphate (SSP), and muriate of potash (MOP) were used as nitrogen, P_2O_5, and potassium fertilizer sources. The oat variety utilized in the experiment was called 'Kent'. It is a plant that grows to a height of about 1.3 to 1.5 meters, lasts 115-120 days, and has a yield potential of 15-20 q/ha. Ten treatments (T_1 =Control (Without any fertilizer), T_2 =RDF (N, P_2O_5, K_2O: 80, 40, 40 kg/ha), T_3=75% of RDN along with Full dose of P & K + Nano- urea@2ml/litre of water, T_4=50% of RDN along with Full dose of P & K + Nano-urea@2ml/litre of water, T_5=75% of RDN along with Full dose of P & K + Nano-urea@4ml/litre of water, T_6= 50% of RDN along with Full dose of P & K + Nano-urea@4ml/litre of water, T_7 = 75% of RDN along with Full dose of P & K + Nano-urea@6ml/litre of water, T_8 = 50% of RDN along with Full dose of P & K + Nano-urea@6ml/litre of water, T_9 = 75% of RDN along with Full dose of P & K + Urea (2% spray), T_{10}= 50% of RDN along with Full dose of P & K + Urea (2% spray). Pre-sowing irrigation was used to help in seed sowing and germination. Five more irrigations were carried out following the pre-sowing irrigation. Three of these five irrigations were given prior to the cutting technique, while the other two were given after the cutting operation to promote grain development. The first measurement of plant height was taken 30 days after emergence, the second at the time of cutting (60 DAS), and the last during harvest. To assess plant height, ten randomly selected plants from each plot were tagged. The amount of dry aerial biomass was first determined using destructive sampling procedures after 30 days of emergence, then again at cutting (60 DAS), and finally at harvest. At ground level, one square meter of vegetation from each plot was cut down and separated into stems and leaves. The samples were then dried in a hot air oven for 48 to 72 hours at 65 to 100 degrees Celsius until they reached a consistent weight. LAI was measured for the crop at 30 DAS, 60 DAS, and harvest time. The breadth of each cut leaf piece was measured after 10 leaves from five randomly selected plant samples were cut into 10-cm rectangular pieces. The surface area of the chopped leaves was determined, and the leaves were then dried separately in the oven. The green leaf laminae of these five leaves were oven-dried and weighed individually. The crude protein% of oat fodder was measured using the Kjeldahl method, which comprises the digestion of organic matter with sulfuric acid in the presence of a catalyst, rendering the reaction product alkaline, followed by distillation in the Markham apparatus and titration of the freed ammonia. Calculate the nitrogen content and multiply the result by the standard factor 6.25 to get the crude protein content. Under particular conditions, the weighted sample is digested with solutions containing 1.25 per cent H_2SO_4 and 1.25% NaOH. The residue that remains is dried and weighed. The dish containing the residue is burned at 550°C. The difference in weight before and after ignition will be the weight of crude fibre present in the sample. The crude protein yield was computed by multiplying the crude protein content by the dry matter yield.

Crude protein (kg ha^{-1}) = Crude protein (%) × dry matter yield (kg ha^{-1})

Crude fibre (kg ha^{-1}) = Crude fibre (%) × dry matter yield (kg ha^{-1})

Chemical analysis of soil samples

Uptake of nitrogen

Nitrogen uptake was calculated from the concentrations of the respective plant parts using the following formula.

$$\text{Update of N} = \frac{\text{Nutrient concentration (\%)} \times \text{Yield of grain/straw}}{100} \text{kg/ha}$$

Nitrogen Use Efficiency (NUE)

NUE was calculated by nitrogen uptake and crop yield obtained by using the following formula in the plots separately.

$$\text{NUE (kg economic yield per kg N uptake} = \frac{\text{Crop yield (kg/ha)}}{\text{Total N uptake (kg/ha)}}$$

Analysis of soil samples

With a soil auger driven to a depth of 15 cm, soil samples were taken from three randomly selected locations in each experimental plot both before and after the crop of oats was harvested. After mixing the soil samples, they were allowed to dry in the shade, ground into powder until they could fit through an 80-grit filter, and then stored for chemical analysis.

