Received: 17 September 2024 | Accepted: 6 November 2024 | Published online: 9 November 2024
DOI: 10.59797/ijsc.v52.i2.159

ORIGINAL ARTICLE
Indian Journal of Soil Conservation

Effect of different tillage regimes and mulching practices on crop yields and water use efficiency of linseed (*Linum usitatissimum*) in South Gujarat conditions

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Handling Editor :
Dr Rakesh Kumar

ABSTRACT

The productivity of linseed (*Linum usitatissimum*) can be significantly enhanced by adopting appropriate natural resource management technologies. However, there is limited research on conservation-based management practices specifically for linseed. This study, therefore, aimed to identify suitable conservation agricultural management practices that improve both crop yield and water use efficiency in linseed cultivation. The present research was conducted in Navsari district, Gujarat, within Agro-climatic Zone - 3 (South Gujarat Heavy Rainfall Zone - I) over three consecutive winter seasons from 2019-2022. Eight treatments involving the combinations of different conservation tillage practices were evaluated using a randomized block design with three replications. The results demonstrated that the maximum yield attributes were recorded under CT + RSM + SGM treatment [conventional tillage + rice straw mulching + sunn hemp (*Crotalaria juncea*) green manuring during the preceding *kharif* season)]. Except for the first year, this treatment was statistically superior to both reduced tillage (RT) and conventional tillage (CT). Similarly, maximum grain and stalk yields were recorded under the treatment CT + RSM + SGM, followed by CT + SGM [conventional tillage + sunn hemp green manuring (during preceding *kharif* season)] and RT + RSM + SGM [reduced tillage + rice straw mulching + sunn hemp green manuring (during preceding *kharif* season)]. Water use efficiency (WUE) was also significantly improved under CT + RSM + SGM treatment. Based on these findings, it is recommended that linseed growers adopt the conventional tillage combined with rice straw mulching and sunn hemp green manuring during preceding *kharif* as an effective tillage and mulching strategy to enhance the crop performance and WUE.

Key words:
Conventional tillage
Reduced tillage
Straw mulching
Soil moisture depletion
Yield

HIGHLIGHTS

- Conventional tillage combined with paddy straw mulching and sunn hemp green manuring during the preceding *kharif* season helps improve linseed yield.
- Conservation agricultural management practices applied in conventional and reduced tillage control soil moisture depletion and improve WUE.
- Green manuring during *kharif*, followed by paddy straw mulching for linseed cultivation, is recommended for the black soil region.

1 | INTRODUCTION

Linseed (*Linum usitatissimum* L.) is a highly nutritious and emerging oilseed crop known for producing high-quality vegetable oil and fibre. It is an excellent vegetarian source of Omega - 3 essential fatty acids, particularly Alpha-Linolenic Acid (ALA), containing twice the amount found in fish oil (Sarkar and Sarkar, 2017). Globally, linseed or flax is one of the oldest oilseed crops, widely cultivated across Asia, America, and Europe for oil, fibre, and seed production. India ranks as the fourth-largest vegetable oil producer in the world, following the USA, China, and Brazil. The demand for edible oils is continuously rising in India due to population growth and improved living standards. Linseed is a major winter (*rabi*) oilseed crop in India, after rapeseed mustard. It is a valuable source of complete protein, high levels of linolenic acid, carbohydrates, vitamins, and minerals, and is cultivated for both seed and fibre production.

Conservation agriculture (CA) is practised on ~ 125 million hectares globally (Kiboi *et al.*, 2017). CA-based management practices have enhanced crop yields and net returns, improved soil fertility and biodiversity, increased WUE, and mitigated greenhouse gas emissions (Giller *et al.,* 2015). Additionally, CA also reduces pests and diseases by integrating crop rotations, which disrupts disease cycles that affect crops (Mourtzinis *et al.,* 2017). The area under CA represents 12.5% of global total cropland, with distribution nearly equal between industrialized regions (52%) and developing regions (48%) (Kassam *et al.,* 2018).

Tillage involves mechanical manipulation of the soil to enhance conditions for crop production. It contributes up to 20% to crop productivity among various production factors (Ali *et al.*, 2017). Proper tillage can alleviate the soil-related constraints, whereas improper tillage can lead to adverse effects such as soil structure degradation, accelerated erosion, depletion of organic matter and fertility, and disruption of water, organic carbon, and nutrient cycles. Conservation tillage is a practice in which at least 30% of the soil surface is covered by plant residues (Ali *et al.*, 2017). In recent years, reduced tillage has become widely adopted globally to control soil erosion and maintain soil fertility. Rani *et al.* (2019) also reported that soils under reduced tillage exhibit higher aggregate stability and water infiltration rates than those under plough tillage. However, limited data on linseed performance under reduced tillage systems are available.

