Journal of Applied and Natural Science 9 (2): 698 - 705 (2017)

# Effect of irrigation scheduling and nitrogen levels on growth, yield and water productivity of linseed (*Linum usitatissimum* L.) under Vertisols

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*Received: August 14, 2016; Revised received: January 24, 2017; Accepted: April 11, 2017*

**Abstract:** A field experiment was conducted during *Rabi* season of 2015-16 at the Instructional *cum* Research Farm, IGKV, Raipur to study the effect of different irrigation scheduling and nitrogen levels on growth, yield attributes, yield, water and nitrogen productivity of linseed (*Linum usitatissimum* L.). The experiment was laid out in split plot design keeping four irrigation schedules *viz*., come-up ($I_1$), one ($I_2$), two ($I_3$) and three irrigation ($I_4$) in main plots and four levels of nitrogen *viz*., control ($N_0$), 30 kg ($N_1$), 60 kg ($N_2$) and 90 kg N ha$^{-1}$ ($N_3$) in sub plots with three replications. Results revealed that highest seed yield was obtained with linseed provided two irrigations (1683 kg ha$^{-1}$) and application of 90 kg N ha$^{-1}$ (1604 kg ha$^{-1}$). Moreover, crop supplied with two irrigations in combination with 90 kg N ha$^{-1}$ ($I_3$×$N_3$) gave significantly (P=0.05) highest seed yield (2097 kg ha$^{-1}$) compared to rest of the treatment combinations. The excessive use of irrigation and fertilizers also affects farmer's economy, as the crop is relatively low yielder. Two irrigations are better than three irrigations in terms of seed yield and water productivity; and application of 60 kg N is better than 90 kg N ha$^{-1}$ in view of nitrogen productivity. The WP and IWP were decreasing as increasing the number of irrigation, but increasing with increasing the levels of nitrogen, while NP was highest with two irrigations (11.09 kg, kg$^{-1}$ N) and application of 60 kg N ha$^{-1}$ (8.90 kg, kg$^{-1}$ N).

**Keywords:** Irrigation scheduling, Linseed, N levels, Nitrogen productivity, Water productivity

## INTRODUCTION

Linseed [*Linum usitatissimum* (L.)] is highly nutritious, unique and emerging among oilseeds for its technical grade vegetable oil and good quality fibre producing ability. Globally, among the oilseeds linseed or flax is one of the oldest oilseed crops grown widely in Asia, America and Europe for oil, fibre and seed purpose. India has fourth largest vegetable oil economy in the world after USA, China and Brazil. Oilseeds are the second largest agricultural commodity after cereals sharing 14 % of gross cropped area, 6 % of gross national product and 10 % of the agriculture product value in the country. The demand, supply and gap of edible oil in India are 18.94, 10.08 and 8.86 (47 %) million tons, respectively (Anonymous, 2015). Chhattisgarh has the third highest yield gap between improved technology and farmer's practice (Singh *et al*., 2015). Chhattisgarh is one of the important linseed growing states of India, where linseed is cultivated in about 0.026 million hectare area with a production of 0.011 million tones but its productivity is low in Chhattisgarh (423 kg ha$^{-1}$) as compared to national (498 kg ha$^{-1}$) and global (877 kg ha$^{-1}$) productivity (Anonymous, 2015). The major reason for low productivity of linseed may be due to adoption of primitive sowing method like *Utera* and perpetual scarcity of basic agro-inputs like irrigation, fertilizers etc.

In the background of shrinking water resources and competition from other sectors, the share of water allocated to irrigation is likely to decrease by 10 to 15 per cent in the next two decades. Efficient use of water is highly critical to sustain agricultural production, more particularly in the context of declining per capita land and water availability. Growing more crops per drop of water use is the key to mitigating the water crisis, and this is a big challenge to many countries, specially in India. Indian as well as Chhattisgarh government are giving more emphasis to grow oilseed and pulse crops in place of summer paddy on account of heavy water requirement. Increase in population and living standards has led to increase in demand of food and fibre which has also resulted in the adoption of irrigation to sustain plant growth (Delfine *et al*., 2000). Water stress is considered one of the most important factors limiting plant performance and yield in the world and impact on growth, leaf photosynthesis, seed and fibre yield of linseed (*Linum usitatissimum* L.) crop (Dutta *et al*., 1995). Increased water productivity (WP) of field crops was possible through proper irrigation scheduling by providing only the water that matches the crop evapotranspiration and providing irrigation at critical growth stages (Kar *et al*., 2007); and WP in agriculture is improved by increasing the crop water use efficiency (WUE) and reduction in water losses from the crop root zone. Managing linseed irrigation at the field scale can be improved by quantifying the water balance and using advanced techniques for irrigation scheduling for more effective and economic use of limited water supplies. The highly positive effect of irrigation on seed and fibre production confirms the key role of supplementary irrigation at critical growth stages, particularly sensitive to water stress. The scheduling of irrigation in linseed plays an important role in the growth and development of linseed crop; and to maximize yield, adequate soil moisture must be maintained during critical period. To improve crop yields, improvement in N productivity (NP) is desirable. Besides other agronomic factors nitrogen is major factor which determine the crop vigor and ultimately yield of linseed, especially when grown under irrigation. Optimum irrigation scheduling with suitable nitrogen level would help in enhancing the yield of linseed apart from higher water and nitrogen productivity in *rabi* planted linseed crop. The specific objective of present study is to find out the optimum schedule of irrigation and optimum dose of nitrogen, and its suitable combination for maximum production of linseed (*Linum usitatissimum* L.) crop.

