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RESEARCH ARTICLE

Impacts of phosphorous and zinc under different nutrient management strategies on the performance of Berseem (*Trifolium alexandrinum*) diploid varieties: A comparative yield and economic analysis

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Abstract

Identifying a high-yielding and economically advantageous berseem variety, along with optimal nutrient management strategies, is crucial for maximizing fodder and forage crops productivity and profitability. To accomplish these objectives, a field experiment was carried out in a split-plot design during the *rabi* season of 2022-2023. The main plot accommodated two different berseem varieties (BL-42 and Mescavi). The subplot consisted of nine different nutrient combinations: Control, 100% recommended dose of phosphorus (RDP), 100% recommended dose of zinc (RDZn), 100% RDP + one Nano spray (P), 75% RDP + two Nano spray (P,) 50% RDP + three Nano spray (P), 100% RDZn + zinc solubilizing bacteria (ZnSB), 75% RDZn + ZnSB, and 50% RDZn + ZnSB. The study assessed the effects of phosphorus and zinc nutrient management on the physiological and morphological responses, yield attributes, and economic attributes of various berseem cultivars. The results revealed that the Mescavi variety outperformed the BL-42 variety regarding physiological growth and biomass yield. The Mescavi exhibited an 18% increase in green fodder output and a 24% increase in dry matter yield compared to the BL-42 variety. In addition, applying 100% RDP+ one Nano spray (P) resulted in a substantial increase of 144% in green fodder production and 330% in dry matter yield compared to the control treatment. Mescavi yielded a gross return of 32793 ₹ ha^{-1} and a net return of 19985 ₹ ha^{-1} compared to the BL-42 variety, with a gross and net return of 27635 ₹ ha^{-1} and 14827 ₹ ha^{-1}, respectively. The treatment comprising of 100% RDP + one Nano spray (P) resulted in the highest gross and net return (37866.67 and 23666.67 ₹ ha^{-1}, respectively) as compared to the control treatment (15512.44 and 4296.94 ₹ ha^{-1}, respectively). The notable differences in output and returns confirmed the effectiveness of specific agronomic approaches in enhancing the profitability and sustainability of fodder farming.

Keywords

Berseem; fodder; green fodder yield; nutrient management; P nano spray; varieties; zinc-solubilizing bacteria.

Introduction

The livestock sector in India contributes to 4.11% to the overall Gross Domestic Product (GDP) surpassing the agricultural crop sector. This is primarily owing to its strong potential for exporting meat, dairy products, wool, leather, and other related goods (1). Globally, India holds the top position in total livestock population (2). However, the livestock sector cannot be sustained shortly without sufficient high-quality feed and fodder resources. Specific nutrient management practices must be implemented to ensure high-quality and abundant fodder. Berseem (*Trifolium alexandrinum*), belongs to the Leguminosae family and is considered a promising winter feed legume (3).

India cultivates approximately 8.4 million hectares of land for fodder production, with Berseem covering 1.9 million hectares (22.6%) making it largest fodder crop in terms of area (4), achieving its maximum yield remains a significant difficulty in India (5). Despite this, achieving optimal yield remains a significant challenge (5), primarily due to poor nutrient management and inappropriate variety selection. Studies indicate that adequate fertilizer application significantly crop production. As a nitrogen-fixing legume, Berseem requires minimal nitrogen input (6). Phosphorus, a vital macronutrient, is crucial in promoting root growth and facilitating the absorption of other necessary nutrients (7). Additionally, it plays an essential function in various metabolic processes by facilitating the transfer of energy molecules (8). Micronutrients are crucial for promoting optimal crop growth and increasing agricultural output. Insufficient supply of micronutrients will prevent the desired outcome of using more productive inputs in crop cultivation. The dearth of zinc in India is a significant challenge for agriculture. Zinc plays a role in the metabolisms of auxin and carbohydrates (9). Zinc deficiency can significantly reduce crop productivity and deterioration in the quality of fodder crops. Moreover, research has revealed that the effectiveness of chemical fertilizers can be improved by combining them with foliar sprays and organic substances like biofertilizers. The combined application of phosphorus through foliar sprays will enhance its functionality within the plant organism (10). Applying zinc-solubilizing bacteria can improve the accessibility of zinc, hence promoting optimal plant growth and development (11). Due to their antagonistic effect, phosphorus and zinc cannot be combined in the same management methods (12). Applying phosphorus through foliar sprays instead of using phosphatic fertilizer in the soil, along with zinc solubilizing bacteria (ZnSB) and zinc fertilizer, can greatly enhance nutrient availability, increase berseem yields, and support sustainable agriculture (13).

The strategic performance of berseem cultivars has been influenced by agro-climatic zones and unique environmental variables (14). Choosing the appropriate berseem variety based on the local environment and using effective nutrient management approaches can significantly improve productivity. This systematic methodology identifies the reasons for the shortage of green fodder, and proposes specific ways to improve milk production. The objective of this experiment was to identify the most appropriate berseem variety and determine the optimal nutrient management practices, and examine the relationship between varietal selection and nutrient management. This study aims to assess the efficacy of several berseem types when subjected to phosphorus and zinc fertilizer schemes under specific environmental and soil conditions to optimize and maintain agricultural productivity.

Materials and Methods

Experimental site

The field trial was carried out during the rabi season of 2022-2023 at the Agronomy Research Farm of the School of Agriculture, Lovely Professional University, Phagwara, Punjab, India. The study area is located at 31^0 22' northern latitude and 75^0 23' east longitude and was situated at 252 m AMSL.

The experimental region features subtropical weather conditions, with cold winters, scorching summers, and a period of distinct rains. Even though the winters are cold, the temperature never falls below zero degrees Celsius, even during the coldest months, which are December to January, and the lowest temperature varies between 4°C and 10°C. The peak summer temperature ranges between 45 ^{0}C and 48 ^{0}C from mid-May to mid-June, which happens only infrequently, while the typical summer temperature remains between 35°C and 45°C. All the meteorological data is represented in Fig. 1.