Mulching enhances water productivity and crop yield by increasing water retention. It extends the moisture availability period, reduces water evaporation losses, and helps maintain soil temperature. Upon degradation, organic mulches contribute organic matter to the soil, improving its nutrient status. Mulching impacts crop growth and yield directly by supplying essential nutrients and indirectly by improving the soil physical properties such as aggregate stability and porosity, which enhance soil quality and stimulate plant growth (Kiboi *et al.*, 2017). Rice straw mulch is a protective layer of organic material applied to the soil surface. It helps reduce moisture loss by minimizing evaporation, decreasing plant water loss, suppressing weed growth, improving soil conditions, and providing habitat for earthworms and soil-dwelling natural enemies.

Despite these benefits, limited information exists on the impact of various CA management practices on the yield and water use efficiency of linseed. Therefore, there is a pressing need to identify and implement effective conservation agricultural-based management practices to enhance both the production and water productivity of linseed crops.

2 | MATERIALS AND METHODS

The present experiment carried out at the Engineering farm, Navsari Agricultural University, Navsari, Gujarat, India, comes under Agroclimatic zone - 3 (20º55'41.38" N and 72º 53'41.18"E), South Gujrat Heavy Rainfall Zone-I) during three consecutive winter seasons, 2019-20 to 2021-22. Soils of this region are heavy textured (clay content 58%) with good water holding capacity, non-saline (EC 0.28 dS/m), pH 7.5 (1: 2.5 soil water) and high inorganic carbon (0.77%), available phosphorus (60.52 kg/ha), available potassium (495.52 kg/ha) and medium in available nitrogen (266.8 kg/ha). The experiment consisted of eight treatment combinations of different conservation tillage practices: CT-conventional tillage (Two ploughing followed by laddering); RT - Reduced tillage (One ploughing followed by laddering); CT + RSM - Conventional tillage + Rice straw mulching (dose in t/ha); RT + RSM - Reduced tillage + Rice straw mulching; CT + SGM - Conventional tillage + sunn hemp green manuring (during preceding *kharif* season); RT + SGM - Reduced tillage + sunn hemp green manuring (during preceding *kharif* season); CT + RSM + SGM - Conventional tillage + Rice straw mulching + sunn hemp green manuring (during preceding *kharif* season) and RT + RSM + SGM - Reduced tillage + Rice straw mulching + sunn hemp green manuring (during preceding *kharif* season). The experiment was replicated three times under a randomized block design. The linseed (local variety) sowing was done with the recommended seed rate (20 kg/ha) during the last fortnight of October. The experimental plot size was 25 m^2, and crop spacing was maintained at 30 cm × 10 cm (Kalal *et al.,* 2023). The recommended doses of fertilizer were used N:P:K: 40:20:45, 50% N, 100% P and K as basal and the remaining 50% N was used after 45 DAS. All other cultivation practices were similar for all the treatments. Two irrigations were applied as per the crop water requirement during all seasons. Five plants per plot were selected to measure growth parameters and yield attributes. Crop yield was recorded after harvest, and data were converted to obtain productivity for a one-hectare land area.

The gravimetric method took the soil samples for moisture content determination at 15 and 30 cm depth (Tripathi *et al.,* 2018). Measurements were taken 30 days after sowing during the growth period. Soil moisture content (SMC in %) was calculated using the equation below (Sharma *et al.,* 2015).

$$SMC(\%) = \frac{Weight\ of\ wet\ soil - Weight\ of\ dry\ soil}{Weight\ of\ dry\ soil} \times 100 \quad ...(1)$$

Irrigation water was applied using the surface irrigation method. The amount of water applied in different treatments was measured using a Parshall flume. The total water used during the cropping season was calculated, and water use efficiency was then calculated by dividing the grain yield (kg/ha) by the total amount of water (mm) applied in the field (Kumari *et al.,* 2018). The rainfall was received 37.05, 38.96 and 76.99 mm during 2019-20, 2020-21 and 2021-22, respectively. Rainfall + irrigation should be used as the total amount of water applied.

$$WUE = \frac{Grain\ yield}{Total\ amount\ of\ water\ applied\ in\ the\ field} \quad ...(2)$$

The data gathered in each observation were statistically evaluated using the analysis of variance technique suggested by Gomez and Gomez (1984). A critical difference (CD) was computed to assess the significance of treatment means at the 5% level of probability.

3 | RESULT AND DISCUSSION

3.1 | Growth Attributes

The growth parameters of linseed (plant height and number of branches per plant) were significantly influenced by the various conservation practices, except for the first year (Table 1). The treatment CT + RSM + SGM significantly enhanced these growth attributes compared to CT and RT. Throughout the study, treatment RT consistently resulted in the lowest plant height and number of branches per plant, although both parameters showed improving trends over time. In contrast, CT demonstrated consistent trends across the years. Anjum *et al.* (2014) similarly observed higher plant growth under conventional tillage compared to reduced tillage in maize. The enhanced plant growth was attributed to greater soil moisture retention throughout the growth period, coupled with lower soil temperatures. The increase in plant growth with more intensive tillage may be due to improved nutrient uptake and moisture availability by the plants.