Determination of available nitrogen in soil

The available nitrogen content of the soil was determined using the Subbiah and Asija (1956) method, which involves oxidatively hydrolysing soil organic matter with hot, alkaline potassium permanganate. Ammonia that had been released was subsequently absorbed, condensed in boric acid, and titrated against a reference standard of 0.02 (N) H_2SO_4.

Determination of available phosphorus in soil

Olsen's method was followed to extract the readily accessible phosphorus from the soil using a 0.5 (M) $NaHCO_3$ solution at a pH of 8.5. The amount of available phosphorus in the extract was calorimetrically determined in accordance with Jackson (1973) using a microprocessor-based UV-VIS Spectrophotometer.

Determination of available potassium in soil

The soil's available potassium was calculated (measured in kg/ha) by extracting the soil with 1 (N) ammonium acetate (adjusted to pH 7.0) and measuring the potassium content using a flame photometer (Jackson, 1973).

Statistical analysis

To determine the difference in significance between the treatments, all experimental data were evaluated using a split-plot design (Gomez and Gomez, 1984).

An analysis of variance (ANOVA) was created using the proc glimmix software in statistical analysis systems (v 9.3, SAS Institute Inc, Cary, NC). For the analysis, replication was treated as a random variable while treatments (main and sub-plots) were treated as fixed effects. The level of significance for all statistical tests was set at 0.05. The means were separated using Fisher's least significant difference test (0.05). The R programme (version 4.1.0) was used to conduct a correlation analysis to ascertain the relationship between various forage quality metrics.

Results and Discussion

Growth attributes

Plant height is a useful indicator of crop health and can be modified through improved agronomic practices and genetic selection. Starting in the early vegetative stage and continuing through the crop's flowering stage, oat plant height increased and was maintained until the crop was near maturity. At harvest,75% of RDN, along with a Full dose of P & K + Nano-urea@6ml/litre of water, obtained the best value of plant height (129.36 cm), which is followed by50% of RDN, along with a full dose of P & K + Nano- urea@4ml/litre of water. The lowest value of plant height (107.56 cm) was obtained from the control.

Leaf Area Index (LAI)

The leaf area index, a crucial component of plant growth, directly impacts photosynthesis, absorption of solar radiation by the crop canopy, and, ultimately, crop output. It serves as a gauge for source size. At harvest, the treatment T6 (i.e., 50% of RDN along with Full dose of P & K + Nano urea @ 4ml/litre of water) observed the highest value of 4.11. The treatment T1(Control) shows a significant difference (3.26) from the treatment (Table 1).

Total Dry Aerial Biomass/m^2

The application of 75% of RDN+full dose of P & K+ Nano urea@ 6 ml/l of water (60 DAS) and harvest time had the highest dry aerial biomass (228.86 g/m^2). However, at harvest, the same results were observed at 75% RDN + full doses of P & K nano urea@6 ml/l of water, observed maximum value of dry aerial biomass (248.47 g/m^2) statistically significant par values with 50% of RDN, along with Full dose of P & K + Nano urea@6ml/litre of water were observed. The lowest value of dry aerial biomass was obtained from the control.

Crop Growth Rate (g/m^2/day)

Crop growth rate (CGR) of oat varied significantly across treatments, with CGR growing gradually between the 30-60 DAS stage. The crop's growth rate increases immediately after harvest, reaches a maximum, and then declines as the plant matures. Between 30 and 60 days after planting, the

Table 1. Effect of nano-urea on growth parameters of Oat (*Avena sativa* L.) (Pooled value 2 years)

