

## Influence of Intercropping Systems on Growth Traits and Yield Components of Chickpea, Linseed, and Wheat

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### ABSTRACT

Monocropping and continuous use of exhaustive crop which ultimate result soil degradation such as reduction of soil organic carbon, leaching and loss of nutrient and soil erosion. The intercropping has the potential to reduce soil degradation by leveraging complementarity and resource utilization between different crop species and increase crop productivity and carbon sequestration. A study was designed with the three crops i.e. wheat, linseed and chickpea with the treatments i.e. T1 (sole wheat), T2 (sole linseed), T3 (sole chickpea), T4 (chickpea-linseed), T5 (chickpea-wheat), T6 (wheat-linseed) and T7 (linseed-chickpea-wheat) in randomized complete design with three replication. The results showed that intercropping concurrently in T4, T6 and T7 has a positive outcome in terms of land utilization and yield advantages by having LER values 1.025, 1.185 and 1.75 respectively. And these treatments have  $k > 1$  and positive value of AYL further validate the benefit of cultivating of these crop species together. Conversely, the T5 has no yield and benefit and has inefficiency in land utilization as evident by LER 0.873 &  $k = 0.767$  and negative value of AYL. From a statistical standpoint, intercropping has no discernible effect ( $p < 0.05$ ) on vegetative growth characteristics of the individual crops when they are cultivated as intercrops other than the no. of pods/plant in chickpea ( $P = 0.0107$ ). According to the findings of this study, the strategic adoption of diversified intercropping systems, such as combining wheat with linseed, chickpea with linseed or linseed-chickpea-wheat, can play a crucial role in supporting agricultural intensification in areas primarily dominated by smallholder farmers. Moreover, these intercropping systems have the potential to provide ecological advantages and contribute positively to the existing monocropping system.

**Keywords:** Intercropping, soil degradation, carbon sequestration, land utilization, ecological sustainability.

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### INTRODUCTION

The existing cereal-focused agricultural systems in South Asia face considerable threats, primarily due to climate change and several other factors including declining soil quality and limited water resources. These challenges undermine the profitability and

attractiveness of farming in the region (Yadav et al., 2016). According to reports, climate fluctuations have been observed to reduce the productivity and efficiency of rice-wheat cropping systems in various agro-ecological regions of Pakistan (Arshad et al., 2018).

In order to enhance productivity and sustainability in the rice-wheat cropping system (RWCS), beneficial approaches include incorporating “legumes” into the rotation and adopting environmentally friendly and biological farming practices (Nawaz et al., 2019). Change in the cropping pattern can be a proficient strategy to conserve the soil. The cropping pattern refers to the distribution of different crops across land, which can vary in both time and space (Ijaz et al., 2019). Intercropping is regarded by proponents as a cropping strategy that is both environmentally responsible and economically

beneficial (Khanal et al., 2021). Row intercropping involves cultivating intercrops alongside one or more crops that are sown in regular rows simultaneously. This practice is widely adopted to optimize resource utilization and productivity, aiming to maximize yields while making efficient use of available resources (Varma et al., 2017). In most cases, intercropping entails the deliberate selection of crops that exhibit varied growth patterns and morphological differences. This approach aims to optimize resource utilization and enhance crop yield or dry-matter output through efficient resource allocation (Lithourgidis et al., 2011).

Intercrops generally demonstrate higher yields per unit area compared to sole crops, as measured by the land equivalent ratio. The land equivalent ratio represents the relative land area required to achieve the same yields as a unit area of a single crop (Cong et al., 2015). To choose crop for intercropping, given the evolving environmental conditions, the specific crop environment, crop compatibility, and the demand and availability of varieties, for the careful selection of crops becomes pivotal (Von Cossel et al., 2019). A potential method for increased biological nitrogen fixing by legumes when grown in close proximity to cereals is intercropping (Cong et al., 2015).

The primary purpose of its cultivation is to produce either seed oil, specifically linseed, or both seed oil and fiber, known as dual-purpose linseed. Additionally, flax fiber is another valuable product derived from its cultivation (Rai et al., 2016). In recent times, linseed oil has garnered attention in the health food industry as a functional food. It is believed to offer various health benefits and exhibit disease-preventive properties, particularly in relation to conditions such as coronary heart disease, certain types of cancer, neurological disorders, and hormonal imbalances (Kasote et al., 2013). Traditionally, flax

fiber has been processed into linen yarns, which serve as the foundation for crafting a wide range of threads and twines (Hocking et al., 1987). Approximately 60-65% of the structural composition of flax fibers is attributed to cellulose, a vital component. Lignin, on the other hand, is another essential element for fiber structure, providing plants with rigidity, and it accounts for approximately 2-5% of the plant material (Zuk et al., 2015).

So, the research has been designed considering the above literature. Wheat (cereal), chickpea (legume) & Linseed (Oil & fiber crop) are cultivated as monocrops and intercrops.:

- To assess the land utilization efficiency under sole cropping and intercropping of wheat, chickpea & linseed
- To evaluate the “soil organic carbon” both in sole cropping and intercropped system
- To assess the influence of intercropping compared to sole cropping on crops productivity and yield advantages.

## MATERIALS AND METHODS

### Experiment Site

The study on comparison of sole cropping and intercropping was carried out at Department of Agronomy experimental station, University of the Punjab, Lahore, Pakistan (31.495 N, 74.297 E). The climate data of the region during the experiment has been given below **Error! Reference source not found.** The maximum temperature 35.4°C was found in April and whereas the lowest temperature recorded during December i.e., 7°C. Considering the rainfall, the month of March received the highest rainfall of 26.3mm & the least recorded value of rainfall (2mm) has been recorded in the month November.