3.2 | Yield Attributes

Different conservation practices significantly influenced the number of capsules per plant in linseed, except during the first year. In contrast, these practices non-significantly affected 1000-grain weight (test weight) and harvest index (Table 1). CT + RSM + SGM markedly increased the number of capsules per plant compared to CT and RT. The lowest number of capsules per plant was consistently observed under RT throughout the study, though its performance showed potential for improvement over time. CT, however, exhibited stable trends across all years of the study. The lowest yield attributes under reduced tillage may be attributed to increased soil bulk density, which negatively impacted root growth. In contrast, conventional tillage treatments likely enhanced water and nutrient availability by improving moisture movement through the soil profile, thereby facilitating nutrient uptake in the rhizosphere and promoting better plant growth and performance. These findings align with Shahid *et al.* (2016), who reported a significant effect of tillage on yield attributes like the number of rows per cob, with conventional tillage resulting in 15.40 rows compared to 13.90 rows under the minimum tillage.

3.3 | Crop yields

Significant variations in linseed grain and stalk yield were observed across the different conservation practices, except in the first year. The highest grain yield was recorded under the treatment CT + RSM + SGM, which was significantly greater than that of CT, RT, CT + RSM and RT + RSM during the second and third years of the experiment (Table 2). The lowest grain yield was consistently observed under RT across all years. Experimental plots treated with paddy straw mulching (CT + RSM, RT + RSM, CT + RSM + SGM and RT + RSM + SGM) produced higher grain yields compared to non-mulched treatments (CT, RT, CT + SGM and RT + SGM). Similarly, stalk yield was significantly higher under CT + RSM + SGM than CT, RT, CT + RSM and RT + RSM, with the lowest stalk yield recorded under RT. Mourtzinis *et al.* (2017) reported a 16% increase in maize grain yield under conventional tillage compared to reduced tillage systems.

3.4 | Soil moisture depletion and Water use efficiency (WUE)

After the first irrigation, year-wise soil moisture content was recorded as 19.2%, 21.2%, and 20.2% during the first,

TABLE 1 Effect of different conservation practices on growth and yield attributes of linseed

Treatment	Plant height at harvest (cm)			No. of branches plant^{-1}			No. of capsules plant^{-1}			Test weight (g)		
	1styear	2nd year	3rd year	1styear	2nd year	3rd year	1styear	2nd year	3rd year	1styear	2nd year	3rd year
CT	59.9	58.9	57.6	6.5	6.6	6.6	49.9	49.097	50.1	6.6	6.5	6.4
RT	57.2	57.4	57.6	6.2	6.4	6.3	47.0	47.1	49.1	6.4	6.6	6.4
CT + RSM	61.1	62.5	62.6	7.1	7.9	7.9	51.3	52.0	53.3	6.8	6.7	6.6
RT + RSM	60.4	62.3	62.4	6.8	8.0	8.2	49.3	51.4	53.1	6.6	6.8	6.6
CT + SGM	61.1	65.8	67.4	6.8	8.5	8.6	50.9	53.7	54.3	6.8	6.9	6.7
RT + SGM	60.2	65.2	66.6	6.4	8.3	8.5	49.0	52.1	53.7	6.7	70	6.7
CT + RSM + SGM	63.1	67.4	69.3	7.3	8.8	9.0	52.0	570	58.4	70	6.8	6.8
RT + RSM + SGM	62.6	66.5	68.2	7.2	8.8	9.0	50.7	55.7	56.8	6.7	6.8	6.8
CD ($p = 0.05$)	NS	6.7	7.2	NS	1.2	1.8	NS	5.7	5.7	NS	NS	NS

TABLE 2 Effect of different conservation practices on grain and stalk yield of linseed

Treatment	Grain yield (kg ha^{-1})			Stalk yield (kg ha^{-1})		
	1styear	2nd year	3rd year	1styear	2nd year	3rd year
CT	1046	1014	1005	1501	1569	1537
RT	946	958	969	1443	1487	1468
CT + RSM	1079	1059	1108	1626	1879	1887
RT + RSM	1050	1129	1147	1541	1895	1912
CT + SGM	1057	1228	1288	1595	2042	2105
RT + SGM	1013	1183	1225	1514	1949	1999
CT + RSM + SGM	1084	1269	1341	1790	2150	2215
RT + RSM + SGM	1062	1198	1260	1699	1984	2052
C.D. ($p = 0.05$)	NS	152.0	160.0	NS	324.0	302.0