Treatment	Plant height (cm) at harvest	Leaf area index (LAI) at harvest	Total Dry Aerial Biomass (g/m^2)		Crop Growth Rate (g/m^2/day) at	
			60 DAS	At harvest	30-60 DAS	61DAS- harvest
T_1	107.56	3.26	115.36	158.63	3.54	3.16
T_2	118.83	3.83	206.45	223.10	6.04	4.95
T_3	119.13	3.96	205.65	220.87	6.11	4.21
T_4	115.63	3.78	206.76	240.60	6.29	5.95
T_5	118.06	3.80	214.50	238.63	7.96	6.35
T_6	121.86	4.11	216.30	245.50	6.86	6.73
T_7	129.36	3.76	228.87	248.47	7.97	7.07
T_8	116.56	3.36	224.30	247.63	7.53	7.05
T_9	119.23	3.46	171.63	211.57	5.03	4.78
T_{10}	113.50	3.63	162.50	193.50	4.97	4.60
S.Em (+)	3.29	0.29	3.81	6.5	0.32	0.25
CD(P=0.05)	9.77	0.86	11.32	19.5	0.96	0.75

T1:Control;T2:RDF (N, P_2O_5, K_2O: 80, 40, 40 kg/ha);T3:75% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water ;T4:50% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water;T5:75% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T6:50% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T7:75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T8:50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T9:75% of RDN along with Full dose of P & K + Urea (2% spray);T10:50% of RDN along with Full dose of P & K + Urea (2% spray)

highest crop growth rate (7.97) was observed with 75% RDN + Full dose of P & K + Nano urea @ 6 ml/litre of water. Throughout this time period, there was no discernible difference in growth between a 75% RDN + Full dose of P & K + Nano urea @ 4 ml/l of water and a 50% RDN + Full P & K + Nano urea @ 6 ml/l of water application rate of 7.96 and 7.53, respectively. The same crop growth rate was observed from 60DAS to harvest. This could be linked to the application of additional nutrients throughout the early vegetative and crop growth stages, resulting in maximum plant height. Aside from this, nitrogen is crucial for photosynthetic activity and protein synthesis, which may stimulate cell division and cell elongation, thereby accelerating vegetative development. This is in conformity with the findings of Chavan et al. (2023), Samanta *et al*. (2022); Lahri *et al*. (2021) and Navya *et al*. (2022).

Growth and growth attributes

Effective Tillers/m²

In this investigation, the effective tiller/m2 was found to be the highest (140.17 effective tillers/m^2) in the treatment with 75% of RDN along with Full dose of P & K + Nano urea @ 6ml/litre of water. This experiment shows that treatments, 75% of RDN along with Full dose of P & K + Nano urea@4ml/ litre of water, 50% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water), 50% of RDN along with Full dose of P & K + Nano urea@6ml/ litre of water. shows statistically at par results of 138.47 effective tillers/m^2, 136.40 effective tillers/ m^2, and 139.77 effective tillers/m^2, respectively, with the highest value.

No. of Grains/ Panicle

The highest no. of grains/panicle (29.02) was recorded at harvest from the treatment with 75% of RDN, along with Full dose of P & K + Nano urea @ 6ml/litre of water. It was statistically at par with 50% of RDN along with a full dose of P & K + Nano urea@4ml/litre of water) and 50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water) treatment with values of 26.52 and 27.91, respectively. The lowest no of grains/ panicle (22.54) was obtained with the treatment T1 (control). It was much lower than the other treatments used in this experiment. Adequate availability of these nutrients is thought to promote carbohydrate accumulation and efficient translocation from source to sink, particularly in reproductive organs. This approach causes a considerable increase in numerous yield-attributing characteristics. These results are in close agreement with numerous researchers, such as Sahu *et al.* (2021) and Pareek *et al.* (2022).

Panicle length

The highest panicle length was observed in treatment, 75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water) of 28.46 cm. It was statistically at par with T5, T6, and T8 treatments with values of 26.53 cm,26.45 cm and 27.11 cm, respectively. The lowest panicle length (22.06 cm) was observed in the T1 (control) treatment. It was significantly lower than other treatments in this experiment.