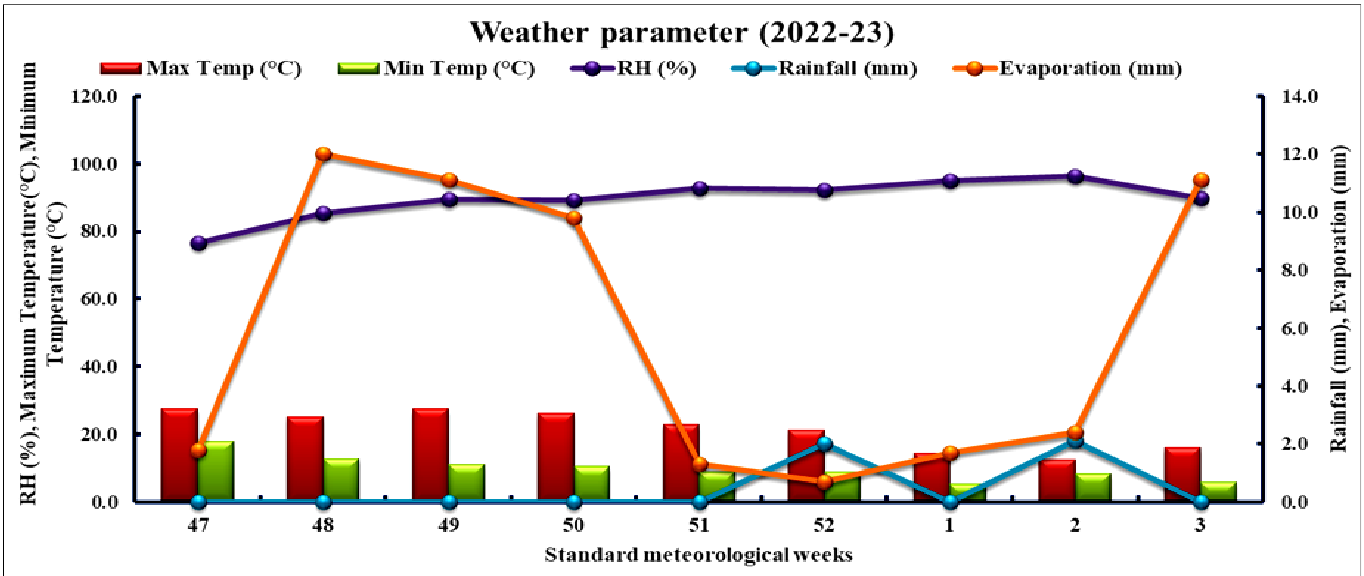

Fig. 1. Meteorological data of the study area during the crop season of 2022-2023.

Experimental treatment details

Table 1 displays the initial physical and chemical parameters of the study area. The study used a split-plot design that was replicated thrice. There were 54 plots with a gross plot area of 20m2 (5 m x 4 m). The study included 18 treatment combinations, two of which were berseem varieties allocated in the main plot and nine nutrient management strategies allocated in the subplot (Table 2).

Table 1. Physical and chemical properties of soil sample

Soil properties	Value	Method employed
Physical properties		
Sand%	46.6	International Pipette Method (15)
Silt%	22.1	
Clay%	31.3	
Textural class	Sandy clay loam	
Chemical soil properties		
EC (ds m^{-1})	0.3	EC bridge (16)
pH	8.2	pH meter (15)
Organic Carbon (%)	0.41	Walkley and Black's Wet Oxidation method (16)
Available N (kg ha^{-1})	181	Alkaline Permanganate Method (17)
Available P_2O_5 (kg ha^{-1})	18.5	Olsen's Method (18)
Available K_2O (kg ha^{-1})	236	Flame Photometer Method (16)
Zinc (ppm)	0.41	DTPA-$CaCl_2$-TEA method (19)

Table 2. Treatments details

Main plot: Berseem varieties	Subplot: Nutrient management
V_1: BL-42	T_1: Control
V_2: Mescavi	T_2: 100%RDP
	T_3: 100% RDZn
	T_4: 100% RDP + 1 Nano spray (P)
	T_5: 75% RDP + 2 Nano spray (P)
	T_6: 50% RDP + 3 Nano spray (P)
	T_7: 100% RDZn + ZnSB
	T_8: 75% RDZn + ZnSB
	T_9: 50% RDZn + ZnSB

The berseem crop requires an RDP of 80 kg ha^{-1} and an RDZn of 30 kg ha^{-1}. Single Super Phosphate (16% P_2O_5) and Zinc Sulphate Monohydrate (33% Zn) were used as nutrient sources and applied basally per the treatments. In the case of nitrogen and potassium, the recommended dose was found 20 kg and 40 kg, which was given in each plot through urea (46% N) and muriate of potash (60% K_2O) as basal dose. The treatment approach involved applying Zinc solubilizing biofertilizer (ZnSB) to berseem seeds at a rate of 6 g kg^{-1}. In addition, the Nano spray of phosphorus (P) was given at 20 DAS (1st spray), 30 DAS (2nd spray), and 40 DAS (3rd spray), respectively. The field was prepared for the experiment by cross-harrowing and using a disc harrow, connected with a tractor. A pass of rotavator was also used to enhance the soil tillage practices. Then, the field was properly levelled with the help of a wooden plank. After the levelling, the experimental plots were properly arranged according to the treatment layout design. The seed rate of the berseem varieties (Mescavi and BL-42) for the experiment was 25 kg ha^{-1} which was sown on 20th November 2022.

Procedure for collecting and estimating yield of fresh and dried fodder

To minimize any border effect, the process of removal of plants was started deliberately from the peripheral rows. After that, the central plot area was harvested, and the green fodder yield was calculated by quantifying the fresh forage yield, which was then converted to tonnes per hectare (20). Then, 500 g of representative green fodder samples were put in a hot air oven at 60 to 70°C until they reached a constant weight (21). The dry weight was then recorded, and the dry matter percentage worked out. After that, the dry matter percentage was multiplied by the net plot-wise green fodder yield to get the dry matter yield (DMY) in kilograms per plot and converted to tonnes per hectare.

$$\mathrm{DMY}\ (\mathrm{t\ ha^{-1}}) = \frac{\text{Green fodder yield } (\mathrm{t\ ha^{-1}}) \text{ x Dry matter content } (\%)}{100}$$

Plant height (cm)

The height of the five randomly selected tagged plants was measured from the ground to the top of the plant. After that, each treatment's average plant height in centimetres was determined for each observation at 30 DAS and 60 DAS.