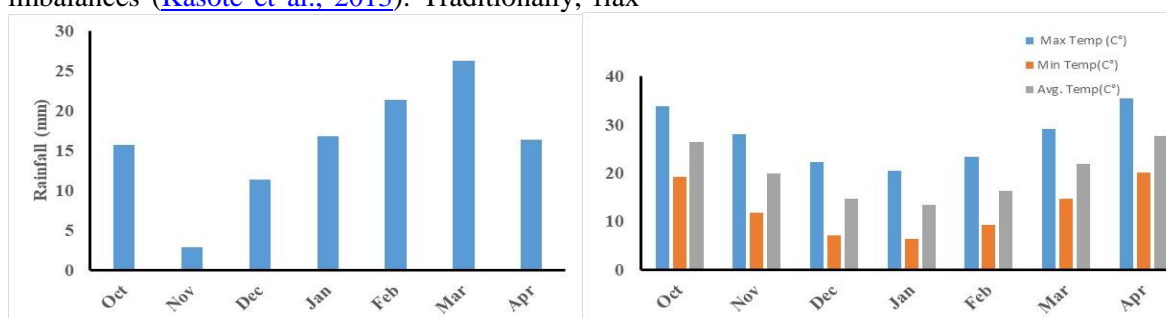


Figure 1. Climatic data predicting Rainfall and temperature

### Treatment Details

As mentioned in the above **Error! Not a valid bookmark self-reference.**, the treatments have been designed for mono cropping and intercropping. Three crops (Wheat, Chickpea & Rice were considered for this research experiment. Sole cropping of wheat,

linseed & chickpea are mentioned as T1, T2 & T3 respectively. In T4, Linseed-Chickpea were intercropped together on the same plot, Likewise for T5 is with Chickpea-Wheat intercropping & T6 was intercropped with Wheat and Linseed. The last

treatment, which is T7, has three intercropped together on the same plot.

The cropping density of sole cropping of wheat (T1), linseed (T2) & chickpea (T3) had 10 rows/plot and 300 plants/plot which had the area of 100 ft<sup>2</sup>. Cropping density in double cropping which is found in linseed-

chickpea (T4), chickpea-wheat (T5) and wheat-linseed (T6) consisted of 5 rows (150 plants/crop) of each crop and 10 rows/plot (300 plants/plot). In T7 each crop (chickpea, wheat, and linseed) contained 3 rows resulting in the plant density of 270 plants/plot).

Table 1. Experimental treatments Detail

Treatment	Description	No. of Rows/100ft <sup>2</sup>			Density plant/100ft <sup>2</sup>		
		Wheat	Chickpea	Linseed	Wheat	Chickpea	Linseed
T1	Sole Wheat	10	-	-	300	-	-
T2	Sole Linseed	10	-	-	300	-	-
T3	Sole Chickpea	10	-	-	300	-	-
T4	Linseed-Chickpea	-	5	5	-	150	150
T5	Chickpea-Wheat	5	5	-	150	150	-
T6	Wheat-Linseed	5	-	5	150	-	150
T7	Linseed-Chickpea-Wheat	3	3	3	90	90	90

### Blocks & Replications

The Experiment had 4 replications of each treatment laying in the 4 blocks, B1, B2, B3, B4. The treatments were placed in the blocks by randomized complete block design to remove the field variations.

### Experiment duration

The sowing of the crops was carried out during rabi season on 22<sup>nd</sup> November, 2023. Due to differences in crop type the harvesting times varied in the experiment. In which wheat is harvested after 140 days of sowing on 10<sup>th</sup> April, 2023. Whereas Linseed and chickpea were harvested after 160 days of sowing on 30<sup>th</sup> April, 2023 on 50% yellowing of capsules/pods.

### Management Practices of the Experiment

The land for the experiment has been prepared by using cultivator is used to cultivate the field. The soil has been leveled and 28 plots have been made manually maintaining the bunds and channels. Before planting experimental crops, Field was subjected to auger sampling. A composite sample was created by combining 6 soil samples. This composite sample served as a control to monitor changes in soil organic carbon. Following the harvest of the field crops on May 3<sup>rd</sup>, soil plots were sampled. For each cropping sequence (monocropping and intercropping), three random soil samples were collected from two different depths: 0 to 15 cm and 15 to 30 cm. The collected soil samples were combined to form composite samples. These composite soil samples were then sun dried, rid

of any visible plant materials, and subsequently ground and sieved for the purpose of analyzing the total organic carbon content. The wheat variety of Akbar-19 has been used @45 kgs/ac. Whereas Punjab-2008 is used for chickpea @30kg/ac & linseed variety Roshni @8kg/ac is sown. The seeds of chickpea & wheat have been soaked in the water the night before sowing. Thiophanate methyl @ 2g/kg has been applied afterwards to the seeds of wheat, chickpea & linseed. Afterwards treated seed were shade dried and used for sowing. Drill sowing has been done in rows while maintaining the distance of row × row 30 cm & plant × plant 10 cm. Planting density of wheat-chickpea & linseed is mentioned in the **Error! Not a valid bookmark self-reference..** Basal dose of DAP was applied according to the rate of 0.5 bags/acre to the whole field. Application of urea was done at basal dose on the whole experimental area with 1.5 bag/acre at sowing. Afterwards, the only plots T1, T2 & T6 were given a second dose of urea at 60 days of sowing, remaining plots were with chickpea plants. As chickpea plants fix nitrogen, they were not fertilized with urea, and they are expected to fulfill the further nitrogen requirement of companion crops too. SOP (sulphate of potash) was applied to the whole field @0.5 bag/acre. As the field was previously sown with rice, the sowing of this experiment was carried out on the residual moisture. 1<sup>st</sup> irrigation was applied 40 days after sowing (DAS). And the second irrigation was applied after 70 days of sowing. Third

irrigation has been applied at 110 days after sowing. Meanwhile the plots which were dried up, irrigated as per need of the soil. Pendimethalin 33% EC has been sprayed as a pre-emergence weedicid has helped to control weeds at early stage. Later on, weeds were removed manually after first and second irrigation. Aphid attack was observed on a few plots which were washed out by water spray. Other than that, the presence of lady bird beetle (*Coccinellidae*) has helped to keep their population in control. Harvesting was done according to physiological maturity of the crop by manual implement sickle and the grains were separated by hitting with sticks on solid surface and stored in the bags. The samples of wheat, chickpea & linseed were collected and analyzed in the laboratory to measure the relevant parameters utilizing weighing balance, sieve and scales.

### Parameters Calculated

#### Culm/stem Length

The wheat culm's was measured by measuring tape. By adding the culm & spike length it gives the total length of the plant stem. In linseed and chickpea stems height was measured to know stem length of the plants.

