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Effect of fertility levels and weed management practices on growth and yield of linseed (*Linum usitatissimum* L.)

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ABSTRACT

Context: *Efficient nutrient supply and weed management practices are important components of crop productivity and profitability under semi-arid climatic conditions of Rajasthan. Optimising fertility levels and identifying effective weed management practices can enhance the yield sustainability and soil productivity of linseed in loamy sandy soils.*

Objective: *The study aimed to evaluate the effects of different fertility levels and weed management practices on growth, yield, yield dynamics and economics of the linseed.*

Challenges: *challenges such as soil fertility depletion, severe weed infestation reducing yields by 42-45% during early growth stages (20-50 DAS), and limited research on herbicide efficacy under semi-arid conditions necessitated targeted evaluation.*

Methods: *A field experiment was conducted at the Experimental Farm, Rajasthan Agricultural Research Institute, Durgapura, Jaipur, during the Rabi seasons of 2016-17 and 2017-18. The experiment was laid out in a factorial randomised block design with three replications, comprising 28 treatment combinations of four fertility levels and seven weed management practices.*

Results: *The 150% RDF treatment significantly improved crop growth parameters such as plant height, number of branches per plant, dry matter accumulation and leaf area index. Yield components, including number of capsules plant^{-1}, seed yield, stover yield, and biological yield were also highest under 150% RDF. Among weed management practices, maximum seed and stover yields were recorded under weed-free treatments. However, the highest net returns and B:C ratio were obtained with the application of Pendimethalin 38.7 CS. The application of 150% RDF and weed-free management achieved the highest productivity, while 150% RDF and Pendimethalin 38.7 CS maximised profitability.*

Contributions: *These findings contribute optimized fertility (150% RDF) and weed management (Pendimethalin 38.7 CS pre-emergence) strategies that boost linseed productivity by up to 43% over weedy checks while maximizing economic returns in nutrient-poor loamy sand soils.*

Implications: *The findings resulted that applying 150% RDF and Pendimethalin 38.7 CS or adopting hand weeding offers an agronomically and economically sustainable strategy for enhancing crop productivity and profitability in loamy sand soils under semi-arid conditions of Rajasthan.*

Keywords: *linseed, nutrient management, pendimethalin, pre & post emergence herbicide, weed management.*

1. Introduction

Linseed (*Linum usitatissimum* L.) is a member of the linaceae family, which is an important oilseed crop valued for both nutrition and industry. It is mainly grown for the extraction of oil and fibre. Linseed oil is widely used in making paints, varnishes, inks, linoleum, soaps, and wood treatment products. [1]. Linseed cake is a better option for milch animals as a feed and also utilized as manure. Linseed is a rich source of omega-3 fatty acids and α-linolenic acid (ALA) which reduces cardiovascular diseases and cancer in human beings. [2].

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Low productivity of linseed in India is a major gap in linseed research, especially in Rajasthan, due to cultivation under conserved soil moisture and restricted nutrient supply during *Rabi* season, where the crop encounters moisture stress conditions at different growth phases which affects the availability of nutrients [3]. Depletion of soil fertility and inadequate supply of nutrients (NPK) reduces yield improvement. Weed infestation remains a significant challenge in early growth stages of linseed (20-50 DAS) [4], which reduces seed and fibre yield by 42-45 per cent [2]. Additionally, limited studies on nutrient management and weed management strategies, like the application of different suitable herbicidal formulations with proper dose, time and proper agro-climatic conditions. Herbicide formulations are the key elements of weed management practices in sustainable linseed production. Addressing these gaps could enhance sustainable linseed production in the semi-arid region of Rajasthan.

This research aims to address soil fertility depletion and weed infestation challenges under local agro-climatic conditions to enhance linseed productivity.

2. Materials and method

2.1 Experimental site

The research experiment was conducted at the experimental farm (field no. 30 and 3(b) of Rajasthan Agricultural Research Institute, Durgapura, Jaipur (SKNAU, Jobner), Rajasthan, India during two consecutive years, 2016-17 and 2017-18. The experimental farm is, geographically, situated at 26^0 51' North latitude, at 75^0 47' East longitude and with an altitude of 390 m above mean sea level and has a tropical climate. This region belongs to IIIa - Semi-arid eastern plain zone (Agro-climatic Zone) of Rajasthan.

2.2 Soil status of experimental field

The topography of the experimental plot is fairly levelled. Soil samples from 0 to 30 cm strata were drawn at random from several spots before laying out the experiment, and a composite sample was prepared and analysed for the estimation of various physicochemical properties. The textural class of the soil was loamy sand in nature, containing 27.50% coarse sand, 53.80% fine sand, 10.7% silt and 8.00% clay (International pipette Method [5]. The experimental site was slightly alkaline in nature with pH 8.3 (glass electrodes pH meter method [6]), electrical conductivity at 25 ^{0}C was 0.15 dSm^{-1} (electrical conductance method, [6]), and low in organic carbon 0.26% (Walkley and Black wet digestion method, [6]). The available nutrients in the soil were low in available nitrogen 139.2 kg ha^{-1} (Alkaline $KMnO_4$ method, [7]), medium in available phosphorus 30.60 kg P_2O_5 ha^{-1} (Olsen's method, [8]) and medium in available potassium 191 kg K_2O ha^{-1} (Flame photometer, [9]). The bulk density of the soil was 1.56 mg m^{-3} (Clod method; [10]), particle density 2.64 mg m^{-3} [10], porosity 40.91% [10] and field capacity 9.5% (pressure plate apparatus; [10]).

2.3 Climate and weather conditions:

Climate of this place is semi-arid, characterized by aridity of the atmosphere and extreme temperature in summer and winter *i.e.* 45.5^0 C and 4^0 C respectively. The average rainfall of this region is between 500-700 mm per annum, which is mostly received during July to September. The sporadic showers in winter is also common. There was a rainfall of 35.8 mm and 15.2 mm during experimentation 2016-17 and 2017-18, respectively.