## MATERIALS AND METHODS

**Experimental site:** A field experiment was conducted during *Rabi* season of 2015-16 at the Instructional *cum* Research Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur (21°4′ N latitude, 81°35′ E longitude and altitude 290.20 meter above mean sea level), Chhattisgarh, India. The soil of the experimental field was clayey in texture (20.45 % sand, 35.36 % silt, 44.19 % clay), neutral in pH (6.68), normal in EC (0.18) and had low in available N (226 kg ha$^{-1}$), medium in available P (12.64 kg ha$^{-1}$), high in available K (367 kg ha$^{-1}$) and low in organic carbon (0.48 %) contents. Before sowing, the soil possessed 29.47 % field capacity, 14.34 % permanent wilting point, 15.13 % available

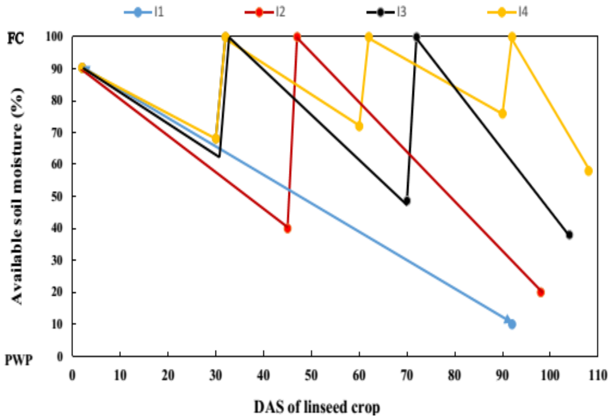


**Fig. 1.** *Moisture depletion pattern of linseed crop as influenced by irrigation scheduling.*

soil moisture and 1.33 g cc$^{-1}$ bulk density. During crop growing period, cumulative rainfall was 16.1 mm while average maximum and minimum temperature, morning and evening relative humidity, and sunshine of 30.7 $^0$C, 15.6 $^0$C, 82.8 %, 35.3 % and 6.5 hours, respectively.

**Treatments detail:** The experiment was laid out in split-plot design with three replications. The treatment consisted of four irrigation scheduling *viz.* come-up irrigation ($I_1$), one irrigation at maximum branching ($I_2$), two irrigations at branching and flowering stage ($I_3$) and three irrigations at branching, before flowering and capsule formation stage ($I_4$) in main plots; and four levels of nitrogen *viz.*, no nitrogen, 30 kg (RDN-50 %), 60 kg (RDN) and 90 kg N ha$^{-1}$ (RDN+50 %) denoted by $N_0$, $N_1$, $N_2$ and $N_3$ respectively, arranged in sub-plots. The come-up irrigation was given to the all treatments just after sowing for maintaining soil moisture to proper germination of linseed crop then irrigation was scheduled according to the treatments, based on available soil moisture content before each irrigation to field capacity. Soil moisture content of the plots was determined gravimetrically in the soil layers 0-15, 15-30, 30-45 and 45-60 cm. The amount of irrigation wa-

**Table 1.** Growth parameters of linseed crop as influenced by irrigation scheduling and levels of nitrogen.

| Treatment | Plant population (m$^2$) | | Plant height at harvest (cm) | Dry matter accumulation plant$^{-1}$ at harvest (g) | Branches plant$^{-1}$ at harvest | |
|---|---|---|---|---|---|---|
| | Initial (20 DAS) | At harvest | | | Primary | Secondary |
| **Irrigation scheduling** | | | | | | |
| $I_1$ - Come-up irrigation | 117.07 | 112.96 | 65.99$^d$ | 1.66$^d$ | 2.33$^d$ | 9.80$^d$ |
| $I_2$ - One irrigation | 115.17 | 102.34 | 81.63$^c$ | 2.53$^c$ | 3.10$^c$ | 15.40$^c$ |
| $I_3$ - Two irrigation | 114.09 | 100.93 | 89.67$^{ab}$ | 3.37$^a$ | 3.50$^a$ | 17.50$^a$ |
| $I_4$ - Three irrigation | 114.18 | 100.60 | 91.13$^a$ | 3.09$^{ab}$ | 3.43$^{ab}$ | 17.42$^{ab}$ |
| SEm± | 4.37 | 4.07 | 0.86 | 0.18 | 0.11 | 0.60 |
| CD (P=0.05) | NS | NS | 2.96 | 0.61 | 0.38 | 2.08 |
| **Levels of nitrogen** | | | | | | |
| $N_0$ - Control | 118.94 | 110.32 | 75.13$^d$ | 2.04$^d$ | 2.63$^d$ | 11.47$^d$ |
| $N_1$ - 30 kg ha$^{-1}$ | 113.34 | 101.14 | 79.26$^c$ | 2.38$^c$ | 3.03$^c$ | 14.15$^c$ |
| $N_2$ - 60 kg ha$^{-1}$ | 114.02 | 102.62 | 85.68$^{ab}$ | 3.05$^{ab}$ | 3.38$^a$ | 17.08$^{ab}$ |
| $N_3$ - 90 kg ha$^{-1}$ | 114.21 | 102.75 | 88.34$^a$ | 3.18$^a$ | 3.32$^{ab}$ | 17.42$^a$ |
| SEm± | 3.15 | 2.86 | 0.53 | 0.06 | 0.11 | 0.23 |
| CD (P=0.05) | NS | NS | 1.56 | 0.18 | 0.32 | 0.66 |