Number of leaves per plant

The leaf number from five tagged plants was manually counted at 30 and 60 DAS, and the average results were calculated.

Leaf length (cm)

The randomly selected leaf length was measured from the same five tagged plants and average values were worked out.

Leaf width (cm)

The leaf width of the same leaves selected for measuring leaf length was recorded from the middle leaf blade, and average values were worked out.

Root length (cm)

Five plants per treatment were uprooted with a digger, and the taproot length in centimetres at 30 DAS and 60 DAS was then measured after thorough washing.

Number of nodules plant^{-1}

The root length of the measured berseem plant was used to count the nodules. Subsequently, the nodules were isolated and quantified per plant at both 30 DAS and 60 DAS (21).

Economic analysis

It was calculated based on the variable costs throughout the production, including costs such as human labour, input expenses, intercultural operations, and machinery used for harvesting fodder crops. The cost of cultivation was calculated by summing up the specific values of inputs, labour charges, and other expenses for all operations throughout the crop-growing period. The net returns and benefit-cost ratio were calculated using the equation below.

Net Returns = Gross returns (₹ ha^{-1}) – Total cost of cultivation (₹ ha^{-1})

$$\text{BCR} = \frac{\text{Net returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

Statistical analysis

The data collected during the field experiment was analyzed using ANOVA, as described by Gomez and Gomez (1984), and analysed using Microsoft Excel and R software. The statistical significance of the experimental data was assessed at a significance level of 5% using the "F test." Whenever the F value was found to be significant, the standard error of the mean (SE m) and the least significant difference (LSD) value (p=0.05) were generated.

Results

Growth attributes

Plant height (cm)

The results revealed that berseem varieties and nutrient management practices significantly affected plant height (Table 3). Plant height was found to have a significant effect at 30 DAS and 60 DAS, with the Mescavi variety (26.04 and 64.67 cm) compared to the BL-42 variety. Compared to BL-42, the Mescavi variety exhibited 6.19% and 2.93% more plant heights at the 30 DAS and 60 DAS. The perusal of data revealed that different nutrient management practices had different impacts on plants' height (Table 3). Applying 100% RDP at 30DAS significantly improved the plant height (26.93 cm) than all the rest of the treatments. However, treatments with 100% RDP+ 1 Nano spray (P), 75% RDP+ 2 Nano spray (P), and 100% RDZn + ZnSB were statistically similar to the highest treatment. However, in the later stage, at 60 DAS, a significant improvement in plant height was recorded by applying 100% RDP with 1 nano spray of (P) (69.23 cm) than all the other treatments (Table 3). The data presented in Fig 2 revealed that berseem varieties' interaction with nutrient management on plant height was significant at 60 DAS. The maximum plant height was found in the Mescavi variety with the application of 100% RDP with 1 nano spray of P (69.53

Table 3. Effect of treatments on the plant heights and number of leaves per plant of berseem

Treatments	Plant height (cm)		No. of leaves plant^{-1}	
	30 DAS	60 DAS	30 DAS	60 DAS
Varieties				
BL-42	24.5^{b}	62.8^{b}	5.4^{b}	17.5^{b}
Mescavi	26.0^{a}	64.7^{a}	5.9^{a}	19.0^{a}
SE m (±)	0.13	0.27	0.06	0.17
LSD (p = 0.05)	0.78	1.64	0.36	1.02
Nutrient management				
Control	23.7^{d}	58.0^{g}	3.35^{f}	13.8^{f}
100% RDP	26.9^{a}	65.4^{c}	7.22^{a}	19.4^{bc}
100% RDZn	25.0^{bcd}	61.8^{ef}	5.47^{bcd}	17.5^{e}
100% RDP+ 1 Nano spray (P)	26.8^{ab}	69.2^{a}	7.47^{a}	21.8^{a}
75% RDP+ 2 Nano spray (P)	25.^{abc}	66.9^{b}	6.02^{b}	20.0^{b}
50% RDP+ 3 Nano spray (P)	24.9^{cd}	64.8^{c}	5.45^{bcd}	19.0^{c}
100% RDZn + ZnSB	25.1^{abcd}	63.5^{d}	5.62^{bc}	18.3^{d}
75% RDZn + ZnSB	25.0^{bcd}	62.8^{de}	4.92^{d}	17.6^{e}
50% RDZn + ZnSB	24.4^{cd}	61.2^{f}	5.05^{cd}	17.1^{e}
SE m (±)	0.64	0.56	0.23	0.31
LSD (p = 0.05)	1.86	1.14	0.67	0.63

cm) which was at par with the BL-42 variety at the same treatment combination. In addition, treatment with 75% RDP+ 2 Nano spray (P) in the Mescavi variety was also at par with the maximum treatment.

Number of leaves plant^{-1}

Mescavi showed a significant enhancement in a number of leaves at 30 DAS and 60 DAS (with counts of 5.88 and 19.08 leaves, respectively) compared to the BL-42 variety (Table 3). Compared to BL-42, the Mescavi variety exhibited a 9.75% and 9.39% higher number of leaves at the 30 DAS and 60 DAS, respectively. Applying 100% RDP with one nano spray of P significantly increased the leaf number per plant at 30 DAS (7.47) than all the rest of the treatments. However, treatment with 100% RDP was statistically at par with the highest treatment. At 60 DAS, a significantly higher number of leaves per plant was observed in the treatment with 100% RDP with one nano spray of P (21.81) than in all the rest of the treatments. Fig. 2 data demonstrated that the combination of several berseem types and nutrition management substantially impacted the number of leaves per plant at 60 DAS. Significantly superior values for the number of leaves per plant were obtained with the Mescavi variety with the application of 100% RDP with one nano spray of P (22.85). They were followed by applying the same treatment in the BL-42 variety (20.77).