2.4 Experimental design and treatment details:

The experiment was conducted in a Factorial Randomised Block Design (FRBD) with three replications. The gross area of the plot is 19.5 m^2 and the net plot size is 10.8 m^2. The row-row distance was 30 cm and the plant-plant distance was 5 cm with a 0.5-meter gap between two plots, and the distance between two replications was 1 meter. There were 28 treatment combinations involving, four fertility levels i.e. F_1- 75 % RDF, F_2-100 % RDF, F_3- 125 % RDF, F_4- 150 % RDF and second factor was seven weed management practices i.e W_1- Control (Weedy check), W_2- One hand weeding 20-25 DAS, W_3- Pendimethalin 30 EC @ 0.75 a.i. kg ha^{-1} as P.E, W_4- Pendimethalin 38.7 CS @ 0.75 a.i. kg ha^{-1} as P.E, W_5- Clodinafop-propargyl 15 WP @ 60 a.i. g ha^{-1} at 20-25 DAS, W_6- Imazethapyr 10 SL @ 40 a.i. g ha^{-1} at 20-25 DAS and W_7- Weed free. The size of the plot, row-row and plant-plant distance were same during the two years of the experiment. The treatments were randomly allotted to different plots using a random number Table of [11].

2.5 Layout:

The experimental field was laid out as per plan, after preparatory cultivation, before sowing. The layout consisted 84 experimental units and was replicated thrice, having 28 (four fertility levels and seven weed management practices) units in each replication. The treatments were allocated randomly by using a random number table in various plots, restricting randomisation in each replication.

2.6 Treatment application for fertilizer doses:

Recommended dose of fertilisers for linseed is 30 kg N ha^{-1} and 15 kg P_2O_5 ha$^{-1,}$ respectively in the experimentation. Accordingly, the fertiliser requirement was calculated as per given per cent RDF doses to treatment for each plot. Half dose of nitrogen and full dose of phosphorus were applied as a basal dose and the remaining half dose of nitrogen was applied at 30 DAS after weed management.

2.7 Treatment application for herbicidal formulations:

Herbicides were applied as per the treatments. All herbicides were calculated as per treatment and the amount dissolved in water. Herbicides were sprayed through foot sprayers with a flat-fan nozzle. Pre-emergence application of Pendimethalin 30 EC and Pendimethalin 38.7 CS were applied, while Clodinafop-propargyl 15 WP and Imazethapyr 10 % SL were applied as post-emergence at 25 DAS.

2.8 Seed and sowing

The seed of variety Parvati (LMH-16-5) was obtained from Rajasthan Agricultural Research Institute, Durgapura. Seeds were sown manually at about 3 cm depth in rows 30 cm apart using a seed rate of 20 kg ha^{-1}.

2.9 Intercultural operation:

2.9.1 Gap Filling:

Where there was no seed germinated in a pit, gap filling was done at 7 DAS by using the seedlings of the same age grown separately

2.9.2 Thinning:

Seeds started germination of 4-6 DAS. Thinning was done at 15 DAS to maintain the optimum plant population. In order to maintain a uniform plant population at 30 cm row spacing, the plant population was maintained by thinning and gap filling.

2.9.3 Irrigation:

Along with pre-sowing irrigation, irrigations were supplied at 30-38 days intervals during various atmospheric conditions to meet the water requirement of the crop using the sprinkler irrigation method.

2.10 Harvesting

The crop was harvested with the help of a sickle at the maturity stage from the net plot size after discarding border rows and plants of the crop to reduce the border effect. The harvested material was kept for sun drying for 5 - 6 days, and thereafter after threshing was done for each treatment separately. Total biological yield and seeds were weighed from different net plots after winnowing and cleaning. Weighed material was subjected to converted in kg ha^{-1}. The harvesting, drying, threshing and winnowing were done for each net plot separately.

4. Data collection:

Data were collected for morphological traits, seed yield, yield components, field duration and quality parameters. Five Linseed plants from the centre two rows of each plot were randomly selected and tagged with a yellow card at maturity to determine yield components and morphological traits.

4.1 Statistical analysis 3.9.8.1

4.1.1 Analysis of variance and test of significance

The statistical analysis of the data was done by the analysis of variance method [12]. The Null Hypothesis was tested by 'F' F-test of significance to know whether observed treatment effects were real or not. From the data in which the treatment effects were significant, the appropriate standard error (SE) and critical difference (CD) at a 0.05 % level of probability (5 % degree of freedom) were calculated. Data have been graphically illustrated at appropriate places.

5. Result

5.1 Effect of fertility level and weed management practices on plant growth parameters of linseed

5.1.1 Plant height (cm)

Linseed plant height in 2017 and 2018 was positively affected by fertility levels and weed management practices (fig. 1). Fertility level F_4 produced significantly the highest plant height (54.09 cm), which was higher than F_1, F_2 and F_3, by 10.47, 6.45 and 2.99 cm, respectively. In the case of weed management practice, W_7 produced the highest plant height (57.90 cm), which was higher than W_1, W_5, W_6, W_3, W_4 and W_2 by 18.39, 13.66, 11.02, 9.68, 5.82 and 2.96 cm, respectively. On the other hand, in 2018, the same RDF F_4 demonstrated the longest plant height by 12.85, 5.46 and 2.54 cm in comparison to F_1, F_2 and F_3 and weed management practice W_7 gave 16.67, 12.73, 9.33, 6.23, 3.53 and 1.69 cm more plant height compared to W_1, W_5, W_6, W_3, W_4 and W_2.

5.1.2 No. of branches plant^{-1}

Data regarded Linseed growth stages under the No. Of branches plant^{-1} as influenced by fertility levels and weed management practices over 2017 and 2018 growing seasons are presented in (fig. 2). In 2017, No. of branches plant^{-1} showed 24.05 %, 13.73 % and 5.75 %, respectively more in F_4 crop compared with F_1, F_2, and F_3. Among the weed management practices, higher branches plant^{-1} was observed in W_7 (6.24) extended (51.45, 28.65, 22.11, 14.70, 10.05 and 5.05 %) over W_1, W_5, W_6, W_3, W_4 and W_2, while in 2018, F_4 produced highest branches plant^{-1} (5.95) which was 20.20%, 11.63% and 5.31 % more as compared to F_1, F_2, and F_3. In weed management practices, W_7 produced 40.58 %, 29.01 % 19.66 %, 12.36 %, 8.10 % and 3.29 % more No. of branches compared to W_1, W_5, W_6, W_3, W_4 and W_2 respectively.