Panicle Weight

The highest panicle length was observed in treatment, 75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water) of 3.13 g. It was statistically comparable to the T5, T6, and T8 treatments, with values of 2.99 g, 3.05 g, and 2.97 g, respectively. The lowest panicle weight (1.88 g) was observed in treatment T1 (control). It was significantly lower than other treatments of this experiment.

Grain yield (q/ha)

The best value at harvest (17.83 q/ha) was achieved with 75% RDN+ Fulldose of P & K + Nano urea@6 ml/l of water. Values of 16.58 q/ha and 17.68 q/ha for 50% of RDN + full doses of P & K+nano urea at 4ml/litre and 6 ml/litre of water, respectively, were statistically comparable. The treatment control produced the lowest grain yield (8.83 q/ha). The experimental results showed that using nano urea significantly altered grain yield. This could be the outcome of nano urea spraying, which boosts yield parameters like as effective tiller density and grain yield per panicle. The total number of grains per panicle may be attributable to the foliar spray of nano urea, which results in increased photosynthesising and transfer of photosynthates from the source to the sink. These results also corroborate the findings Algym *et al.* (2020), Hafize and Bati (2023) and Aniket *et al*. (2024).

Straw yield (q/ha)

Different nano-urea applications also increase straw yield; likewise, they increase grain yield. The highest straw yield (68.26 q/ha) was observed in the treatment with 75% RDN, along with Full dose of P & K + Nano urea @ 6ml/litre of water. The lowest straw yield (40.65 q/ha) was obtained with the treatment T1 (control). It was significantly lower than other treatments in this experiment.

Forage yield and quality attributes

Green forage yield (q/ha)

Table 2 shows that, compared to the control treatment (121.18 q/ha), the combination of 75% RDN and Full dose of P & K + Nano urea @ 6ml/litre of water produced the highest green forage yield (272.83 q/ha). Urea's nano-size aids in the plant's uptake and nutrient utilization efficiency, as well as its penetration into the plant from the leaf surface upon which it is sprayed (Ding *et al*., 2020). The increased dry matter yield could be attributed to improved crop growth and photosynthetic activity, which led to a better carbohydrate supply, improved partitioning of photosynthates, and greater nutrient accumulation, all of which resulted in higher dry matter content and green biomass yield. The similar findings were reported by Meena *et al.* (2021).

Dry matter yield (q/ha)

Total dry matter yield data for oats showed that at 60 days after sowing (during harvest), the application of nano urea significantly impacted dry matter production. Dry matter production peaked at 61.50 q/ha at 75% of RDN along with a full dose of P and K+nano urea@ at 6 ml/litre of water, whereas the control produced the least at 23.14 q/ha. The increased dry matter production might be attributed to improved crop growth and photosynthetic activity, resulting in a better supply of carbohydrates, more efficient photosynthate partitioning, and, ultimately, higher nutrient accumulation. The dry matter content and green biomass output increased, resulting in a larger dry matter yield. Similar findings were

Table 2. Effect of nano-urea on yield and yield attributes of Oat (*Avena sativa* L.) (Pooled value 2 years)

Treatment	Effective tiller/m^2	No. of grains/ panicle	Panicle length (cm)	Panicle weight (cm)	Grain Yield (q/ha)	Straw yield (q/ha)	Harvest Index
T_1	120.70	22.54	22.06	1.88	8.83	40.65	16.46
T_2	134.32	24.49	26.00	2.54	13.80	60.94	18.75
T_3	133.71	22.66	25.69	2.62	13.66	63.25	17.68
T_4	135.77	23.17	24.80	2.95	13.42	63.68	17.39
T_5	138.47	24.53	26.53	2.99	14.61	64.75	18.37
T_6	136.40	26.52	26.45	3.05	16.58	66.16	20.04
T_7	140.17	29.02	28.46	3.13	17.83	68.26	20.68
T_8	139.77	27.91	27.11	2.97	17.68	63.85	20.27
T_9	131.70	25.11	22.49	2.60	13.72	62.50	17.61
T_{10}	126.80	24.76	23.77	2.63	13.34	58.38	17.74
S.Em (+)	1.29	1.27	0.80	0.05	0.43	1.52	0.40
CD (P=0.05)	3.83	3.77	2.39	0.17	1.29	4.52	1.21