Leaf length (cm)

The leaf length is important for proper leaf development and photosynthetic efficiency which are interrelated with the yield and nutritional value of fodder crops. Mescavi showed higher leaf length at 30 DAS and 60 DAS (1.80 and 3.45 cm) and was significantly higher than the BL-42 variety (Table 4). Compared to BL-42, the Mescavi variety exhibited 5.38% and 4.42% higher leaf length at the 30 DAS and 60 DAS, respectively. Applying 100% RDP with one nano spray of P significantly increased the leaf length of plants at 30 DAS (2.20 cm) than all the rest of the treatments except with 100% RDP, where it was found to be at par with each other (Table 4). In the later stage, at 60 DAS, significantly higher leaf length in plants was obtained with the application of 100% RDP with one nano spray of P (3.74 cm) than all the other treatments and was found to be statistically at par with 100% RDP and 75% RDP + 2 nano spray of P application (Table 4). The data revealed that

Table 4. Effect of treatments on the leaf length and leaf width of berseem

Treatments	Leaf length (cm)		Leaf width (cm)	
	30 DAS	60 DAS	30 DAS	60 DAS
Varieties				
BL-42	1.71^{b}	3.30^{b}	0.79^{b}	1.31^{b}
Mescavi	1.80^{a}	3.45^{a}	0.86^{a}	1.33^{a}
SE m (±)	0.01	0.02	0.01	0.003
LSD ($p = 0.05$)	0.05	0.13	0.04	0.02
Nutrient management				
Control	1.44^{c}	2.69^{f}	0.68^{c}	1.10^{f}
100%RDP	2.11^{a}	3.62^{ab}	1.03^{a}	1.34^{d}
100% RDZn	1.60^{bc}	3.29^{d}	0.78^{bc}	1.32^{d}
100% RDP+ 1 Nano spray (P)	2.14^{a}	3.74^{a}	1.00^{a}	1.44^{a}
75% RDP+ 2 Nano spray (P)	1.78^{b}	3.66^{ab}	0.84^{b}	1.39^{b}
50% RDP+ 3 Nano spray (P)	1.66^{b}	3.53^{bc}	0.81^{bc}	1.37^{bc}
100% RDZn + ZnSB	1.69^{b}	3.40^{cd}	0.81^{bc}	1.34^{cd}
75% RDZn + ZnSB	1.69^{b}	3.35^{d}	0.75^{bc}	1.32^{d}
50% RDZn + ZnSB	1.67^{b}	3.10^{e}	0.73^{bc}	1.27^{e}
SE m (±)	0.08	0.08	0.053	0.02
LSD ($p = 0.05$)	0.22	0.17	0.153	0.03

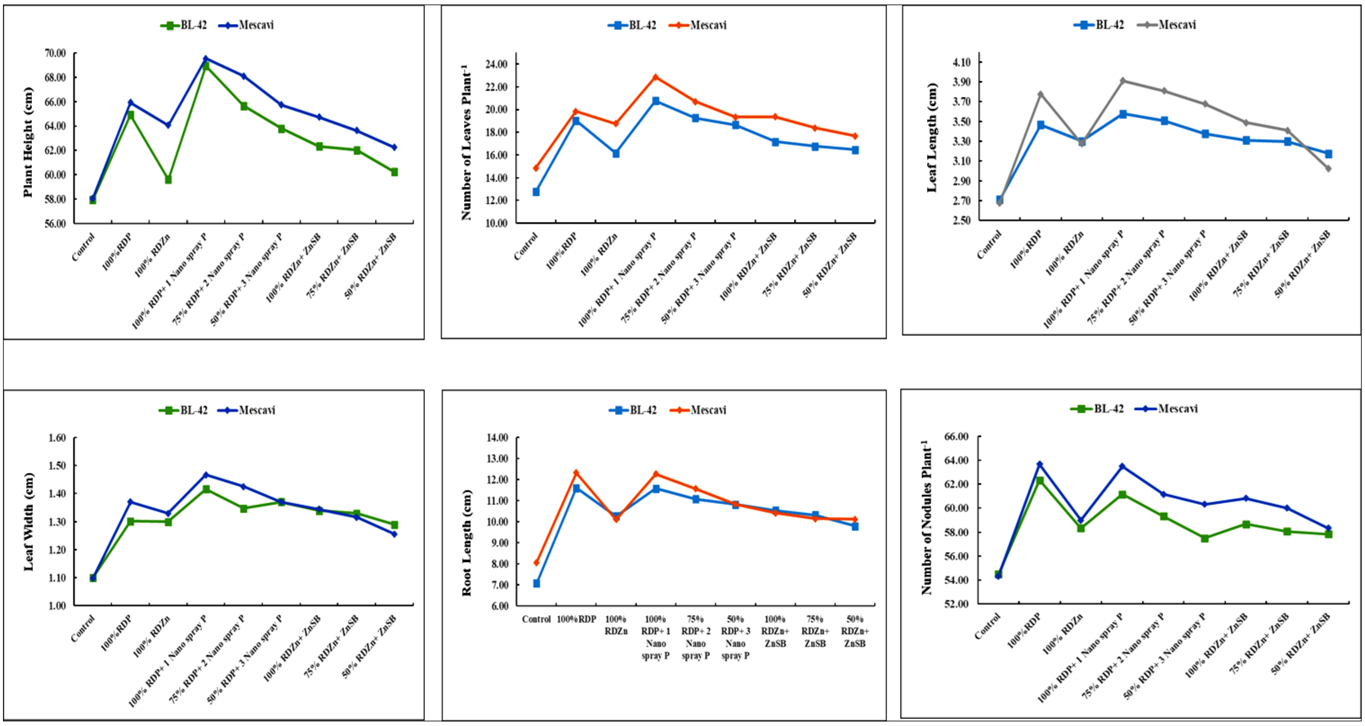

Fig. 2. Interaction effect of varieties and nutrient management on plant height (cm), number of leaves Plant^{-1}, leaf length (cm), leaf width (cm), root length (cm), and number of nodules plant^{-1}.

berseem varieties' interaction with nutrient management on leaf length was significant at 60 DAS (Fig. 2). Leaf length obtained under the Mescavi variety with the application of 100% RDP with one nano spray of P was significantly superior to all other treatment combinations. It was statistically at par when 100% RDP, 75% RDP+ 2 Nano spray (P) and 50% RDP+ 3 Nano spray (P) were applied in the same variety (Fig. 2).