5.1.3 Dry matter accumulation plant^{-1}

Dry matter accumulation plant^{-1} was significantly influenced by fertility levels and weed management practices during 2017 and 2018 in linseed (fig. 3). In 2017, fertility levels F_4 (13.40 g) produced 23.95 %, 11.76 % and 5.34 % more dry matter compared to F_1, F_2, and F_3, respectively. Among the weed management practices, the highest dry matter accumulation plant^{-1} was observed in W_7 (13.87 g), which was higher than W_1, W_5, W_6, W_3, W_4 and W_2 by 51.58 %, 22.63 %, 14.63 %, 8.70 %, 6.28 % and 3.74 % respectively. In 2018, F_4 (13.89 g) produced significantly the highest dry matter over F_1, F_2, and F_3 by 23.90 %, 11.74 % and 5.30 %. Among weed management practices W_7 produce 43.57 %, 22.74 %, 14.67 %, 8.74 %, 6.40 % and 3.37 % highest dry matter accumulation over W_1, W_5, W_6, W_3, W_4 and W_2.

5.1.4 Leaf Area Index (LAI)

Fertility levels F_4 (1.00 and 1.03) produce significantly highest LAI over F_1, F_2, and F_3 by 29.87 %, 17.65 % and 7.53 % in 2017 and 33.77 %, 17.04 % and 7.29 % in 2018 (fig. 4). Among different weed management practices highest LAI observed in treatment W_7 (1.16 and 1.18) by 110.91 %, 70.59 %, 56.75 %, 34.88 %, 6.42 % and 2.65 % in 2017 and 103.44 %, 66.20 %, 55.26 %, 31.11 %, 6.31 % and 5.35 % in second year of experiment (2018) over W_1, W_5, W_6, W_3, W_4 and W_2.

5.2 Effect of fertility level and weed management practices on plant growth indices of linseed

5.2.1 Crop Growth Rate (CGR) g m^{-2} day^{-1}

Linseed CGR in 2017 and 2018 was positively affected by fertility levels and weed management practices (Table 1). Fertility level F_1 produced highest CGR (1.59 g m^{-2} day^{-1}), which was higher than F_2, F_3 and F_4, by 16.91 %, 9.65 % and 6 %, respectively. In case of weed management practice W_6 produced the highest CGR (1.70 g m^{-2} day^{-1}), which was higher than W_4, W_3, W_1, W_5, W_2 and W_7 by 33.86 %, 26.86 %, 25%, 13.33 %, 11.84 % and 3.66 %, respectively in 2017. On the other hand, in 2018 the same fertility level F_4 demonstrated the longest CGR (2.07 g m^{-2} day^{-1}) by 43.75 %, 15.00 % and 11.29 % in comparison to F_1, F_2 and F_3 and in weed management practice W_6 gave higher CGR (2.21 g m^{-2} day^{-1}) by 43.50 %, 42.58 %, 34.76 %, 30.77 %, 13.33 % and 12.75 % compared to W_4, W_5, W_2, W_1, W_7 and W_3 respectively.

5.2.2 Relative Growth Rate (RGR) mg g^{-1} day^{-1}

RGR was significantly influenced by fertility levels and weed management practices during 2017 and 2018 in linseed (Table 1). In 2017 fertility levels F_1 (4.62 mg g^{-1} day^{-1}) produced 0.92, 0.86 and 0.91 mg g^{-1} day^{-1} more RGR compared to F_2, F_3, and F_4 respectively. In 2018 F_4 produce significantly highest dry matter (4.88 mg g^{-1} day^{-1}) over F_1, F_3, and F_2 by 0.95, 0.27 and 0.09 mg g^{-1} day^{-1}. Among the weed management practices in 2017, the highest RGR was observed in W_6 (4.60 mg g^{-1} day^{-1}) by 1.45, 1.22, 0.88, 0.75, 0.26 and 0.02 mg g^{-1} day^{-1} compared to W_4, W_3, W_2, W_7, W_5 and W_1 respectively. In the second year of experiment (2018), treatment W_6 observed maximum RGR (5.81 mg g^{-1} day^{-1}) compared to W_4, W_2, W_5, W_7, W_3 and W_1 by 2.20, 2.03, 1.48, 1.48, 0.97 and 0.64 mg g^{-1} day^{-1}, respectively.

5.2.3 Leaf Area Duration (LAD) days

The LAD was significantly different by the fertility levels and weed management practices in both years. Fertility level F_4 produced maximum LAD (29.88 days), which was higher than F_1, F_2, and F_3 by 6.81, 4.29 and 1.99 days. Among different weed management practices higher LAD was observed W_7 (34.89 days) by 18.48, 14.60, 12.61, 9.13, 2.29 and 0.86 day compared to W_1, W_5, W_6, W_3, W_4 and W_2 respectively in 2017. In the second year of experiment (2018) fertility level F_4 produced maximum LAD (30.77 days), which was higher than F_1, F_2, and F_3 by 7.55, 4.43 and 1.82 days. In different weed management practices, higher LAD was observed W_7 (35.55 days) by 18.15, 14.23, 12.88, 8.39, 2.14 and 1.82 days compared to W_1, W_5, W_6, W_3, W_4 and W_2.

5.2.4 Net Assimilation Rate (NAR) mg cm^{-2} day^{-1}

Linseed NAR in 2017 and 2018 was positively affected by fertility levels and weed management practices (Table 1). Fertility level F_2 produced the highest NAR (1.25 mg cm^{-2} day^{-1}), which was higher than F_1, F_3 and F_4, by 0.80 %, 4.17 % and 5.04 %, respectively. In case of weed management practice W_5 produced the highest NAR (1.46 mg cm^{-2} day^{-1}), which was higher than W_2, W_4, W_7, W_3, W_1 and W_6 by 61.62 %, 55.34 %, 46 %, 25 %, 15.94 % and 3.55 %, respectively in 2017. On the other hand, in 2018 the fertility level F_1 demonstrated the longest NAR (1.23 mg cm^{-2} day^{-1}) by 4.23 %, 7.89 % and 10.81 % in comparison to F_2, F_3 and F_4 and in weed management practice W_1 gave higher NAR (1.44 mg cm^{-2} day^{-1}) by 53.19 %, 50 %, 46.94 %, 22.03 %, 11.63 %, and 4.35 % compared to W_7, W_2, W_4, W_3, W_6 and W_5 respectively.