#### 100-Grain wt. (Test wt.)

100 grains of wheat, chickpea & linseed were taken and weighed to calculate the test weight.

#### Grain wt./plant

For wheat, the total number of seeds present on all tillers were calculated to acquire grain wt./plant. Likewise, No. of seeds contained by all capsules present on one plant were calculated. In Chickpea the pods/plant containing were evaluated to know the grain wt./plant.

#### Chlorophyll

Chlorophyll of the plants was determined at 90 DAS of the 3 crops (chickpea, wheat, linseed). SPAD-502Plus was used to take the readings for the chlorophyll. Three samples/crop/plot were used for the measurements.

#### No. of Spikes (wheat), pods (chickpea) & capsules (Linseed)

In wheat crop the sikes' size was also calculated including its hair length. The total grains present in spike were calculated to estimate no. of grains/spike. And these grains were weighed to measure the grain wt./spike. Likewise, no. of pods/plant (chickpea) & no. of capsules/plant (linseed) were also estimated.

#### No. of tillers or branches/plant

No. of tillers/plant were counted and took average to know the number of tillers present on a wheat plant. No. of branches/plant in linseed and chickpea were counted.

### Biological yield

It is total plant dry biomass accrued by plant depicting the efficiency of plants to utilize the inputs. Wheat, chickpea & linseed dry biomass was measured separately in tons/ha.

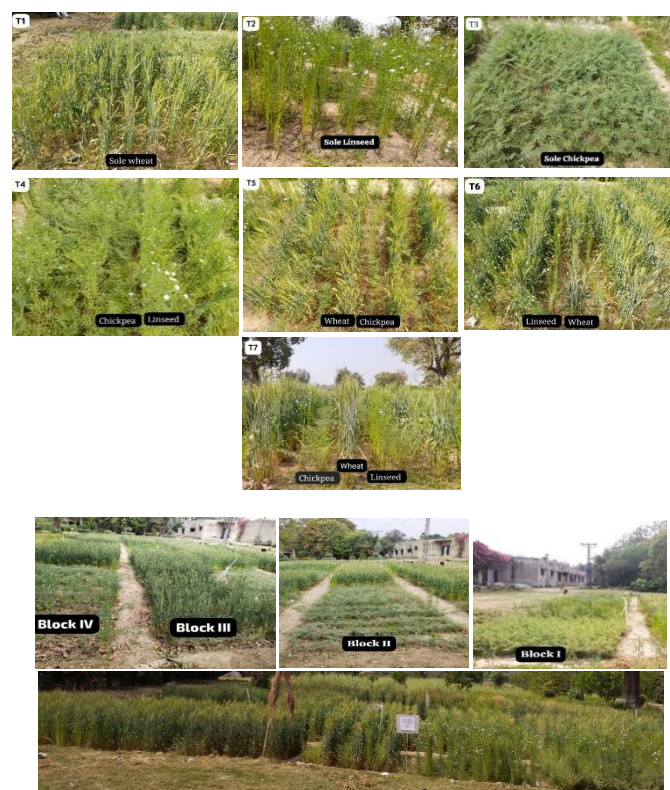


Figure 2. Treatments distribution in field.

### Economic yield

It's the desired part of plant produce for which the crop was grown. Grains in spike were calculated as economic yield of wheat. Pods containing grains of chickpea made its economic yield. Similarly, capsules of linseed contain seed which were calculated as its economic yield.

### Harvest Index

It is ratio of economic yield to the biological yield multiplied by 100. The harvest index of crops was calculated by the following formula:

$$\text{Harvest Index} = \frac{\text{Economic Yield}}{\text{Biological Yield}} \times 100 \quad 0.1$$

### Land Equivalent Ratio (LER)

Willey (1979) found that the Land Equivalent Ratio (LER), a measure representing the amount of land required for individual crops to achieve equivalent yields as intercropping, is arguably the most universally relevant indicator for expressing the yield advantage (Mead & Willey, 1980).

$$LER = L_a + L_b \quad 0.2$$

$$LER = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}} \quad 0.3$$

Where,

$L_a$ =Partial LER of crop a

$L_b$ =Partial LER of crop b

$Y_{aa}$ =Yield of crop "a" grown as a sole crop

$Y_{bb}$ =Yield of crop "b" grown as sole crop

$Y_{ab}$ = Yield of crop "a" in intercropping with crop "b"

$Y_{ba}$ = yield of crop "b" in intercropping with crop "a"

### Relative Crowding Coefficient (k)

This indicator is used to evaluate the overall effects and advantages of intercropping. The crop with the highest K value in a mixture is considered to exhibit a greater relative dominance of one species over the other.

$$K = k_{ab} \times k_{ba} \quad 0.4$$

$$k_{ab} = \frac{Y_{ab} \times Z_{ba}}{(Y_{aa} - Y_{ab}) \times Z_{ab}} \quad 0.5$$

$$k_{ba} = \frac{Y_{ba} \times Z_{ab}}{(Y_{bb} - Y_{ba}) \times Z_{ba}} \quad 0.6$$

$K$ =relative crowding coefficient

$k_a$ =RCC of crop a as an intercrop with crop b

$k_b$ =RCC of crop b sown in combination with crop a

$Y_{ab}$ = yield of crop a while intercropped with crop b

&  $Y_{ba}$  is crop b yield as an intercropped with crop a

$Z_{ab}$  is the sowing proportion of crop a as an intercrop with b &  $Z_{ba}$  is crop b sowing proportion as an intercrop with a crop

$Y_{aa}$  &  $Y_{bb}$  are yields of crop a & b respectively in sole cropping

If the value of K is equal to 1, it indicates that there is an equal level of competition between different species and within the same species. However, if  $K_a$  and  $K_b$ , representing different crops, deviate from 1, the crop with the higher K value can be considered as the dominant crop.