Leaf width (cm)

Mescavi showed higher leaf width in plants at 30 DAS and 60 DAS (0.86 and 1.33 cm) than in the BL-42 variety (Table 4). Compared to BL-42, the Mescavi variety exhibited 9.42% and 1.52% higher leaf width at the 30 DAS and 60 DAS, respectively. Various nutrient management practices showed varying effects on the leaf width of plants. Application of 100% RDP at 30DAS significantly improved the leaf width (1.03 cm) which was found to be statistically at par with 100% RDP + 1 nano spray of P. In the later stage, at 60 DAS, the highest leaf width was observed in the treatment with 100% RDP with one nano spray of P (1.44 cm) followed by 75% RDP + 2 nano spray of P (Table 4). The data presented in Fig 2 revealed that berseem varieties' interaction with nutrient management on leaf width was significant at 60 DAS. Significant improvement in leaf width was found in the Mescavi variety with the application of 100% RDP with one nano spray of P (1.47 cm), which was found statistically similar to treatment with 75% RDP+ 2 Nano spray (P) in the same variety.

Root length (cm)

At 30 DAS and 60 DAS, the root length of the Mescavi variety plants was recorded higher (5.18 and 10.65 cm) than the BL-42 variety (Table 5). Compared to BL-42, the Mescavi variety exhibited 12.35% and 2.97% higher root lengths at the 30 DAS and 60 DAS, respectively. Applying 100% RDP at 30DAS significantly improved the root length (5.64 cm) than all the rest of the treatments. However, treatment with 100% RDP with one nano spray of P and 75% RDP with two nano sprays of P were similar to the highest treatment. In the later stage, at 60 DAS, significantly higher root length was observed in the treatment with 100% RDP (11.96 cm) than all the other treatments. However, it was at par with 100% RDP + 1 nano spray of P treatment (Table 5). The maximum root length in plants was found in the Mescavi variety with the application of 100% RDP (12.32 cm), which was found statistically at par with treatment with 100% RDP + 1 nano spray of P in the same variety.

Number of nodules plant^{-1}

The nodule count per plant was significantly affected by different berseem varieties and nutrient management practices (Table 5). The number of nodules per plant of the Mescavi variety plants was significantly higher at 30 DAS and 60 DAS (18.97 and 60.13) than the BL-42 variety (Table 5). Compared to BL-42, the Mescavi variety exhibited a 3.28% and 2.54% higher number of nodules per plant at the 30 DAS and 60 DAS, respectively (Table 5). The application of 100% RDP enhanced the number of nodules per plant at 30 DAS (19.90) compared to the rest of the treatments (Table 5). However, treatments with 100% RDP with 1 nano spray of P, 75% RDP with two nano spray of P, and 100% RDZn + ZnSB were statistically at par with the highest treatment. The highest nodule count per plant was found in the Mescavi variety with the application of 100% RDP (63.67 nodules plant^{-1}), which was found to be similar to treatment with 100% RDP + 1 nano spray of P in the same variety.

Table 5. Effect of treatments on the root length and nodule count per plant of berseem

Treatments	Root length (cm)		No. of nodules plant^{-1}	
	30 DAS	60 DAS	30 DAS	60 DAS
Varieties				
BL-42	4.61^{b}	10.3^{b}	18.4^{a}	58.6^{b}
Mescavi	5.18^{a}	10.7^{a}	19.0^{a}	60.1^{a}
SE m (±)	0.08	0.05	0.29	0.23
LSD (p = 0.05)	0.50	0.28	1.74	1.38
Nutrient management				
Control	3.78^{d}	7.57^{f}	17.3^{c}	54.4^{f}
100%RDP	5.64^{a}	12.0^{a}	19.9^{a}	63.0^{a}
100% RDZn	4.70^{c}	10.2^{de}	18.4^{cd}	58.7^{de}
100% RDP+ 1 Nano spray (P)	5.54^{ab}	12.0^{a}	19.8^{ab}	62.3^{a}
75% RDP+ 2 Nano spray (P)	5.19^{abc}	11.3^{b}	18.7^{abc}	60.3^{b}
50% RDP+ 3 Nano spray (P)	5.00^{bc}	10.9^{c}	18.6^{bcd}	59.0^{cde}
100% RDZn + ZnSB	4.92^{c}	10.5^{cd}	18.7^{abc}	59.8^{bc}
75% RDZn + ZnSB	4.66^{c}	10.2^{de}	18.5^{cd}	59.0^{cd}
50% RDZn + ZnSB	4.63^{c}	9.96^{e}	18.1^{cd}	58.1^{e}
SE m (±)	0.20	0.19	0.45	0.41
LSD (p = 0.05)	0.59	0.39	1.29	0.84

Yield attributes

Green fodder yield (t ha^{-1})

Mescavi variety produced significantly higher green fodder production (16.43 t ha^{-1}) than the BL-42 variety (Table 6). Compared to the BL-42 variety, the Mescavi variety exhibited 18.78% higher green fodder yield at 60 DAS (Table 6). The combination of 100% RDP with 1 nano spray of P was the most productive and was found to be significantly higher, reaching 18.93 tons per hectare of green fodder at 60 DAS compared to all the remaining treatments (Table 6). In addition, it was also observed that treatments 100% RDZn + ZnSB and 75% RDP + 2 Nano spray (P) were found to be statistically at par with each other (Table 6). Fig. 3 data demonstrated that the combination of several berseem types and nutrition management substantially impacted the green fodder yield. Significantly higher green fodder yield was found in the Mescavi variety with the application of 100% RDP with one nano spray of P (20.97 t ha^{-1}).