5.3 Effect of different fertility levels and weed management practices on yield and yield components of linseed.

5.3.1 No. of capsules plant^{-1}

No. of capsules per plant^{-1} was significantly influenced by fertility levels and weed management practices during 2017 and 2018 in linseed (Table 2). F_4 fertility level produced 23.72 %, 13.30 % and 5.58 % more capsule plant^{-1} compared to F_1, F_2 and F_3 respectively in 2017 and the same fertility level produced 25.4 %, 14.19 % and 6.33 % more capsule plant^{-1} compared to F_1, F_2 and F_3 in 2018. In weed management practices, W_7 produced the highest No. of capsules plant^{-1} and it was 43.41 %, 23.97 %, 17.06 %, 15.36 %, 8.23 % and 4.47 % more than W_1, W_5, W_6, W_3, W_4 and W_2 respectively in 2017 and same weed management practices produce 43.55 %, 24.13 %, 17.27 %, 16.47 %, 8.29 % and 4.62 % more No. of capsule plant^{-1} compared to W_1, W_5, W_6, W_3, W_4 and W_2 in 2018.

5.3.2 Seed yield (kg ha^{-1})

Seed yield was significantly influenced by fertility levels and weed management practices during 2017 and 2018 in linseed (Table 2). F_4 fertility level produced the highest seed yield in both years and it produced 23.84 %, 13.43 % and 5.68 % more yield as compared to F_1, F_2 and F_3 respectively in 2017. The same fertility level F_4 produced 23.75 %, 13.48 % and 5.72 % more seed yield over F_1, F_2 and F_3 respectively in 2018. Among different weed management practices W_7 produced highest seed yield and it was 43.39 %, 23.95 %, 17.10 %, 13.62 %, 8.18 % and 4.46 % higher than W_1, W_5, W_6, W_3, W_4 and W_2 respectively in 2017 and same weed management practices produce highest seed yield over W_1, W_5, W_6, W_3, W_4 and W_2 by 43.63 %, 24.18 %, 17.15 %, 13.74 %, 8.33 % and 4.59 % respectively in second year of study (2018).

2.3.3 Stover yield (kg ha^{-1})

The stover yield differed significantly across all treatments in both years (Table 2). F_4 fertility level produced the highest stover yield in both years (2017 and 2018) and it produced 20.11 %, 11.10 % and 5.19 % more stover yield (3142 kg ha^{-1}) as compared to F_1, F_2 and F_3. Among different weed management practices W_7 produced highest stover yield (3220 kg ha^{-1}) and it was 34.06 %, 22.15 %, 13.66 %, 6.83 %, 5.64 % and 3.44 % higher than W_1, W_5, W_6, W_3, W_4 and W_2 respectively in 2017. In the second year of experiment, fertility level F_4 produced maximum stover yield (3230 kg ha^{-1}) as compared to F_1, F_2 and F_3 by 19.76 %, 11.11 % and 5.21 %. In weed management practices W_7 produced highest stover yield (3310 kg ha^{-1}) by 34.06 %, 22.14 %, 13.67 %, 6.80 %, 5.65 % and 3.46 % as compared to W_1, W_5, W_6, W_3, W_4 and W_2 respectively in 2018.

2.3.4 Biological yield (kg ha^{-1})

Biological yield was significantly influenced by fertility levels and weed management practices during 2017 and 2018 in linseed (Table 2). F_4 fertility level produced the highest biological yield in both the years and it produced 20.89 %, 11.74 % and 5.33 % more biological yield as compared to F_1, F_2 and F_3 respectively in 2017. In second year of study same fertility level F_4 produced 20.89 %, 11.79 % and 5.35 % more biological yield compared to F_1, F_2 and F_3 respectively in 2018. Among different weed management practices W_7 produced highest biological yield and it was 36.66 %, 22.68 %, 14.65 %, 8.74 %, 6.37 % and 3.73 % higher than W_1, W_5, W_6, W_3, W_4 and W_2 respectively in 2017 and same weed management practices W_7 produce highest biological yield over W_1, W_5, W_6, W_3, W_4 and W_2 by 36.68 %, 22.73 %, 14.69 %, 8.77 %, 6.39 % and 3.77 % respectively in second year of study (2018).

5.4 Economic analysis

5.4.1 Gross Returns (₹ ha^{-1})

GR (₹ ha^{-1}) was significantly influenced by fertility levels and weed management practices during 2017 and 2018 in linseed (Table 3). F_4 fertility level produced 23.84 %, 13.41 % and 5.68 % more GR compared to F_1, F_2 and F_3 respectively in 2017 and the same fertility level produced 23.78 %, 13.47 % and 5.72 % more GR compared to F_1, F_2 and F_3 in 2018. Among different weed management practices W_7 produced highest GR and it was 43.45 %, 24.00 %, 17.05 %, 13.62 %, 8.16 % and 4.45 % more than W_1, W_5, W_6, W_3, W_4 and W_2 respectively in 2017 and same weed management practices produce 46.32 %, 24.14 %, 17.19 %, 13.75 %, 8.29 % and 4.97 % more No. of capsule plant^{-1} compared to W_1, W_5, W_6, W_3, W_4 and W_2 in 2018.

5.4.2 Net Returns (₹ ha^{-1})

Data regarded linseed economics under the net returns as influenced by fertility levels and weed management practices during both the years of study. F_4 fertility level produced the highest NR and it produce 51.15 %, 26.08 % and 10.30 % more NR (₹. 41,405 ha^{-1}) as compared to F_1, F_2 and F_3. Among different weed management practices W_4 produced highest NR (₹. 41,184 ha^{-1}) and it was 74.16 %, 27.57 %, 19.70 %, 13.96 %, 11.89 % and 5.35 % higher than W_1, W_5, W_7, W_6, W_3 and W_2 respectively in 2017. In the second year of experiment fertility level F_4 produce maximum NR (₹. 45,537 ha^{-1}) as compared to F_1, F_2 and F_3 by 48.26 %, 25.03 % and 9.98 %. In weed management practices W_4 produced highest NR (₹. 45,122 ha^{-1}) by 69.90 %, 26.43 %, 16.35 %, 13.48 %, 11.29 % and 4.50 % as compared to W_1, W_5, W_7, W_6, W_3 and W_2 respectively in 2018.