### Actual Yield Loss (AYL)

Unlike other indices, the actual yield loss index, which considers the yield per plant, offers a greater amount of information regarding competition. The AYL (proportionate yield loss of intercrops compared to the mono crop), indicated by its sign, is a measure which was used to quantify this yield loss.

$$AYL = AYL_a + AYL_b \quad 0.7$$

$$AYL_a = \frac{Y_{ab}/Z_{ab}}{Y_{aa}/Z_{aa}} - 1 \quad 0.8$$

$$AYL_b = \frac{Y_{ba}/Z_{ba}}{Y_{bb}/Z_{bb}} - 1 \quad 0.9$$

$AYL_a$ =Actual yield loss of crop a

$AYL_b$ =AYL of crop b

When the main objective is to compare yields on a per-plant basis, the AYL can take on positive or negative values, indicating the presence of either advantages or disadvantages in intercrops.

## RESULTS

### Yield Data

#### Wheat

##### Biological yield

The Biological yield of wheat is one of the crucial parameters to estimate the effect of solo crops & intercrops. Sole cropping showed statistically significant biological yield with respect to intercropping (**Error! Reference source not found.**). The sole cropping of wheat yielded the highest biological yield of 15166 kgs/ha followed by chickpea-wheat intercropping (7749 kg/ha). The lowest biological yield i.e., 4925.92 kgs/ha has been observed in the last treatment (chickpea-wheat-linseed) intercropping.

##### Economic yield

The grain yield of wheat is also considered as economic yield. The economic yield of sole cropping is significant with reference to the intercropping (**Error! Reference source not found.**). Maximum yield of grains (3333.3 kg/ha) has been recorded in the solo cropping of wheat followed by grain yield in chickpea-wheat intercropping (1721 kg/ha). Wheat grown in association with the linseed has lesser grain yield than the former two treatments, but more than the yield obtained in chickpea-wheat-linseed i.e., 1111.1kgs/ha.

##### Harvest index

In this experiment the harvest index is an important indicator of crops' efficiency to resource assimilation in the varying cropping systems. The analysis of variance depicted of harvest index in the table (**Error! Reference source not found.**) shows no significant differences among the mean values. The highest harvest index has been represented by the wheat sown in wheat-linseed cropping association. While other combinations of cropping have close values of harvest index with the values; 22.89 in the Chickpea-wheat-linseed cropped together, 22.7 in the Chickpea-Wheat & 21.17 in the sole wheat plot.

## Linseed

### Biological Yield

The biological yield of linseed in the monocropping has highly significant difference ( $<0.001$ ) among mean values than intercropping as given in **Error! Reference source not found.** The peak value of linseed's biological yield is recorded in the exclusive cropping of linseed (1147.22 kg/ha). The yield of linseed found in the associated cropping of wheat-linseed in the same experimental plot represents the second highest recorded value (648.61 kg/ha). The least biological yield value (380.55 kg/ha) is represented in the treatment with the three crops grown in same plot.

### Economic yield

The tabulated values of economic yield of linseed in **Error! Reference source not found.** are statistically analyzed and monocropping is highly significant with  $P < 0.001$  with respect to intercropping. Highest value of linseed grain yield (289 kg/ha) is shown in treatment with individual cultivation of linseed. Then the second high economic yield of linseed has been observed in the intercropping of linseed-chickpea (158.5 kg/ha) followed by the treatment with wheat-linseed grown together (150.25 kg/ha). The lowest linseed gains yield/ha in the experiment is shown in the treatment chickpea-wheat-linseed i.e., 120.33 kg/ha.

### Harvest Index

The harvest Index (which is a ratio of economic yield linseed to its biological yield calculated according to equation **Error! Reference source not found.**) of this experiment has been analyzed statistically & the results in **Error! Reference source not found.** The results show no significant difference in the treatment values. Treatment with Linseed grown along chickpea has the highest harvest index (49.125). The second maximum reading of harvest index i.e., 33.14 is recorded in chickpea-wheat-linseed cultivation in the same plot. The harvest index obtained in the treatments sole linseed & wheat-linseed are 26.16 & 23.61 respectively while the later reading is the lowest obtained harvest index of the experiment.

## Chickpea

### Biological yield

The biological yields of chickpea in different cropping scenarios presented in **Error! Reference source not found.** The results show highly significant difference of monocropping regarding to intercropping. Chickpea cropped alone has yielded the highest recorded value i.e., 6412.5 kgs/ha which is followed by the yield 3165 kg/ha found in treatment wheat-chickpea cropped together. Linseed-chickpea cropping scenario has produced biological yield with

the value of 3010 kg/ha. Minimum biological yield of linseed has been obtained in the treatment of chickpea-wheat-linseed (2025 kg/ha).

### Economic yield

The economic yield of chickpea given above in **Error! Reference source not found.** The tabulated values show  $P < 0.001$  depicting the highly significant difference among the means of monocropping and intercropping. The maximum recorded chickpea grain yield (1568 kg/ha) in the experiment has been found in the in the treatment of only chickpea grown plot. Whereas the second highest grain yield of chickpea has been obtained in the Linseed-chickpea cropping (742.8 kg/ha) followed by wheat-chickpea intercropping (555.5 kg/ha) & chickpea-wheat linseed intercropping (509.25).

### Harvest Index

The harvest index values of chickpea crop which are presented in **Error! Reference source not found.** depict no significant difference in the mean values analyzed by the statistical analysis. Maximum ratio of chickpea economic yield to its biological yield (called harvest index) has been described in the treatment with chickpea-wheat-linseed intercropped together i.e., 25.48 followed by sole cropping of chickpea (24.63). The lowest harvest index in the chickpea intercropping has been recorded in the wheat-chickpea intercropping i.e., 18.525. LER:

LER index is commonly utilized to evaluate the yield benefits of intercropping and is widely employed. The land area needed for mono-cropping to achieve the same yield as intercropping is referred to as the relative land requirement. The above statistically analyzed data Table 3 depicts the highly significant difference ( $P < 0.001$ ) among LER values among different cropping scenarios.

As  $LER > 1$  depicts the advantage of monocropping over the intercropping of a crop. And assessing the outcomes of the experiment it is concluded that all the cropping scenarios except the chickpea-wheat intercropping (where  $LER = 0.873$ ) are giving  $LER > 1$ . Maximum LER is observed in Wheat-linseed intercropping (1.185) with the yield advantage of 18% compared to sole cropping of these crops. The combination of the crops had a positive impact on the development & productivity of these crops. While other treatments Linseed-chickpea cropping contained 1.025 as LER value & wheat-chickpea-linseed has obtained 1.075 both referring to the situations of the systems in intercropping.