Dry fodder yield (t ha^{-1})

Mescavi variety showed the highest dry matter yield (1.98 t ha^{-1}) than the BL-42 variety (Table 6). Compared to the BL-42 variety, the Mescavi variety exhibited 49.9% higher dry matter yield at 60 DAS. Combining 100% RDP

Table 6. Effect of treatments on the green fodder yield and dry fodder yield of berseem

Treatments	Green fodder yield (t ha^{-1})	Dry matter yield (t ha^{-1})
	60 DAS	60 DAS
Varieties		
BL-42	13.8^{b}	1.32^{b}
Mescavi	16.4^{a}	1.98^{a}
SE m (±)	0.29	0.05
LSD (p = 0.05)	1.75	0.28
Nutrient management		
Control	7.94^{e}	0.47^{e}
100% RDP	17.2^{b}	2.09^{b}
100% RDZn	14.9^{cd}	1.45^{c}
100% RDP + 1 Nano spray (P)	18.9^{a}	2.81^{a}
75% RDP + 2 Nano spray (P)	17.3^{b}	2.18^{b}
50% RDP + 3 Nano spray (P)	15.7^{c}	1.61^{c}
100% RDZn + ZnSB	15.1^{cd}	1.54^{c}
75% RDZn + ZnSB	14.9^{cd}	1.44^{c}
50% RDZn + ZnSB	14.2^{d}	1.25^{d}
SE m (±)	0.50	0.06
LSD (p = 0.05)	1.44	0.18

with one nano spray of P was the most productive, reaching 2.81 tons per hectare of dry matter at 60 DAS. This treatment has shown significantly superior efficacy compared to all other treatments. It was also observed that 100% RDP treatment was statistically similar to 75% RDP + two Nano spray (P) applications (Table 6). Fig 4 demonstrated that the combination of several berseem types and nutrition management substantially impacted dry matter yield at 60 DAS. Significant improvement in dry matter yield was found in the Mescavi variety with the application of 100% RDP with one nano spray of P (3.52 t ha^{-1}).

Economics of production

Cost of cultivation

It was calculated by adding the specific values of inputs, labour charges, and other requirements of the crop throughout its growing period. The data presented in Table 7 expressed that the cost of cultivation for berseem was not affected by the varieties. Additionally, it was also found that, among the second aspects of the study, the use of 100% RDP with 1 nano spray of P was associated with a higher cost of cultivation. Whereas, the treatment with control dealt with the lowest cost of cultivation.

Gross return and Net return

The findings suggested that both gross and net returns were significantly affected by the varieties of berseem and different treatment combinations (Table 7). Mescavi showed the maximum gross and net return, with 32852.6 and 20489.3 ₹ ha^{-1} over the gross return and net return of the BL-42 variety, which were 27656.5 and 15293.2 ₹ ha^{-1}. Application of 100% RDP with one nano spray of P received maximum gross and net return, amounting to 37866.7 and 23666.7 ₹ ha^{-1} (Table 7).

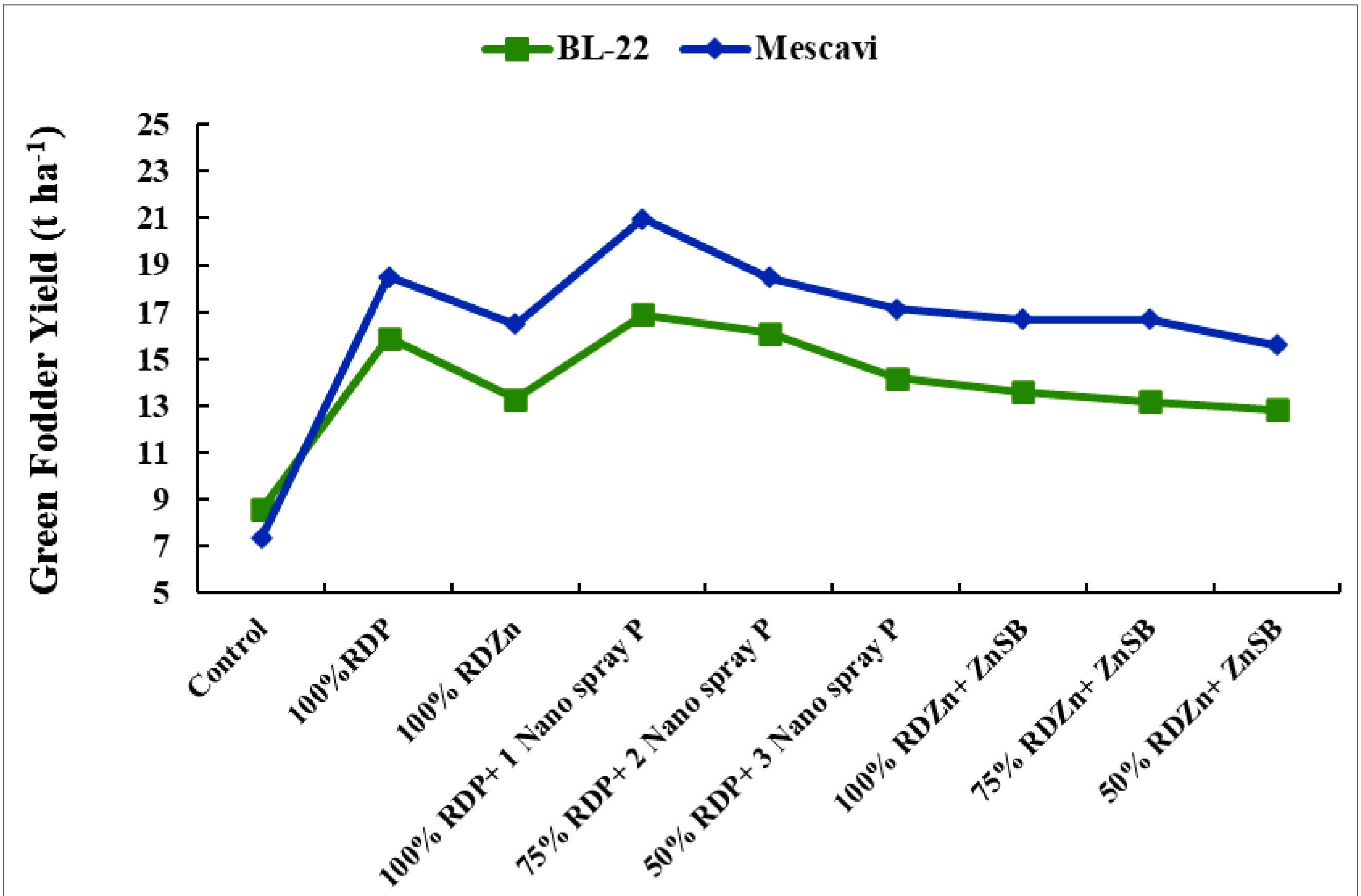

Fig. 3. Interaction effect of varieties and nutrient management on green fodder yield (t ha^{-1}).