5.4.3 B:C ratio

Linseed BCR in 2017 and 2018 was positively affected by fertility levels and weed management practices (Table 3). Fertility level F_4 produced the highest BCR, which was higher than F_1, F_2 and F_3, by 20.56 %, 11.28 % and 4.83 %, respectively. In case of weed management practice, W_4 produced the highest BCR (2.25), which was higher than W_1, W_7, W_5, W_2, W_3 and W_6 by 30.05 %, 28.57 %, 12.5 %, 10.29 %, 7.65 % and 6.13 %, respectively in 2017. On the other hand, in 2018 the fertility level F_4 demonstrated the largest BCR (1.28) by 20.63 %, 11.22 % and 5.07 % in comparison to F_1, F_2 and F_3 and in weed management practice W_4 gave higher BCR (2.36) by 29.67 %, 28.26 %, 12.38 %, 10.28 %, 7.76 %, and 6.31 % compared to W_1, W_7, W_5, W_2, W_3 and W_6 respectively.

6. Discussion

6.1 Growth dynamics

During both consecutive years of investigation (2017 & 2018), fertility level F_4 recorded significantly maximum plant height of the crop. This might be due to adequate availability of nutrients during entire cycle of the crop that imparts higher photosynthetic rate and ultimately led to higher plant height. [13] also reported that plants with an adequate dose of RDF grow rapidly. During both the year of the experiment, W_7 recorded the significantly highest plant height. Among herbicide formulations, W_4 has secured significantly highest plant height might be because least competition with weed population and fetching adequate land space, nutrients and moisture to the crop enhanced the plant height. Similar findings were also reported by [14].

No. of branches were recorded as maximum with the application of 150 % RDF i.e F_4. This may be attributed to the existing adequate nourishment with 150 % RDF. Research results are in line with the findings of [15]. Significantly maximum branches plant^{-1} in linseed were observed in the weed-free check (W_7) at all the growth stages of crop. In the weedy check (W_1), the number of branches was counted less in numbers than the wider ones. The probable reason for more branching in wider spacing is weed weed-free environment with adequate availability of occupying space, nutrients and moisture in the soil. Among herbicide formulations, Pendimethalin 38.7 CS (W_4) has produced significantly higher branches through the entire growing phase. These results are in conformity with the research findings concluded by [16].

Dry matter accumulation is the result of photosynthetic activity and its photo-morphogenesis. Significantly higher dry matter accumulation per plant^{-1} was recorded with fertility levels F_4 (Table 1). This was due to a larger number of leaves and leaf area plant$^{-1,}$ which might have increased photosynthates produced and its accumulation at a higher rate and quantity through process of plant metabolism, which ultimately reflected in dry matter production. These findings are in agreement with [17] who recorded higher accumulation of dry matter plant^{-1} with 150 % RDF doses. Dry matter accumulation in plant^{-1} was recorded significantly higher under treatment W_7. This might be due to adequate availability of nutrients for better proliferation because of no competition with the weedy population. Among herbicide formulations, W_7 has been noted to have significantly higher dry matter accumulation might be due to less weed plants competing for nutrition, space and moisture, etc. These results are in conformity with the findings of [18].

Leaf area index was found to be significantly highest in treatment F_4, this may be because of adequate availability of nutrients to the crop through the successive growth phases. During both consecutive years of experimentation, among all weed management practices, W_7 recorded the significantly highest LAI it may be caused by no competition with weed plants. Among herbicide formulations, W_7 has secured significantly highest leaf area.

6.2 Growth indices

Growth analysing parameters *viz*., CGR, RGR, NAR, and LAD were significantly influenced by fertility levels (Table 1). However, it is well well-known fact that adequate fertilisation to crops is known to improve various physiological and metabolic processes in the plant system. Nitrogen is required in the synthesis of proteins, chlorophyll and other organic compounds in the plant system.

Phosphorus is required for the growth and development of plants and plays an important role in the conservation and transfer of energy in the metabolic reactions and act as an energy currency within the plants. Thus, phosphorus application affects photosynthesis, biosynthesis of proteins, phospholipids and nucleic acids, membrane transport and cytoplasmic streaming. The greater availability of nutrients in soil due to increasing fertiliser application might have enhanced meristematic activity (multiplication and elongation of cells) leading to increased plant dry matter accumulation in fertility level F_4.

The above growth analysing parameters were significantly influenced by different weed management practices (Table1). However, W_7 has recorded significantly higher growth rates and all analysis factors over other management measures. Among herbicide formulations, growth analysis factors were observed significantly higher in W_4 over other herbicides. This might be due to a better weed free ecosystem remaining available to the above proposed treatment practices. These results in linseed crop are in close conformity with the findings of [19] in mustard, [20] in *Rabi* groundnut, and [21] in castor.

6.3 Yield and yield dynamics

The number of capsules plant^{-1} were significantly maximum in fertility level F_4 (60.5 & 65.5) and was substantially reduced as the fertility levels were reduced in 2017 & 2018 (Table 2). This might be due to lower production of photosynthates and reduced nutritional area plant^{-1} which might have decreased the growth rate of crop under reduced fertility levels. Such types of advantages of 150 % doses of RDF were also reported by [22] & [23]. The mean number of capsules plant^{-1} were observed significantly maximum W_7 (63.10 & 67.90). This might be due to higher production of photosynthates because of a larger number of leaves and LAI of linseed under weed free condition through the entire growth phase (Figure 4). Among the herbicides, W_4 (58.30 & 62.70) recorded a significantly higher number of capsules plant^{-1} over all the formulations utilised. It may be because of less crop weed competition were entertained during vegetative and reproductive phases of crop. These results are similar with the findings of [18] & [16].

Varied differences in growth attributes *viz.* plant height, branches, leaves, leaf area and dry matter accumulation and yield attributes *viz.* number of capsules plant^{-1} resulted into considerable variation in seed yield among different fertility levels during both consecutive years of investigation. Significantly higher seed yield, stover yield and biological yield were recorded in F_4 (Table 2). Similar findings were also reported by [17] & [23]. Various growth and yield attributes (Table 2) were influenced due to different weed management practices which ultimately resulted in significant variation in crop yield ha^{-1}. Seed yield was substantially higher in W_7 and it was reduced significantly with an increase in weed population during the course of the investigation in both consecutive years. The increased crop yield ha^{-1} in W_7 might be attributed to increased plant nutrition, space and moisture due to no or less crop weed competition, which facilitated more uptakes of nutrients and soil moisture per unit area coupled with better interception of light which might have increased leaf area (Table 2) and leaf mass which resulted in better translocation of photosynthates which might have contributed towards the development of plant and finally increased crop seed yield, stover yield and biological yield. Among herbicide formulations, W_4 has recorded significantly higher seed, stover and biological yield over rest of the formulations applied.