### Area Time Equivalency Ratio (ATER)

LER overlooks the duration of crop presence in the field and focuses solely on harvested products rather than considering the desired yield percentage of each

crop. Additionally, there is uncertainty in determining the suitable yield of a sole crop to standardize the mixture yield in LER calculations.

Consequently, the area time equivalent ratio (ATER) was introduced to provide a more accurate assessment of the advantages of intercropping over solitary cropping. As per the interpretation of ATER, a value of 1 signifies no advantage in yield, a value less than 1 indicates no effect of intercropping, and a value greater than 1 implies a yield advantage.

The ATER of the experiment Table 3 slightly differs from the LER values as in wheat-linseed intercropping having 1.097 value lesser than LER value of 1.185. ATER doesn't miscalculate the resource utilization. The least ATER (0.815) has been recorded in the chickpea-wheat intercropping. Intercrops in Linseed-chickpea & wheat-chickpea-linseed intercropping

have the ATER >1 Interpreting the usefulness of the treatments over monocrops.

**RCC (K)**

Although the k values have not been statistically analyzed but the yield benefit is present when the value of K is greater than 1. When K equals 1, there is no yield advantage, and when K is less than 1.00, it indicates a yield disadvantage.

In Table 3 the k value in chickpea-wheat (kb=1.123) depicts the yield advantage of wheat but loss of chickpea yield (ka=0.767). Wheat-linseed intercropping is depicting the benefit in intercropping with ka & kb are >1 and similar results are established by linseed-chickpea combination. In scenario of chickpea-wheat-linseed the crops are separately having k<1 suggesting disadvantage in the combination.

Table 2. Effect of mono cropping & intercropping of wheat, chickpea & linseed-Yield Data

Treatments	Biological Yield (kgs/ha)			Economic Yield (kgs/ha)			Harvest Index		
	Wheat	Chickpea	Linseed	Wheat	Chickpea	Linseed	Wheat	Chickpea	Linseed
<b>T1</b>	15166.6a	-	-	3333.3a	-	-	22.2b	-	-
<b>T2</b>	-	-	1147.2a	-	-	289a	-	-	26.2a
<b>T3</b>	-	6412.5a	-	-	1568.7a	-	-	24.6a	-
<b>T4</b>	-	3010b	620.8b	-	742.8b	158.5b	-	23.7a	49.1b
<b>T5</b>	7749.9b	3165b	-	1721.1c	555.5b	-	22.4b	18.5a	-
<b>T6</b>	6916.6b	-	648.6b	2214.3b	-	150.3bc	32.2a	-	23.6b
<b>T7</b>	4925.9c	2025c	380.5c	1111.1d	509.3b	120.3c	22.9b	25.5a	33.1b
<b>Mean</b>	8689.8	3614.4	699.5	2094.9	844.1	179.5	24.9	23.1	33.1
<b>P(0.05)</b>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.4105	0.7096	0.154
<b>LSD<sub>0.05</sub></b>	1.96	0.59	0.55	0.39	0.38	36.55	ns	ns	ns

Table 3. LER, ATER & AYL in monocrops & intercrops

Treatments	Land Equivalent Ratio (LER)			Actual Yield Loss			Area time equivalent Ratio	Relative Crowding Coefficient (K)			
	La	Lb	Lc	AYLa	AYLb	AYLc		Ka	Kb	KLc	Total
<b>Chickpea-Wheat</b>	0.4b	0.5a	-	-0.3b	0.03a	-	0.82	0.78	1.12	-	1.31
<b>Wheat-Linseed</b>	0.7a	0.5a	-	0.3a	0.04a	-	1.1	2.2	1.15	-	2.8
<b>Linseed-Chickpea</b>	0.6ab	0.5a	-	0.1ab	0.05a	-	1	1.3	1.2	-	1.25
<b>Linseed-Chickpea-Wheat</b>	0.4b	0.3a	0.3	0.39b	0.03a	0.001	1	0.73	0.5	0.5	0.21
<b>Mean</b>	0.5	0.5	0.33	0.01	0.001	0.001					
<b>P (0.05)</b>	0.08	0.23		<b>0.09</b>	<b>0.96</b>						
<b>LSD (0.05)</b>	ns	ns		<b>ns</b>	<b>ns</b>						

Table 4. Plant Height, No. of tillers/plant &amp; Chlorophyll (Wheat, Chickpea &amp; Linseed) in monocrops &amp; intercrops

Treatments	Wheat			Linseed			Chickpea		
	Plant Height (cm)	No of tillers	Chlorophyll	Plant Height (cm)	No of tillers	Chlorophyll	Plant Height (cm)	No of tillers/	Chlorophyll
<b>Sole Wheat</b>	82a	8.8a	48.3a	92.3a	2.3a	44.8a	60.5a	3.5a	45.2a
<b>Chickpea+ Wheat</b>	83.8a	10.7a	49.9a	91.5a	2a	49.2a	63.3a	3ab	49.38a
<b>Wheat + Linseed</b>	84a	10.5a	45.8a	84.8a	1.5a	46.1a	61.5a	2.8b	51.2a
<b>Chickpea+ Wheat+ Linseed</b>	85a	8.8a	47.8a	89.8a	2.5a	44.7a	60.5a	3.3ab	43.7a
<b>Mean</b>	83.9	9.7	47.9	89.5	2.06	46.19	61.43	3.13	47.35
<b>P (0.05)</b>	0.9	0.76	0.26	0.44	0.54	0.72	0.98	0.16	0.3
<b>LSD (0.05)</b>	ns	ns	ns	ns	ns	ns	ns	ns	ns

### Actual Yield Loss (AYL)

The AYL quantifies the amount of yield that is either lost or gained through intercropping compared to the yield of the corresponding individual crop. Additionally, the partial AYL (for main crops) and AYL (for intercrops) illustrate the proportionate yield loss or gain of each species in intercropping relative to their yields when grown as solitary crops.