**Table 2.** Yield attributes and yield of linseed crop as influenced by irrigation scheduling and levels of nitrogen.

| Treatment | Capsules plant$^{-1}$ | | Capsule fertility (%) | Seeds capsule$^{-1}$ | Seeds plant$^{-1}$ | Test wt. | Seed yield (kg ha$^{-1}$) | Stover yield |
|---|---|---|---|---|---|---|---|---|
| | Filled | Un-filled | | | | | | |
| **Irrigation scheduling** | | | | | | | | |
| $I_1$- Come-up irrigation | 14.33$^{d}$ | 29.83 | 33.01$^{d}$ | 7.62 | 109.94$^{d}$ | 7.16 | 811$^{d}$ | 1788$^{d}$ |
| $I_2$ - One irrigation | 28.18$^{c}$ | 18.92 | 58.90$^{c}$ | 7.68 | 216.17$^{c}$ | 7.28 | 1367$^{c}$ | 3241$^{c}$ |
| $I_3$ - Two irrigation | 34.08$^{a}$ | 11.67 | 73.66$^{a}$ | 7.74 | 263.75$^{a}$ | 7.34 | 1683$^{a}$ | 3784$^{ab}$ |
| $I_4$ - Three irrigation | 32.30$^{b}$ | 18.22 | 63.42$^{b}$ | 7.71 | 249.44$^{b}$ | 7.31 | 1572$^{ab}$ | 3814$^{a}$ |
| SEm± | 0.49 | 0.28 | 0.39 | 0.03 | 3.92 | 0.09 | 37 | 91 |
| CD (P=0.05) | 1.70 | 0.98 | 1.34 | NS | 13.57 | NS | 129 | 317 |
| **Levels of nitrogen** | | | | | | | | |
| $N_0$ - Control | 19.08$^{d}$ | 23.43 | 46.16$^{d}$ | 7.65 | 146.15$^{d}$ | 7.22 | 1013$^{d}$ | 2240$^{d}$ |
| $N_1$ - 30 kg ha$^{-1}$ | 25.90$^{c}$ | 19.15 | 57.41$^{c}$ | 7.68 | 199.54$^{c}$ | 7.26 | 1270$^{c}$ | 2939$^{c}$ |
| $N_2$ - 60 kg ha$^{-1}$ | 31.68$^{ab}$ | 18.88 | 61.58$^{ab}$ | 7.70 | 244.39$^{ab}$ | 7.30 | 1547$^{ab}$ | 3673$^{ab}$ |
| $N_3$ - 90 kg ha$^{-1}$ | 32.32$^{a}$ | 17.17 | 63.83$^{a}$ | 7.71 | 249.22$^{a}$ | 7.32 | 1604$^{a}$ | 3774$^{a}$ |
| SEm± | 0.27 | 0.64 | 0.79 | 0.03 | 2.30 | 0.10 | 33 | 82 |
| CD (P=0.05) | 0.80 | 1.87 | 2.32 | NS | 6.72 | NS | 95 | 240 |

**Table 3.** Interaction effect of irrigation scheduling and levels of nitrogen on seed yield of Linseed (kg ha$^{-1}$).

| Treatment | Levels of nitrogen (N kg ha$^{-1}$) | | | | |
|---|---|---|---|---|---|
| | $N_0$–Control | $N_1$–30 | $N_2$–60 | $N_3$–90 | Mean |
| **Irrigation scheduling** | | | | | |
| $I_1$ - Come-up irrigation | 688 | 735 | 885 | 935 | 811 |
| $I_2$ - One irrigation | 996 | 1277 | 1586 | 1611 | 1367 |
| $I_3$ - Two irrigation | 1198 | 1552 | 1885 | 2097 | 1683 |
| $I_4$ - Three irrigation | 1169 | 1514 | 1831 | 1774 | 1572 |
| Mean | 1013 | 1270 | 1547 | 1604 | |
| | | | | SEm± | CD (P=0.05) |
| Levels of nitrogen at same irrigation scheduling | | | | 65 | 190 |
| Irrigation scheduling at same or different levels of nitrogen | | | | 68 | 208 |

ter was calculated using the following formulae.