second, and third years, respectively. Soil moisture depletion was the lowest under RT + RSM + SGM, with values of 22.0%, 16.7%, and 16.6% in the first, second, and third years, respectively, followed by CT + RSM + SGM (Fig. 1). Treatments without paddy straw mulching (CT, RT, CT + SGM and RT + SGM) exhibited the higher soil moisture depletion as compared to those with paddy straw mulching (CT + RSM, RT + RSM, CT + RSM + SGM and RT + RSM + SGM). The lowest WUE was observed under RT, with 6.9, 6.9, and 5.5 kg/ha/mm values during the first, second and third years, respectively. In contrast, the highest WUE was recorded under CT + RSM + SGM, significantly outperforming CT, RT and CT + RSM in the second year. CT, RT, CT + RSM and RT + RSM in the third year (Fig. 2). Treatments incorporating green manuring (CT + SGM, RT + SGM, CT + RSM + SGM and RT + RSM + SGM) showed higher WUE compared to those without green manuring (CT, RT, CT + RSM and RT + RSM). The lower WUE under reduced tillage, compared to conventional tillage, may be attributed to decreased water storage capacity (Xiao *et al.,* 2019). Reduced tillage often leads to lower infiltration rates than deep-ploughed conventional tillage, resulting in lower crop yield and WUE.

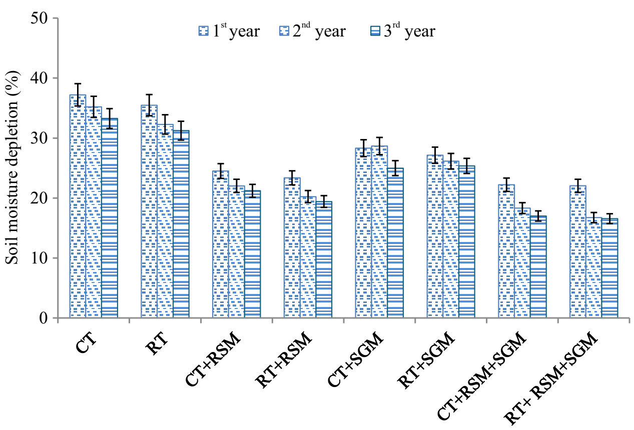

FIGURE 1 Effect of different conservation practices on soil moisture depletion of linseed

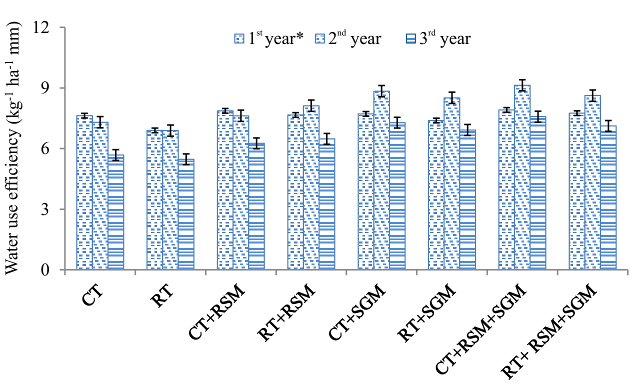

FIGURE 2 Effect of different conservation practices on water use efficiency of linseed (*denoted NS @ p=0.05)

5 | CONCLUSIONS

Based on the results, the overall yield was the maximum under conventional tillage combined with paddy straw mulching and sunn hemp green manuring during the preceding *kharif* season. Additionally, soil moisture depletion and WUE were the most favourable under conservation agricultural management practices applied in conventional and reduced tillage, compared to treatments without conservation measures. Thus, it may be recommended that linseed cultivators in black soil regions adopt conservation agricultural management practices such as green manuring (during the *kharif* season) and paddy straw mulching in combination with conventional tillage to improve crop yield, enhance water use efficiency, and reduce the soil moisture depletion.

ACKNOWLEDGEMENTS

We are thankful to the Department of Agricultural Engineering, N.M. College of Agriculture, Navsari Agricultural University, Navsari Gujrat, India, for providing facilities for the smooth running of work.

DATA AVAILABILITY STATEMENT

Available with authors on request.

CONFLICT OF INTEREST

We have no conflict of interest.

AUTHOR'S CONTRIBUTION

This work was carried out as research project work of Reena Kumari. Yogesh Garde helped in data analysis. Babloo Sharma and Pratibha Kumari improved paper writing and literature, improving language.

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How to cite this article: Kumari, R., Garde, Y., Sharma, B. and Kumari, P. 2024. Effect of different tillage regimes and mulching practices on crop yields and water use efficiency of linseed (*Linum usitatissimum*) in South Gujarat conditions. *Indian J. Soil Cons.,* **52** (Global Soils Conference - 2024 Special Issue): S63-S67.