Such a type of advantage with weed-free check on yield was reported by [18] & [16].

6.4 Economics

Gross return was substantially higher under fertility level F_4 (₹. 77047 & ₹. 81399) and weed management practices W_7 (₹. 80,097 & ₹. 84,692) and it was reduced significantly with increase in weed population during the course of investigation during both consecutive years (Table 3). Among herbicide formulations, W_7 recorded significantly higher gross return over rest of formulations applied. Such type of advantage with weed-free check on yield was reported by [18] & [16].

Net return from linseed crop were recorded in fertility level F_4 (₹. 41,405 & ₹. 45537), which was significantly higher than rest of the low doses of RDF and weed management practices W_4 (₹. 41,184 & ₹. 45,122) recorded higher net returns. In the treatment W_4 limited labour requirement for the spray of the chemical formulation as compared to the rest of the weed management practices. The results are in conformity with those reported by [23] & [18].

Maximum BCR was recorded F_4 (2.17 & 2.28) and W_4 (2.25 & 2.36) among fertility levels and different weed management practices, respectively (Table 3). It might be due to either a higher yield was attained or less monetary input being required. That could contribute to enhancing the net monetary return from the treatments applied under both factors. The results are in conformity with research findings of [24] & [18].

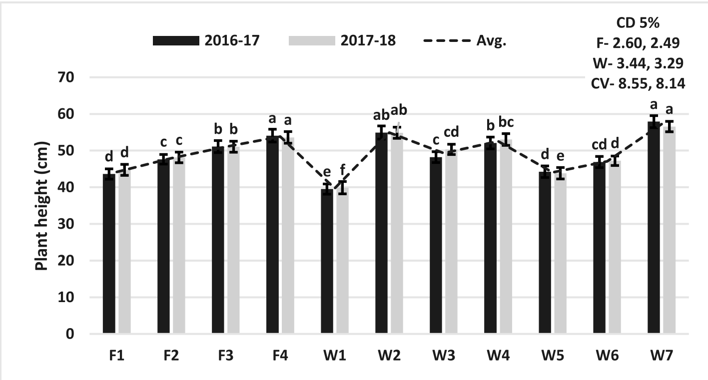

Fig. 1

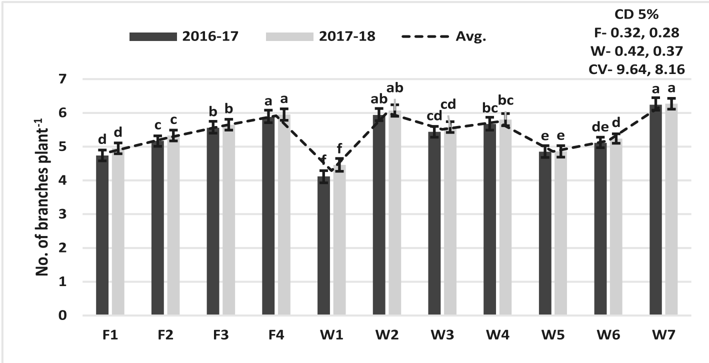

Fig. 2

F_1- 75 % RDF, F_2- 100 % RDF, F_3- 125 % RDF, F_4- 150 % RDF, W_1- Control (Weedy check), W_2- One hand weeding 20-25 DAS, W_3- Pendimethalin 30 EC @ 0.75 a.i. kg ha^{-1} as P.E, W_4- Pendimethalin 38.7 CS @ 0.75 a.i. kg ha^{-1} as P.E, W_5- Clodinafop-propargyl 15 WP @ 60 a.i. g ha^{-1} at 20-25 DAS, W_6- Imazethapyr 10 SL @ 40 a.i. g ha^{-1} at 20-25 DAS and W_7- Weed free

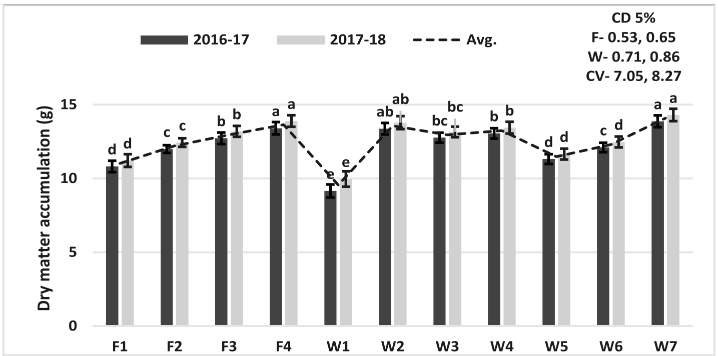

Fig. 3

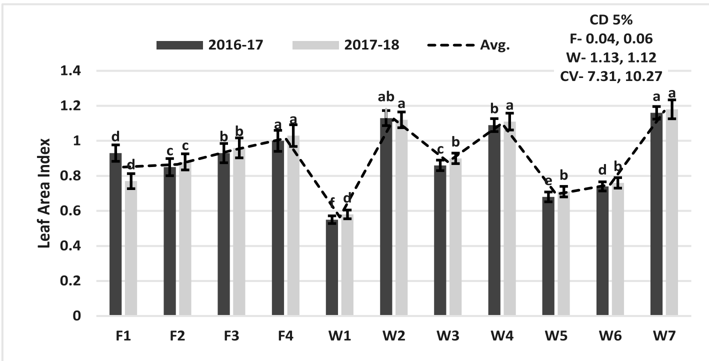

Fig. 4

F_1- 75 % RDF, F_2- 100 % RDF, F_3- 125 % RDF, F_4- 150 % RDF, W_1- Control (Weedy check), W_2- One hand weeding 20-25 DAS, W_3- Pendimethalin 30 EC @ 0.75 a.i. kg ha^{-1} as P.E, W_4- Pendimethalin 38.7 CS @ 0.75 a.i. kg ha^{-1} as P.E, W_5- Clodinafop-propargyl 15 WP @ 60 a.i. g ha^{-1} at 20-25 DAS, W_6- Imazethapyr 10 SL @ 40 a.i. g ha^{-1} at 20-25 DAS and W_7- Weed free

Table 1. Effect of fertility levels and weed management practices on plant growth indices of linseed