Gross irrigation requirement (mm) = Net irrigation requirement (mm)/ Field efficiency

Net irrigation requirement (mm) = 100 – [(FC-PWP) × BD × ρ × 10/100]

Where, FC, PWP and BD are field capacity, permanent wilting point and bulk density of the soil, respectively.

ρ = Soil moisture fraction on gravimetric basis or allowable depletion level

In control plot there was no use of nitrogen but, the main plot of come-up irrigation the whole amount of N was applied as basal dressing at the time of sowing and in the main plot of one irrigation at maximum branching, the half dose of nitrogen was applied as basal dressing at the time of sowing, while remaining half nitrogen was top dressed during irrigation. In the main plot of two and three irrigations, the half dose of nitrogen was applied as basal dressing at the time of sowing, while remaining half nitrogen was top dressed in two equal splits during first and second irrigation.

**Crop management:** Linseed (cv: *RLC-92*) was planted on 21$^{st}$ November, 2015 with the seed rate of 25 kg ha$^{-1}$. After that recommended dose of $P_2O_5$ and $K_2O$ (30:30 kg ha$^{-1}$) were applied as basal dressing to all sub-plots treatments. The crop was harvested on 20$^{th}$ February to 08$^{th}$ March, 2016 at physiological maturity. All the recommended agronomic management practices were followed except for the treatments.

**Statistical analysis:** Standard procedures were adopted for recording the data on various growth and yield parameters. Data collected were statistically analyzed by using the procedure suggested by the Gomez and Gomez (1984). The differences among treatments were compared by applying 'F' test of significance at 5 per cent level of probability.

**Computation of water and nitrogen productivity (WP and NP):** Water productivity [WP (kg mm$^{-1}$)] was calculated by the dividing the linseed yield by the total water used (sum of applied water and effective rainfall), whereas, irrigation water productivity [IWP (kg mm$^{-1}$)] was calculated by the dividing the linseed yield by the irrigation water used. Nitrogen productivity [NP (seed yield kg ha$^{-1}$ per kg N ha$^{-1}$ applied)] or agronomic efficiency (AE) is the economic yield per unit of N applied are calculated by following formula used by Siqua *et al.* (2013):

NP (kg, kg$^{-1}$ N) = Seed yield in fertilized plot (kg ha$^{-1}$) - Seed yield in control plot (kg ha$^{-1}$) / N applied (kg ha$^{-1}$)

## RESULTS AND DISCUSSION

**Growth parameters**: Data presented in Table 1 showed that, non-significant (P=0.05) difference was observed on plant population at initial and harvest stage. This indicates that each treatment had no significant influence on emergence of the seeds from the soil and survival rates of the seedlings. Similarly, Gudeta (2015) reported that the number of plants meter$^{-2}$ was unaffected by the different rates of both nitrogen and sulphur as well as by their interaction in linseed

**Table 4.** Seasonal irrigation water quantities, saving and productivities of linseed crop as influenced by irrigation scheduling and levels of nitrogen.

| Treatment | Effective rainfall (mm) | Come-up irrigation (mm) | Irrigation requirement (mm) | Total water use (mm) | Irrigation water saving (%) | Water productivity (kg mm$^{-1}$) | Irrigation water productivity (kg mm$^{-1}$) | Nitrogen productivity (kg, kg$^{-1}$ N) |
|---|---|---|---|---|---|---|---|---|
| **Irrigation scheduling** | | | | | | | | |
| $I_1$ - Come-up irrigation | 14.2 | 50 | - | 64.20 | 100.00 | 12.63$^a$ | - | 2.54$^d$ |
| $I_2$ – One irrigation | 14.2 | 50 | 74.01 | 138.21 | 59.81 | 9.89$^b$ | 18.48$^a$ | 8.68$^{abc}$ |
| $I_3$ - Two irrigation | 14.2 | 50 | 133.16 | 197.36 | 27.69 | 8.53$^c$ | 12.64$^b$ | 11.09$^a$ |
| $I_4$ - Three irrigation | 14.2 | 50 | 184.14 | 248.34 | - | 6.33$^d$ | 8.54$^c$ | 9.78$^{ab}$ |
| | - | - | - | - | - | 0.33 | 0.43 | 1.29 |
| | - | - | - | - | - | 1.15 | 1.68 | 4.45 |
| **Levels of nitrogen** | | | | | | | | |
| $N_0$ - Control | 14.2 | 50 | 97.83 | 162.03 | - | 7.17$^d$ | 9.60$^d$ | - |
| $N_1$ – 30 kg N ha$^{-1}$ | 14.2 | 50 | 97.83 | 162.03 | - | 8.66$^c$ | 12.38$^c$ | 8.57$^{ab}$ |
| $N_2$ - 60 kg N ha$^{-1}$ | 14.2 | 50 | 97.83 | 162.03 | - | 10.55$^{ab}$ | 15.18$^{ab}$ | 8.90$^a$ |
| $N_3$ - 90 kg N ha$^{-1}$ | 14.2 | 50 | 97.83 | 162.03 | - | 11.00$^a$ | 15.71$^a$ | 6.57$^b$ |
| | - | - | - | - | - | 0.22 | 0.33 | 0.71 |
| | - | - | - | - | - | 0.64 | 0.97 | 2.13 |