T1:Control;T2:RDF (N, P_2O_5, K_2O: 80, 40, 40 kg/ha);T3:75% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water ;T4:50% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water;T5:75% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T6:50% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T7:75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T8:50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T9:75% of RDN along with Full dose of P & K + Urea (2% spray);T10:50% of RDN along with Full dose of P & K + Urea (2% spray)

reported by Singh *et al.* (2012), Meena *et al*. (2021), and Theerthana *et al.* (2022).

Crude protein percentage (%)

The highest value of crude protein percentage (14.24%) was observed when 75% of RDN along with Full doses of P & K + Nano urea@ 6 ml/liter of water; this value was statistically equivalent to that observed when 50% of RDN + Full doses of P & K + Nano urea@2 ml/liter of water, whereas, the lowest amount of crude protein (10.69%) was obtained from control.

Crude protein yield (q/ha)

It shows that crude protein yield was the highest (8.74 q/ha), 75% of RDN, with Full dose of P & K + Nano urea @ 6ml/litre of water. This observation shows that T2, T4, T5, T6, T8, showing significantly at par results of 6.67 q/ha, 7.76 q/ha,7.13 q/ha,7.37 q/ha,7.21 q/ha respectively. The lowest crude protein yield (2.93 q/ha) was obtained with the treatment T1 (control). It was significantly lower than other treatments in this experiment. Nitrogen is a structural element of cells and cell walls, which improves fodder quality by boosting protein content. Meena et al. (2021) showed similar results.

Crude fibre percentage (%)

The maximum proportion of crude fibre (%) was found in 75% of RDN along with a full dose of P & K + Nano urea @ 6 ml/litre of water, making it statistically significant from control, which is followed by 50% of RDN along with full doses of P and K +nano urea @ 4 ml per litre of water. The lowest crude fibre percentage (38.50%) was obtained from the control. This might be due to increased fertiliser treatment delaying maturity, particularly through nitrogen; the crude fibre content decreased as nutrient input increased.

Crude fibre yield (q/ha)

In this current investigation, the highest crude fibre yield (29.10 q/ha) was obtained with 75% RDN, along with a Full dose of P & K + Nano urea @ 6ml/litre of water. The significant results (27.16 q/ha) were observed in treatment 50% of RDN, along with the Full dose of P & K + Nano urea@6ml/litre of water. The lowest crude fibre yield (9.75 q/ha) was

Table 3. Effect of nano-urea on forage yield and attributes of Oat (*Avena sativa* L.) (Pooled value 2 years)

Treatment	Green Forage Yield(q/ha)	Dry matter Yield(q/ha)	Crude Protein (%)	Crude Protein Yield (q/ha)	Crude Fiber (%)	Crude Fiber Yield (q/ha)
T_1	121.18	23.14	10.69	2.93	38.50	9.75
T_2	262.22	54.76	12.29	6.67	46.00	25.19
T_3	244.44	52.53	12.34	5.60	43.57	22.89
T_4	264.44	55.40	13.97	7.16	43.50	24.10
T_5	268.89	56.82	12.58	7.13	43.00	24.45
T_6	266.66	58.13	12.69	7.37	46.57	24.28
T_7	272.83	61.50	14.24	8.72	47.33	29.10
T_8	265.55	57.92	12.41	7.21	46.90	27.16
T_9	238.89	50.85	11.05	5.65	42.16	19.58
T_{10}	220.00	45.87	12.12	5.54	44.00	20.18
S.Em (+)	24.4	6.6	0.36	0.81	0.79	0.81
CD (*P*=0.05)	72.7	19.7	1.08	2.41	2.34	2.41

T1:Control;T2:RDF (N, P_2O_5, K_2O: 80, 40, 40 kg/ha);T3:75% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water ;T4:50% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water;T5:75% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T6:50% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T7:75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T8:50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T9:75% of RDN along with Full dose of P & K + Urea (2% spray);T10:50% of RDN along with Full dose of P & K + Urea (2% spray)