Treatments	Crop Growth Rate (CGR) g m^{-2} day^{-1}		Relative Growth Rate (RGR) mg g^{-1} day^{-1}		Leaf Area Duration (LAD) days		Net Assimilation Rate (NAR) mg cm^{-2} day^{-1}	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Fertility levels								
F_1	1.59^{a} ±0.16	1.44^{b} ±0.17	4.62^{a} ±0.48	3.93^{b} ±0.51	23.07^{d} ±1.41	23.22^{d} ±1.28	1.24^{a} ±0.051	1.23^{a} ±0.046
F_2	1.36^{b} ±0.10	1.80^{ab} ±0.14	3.70^{b} ±0.32	4.79^{a} ±0.45	25.59^{c} ±1.16	26.34^{c} ±1.38	1.25^{a} ±0.047	1.18^{b} ±0.044
F_3	1.45^{a} ±0.07	1.86^{a} ±0.16	3.76^{b} ±0.27	4.61^{a} ±0.45	27.89^{b} ±1.63	28.95^{b} ±1.71	1.20^{ab} ±0.046	1.14^{bc} ±0.048
F_4	1.50^{a} ±0.07	2.07^{a} ±0.15	3.71^{b} ±0.29	4.88^{a} ±0.42	29.88^{a} ±1.79	30.77^{a} ±1.87	1.19^{b} ±0.046	1.11^{c} ±0.047
SEm±	0.08	0.14	0.24	0.37	0.42	0.61	0.02	0.02
CD at 5%	0.22	0.40	0.69	1.05	1.20	1.74	0.05	0.05
Weed management practices								
W_1	1.36^{bc} ±0.23	1.69^{bc} ±0.37	4.58^{a} ±0.75	5.17^{ab} ±1.16	16.41^{f} ±0.66	17.40^{d} ±0.75	1.38^{b} ±0.054	1.44^{a} ±0.033
W_2	1.52^{abc} ±0.11	1.64^{bc} ±0.08	3.72^{ab} ±0.39	3.78^{bc} ±0.12	34.03^{ab} ±1.26	33.73^{a} ±1.34	0.99^{d} ±0.010	0.96^{d} ±0.011
W_3	1.34^{c} ±0.11	1.96^{ab} ±0.19	3.38^{b} ±0.36	4.84^{abc} ±0.48	25.76^{c} ±0.91	27.16^{b} ±0.91	1.28^{c} ±0.028	1.18^{c} ±0.020
W_4	1.27^{c} ±0.10	1.54^{bc} ±0.14	3.15^{b} ±0.33	3.61^{c} ±0.30	32.60^{b} ±1.12	33.41^{a} ±1.44	1.03^{d} ±0.014	0.98^{d} ±0.017
W_5	1.50^{abc} ±0.12	1.55^{bc} ±0.26	4.34^{a} ±0.45	4.33^{bc} ±0.77	20.29^{e} ±0.84	21.32^{c} ±0.89	1.46^{a} ±0.039	1.38^{a} ±0.039
W_6	1.70^{a} ±0.13	2.21^{a} ±0.15	4.60^{a} ±0.43	5.81^{a} ±0.37	22.28^{d} ±0.77	22.67^{c} ±0.91	1.41^{ab} ±0.015	1.29^{b} ±0.025
W_7	1.64^{ab} ±0.11	1.95^{ab} ±0.13	3.85^{ab} ±0.34	4.33^{bc} ±0.20	34.89^{a} ±1.09	35.55^{a} ±1.60	1.00^{d} ±0.007	0.94^{d} ±0.019
SEm±	0.10	0.18	0.32	0.49	0.56	0.81	0.03	0.02
CD at 5%	0.29	0.52	0.92	1.38	1.59	2.30	0.07	0.06
CV (%)	**8.70**	**9.59**	**8.40**	**8.16**	**7.31**	**10.27**	**7.09**	**6.26**

F_1- 75 % RDF, F_2- 100 % RDF, F_3- 125 % RDF, F_4- 150 % RDF ,W_1- Control (Weedy check), W_2- One hand weeding 20-25 DAS, W_3- Pendimethalin 30 EC @ 0.75 a.i. kg ha^{-1} as P.E, W_4- Pendimethalin 38.7 CS @ 0.75 a.i. kg ha^{-1} as P.E, W_5- Clodinafop-propargyl 15 WP @ 60 a.i. g ha^{-1} at 20-25 DAS, W_6- Imazethapyr 10 SL @ 40 a.i. g ha^{-1} at 20-25 DAS and W_7- Weed free.

Table 2. Effect of fertility levels and weed management practices on yield and yield dynamics of linseed

Treat.	No. of capsules plant^{-1}		Seed yield (kg ha^{-1})		Stover yield (kg ha^{-1})		Biological yield (kg ha^{-1})	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Fertility levels								
F_1	48.9^{d} ±1.16	52.3^{d} ±1.71	1037^{d} ±24.58	1061^{d} ±34.84	2624^{d} ±67.51	2697^{d} ±69.39	3661^{d} ±79.63	3758^{d} ±101.18
F_2	53.4^{c} ±1.53	57.0^{c} ±1.66	1132^{c} ±32.5	1157^{c} ±33.72	2828^{c} ±60.80	2907^{c} ±62.49	3961^{c} ±77.68	4064^{c} ±93.74
F_3	57.3^{b} ±1.67	61.6^{b} ±1.79	1215^{b} ±35.42	1242^{b} ±35.97	2987^{b} ±83.97	3070^{b} ±86.31	4202^{b} ±118.64	4312^{b} ±119.66
F_4	60.5^{a} ±1.79	65.5^{a} ±2.07	1284^{a} ±37.81	1313^{a} ±41.31	3142^{a} ±91.04	3230^{a} ±95.58	4426^{a} ±128.12	4543^{a} ±129.10
SEm±	0.94	1.15	20	23	55	56	62	75
CD at 5%	2.67	3.25	57	66	156	160	177	212
Weed management practices								
W_1	44.0^{f} ±1.35	47.3^{e} ±2.16	931^{f} ±28.61	951^{f} ±42.85	2402^{d} ±72.79	2469^{d} ±74.82	3333^{e} ±88.65	3421^{e} ±102.41
W_2	60.4^{ab} ±1.57	64.9^{ab} ±2.19	1278^{ab} ±33.27	1306^{ab} ±42.81	3113^{a} ±100.08	3199^{a} ±102.87	4391^{ab} ±127.57	4506^{ab} ±144.20
W_3	54.7^{cd} ±1.65	58.3^{cd} ±1.90	1175^{cd} ±35.33	1201^{cd} ±38.17	3014^{ab} ±86.88	3099^{ab} ±89.30	4189^{bc} ±112.9	4299^{bc} ±116.72
W_4	58.3^{bc} ±1.78	62.7^{bc} ±2.26	1234^{bc} ±37.65	1261^{bc} ±44.44	3048^{ab} ±86.57	3133^{ab} ±88.98	4282^{b} ±115.54	4395^{ab} ±130.20
W_5	50.9^{e} ±0.84	54.7^{d} ±2.07	1077^{e} ±38.90	1100^{e} ±40.71	2636^{c} ±84.54	2710^{c} ±86.90	3713^{d} ±107.02	3810^{d} ±120.22
W_6	53.9^{de} ±0.73	57.9^{d} ±1.93	1140de ±36.61	1166de ±37.58	2833^{bc} ±81.95	2912^{bc} ±84.24	3973^{c} ±106.73	4077^{cd} ±119.71
W_7	63.1^{a} ±2.02	67.9^{a} ±2.32	1335^{a} ±42.74	1366^{a} ±45.12	3220^{a} ±91.93	3310^{a} ±94.49	4555^{a} ±129.73	4676^{a} ±138.76
SEm±	1.24	1.52	26	31	73	75	82	99
CD at 5%	3.53	4.30	75	87	206	211	234	281
CV (%)	**7.84**	**8.90**	**7.84**	**8.90**	**8.68**	**8.68**	**7.03**	**8.23**