In chickpea-wheat, 29% yield has been reduced compared to monocropping, while 3.4% yield advantage is gained in wheat as an intercrop. Whereas in the second treatment (wheat-linseed), there is yield advantage in both crops which is 33% in wheat & 4% in linseed. In the third treatment (Linseed-chickpea) the linseed obtained the benefit of 9.7% than linseed production in monocrop but the chickpea has lessened its intercrop production by 5.3% with overall advantage of 4.4% with both crops grown together. In AYL values for linseed-chickpea-wheat crops group, linseed gained 24% more production & wheat obtained 0.1% increase in yield whereas 2.6% decrease in the yield has been observed in chickpea in this system.

### Plant Height

Plant height of wheat in **Error! Reference source not found.** depicts no significant differences in mean values in mono cropping & intercropping. Maximum height of culm is recorded (85cm) in chickpea, wheat & linseed intercropping. While the least value of culm length (82cm) is recorded in sole wheat cropping system.

Similarly, statistical analysis depicts no significant differences in mean values of linseed plant's height in mono cropping & intercropping **Error! Reference**

**source not found.** The highest recorded value of plant height is established by sole linseed plants (92.25 cm). whereas wheat-linseed cropping is showing the least recorded value of 84.75cm.

The tallness of the chickpea plants presented in the table has been analyzed for the different treatments **Error! Reference source not found.** The tallest plants have been found in linseed-chickpea intercropping (63.25 cm). whereas the lowest plant height is recorded in sole chickpea & chickpea-wheat-linseed intercropping i.e., 60.5 cm.

### No. of branches/tillers per plant

As the wheat plant has different tillers per plant so the mean values presented by statistical analysis show different tillers/plant in the **Error! Reference source not found.** The highest number of tillers are present in chickpea-wheat intercropping i.e., 10.75, followed by wheat-linseed intercropping with the value of 10.5. Then an equal number of tillers have been found in sole wheat & wheat-chickpea-linseed intercropping (8.75).

Linseed plant has varying no. of branches branching among the different treatments as shown by the above **Error! Reference source not found.** The means presented in table are depicting the maximum recorded value in chickpea-wheat-linseed treatment with 2.5 branches/plant, followed by sole linseed (2.25) & linseed-chickpea intercropping with the value of 2. The least recorded mean in the table is established by wheat-linseed intercropping (1.5).

The mean values of the no. of main branches/plant of chickpea have been depicted as above in **Error! Reference source not found.** The maximum recorded value in the table is in sole chickpea i.e., 3.5,

whereas lowest no. of branches/plant have been recorded in wheat-chickpea (2.75).

### Chlorophyll

Chlorophyll is the key to food production in plants and it has been tested in the following experiment. It has been statistically analyzed and mono cropping & intercropping have no significance among mean value of chlorophyll (**Error! Reference source not found.**). In wheat plants, its readings show that wheat intercropped with chickpea shows the highest value of chlorophyll i.e., 49.9 followed by sole wheat cropping with the value 48.325 & wheat grown along with linseed recording 47.825. While, wheat intercropped with linseed depicts the lowest reading of chlorophyll which is 45.8.

The means of chlorophyll found in linseed has been exhibited in the above table 4. The table represents the highest recorded value of chlorophyll in linseed-chickpea intercropping while lowest reading of 44.7 is recorded in chickpea-wheat-linseed intercropping.

As the chickpea fixes aerial N through rhizobia too, the maximum chlorophyll reading has been recorded in the chickpea plants in the experiment. Highest chlorophyll reading found in wheat-chickpea intercropping (51.15) followed by linseed-chickpea (49.38). The lowest value of chlorophyll is found in chickpea-wheat-linseed i.e., 43.74.

### Parameters of Wheat

#### 100-Grain weight (Test wt.) in Wheat

Mono-cropped wheat shows the highest 100-grain weight value of 6.6g as given in **Error! Reference source not found.** . While wheat plots grown in combination with chickpea plants, showed the second highest grain weight. Treatments representing wheat combination with linseed plants & other with all three crops intercropped have the lowest grain weight of 5.8 g. Overall, the mean values for 100-grain weight are non-significant for monocropping and intercropping.

#### Grain weight/plant in Wheat

In the **Error! Reference source not found.** the highest value of grain weight per plant is found in wheat intercropped with linseed plants 29.92 g, followed by chickpea and wheat intercropped plots showing 28.49 g. Lowest grain weight per plant is recorded in chickpea, wheat & linseed intercropped plots i.e., 22.15 g.

#### No. spikes/plant in Wheat

The mean values of No. of spikes/plant are varying representing the highest no. of spikes/plant in plots having intercropping of chickpea and wheat i.e., 10.75. The second highest no. of spikes/plant have been found in plots having all three crops chickpea,

linseed & wheat intercropped and stating value 9.5. The least no. of spikes/plant recorded is 7 which is in sole cropping of wheat.

#### No. of grains/spike in Wheat

The wheat crop yielded the difference among the mean values of No. of grains present in a spike. Wheat intercropped with linseed presents extreme value of no. of grains/spike, which is 58.25, tracked by sole wheat with 49.5, then plot with all three crops depicts value of 40.5 & Wheat intercropped with chickpea illustrates value of 40.25.

#### Spikes length in Wheat

The spikes length has been recorded including the hair of the spike and the topmost spike length is present in wheat-linseed intercropping that is 17.62cm with second highest reading, 16.8cm is established in wheat & chickpea intercropped plots. Sole wheat has shown the minimum reading of spikes length i.e., 15.62cm.

#### Grain wt./spike in Wheat

The means presented in the **Error! Reference source not found.** show non-significant relation of grain wt./spike and wheat sole & intercropping scenarios. Wheat intercropping with linseed depicts the peak value (3.41 g) of grain wt./spike. While minimum value (2.33 g) recorded in the chickpea, wheat & linseed intercropping.

### Linseed

#### 100-seed wt. in Linseed

The test weight (g) of the seeds in **Error! Reference source not found.** of the linseed has been the peak value of 100-seed weight (0.53g) is shown in chickpea-wheat-linseed intercropping, followed by sole linseed cropping (0.5g). The lowest 100-seed wt. is present in wheat-linseed intercropping with the value of 0.47g.