**Table 5.** Correlation coefficients of seed yield of linseed with respect to growth parameter, yield attributes, water and nitrogen use.

| | SY | PH | NPB | NSB | DMA | NFC | NUFC | NSC | NSP | TSW | TWU |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PH | 0.971** | | | | | | | | | | |
| NPB | 0.943** | 0.954** | | | | | | | | | |
| NSB | 0.987** | 0.921** | 0.932** | | | | | | | | |
| DMA | 0.976** | 0.954** | 0.877** | 0.957** | | | | | | | |
| NFC | 0.992** | 0.996** | 0.937** | 0.987** | 0.956** | | | | | | |
| NUFC | -0.850** | -0.847** | -0.863** | -0.815** | -0.799** | -0.826** | | | | | |
| NSC | 0.526* | 0.524* | 0.549* | 0.515* | 0.469* | 0.466$^{NS}$ | -0.699** | | | | |
| NSP | 0.993** | 0.963** | 0.939** | 0.988** | 0.957** | 1.000** | -0.831** | 0.483$^{NS}$ | | | |
| TSW | 0.793** | 0.754** | 0.832** | 0.797** | 0.783** | 0.797** | -0.732** | 0.691** | 0.791** | | |
| TWU | 0.720** | 0.836** | 0.764** | 0.712** | 0.695** | 0.714** | -0.716** | 0.467$^{NS}$ | 0.718** | 0.630** | |
| TNU | 0.545* | 0.449$^{NS}$ | 0.477$^{NS}$ | 0.570* | 0.536* | 0.522* | -0.303$^{NS}$ | 0.308$^{NS}$ | 0.522* | 0.423$^{NS}$ | -0.000$^{NS}$ |

Where: SY= Seed yield; PH= Plant height; NPB= No. of primary branches per plant; NSB= No. of secondary branches per plant; DMA= Dry matter accumulation per plant; NFC= No. of filled capsules per plant; NUFC= No. of un-filled capsules per plant; NSC= No. of seeds per capsules; NSP= No. of seeds per plant; TSW= Thousand seed weight (g); TWU= Total water use; TNU= Total nitrogen use, *, ** *indicates significant at 5 % and 1 % probability level respectively*

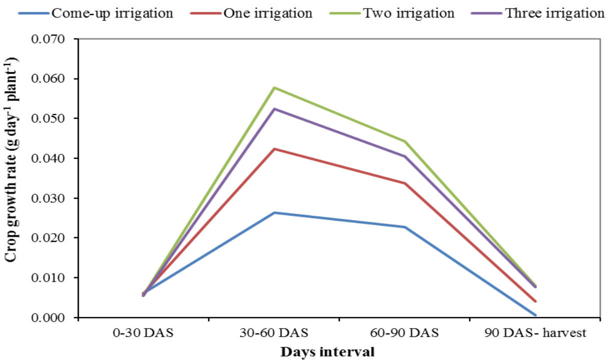


**Fig. 2 a.** *Crop growth rate (g day$^{-1}$ plant$^{-1}$) at various stages of linseed as influenced by irrigation scheduling.*

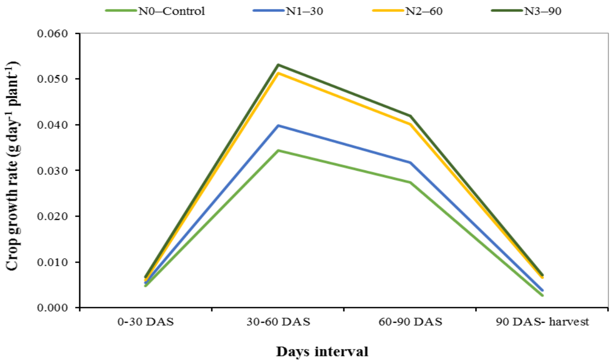


**Fig. 2 b.** *Crop growth rate (g day$^{-1}$ plant$^{-1}$) at various stages of linseed as influenced by levels of nitrogen.*

(*Linum usitatissimum* L.) crop at Ethiopia. The tallest plant (91.13 cm) was observed with the application of three irrigation ($I_4$), however application of two irrigation ($I_3$) was observed statistically (P=0.05) at par with the same irrigation level. The significantly (P=0.05) highest dry matter accumulation (3.37 g), primary (3.50) and secondary branches (17.50) plant$^{-1}$ were recorded with two irrigation ($I_3$), however, application of three irrigation ($I_4$) was observed statistically at par with the same treatment. The higher value might be due to availability of soil moisture as well as nutrients during crop growth and high water retention in the root zone (Fig. 1). Similar results were reported by Istanbulluoglu *et al.* (2015) in linseed (*Linum usitatissimum* L.) crop at Turkey. With respect to levels of nitrogen, use of 90 ($N_3$) and 60 kg N ha$^{-1}$ ($N_2$), were equally effective and obtained significantly (P=0.05) taller plant (88.34 and 85.68 cm), dry matter accumulation (3.18 and 3.05 g), primary (3.32 and 3.38) and secondary branches plant$^{-1}$ (17.42 and 17.08), respectively, while significantly lowest value of above growth parameters was observed with no nitrogen ($N_0$). Nitrogen is an essential element for flax growth to build up protoplasm and protein structure which induce cell division, meristematic activity and further increased cell number and size with an overall growth in flax growth, consequently more fibre and seed production. The increment in the growth parameters might be due to increased availability of nitrogen and other nutrients which enhanced production of photosynthetic assimilates from increased photosynthetic rate. Similarly, Khajani *et al.* (2012) reported that the number of branches plant$^{-1}$ was increased significantly with increase in N levels in linseed (*Linum usitatissimum* L.) crop at Tehran, Iran; and Gudeta (2015) reported that the plant height and number of branches plant$^{-1}$ were increased significantly (P<0.01) with increase in N levels from 0 to 69$^{-1}$ kg ha in linseed (*Linum usitatissimum* L.) crop at Turkey.