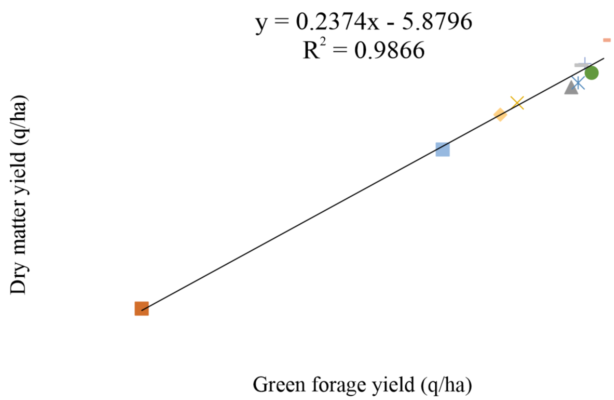

Fig. 1. Correlation between Green forage yield (q/ha) and dry matter yield (q/ha)

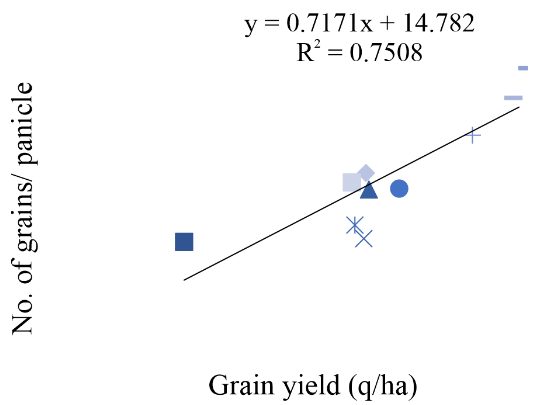

Fig. 2. Correlation between Grain yield (q/ha) and no. of panicles/plant

obtained with the treatment T1 (control). Fertilizer application at higher levels, especially nitrogen, might cause delayed maturity. Lower fertilizer doses can cause forced maturity and short life spans, perhaps affecting fiber synthesis. This supports the findings of Pathan *et al.* (2012) and Singh et al. (2012).

Nutrient status of the post-harvest soil

Available nitrogen

The influence of conventional fertilization along with nano urea on the availability of nitrogen, phosphorus and potassium in the post-harvest soil was presented in Table 4. Recorded data clearly narrated no significant effect of different nitrogen fertilization, along with nano urea application, on the post-harvest soil in the availability of nitrogen.

The maximum available nitrogen in post-harvest soil was found in the T_1 (Control) treatment of 128.50 kg/ha. The lowest available nitrogen was found in the T_7 treatment (i.e., 75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water). There is no significant difference between the available nitrogen status in post-harvest soil.

Available phosphorus

The maximum available phosphorus in post-harvest soil was found in the T_8 treatment (i.e., 50% of RDN along with Full dose of P & K + Nano urea @ 6ml/litre of water, 43.77 kg/ha). The lowest available phosphorus was found in the T_1 treatment (Control) of 43.13 kg/ha. There is no significant difference between the available phosphorus status in post-harvest soil.

Available potassium

The maximum available potassium in post-harvest soil found in the T_7 treatment (i.e., 50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water) of 149.57 kg/ha. The lowest available potassium was found in the T_1 treatment (Control) of 121.30 kg/ha. There is no significant difference between the available potassium status in post-harvest soil.

Uptake and Use efficiency of Nitrogen

Nitrogen Uptake

Nitrogen uptake was measured by the nitrogen content of the crop after harvest and the nitrogen status of post-harvest soil (Table 5). From this current investigation the nitrogen uptake was found highest in treatment T_7 (i.e., 50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water) of 142.68 kg/ha. The lowest uptake was found in the treatment T_1 (control) of 76.10 kg/ha nitrogen uptake.