#### Seed wt./plant in linseed

The capsules present on a plant of linseed have seeds which vary from the rest of the plants in the other treatments. Highest Seed weight/plant is recorded in linseed-chickpea intercropping followed by chickpea-wheat-linseed intercropping (0.818g) & sole linseed cropping (0.817g). The lowest mean value is established by wheat-linseed intercropping i.e., 0.730g.

#### No. of capsules/plant in linseed

The treatment with linseed sown solely has the peak value of No. of capsules/plant i.e., 25 followed by the cropping of linseed with chickpea (24 capsules/plant) & the Linseed-wheat intercropping (21 capsules/plant). The lowest value has been established by wheat-linseed-chickpea intercropping which is 18.75.

Table 5. Wheat Parameters in monocrops &amp; intercrops (100-Grain wt., Grain wt./plant, No. of spikes/plant, Spike Length, Grain wt./spike)

Treatments	100 Grain wt. (g)	Grain Weight (g)	No. of spikes	No of Grains	Spike length (cm)	Grain wt./spike (g)
Sole Wheat	6.6a	23.3a	7b	49.5ab	15.6a	3.3a
Chickpea+ Wheat	6.21a	28.5a	10.8a	40.3b	16.8a	2.5a
Wheat + Linseed	5.8a	29.9a	9ab	58.3a	17.6a	3.4a
Chickpea+ Wheat+ Linseed	5.8a	22.2a	9.5ab	40.5b	16a	2.3a
Mean	6.1	26	9.06	47.13	16.7	2.9
P (0.05)	0.89	0.63	0.09	0.01	0.24	0.33
LSD (0.05)	ns	ns	ns	ns	ns	ns

Table 6. Linseed Parameters monocrops &amp; intercrops (100 Grain-wt., Seed wt./plant, No. of capsules/plant, No. of seeds/capsule, No. of seeds/plant)

Treatments	100_Seed wt. (g)	Seed Wt. plant <sup>-1</sup> (g)	No. of Capsules plant <sup>-1</sup>	No. of Seeds capsule <sup>-1</sup>	No. of Seeds plant <sup>-1</sup>
Sole Linseed	0.5a	0.82a	25a	7a	164.6a
Linseed +Chickpea	0.49a	0.91a	24.5ab	7.5a	182a
Wheat + Linseed	0.47a	0.73a	21.25ab	7.5a	156.25a
Chickpea+ Wheat+ Linseed	0.53a	0.82a	18.8b	8.25a	155.5a
Mean	0.49	0.82	22.37	7.56	164.6
P (0.05)	0.57	0.38	0.14	0.29	0.18
LSD (0.05)	ns	ns	ns	ns	ns

Table 7 Chickpea Parameters monocrops &amp; intercrops (100 Grain-wt., Grain wt./plant, No. of pods/plant)

	100_GW (g)	GW per plant (g)	No. of Pods plant <sup>-1</sup>
Sole Chickpea	19.45a	7.9a	38.8a
Linseed +Chickpea	13.6a	3.621ab	27.3ab
Wheat + Chickpea	13.25a	1.54b	12b
Chickpea+ Wheat+ Linseed	18.75a	2.25b	12b
Mean	16.26	3.85	22.5
P (0.05)	0.44	0.06	0.01
LSD (0.05)	ns	ns	15.907

**No. of seeds/capsule in linseed**

The cropping design of chickpea-wheat-linseed intercropping exhibits highest value of No. of seeds/capsule with the value of 8.25 seeds. The

minimum number of seeds/capsules are depicted in sole linseed cropping which are 7. The other two scenarios (Linseed-Wheat & Linseed-Chickpea) have a similar value i.e., 7.5 No. of seeds/capsule.

### No. of seeds/plant in Linseed

The highest estimate of number of seeds/plants is found in linseed-chickpea with 182 seeds/plant. While the second highest mean value has been recorded in sole linseed cropping system (164 seeds/plant). Least no. of seeds per plant (155.5) are present in the cropping scenario where wheat-linseed-chickpea intercropping is practiced.

### Chickpea

#### 100-grain weight in chickpea

The maximum 100-grain weight in **Error! Reference source not found.** has been recorded in sole chickpea (19.45g) followed by chickpea-wheat-linseed intercropping (18.75g). The lowest recorded readings are 13.6g & 13.25g found in linseed-chickpea & wheat-chickpea respectively.

#### Grain wt./plant in chickpea

The mean value grain wt. per plant in sole chickpea (7.99g) is the maximum among the given values of different scenarios for cropping. The second highest grain wt./plant is recorded in linseed-chickpea intercropping i.e., 3.6g. The lowest reading of the grain wt. per plant has been shown in wheat-chickpea intercropping (1.53g)

#### No. of pods/plant in chickpea

No. of pods/plant in chickpea in **Error! Reference source not found.** show the significant variations among means in different treatments. Sole chickpea cropping presents maximum no. of pods/plant (38.75) and is statistically significant from wheat-chickpea & chickpea-wheat-linseed intercropping. The second highest value is found in linseed-chickpea intercropping (27.25).

### DISCUSSION

The experiment was conducted to accomplish the objective of evaluating the efficiency of the cropping systems by comparing the performance of the crops (wheat, chickpea, and linseed) in both sole cropping and intercropping systems and their impact on soil organic carbon (SOC) This assessment would offer valuable insights into the potential benefits of cultivating these crops together.

Based on the field experiment results, it was discovered that intercropping combinations, such as linseed-chickpea ( $LER = 1.025 \pm 0.175$ ), wheat-linseed ( $LER = 1.185 \pm 0.189$ ), and linseed-chickpea-wheat ( $LER = 1.075 \pm 0.143$ ), can effectively enhance land productivity (**Error! Reference source not found.**). In chickpea-wheat intercropping resulted in inefficiency in land utilization compared to mono cropping ( $LER = 0.873a \pm 0.302$ ). Notably, ([Martin-Guay et al., 2018](#)) and ([Yu et al., 2015](#)) reported global

average LERs of  $1.30 \pm 0.01$  and  $1.22 \pm 0.02$ , respectively. ([Dowling et al., 2021](#)) also reported  $LER > 1$  for legume/oilseed intercropping. The present study's average LER (1.039) reinforces the idea that intercropping cereal/oilseed, oilseed/legume, or cereal/oilseed/legume offers a considerable advantage in land utilization.