**Crop growth rate (g day$^{-1}$ plant$^{-1}$):** Crop growth represents the net result of photosynthesis, respiration and canopy area interception. The data on CGR of linseed computed for the period of 0-30, 30-60, 60-90 and 90 DAS-harvest stages are depicted in Fig. 2 a and b. It is obvious from the data that crop growth of linseed increased considerably up to 30-60 DAS, thereafter decreased steadily up to physiological maturity of the crop which might be senescence of leaf. As indicated in Fig. 2 a, Crop provided with two irrigations ($I_3$) registered the maximum crop growth rate of 0.058, 0.044 and 0.008 g day$^{-1}$ plant$^{-1}$ at 30-60, 60-90 DAS and 90 DAS-harvest periods, respectively being greater than $I_1$, $I_2$ and $I_4$ schedules of irrigation. Fig. 2 b depicts that the application of nitrogen enhanced the crop growth rate in all the periods of observation. However, maximum crop growth rate of 0.53 and 0.042 g day$^{-1}$ plant$^{-1}$ was observed with the application of 90 kg N ha$^{-1}$ ($N_3$) at 30-60 and 60-90 DAS, respectively being greater than $N_0$, $N_1$ and $N_2$. Likewise, Gabiana *et al.* (2005) also pointed out that irrigated linseed produced maximum growth rate being 31 % higher compared to un-irrigation crop at Canterbury, which confirm the result of present experiment.

**Yield parameters:** Two irrigation ($I_3$) recorded the significantly (P=0.05) highest filled capsules (34.08) and lesser un-filled capsules plant$^{-1}$ (11.67) which resulted higher capsule fertility % (73.66) and number of seeds plant$^{-1}$ (263.75) over rest of the irrigation scheduling, while significantly (P=0.05) inferior value of above yield attributes were observed with come-up irrigation ($I_1$). The data presented in Table 2, reported that by giving two irrigation ($I_3$) the number of filled capsules plant$^{-1}$, number of seeds plant$^{-1}$ and capsule fertility % increased by about 137, 140 and 123 %, respectively, while number of un-filled capsules plant$^{-1}$ decreased by 156 % from come-up irrigation ($I_1$). However, number of seeds capsule$^{-1}$ and test weight were observed non-significant (P=0.05) difference. These results are in line with the findings of Mirshekari *et al.* (2012) at Iran and Istanbulluoglu *et al.* (2015) at Turkey both in linseed (*Linum usitatissimum* L.) crop. With respect to levels of nitrogen, application of 90 kg N ha$^{-1}$ ($N_3$) recorded the significantly (P=0.05) superior number of filled and un-filled capsules plant$^{-1}$; number of seeds plant$^{-1}$ and capsule fertility % over rest of the levels of nitrogen, but statistical-

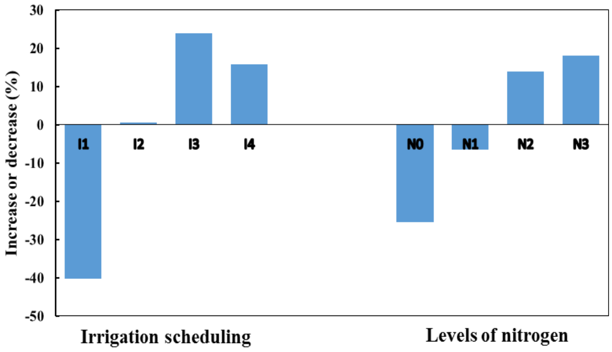


**Fig. 3.** *Percentage increase or decrease over mean yield of linseed as influenced by irrigation scheduling and levels of nitrogen.*

ly on par with application of 60 kg N ha$^{-1}$ ($N_2$), while significantly (P=0.05) inferior value of above yield attributes was found with no nitrogen ($N_0$). These results concur the findings reported by Rahimi *et al.* (2011) and Khajani *et al.* (2012) both in linseed (*Linum usitatissimum* L.) crop at Iran. The increments might be due to increased availability of soil moisture as well as nutrients during crop growth and high dry matter accumulation plant$^{-1}$.