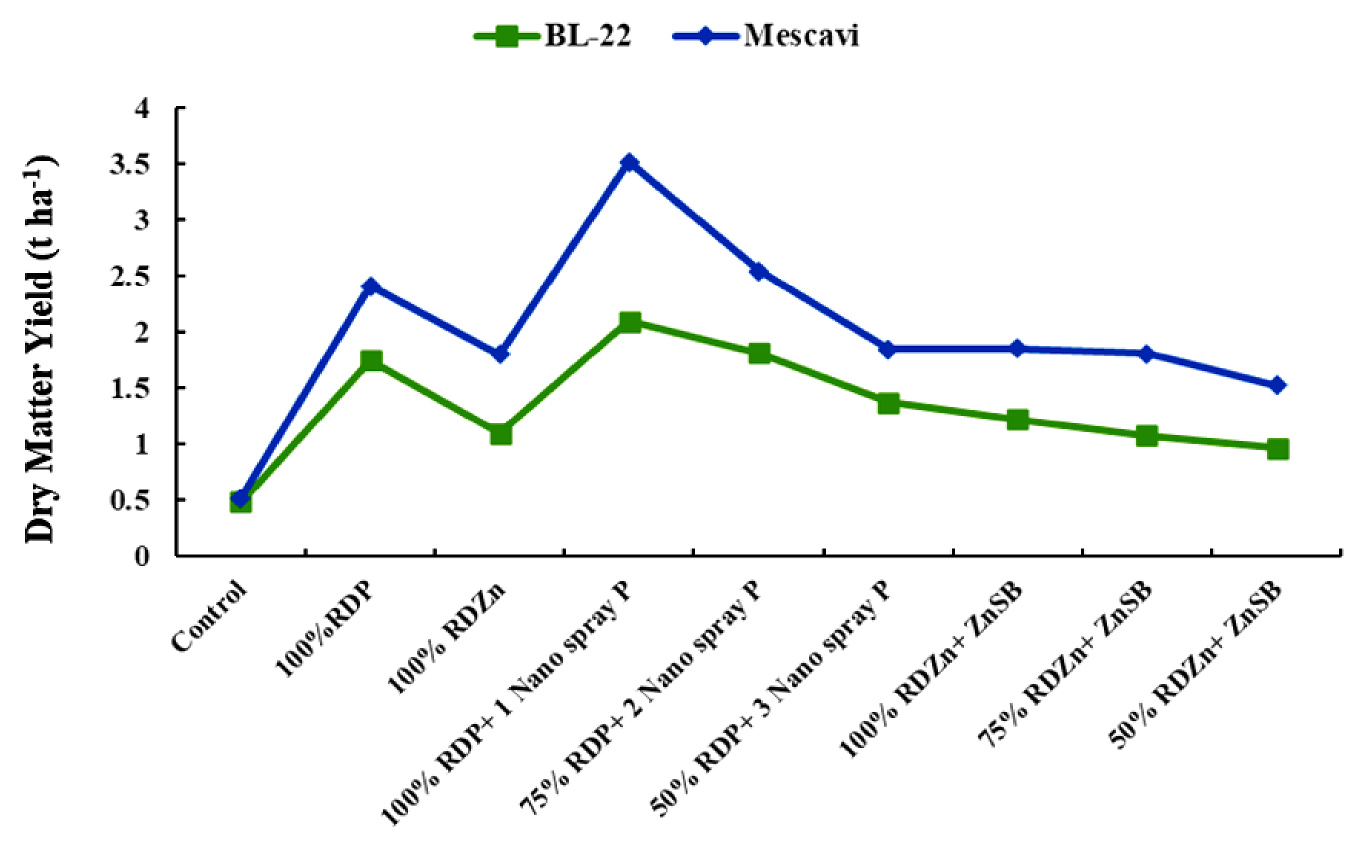

Fig. 4. Interaction effect of varieties and nutrient management on dry matter yield (t ha^{-1}).

Benefit-cost ratio

The result suggested significant variation in the benefit-cost ratio due to both study aspects (Table 7). Mescavi recorded the highest benefit-cost ratio at 1.62, surpassing the BL-42 variety (1.24). Further, the highest benefit-cost ratio was found in the treatment with 100% RDP with one nano spray of P, standing at 1.67, which was found to be statistically at par with the treatments with 100% RDP (1.50), 75% RDP + 2 Nano spray (P) (1.63) and 50% RDP + 3 Nano spray (P) (1.54). The lowest benefit-cost ratio was recorded for the treatment with control at 1.20, compared to the other treatments (Table 7).

Table 7. Effect of treatments on the economics of berseem

Treatments	Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B:C ratio
	60 DAS	60 DAS	60 DAS	60 DAS
Varieties				
BL-22	12807.8	27656.5^{b}	15293.2^{b}	1.24^{b}
Mescavi	12807.8	32852.6^{a}	20489.3^{a}	1.62^{a}
SEm (±)	-	574.2	574.21	0.05
LSD (p = 0.05)	-	3494.0	3494.01	0.31
Nutrient management				
Control	7215.5	15875.8^{e}	8660.3^{e}	1.20^{c}
100% RDP	13740.0	34380.0^{b}	20640.0^{b}	1.50^{ab}
100% RDZn	12780.0	29760.0^{cd}	16980.0^{cd}	1.33^{bc}
100% RDP + 1 Nano spray (P)	14200.0	37866.7^{a}	23666.7^{a}	1.67^{a}
75% RDP + 2 Nano spray (P)	13120.0	34570.0^{b}	21450.0^{ab}	1.63^{a}
50% RDP + 3 Nano spray (P)	12320.0	31326.7^{c}	19006.7^{bc}	1.54^{ab}
100% RDZn + ZnSB	12980.0	30280.0^{cd}	17300.0^{cd}	1.33^{bc}
75% RDZn + ZnSB	12650.0	29834.4^{cd}	17184.4^{cd}	1.36^{bc}
50% RDZn + ZnSB	12265.0	28397.8^{d}	16132.8^{d}	1.32^{bc}
SEm (±)	-	997.8	997.8	0.09
LSD (p = 0.05)	-	2874.2	2874.2	0.25

Discussion

Growth attributes

Plant height and the number of leaves per plant are fundamental vegetative growth characteristics. In contrast, the number of leaves per plant directly influences the green fodder yield and nutritional quality of the fodder crops. Several factors influence these characteristics, including the genetic traits of different crop varieties, nutrient management practices and their availability, environmental factors, and soil health (22-24).