Intercropping of this experiment provided the yield advantage relative to monocropping (suggested by AYL values) in linseed-chickpea, wheat-linseed & linseed-chickpea-wheat of 4.4%, 37% and 22% respectively **Error! Reference source not found.** Whereas, chickpea-wheat, there was a 29% reduction in overall yield compared to monocropping. In the studies conducted by ([Zhou et al., 2023](#)) and ([D. Meena et al., 2018](#)) it was observed that intercropping chickpea and flax resulted in increased land productivity compared to cultivating these crops separately. The advantage of yield in intercropping of Linseed-chickpea has also been validated by ([Tanwar et al., 2011a](#)), ([Sharma & Goswami, 2010](#)) and ([Dowling et al., 2023](#)). Similar results has been produced by a study which analyzed different geometrical layouts for intercropping wheat and linseed and found that the intercropping system yielded higher net financial gains per hectare compared to cultivating wheat or linseed alone ([Nazir et al., 2006](#)). Intercropping primarily offers the advantage of enhanced productivity ([Qin et al., 2013](#)) in resource-constrained environments by efficiently utilizing available solar radiation, water, and nutrient resources ([Dong et al., 2018](#)).

([Hiebsch & McCollum, 1987](#)) suggested that when the component crops have different growth durations, there is a likelihood that LER could exaggerate the advantages of intercropping. When there are variations in the time each intercrop component covers the land, ATER (Area Time Equivalence Ratio) offers more accurate estimations compared to LER ([Awal et al., 2007](#)). The ATER values were found to be lower than the LER values in wheat-linseed, and linseed-chickpea-wheat intercropping, indicating a potential overestimation of resource utilization. This overestimation may be attributed to the considerable variations in the maturity periods of the crops. Specifically, the longer stay of linseed & chickpea on the land allowed them enough time to compensate for the competition from the wheat.

Neither ATER nor LER can adequately measure the competitive abilities of component crops in intercropping. To assess these abilities accurately, one must consider A, k, and CR as evaluation parameters ([Wahla et al., 2009](#)). ([Khonde et al., 2018](#)) & ([Feng et al., 2021](#)) have likewise assessed the competitiveness in intercrops with these indices. According to the values obtained by these competition indices, wheat

( $k_b = 1.123$ ) is more competitive than chickpea crop ( $k_a = 0.767$ ), as indicated by the  $k$  (RCC) value in **Error! Reference source not found.** Similarly, wheat has been more competitive in wheat-linseed intercropping with greater  $k$  value. ([Gitari et al., 2020](#)) used CR for calculating competitiveness in potato/legume. The narration (of wheat dominance) is further validated by utilizing the CR value which narrated that CR values of wheat which are greater than others in chickpea-wheat & wheat-linseed cropping sequences. Correspondingly, A value in **Error! Reference source not found.** for these cropping combinations also suggest the dominance of wheat crop. ([Amanullah et al., 2020](#))

Intercropping did not demonstrate any noteworthy impact ( $p < 0.05$ ) on the phenological and vegetative growth parameters like plant height, no. of branches (linseed, chickpea) and tillers (wheat) as given in above **Error! Reference source not found.**, of the component crops. The intercropping experiment by ([Abate & Alemayehu, 2018](#)) have also similar results showing non-significance in growth and yield determining components. And ([Bargaz et al., 2015](#)) also reported similar results that the effect on wheat growth parameters is non-significant under intercropping system. Similarly, reproductive parts of plants (capsules, spikes, pods) also didn't exhibit significance in monocrops and intercrops as analyzed statistically (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). However, there was a significant distinction ( $p \leq 0.05$ ) observed in the number of pods per plant in chickpea when comparing intercropping with sole cropping. It is speculated that less no. of pods/plant in chickpea are due to competitiveness of fellow crops like chickpea and linseed in intercropping. As the dominance of wheat over the chickpea suggested by ([Mashhadi et al., 2014](#)) and ([Kherif et al., 2021](#)).

Research shows that wheat (average CGR: 31.8  $\text{g/m}^2/\text{day}$  and 42.9  $\text{g/m}^2/\text{day}$  at 104 & 138 days of sowing respectively) exhibits a greater growth rate in terms of CGR (Crop Growth Rate) compared to other crops, as well as a similar trend in biomass accumulation. These findings suggest that wheat plants, credits to their taller height and faster growth, have a competitive advantage in efficiently utilizing environmental resources as the similar trend in plants is witnessed by ([Kishore et al., 2021](#)).

Land-use practices and cultivated crop species impact soil organic matter levels. In this experiment, soil analysis for soil organic carbon (SOC) suggests the maximum increase in SOC accumulation in intercropped soils (linseed-chickpea-wheat intercropping) at both sampling depths. ([Cong et al., 2015](#)) reported increase in the SOC in intercropping

because of complementary effect of crops grown together. In this experiment, the only loss in SOC is Observed in wheat-linseed intercropping (0.773  $\text{g/kg}$  vs 0.825  $\text{g/kg}$ ) at 15cm soil depth. The reason for this loss is speculated that incorporation of no leguminous crop in this crop practice these crops as ([Zhang et al., 2021](#)) discussed that plant species leguminous/non-leguminous influence the carbon loss in the soil. ([B. Meena et al., 2018](#)) affirms the idea of legumes incorporation in cropping system improve the SOC.

## CONCLUSION

The findings of this study strongly support the idea that intercropping, particularly combinations like chickpea-linseed, wheat-linseed, and linseed-wheat-chickpea, offer substantial advantages with average  $LER > 1$  in both yield enhancement and resource utilization when compared to sole cropping methods. The results highlight the potential of intercropping systems to boost agricultural productivity while conserving resources. Furthermore, the intercropping approach proves to be ecologically sustainable, as it leads to better soil organic carbon (SOC) preservation than conventional monocropping practices. This implies that adopting intercropping strategies can contribute to long-term environmental health and resilience. By optimizing resource allocation and fostering mutualistic interactions between crops, intercropping presents a promising pathway towards achieving sustainable agriculture. In conclusion, embracing intercropping techniques has the potential to address challenges related to food security and resource conservation, making it a valuable and environmentally sound practice for modern agricultural systems.

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