Nitrogen Use Efficiency

Nitrogen use efficiency had been calculated by the nitrogen uptake and yield of the crop. Here in this investigation the nitrogen use efficiency was found highest in the T_5 (i.e., 75% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water) treatment of 74.98 kg economic yield/kg N uptake.

Table 4. Effect of nano urea application on available nitrogen, phosphorus and potassium (kg/ha) content of post-harvest soil of dual-purpose oats during *rabi* season of 2022-23

Treatments	Available nutrient status of post-harvest soil (after oat cultivation)		
	Available N in soil (kg/ha) 2022-23	Available P in soil (kg/ha) 2022-23	Available K in soil (kg/ha) 2022-23
T_1	128.50	43.13	121.30
T_2	112.55	43.47	129.90
T_3	114.97	44.73	127.17
T_4	112.17	43.43	129.73
T_5	118.63	43.50	135.03
T_6	117.00	43.50	143.37
T_7	107.87	43.50	149.57
T_8	114.61	43.77	133.70
T_9	115.73	43.57	128.83
T_{10}	118.77	43.60	125.93
SEm(±)	2.56	0.32	5.79
CD at 5 %	NS	NS	NS
Initial Value	196.5	47.2	198.4

T_1:Control;T_2:RDF (N, P_2O_5, K_2O: 80, 40, 40 kg/ha);T_3:75% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water ;T_4:50% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water;T_5:75% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T_6:50% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T_7:75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T_8:50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T_9:75% of RDN along with Full dose of P & K + Urea (2% spray);T_{10}:50% of RDN along with Full dose of P & K + Urea (2% spray)

Table 5. Effect of nano urea application on nitrogen uptake (kg/ha) and Nitrogen Use Efficiency (NUE) of dual-purpose oats during the *rabi* season of 2022-23:

Treat-ments	Nitrogen uptake (kg/ha)	Nitrogen Use Efficiency (NUE) (kg economic yield/kg N uptake)
T_1	76.1	59.01
T_2	101.46	65.09
T_3	102.36	74.15
T_4	114.68	67.03
T_5	106.25	74.98
T_6	111.08	74.48
T_7	142.68	61.08
T_8	117.59	69.15
T_9	101.21	75.36
T_{10}	89.91	79.49

T_1:Control;T_2:RDF (N, P_2O_5, K_2O: 80, 40, 40 kg/ha);T_3:75% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water ;T_4:50% of RDN along with Full dose of P & K + Nano urea@2ml/litre of water;T_5:75% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T_6:50% of RDN along with Full dose of P & K + Nano urea@4ml/litre of water;T_7:75% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T_8:50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water;T_9:75% of RDN along with Full dose of P & K + Urea (2% spray);T_{10}:50% of RDN along with Full dose of P & K + Urea (2% spray)

The lowest nitrogen use efficiency was found in treatment T_1 (Control) of 59.01 kg economic yield/kg N uptake. The lowest nitrogen use efficiency was found in among the nano urea application treatment T_7 (i.e., 50% of RDN along with Full dose of P & K + Nano urea@6ml/litre of water) of 61.08 kg economic yield/kg N uptake.

Nitrogen is one of the most critical macronutrients required by plants, and it is also the most mobile in the soil environment. Thus, the availability of nitrogen (N), as well as its uptake and utilisation by crops, is closely correlated with productivity. However, many abiotic and biotic factors in the soil-plant system, such as cultivar, fertiliser input, weather, pest management, crop residue irrigation, and drainage, control these processes (Singh et al., 2016).

Conclusion

As a result of the experiment described above, it was discovered that applying 75% of RDN in conjunction with the full dose of both P and K as well as nano urea at a concentration of 6 millilitres per litre of water resulted in the highest green fodder yield (272.83 q/ha) and other forage quality attributes, including dry matter yield (61.50 q/ha), crude protein (14.24%), and crude fibre (47.33%). The identical findings were found for yield and yield contributing properties of dual-purpose oat, such as grain yield (17.83 q/ha), number of grains per panicle, number of effective tillers per plant, as well as growth characteristics.

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