Regarding berseem plant height, the Mescavi variety exhibits genetic advantages over the BL-42 variety in influencing rapid growth in the initial stages, an essential trait for short-term fodder production. During both observed growth stages in the experiment, the Mescavi variety showed maximum leaf length and width and leaf count per plant, which are important parameters for deciding the fodder crops' forage yield and quality. The Mescavi variety has some genetic potential for rapid leaf development and higher photosynthetic efficiency attributed to early fodder production (25). The superior root length and increased number of nodules per plant in the Mescavi indicate its genetic superiority in increasing biological nitrogen fixation, nutrient uptake, and growth characteristics (5, 7).

The correlation between nutrient management strategies and plant height indicates the importance of proper management of nutrients in promoting crop growth. The initial effectiveness of applying 100% RDP and 100% RDZn resulted in the promotion of all growth characteristics compared to other treatments. This can be attributed to the quick availability of P and Zn, which are easily absorbed by plants and play a pivotal role in enhancing growth (26-28). Albeit, the combination of foliar sprays of phosphorus with phosphatic fertilizer and zinc-solubilizing bacteria with zinc fertilizer underscores the benefits of integrating biological amendments (29). The recommended dose of phosphorus can be reduced (up to 25%) by applying two foliar sprays with the same sustained performance of berseem (9, 30). Meanwhile, the recommended dose of zinc can be lowered (up to 25%) by treating it with zinc-solubilizing bacteria (31).

Yield attributes

Several variations in the yield performance of berseem varieties, were observed, likely due to correlated factors such as genetic variation, nutrient management, and soil characteristics. The Mescavi variety exhibited higher yield efficiency, potentially attributed to the genetic potential of specific cultivars that enhances photosynthetic efficacy, nitrogen intake, and quick growth characteristics (13). Mescavi variety demonstrates superiority over BL-42 due to its genetic traits, like enhanced leaf development, a well -structured root system, and improved nodulation ability. These traits are crucial for achieving a greater biomass production (32).

In the Indo-Gangetic plains, the differential performance of the Mescavi variety suggests a synergistic interaction between genotype and environmental conditions. The superior performance of this particular variety may be attributed to genetic traits, like enhanced leaf size, root growth, and nodule formation capability, that are essential for maximizing biomass production (32). This indicates the importance of selecting varieties based on the adaptability to local factors such as climatic conditions, water availability, and edaphic factors to optimize fodder production (33).

Regarding nutrient management approaches, integrating a 100% RDP with one nano spray of phosphorus (P) exhibited a synergistic effect on both green and dry fodder yield. This positive efficacy may be attributed to the complementary action of the foliar spray of phosphorus with soil-applied phosphatic fertilizer in improving the availability of phosphorus (P) (9). The availability of this resource is crucial for the optimal development of roots and the quick growth of plants, which is directly linked to the accumulation of plant biomass and the feed yield (34-36). Foliar phosphorus sprays provide immediate phosphorus availability, while zinc-solubilizing bacteria (ZnSb) improve zinc availability. The green and dry fodder yield obtained from the treatment of 100% RDP remained at par with 75% RDP with two nano sprays of phosphorus (P) because of higher phosphorus availability in foliar sprays than higher soil application (37- 40). Similarly, in Zinc management, 100% RDZn, 75% RDZn with ZnSB yielded similar results in terms of green and dry fodder yield because of (Zn) availability (41-43).

Economic attributes

The cost of cultivation was highest for the 100% RDP with one nano spray of (P), followed by 100% RDP. However, application nano sprays of phosphorus as foliar application decreases the level of phosphatic fertilizer and thereby lowers the cost of cultivation (44). In zinc nutrition, reducing the soil level by applying zinc fertilizer using zinc-solubilizing bacteria minimizes the cultivation cost (44-45).

Regarding economic returns, the Mescavi variety outperformed the BL-42 variety. The net returns from the Mescavi variety (Rs 20489) were significantly higher than Rs 15293 from BL-42. The Benefit-Cost (BC) ratio of the Mescavi variety was also considerably higher (1.62) than that of BL-42(1.24).

The superior economic performance of the Mescavi variety may be attriuted to its genetic ability and particular genetic traits that enhance green fodder yield. Supporting this outcome, several studies have indicated that genotypic differences among berseem varieties caused significant variations in biomass yield and economic returns (46). This also indicates that variety selection is an important factor in increasing the economic stability of berseem cultivation (7).

Regarding the second aspect of the study, the application of 100% RDP with one nano spray of phosphorus (P) resulted in higher gross and net return (37866.7 and 23666.7 ₹ ha^{-1}, respectively) than the treatment with control (15875.8 and 8660.3 ₹ ha^{-1}, respectively). However, in terms of net return, treatment with 75% RDP with two nano sprays remained at par with the maximum treatment due to its green fodder production and lower cost of cultivation. While the Benefit to Cost Ratio (BCR) was highest with the application of 100% RDP with one nano spray of P, it remained at par with 75% RDP with two nano sprays of P, 50% RDP with three nano spray of P, and 100% RDP because reduced cultivation costs. These findings align with previous studies on Berseem (26, 47-50).

Conclusion

The study concludes that the yield of berseem can be significantly affected by the appropriate combination of varieties and nutrient management practices. While applying a 100% recommended dose of phosphorus (RDP) with a single nano spray of phosphorus (P) can produce higher green fodder and dry matter yield, treatment with 75% RDP with two nano sprays of P provides the same economic benefit. The Mescavi variety is highly recommended over the BL-42 variety for short-duration purposes.

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Authors' contributions

GRV, PKV and SS prepared the research plan and conducted the research work and analysis. AM, TP and Rajeev helped write and proofread the manuscript. All authors approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors declare no conflict of interest.

Ethical issues: None

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