**Seed yield:** The seed yield, the ultimate result of various interacting growth factors and yield contributing character, influenced significantly due to irrigation scheduling and levels of nitrogen (Table 2). Highest seed yield (1683 kg ha$^{-1}$) was harvested from two irrigation ($I_3$), however, three irrigation ($I_4$) was found at par (P=0.05), while the lowest seed yield (811 kg ha$^{-1}$) was harvested from come-up irrigation ($I_1$). The data reported that by giving one ($I_2$) and two irrigation ($I_3$) the seed yield increased by about 69 and 108 %, respectively from come-up irrigation ($I_1$), while giving three irrigation ($I_4$) seed yield would be decreased by 7 % as compare to two irrigation ($I_3$). Fig. 3 revealed that, the application of come-up irrigation ($I_1$) gave 40 % less seed yield and one irrigation ($I_2$) gave equal seed yield compare to mean seed yield (1358 kg ha$^{-1}$), while with the application of two ($I_3$) and three irrigation ($I_4$) produced 24 and 17 % higher seed yield, respectively. The higher seed yield with the application of linseed in two irrigations might be due to higher dry matter accumulation, number of filled capsule and number of seeds plant$^{-1}$. Similar results were reported by Istanbulluoglu *et al.* (2015) at Turkey in linseed (*Linum usitatissimum* L.) crop. As regards to levels of nitrogen, the statistically (P=0.05) highest seed yield (1604 kg ha$^{-1}$) was observed with the application of 90 kg N ha$^{-1}$ ($N_3$) followed by 60 kg N ha$^{-1}$ (1547 kg ha$^{-1}$) and the lowest seed yield (1013 kg ha$^{-1}$) was harvested from no nitrogen ($N_0$). The enhancement of seed yield from use of 60 to 90 kg N ha$^{-1}$ was not significant due to increased nitrogen application resulting in increased crop nitrogen use without corresponding increase in yield. The data presented in Table 2, exhibited that increasing the levels of nitrogen from zero to 30 and 60 kg ha$^{-1}$, the seed yield was sharply increased by 25 and 53 % respectively. The no nitrogen ($N_0$) and the application of 30 kg N ha$^{-1}$ ($N_1$) treatments gave 25 and 7 % less seed yield, respectively compare to mean seed yield (1358 kg ha$^{-1}$), while 60 kg N ($N_2$) and 90 kg N ha$^{-1}$ ($N_3$) resulted in 14 and 18 % higher seed yields in respective treatments (Fig. 3). The higher seed yield of linseed was observed with the application of 90 kg N ha$^{-1}$ that might be due to higher dry matter accumulation, number of filled capsule and number of seeds plant$^{-1}$. Similar results in linseed (*Linum usitatissimum* L.) crop were reported by Rahimi *et al.* (2011) at Iran, Khajani *et al.* (2012) at Iran and Gudeta (2015) at Ethiopia.

**Interaction analysis of seed yield:** The interaction between irrigation scheduling and levels of nitrogen had significant (P=0.05) effect on seed yield of linseed (Table 3). The average seed yield varied from 688 to 2097 kg ha$^{-1}$. Treatment received two irrigations when combined with 90 kg N ha$^{-1}$ ($I_3 \times N_3$) gave significantly (P=0.05) highest seed yield (2097 kg ha$^{-1}$) over other treatment combinations. The next best treatment combinations were observed with the application of two irrigations with 60 kg N ha$^{-1}$ ($I_3 \times N_2$) and three irrigations with 60 kg N ha$^{-1}$ ($I_4 \times N_2$) *i.e.* 1885 and 1831 kg ha$^{-1}$ respectively, both being significantly (P=0.05) higher from rest of the treatment combinations except three irrigations with 90 kg N ha$^{-1}$ ($I_4 \times N_3$). Linseed grew with only come-up irrigation without nitrogen ($I_1 \times N_0$) produced lesser seed yield (688 kg ha$^{-1}$). The data clearly reported that the seed yield obtained more than three times (309 %) by the use of suitable combination of irrigation scheduling and levels of nitrogen. Similar results were reported by Katole and Sharma (1990) at Rajasthan, India in linseed (*Linum usitatissimum* L.) crop.

**Correlation analysis:** Considering the possibility of high yield through growth and yield attributes, as primary interest in crop production, therefore, requires understanding the amount of the magnitude of correlations among various growth and yield traits. The correlation coefficients of seed yield with plant height, number of primary and secondary branches plant$^{-1}$; dry matter accumulation plant$^{-1}$, filled capsules plant$^{-1}$, seeds plant$^{-1}$ and 1000 seeds weight by linseed were highly significant at 1 % level of significance and; number of seeds capsule$^{-1}$ and water use were significant at 5 % level of significance (Table 5). All the characters, except number of un-filled capsules plant$^{-1}$ showed positive associations, whereas, the number of un-filled capsules plant$^{-1}$ was negatively associated with seed yield. These findings are similar to Mirshekari *et al.* (2012) at Iran in linseed (*Linum usitatissimum* L.) crop.