F_1- 75 % RDF, F_2- 100 % RDF, F_3- 125 % RDF, F_4- 150 % RDF ,W_1- Control (Weedy check), W_2- One hand weeding 20-25 DAS, W_3- Pendimethalin 30 EC @ 0.75 a.i. kg ha^{-1} as P.E, W_4- Pendimethalin 38.7 CS @ 0.75 a.i. kg ha^{-1} as P.E, W_5- Clodinafop-propargyl 15 WP @ 60 a.i. g ha^{-1} at 20-25 DAS, W_6- Imazethapyr 10 SL @ 40 a.i. g ha^{-1} at 20-25 DAS and W_7- Weed free.

Table 3. Effect of fertility levels and weed management practices on economics of linseed

Treat.	Gross Returns (₹ ha^{-1})		Net Returns (₹ ha^{-1})		BCR	
	2016-17	**2017-18**	**2016-17**	**2017-18**	**2016-17**	**2017-18**
Fertility levels						
F_1	62216^{d}	65758^{d}	27393^{d}	30715^{d}	1.80^{d}	1.89^{d}
F_2	67936^{c}	71737^{c}	32840^{c}	36421^{c}	1.95^{c}	2.05^{c}
F_3	72908^{b}	76993^{b}	37539^{b}	41404^{b}	2.07^{b}	2.17^{b}
F_4	77047^{a}	81399^{a}	41405^{a}	45537^{a}	2.17^{a}	2.28^{a}
SEm±	1197	1436	1197	1436	-	-
CD at 5%	3395	4072	3395	4072	-	-
Weed management practices						
W_1	55836^{f}	58968^{f}	23646^{d}	26558^{d}	1.73^{c}	1.82^{c}
W_2	76683^{ab}	80989^{ab}	39093^{ab}	43179^{ab}	2.04^{b}	2.14^{b}
W_3	70497^{cd}	74455^{cd}	36807^{abc}	40545^{abc}	2.09^{b}	2.19^{b}
W_4	74052^{bc}	78210^{bc}	41184^{a}	45122^{a}	2.25^{a}	2.36^{a}
W_5	64594^{e}	68219^{e}	32284^{c}	35689^{c}	2.00^{b}	2.10^{b}
W_6	68429de	72270de	36139^{bc}	39760^{abc}	2.12^{ab}	2.22^{ab}
W_7	80097^{a}	84692^{a}	34407^{bc}	38782^{bc}	1.75^{c}	1.84^{c}
SEm±	1584	1900	1584	1900	-	-
CD at 5%	4491	5386	4491	5386	-	-
CV (%)	**7.8**	**8.9**	**7.10**	**7.80**	**-**	**-**

F_1- 75 % RDF, F_2- 100 % RDF, F_3- 125 % RDF, F_4- 150 % RDF ,W_1- Control (Weedy check), W_2- One hand weeding 20-25 DAS, W_3- Pendimethalin 30 EC @ 0.75 a.i. kg ha^{-1} as P.E, W_4- Pendimethalin 38.7 CS @ 0.75 a.i. kg ha^{-1} as P.E, W_5- Clodinafop-propargyl 15 WP @ 60 a.i. g ha^{-1} at 20-25 DAS, W_6- Imazethapyr 10 SL @ 40 a.i. g ha^{-1} at 20-25 DAS and W_7- Weed free

Conclusion

Application of 150 % RDF was found as the best fertility level which produces significantly highest growth and yield dynamics in linseed. It also reflects 19.93 %, 11.10 % and 10.4% highest seed yield compared to application of 75 % RDF, 100 % RDF and 125 % RDF. Maximum net return (₹. 43,471 ha^{-1}) and B:C ratio (2.23) were recorded with the application of 150 % RDF. Pre-emergence application of Pendimethalin 38.7 CS recorded highest net return (₹. 43,153 ha^{-1}) and B:C ratio (2.30) over rest of the weed management practices.

Authors contributions

DS: Writing-original draft, Formal analysis, Conceptualisation. **KCG:** Writing-review & editing, Visualisation, Supervision, **AG**: Writing-original draft & editing, Validation, Methodology, Data curation. **AM**: Writing-review & editing, Validation, Supervision. **RS**: Writing-review & editing, Software, **LRY**: Supervision, Resources, Investigation, S**AA**: Writing-review & editing, Validation, Data curation.

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issue: None

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Data availability

Data will be made available on request.

Future scope of the study

Future research should explore integrating 150% RDF with Pendimethalin 38.7 CS under varying irrigation regimes and soil types beyond loamy sand in semi-arid zones. Long-term studies on nutrient cycling, weed flora shifts, and biofertilizer combinations could enhance sustainability and linseed productivity. Additionally, evaluating climate-resilient varieties with these practices will support adaptation to moisture stress in Rajasthan.

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