**Water and nitrogen productivity:** The highest water utilized by three irrigation ($I_4$) and lowest water utilized by come-up irrigation ($I_1$), however, WP tended to decrease with the increase in number of irrigation and maximum WP (12.63 kg $mm^{-1}$) was recorded with the crop grew with only come up irrigation ($I_1$) and the lowest WP (6.33 kg $mm^{-1}$) was recorded from the application of three irrigation ($I_4$). As for the IWP, the significantly (P=0.05) highest (18.48 kg $mm^{-1}$) and lowest (8.54 kg $mm^{-1}$) were recorded in one ($I_2$) and three irrigation ($I_4$), respectively. The decrease in WP could be attributed to the fact that the increase in yield was not in proportion to the increase in consumptive use of water. Similar results were reported by Kar *et al*. (2007) at Bhubaneshwar, India in linseed (*Linum usitatissimum* L.) crop. The highest NP (11.09 kg, $kg^{-1}$ N) was obtained from two irrigation ($I_3$), while the lowest NP (2.54 kg, $kg^{-1}$ N) was observed from come-up irrigation ($I_1$). The biggest saving in irrigation water (59.81 %) was obtained in the treatment irrigated once ($I_2$), while the lowest (27.69) irrigated with twice ($I_3$). The WP, IWP, irrigation water saving and NP were increased by 35, 48, 28 and 13 %, respectively, when applied two irrigation ($I_3$) over three irrigation ($I_4$) in linseed. As regards to levels of nitrogen, increasing N levels improved WP and IWP. The highest WP and IWP (11.00 and 15.71 kg $mm^{-1}$, respectively) were obtained with the application of 90 kg N $ha^{-1}$ ($N_3$), while the lowest WP and IWP (7.17 and 9.60 kg $mm^{-1}$, respectively) were obtained from no nitrogen ($N_0$). As for the NP, the highest (8.90 kg, $kg^{-1}$ N) and lowest (6.57 kg, $kg^{-1}$ N) were recorded with the application of 60 ($N_2$) and 90 kg N $ha^{-1}$ ($N_3$), respectively. The higher dose of nitrogen (more than 60 kg $ha^{-1}$) showed less efficient utilization of nitrogen by crop may be due to comparatively more loss of nitrogen in the soil. The WP and IWP were increased by 53 and 64 % respectively, when applied 90 kg N $ha^{-1}$ ($N_3$) over control (no nitrogen), while NP was increased by 35 %, when applied 60 kg N $ha^{-1}$ ($N_2$) over 90 kg N $ha^{-1}$ ($N_3$) in linseed. Similar results were reported by Awasthi *et al.* (2011) at Kanpur, India in linseed (*Linum usitatissimum* L.) crop.

The present study mainly focused on identifying appropriate and economically optimum schedules of irrigation and nitrogen fertilizers for yield and profit maximization of linseed and standardized the Chhattisgarh farmers in India. Timely irrigation at the moisture sensitive stages of the crop and application of N fertilizer at optimum levels becoming obvious, as soil moisture and soil fertility has declined from time to time. Excessive use of irrigation and fertilizers also affects farmer's economy, as the crop is relatively low yielder. The number of branches, dry matter accumulation, number of filled capsules and seeds $plant^{-1}$ were most important growth and yield contributing component in linseed. As these parameters increases, the yield was increased. In present studies provide a clear picture about two irrigations are better than three irrigations in terms of seed yield and water productivity; and application of 60 kg N is better than 90 kg N $ha^{-1}$ in view of nitrogen productivity. The double linseed yield obtained by proper irrigation scheduling, 58 % more yield by optimum use of nitrogen and three times by the use of suitable combination of irrigation scheduling and levels of nitrogen.

## Conclusion

Based on the above findings it was concluded that the application of two irrigation ($I_3$) produced higher value of important growth, yield attributes and seed yield of linseed (1683 kg $ha^{-1}$). Among different levels of nitrogen, application of 90 kg N $ha^{-1}$ ($N_3$) was produced higher value of important growth, yield attributes and seed yield of linseed (1604 kg $ha^{-1}$). The WP and IWP were decreasing as increasing the number of irrigation, but increasing with increasing the levels of nitrogen, while NP was highest (11.09 and 8.90 kg, $kg^{-1}$ N) with the application of two irrigation ($I_3$) and 60 kg N $ha^{-1}$ ($N_2$), respectively. The interaction between irrigation scheduling and levels of nitrogen, the combination of two irrigations ($I_3$) × 90 kg N $ha^{-1}$ ($N_3$) was recorded significantly higher seed yield (2097 kg $ha^{-1}$). Excessive use of irrigation and fertilizers also affects farmer's economy, as the crop is relatively low yielder. Two irrigations are better than three irrigations in terms of seed yield and water productivity; and application of 60 kg N is better than 90 kg N $ha^{-1}$ in view of nitrogen productivity. The double linseed yield obtained by proper irrigation scheduling, 58 % more yield by optimum use of nitrogen and three times by the use of suitable combination of irrigation scheduling and levels of nitrogen.

## ACKNOWLEDGEMENTS

The authors acknowledge the support and guidance received by Indira Gandhi Krishi Vishwavidyalaya, Raipur and Director, Department of Agriculture, Govt. of C.G. during the course of this investigation.

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