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Agro-economic Assessment of Wheat (*Triticum aestivum*) Canola (*Brassica napus)* Intercropping Systems under Different Spatial Patterns

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Abstract

Intercropping can improve crop yields, but intercropping under different spatial patterns at large scale in central Punjab, Pakistan has not been studied. In this research, the feasibility of wheat-canola intercropping systems under two spatial patterns (row and mixed intercropping) was carried out to evaluate the interaction between the crops and their effects on their productivity. The treatments included sole wheat, sole canola, one wheat row alternating with one canola row, two wheat rows alternating with two canola rows, four wheat rows alternating with four canola rows and mixed intercropping of wheat + canola (broadcast method). Number of lines of wheat and canola were kept same in intercropping treatments as in their pure stand. Wheat (*Triticum aestivum* L.) cv. sehar-2006 and canola (*Brassica napus* L.) hybrid Hyola-401 were used as experimental materials. The results revealed that yield and various yield contributing traits of wheat and canola were influenced significantly by different intercropping treatments. The sole crop of wheat and canola gave higher economic yield i.e., 4.02 and 1.47 t ha^{-1}, respectively. Among intercropping treatments, four rows of wheat alternating with four rows of canola gave higher total land-equivalent ratio (LER) of 1.37, net benefits of Rs. 107492 and benefit cost ratio of 2.76. In this study, row intercropping resulted in consistent over-yielding (LER), and seemed to be enhanced by one to four alternating rows of wheat and canola. Therefore, for higher crop productivity and economic returns, farmers should cultivate wheat-canola in the pattern of four rows of wheat along with four rows of canola.

Keywords: Intercropping; Canola; Wheat; Land-equivalent ratios

Introduction

Intercropping is an advanced agro-technique, which involves growing of two or more than two crops in the same field at the same time. Intercropping increases diversity in the cropping system and resulted in higher yield on a certain piece of land by making more effective usage of the existing growth resources such as light, heat and water with a combination of crops of diverse rooting ability, canopy arrangement, height, and nutrient requirements based on the corresponding exploitation of growth resources by the component sole crops (Liebman and Dyck, 1993; Lithourgidis *et al*., 2011). So, in modern agriculture, it can help increase crop productivity particularly at small farms of Pakistan as it satisfies the diversified demands of the farm people (Imran *et al*., 2011).

Intercropping results in increased overall yield of the mixture as compared to any of the component crops. This may be due to some of the potential benefits for intercropping systems such as high productivity and profitability (Yildirim and Guvence, 2005), reducing damage caused by pests, diseases and weeds (Sekamatte *et al*., 2003; Banik *et al*., 2006) and efficient use of environmental resources (Knudsen *et al*., 2004; Eskandari and Ghanbari, 2009) through the complementary effects of two or more crops grown simultaneously on the same piece of land. Land equivalent ratio (LER) could be used to compare yield performance of intercrop and component sole crop (Willey, 1979). If LER is > 1 then over-yielding occurs. Yield improvements were observed in different wheat-canola intercropping systems as four rows of wheat alternating with two rows of hybrid canola recorded higher LER, net income, benefit-cost ratio and marginal rate of return (Khan *et al*., 2012). In canola-based wheat intercropping systems, different growth and yield components were significantly influenced by intercropping patterns, where canola + one row of wheat produced the highest canola seed yield, LER, cost benefit ratio and net income (Ali *et al.*, 2000).

Wheat (*Triticum aestivum* L.) an important cereal crop, belonging to family Poaceae, is the leading food grain. It plays a vital role in Pakistan's food economy, both in terms of production and consumption. Likewise, canola (*Brassica napus* L.) has gained considerable importance these days, because of substantial foreign exchange of

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Pakistan is spent on the import of edible oil. The sowing seasons of both wheat and canola overlaps, and we surmise that both may offer unique opportunities of their intercropping. Farmers are not generally practicing intercropping of wheat with canola in the country for the purpose of grain yield. Thus, there is need to develop the best sustainable intercropping system to increase the production of wheat and canola crops concurrently. This study was particularly focused on growing wheat and canola crop simultaneously under two spatial patterns (row and mixed intercropping) for sorting out the best combinations.

It is assumed that, if properly accomplished, the intercropping of wheat with canola may be superior to their component sole crops in terms of higher economic return and benefit cost ratio (BCR) that ultimately help overcome the lack of oilseeds in the country. Therefore, this study was conducted to investigate the agro-economic advantages of wheat-canola intercropping systems under sub-tropical to tropical agro-ecological conditions of Pakistan to increase the area and production of wheat along with canola crop.

Materials and Methods

Soil and Site

The possibility of wheat-canola intercropping systems under two spatial patterns (mixed and row intercropping) were carried out to investigate their effects on yield and yield contributing traits of both crops at the Agronomic Research Area, University of Agriculture, Faisalabad (31.25˚ N and 73.09˚ E), Pakistan during the winter of 2009-10. The experimental soil belonged to Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification and Haplic Yermosols in FAO classification scheme). Weather data during the whole period of experimentation are presented in Table 1.

Experimental Materials and Details

Wheat (*Triticum aestivum* L.) variety "Sehar-2006" was obtained from Agronomic Farm University of Agriculture, Faisalabad and seeds of hybrid canola, Hyola-401 were obtained from ICI Seeds Pvt. Ltd., Pakistan. The experiment was laid out in a randomized complete block design (RCBD) with four replications in plots measuring 6.0 m×2.4 m. The treatments included sole crop of wheat (row to row distance 30 cm), sole crop of canola (row to row distance 30 cm), one row of wheat alternating with one row of canola (30 cm apart one wheat row), two rows of wheat alternating with two rows of canola (45 cm apart two wheat rows), four rows of wheat alternating with four rows of canola (75 cm apart four wheat rows) and mixed intercropping of wheat + canola sown by broadcast method.

Crop Husbandry

For seedbed preparation, a pre-soaked irrigation of 10 cm was applied. When soil reached at proper moisture condition (field capacity), the field was cultivated twice with the help of cultivator each followed by planking. Wheat and canola seed were sown simultaneously on a well-prepared seed bed using a single row hand drill on November 26, 2009. Both the crops were also sown as pure stand in 30 cm spaced rows. The number of rows of wheat and canola were kept same in intercropping treatments as in their pure stand. The wheat was kept as main crop as inputs were used according to requirement of wheat. Wheat and canola seed were used at 125 and 5 kg ha^{-1}, respectively. Nitrogen (N) and phosphorus (P) in the form of urea and diammonium phosphate (DAP) were applied at 120 and 110 kg ha^{-1}, respectively. Half of the N and full dose of P were applied at the time of sowing, while the remaining half of N was applied with the first irrigation. The first irrigation was applied at tillering, followed by 3 irrigations were adjusted according to the climatic conditions and need of the crop.

Growth and Yield Data

Data regarding yield and yield contributing traits of wheat and canola were recorded by using standard sampling procedures. In wheat and canola, heights of 10 plants were taken randomly from base to tip of the plants by using a meter rod at maturity and then their averages were calculated. For calculation of number of fertile tillers of wheat, an area of 1 m^2 was randomly measured from each plot and two samples were taken. Number of grains per spike and number of seeds per silique was counted manually from each plot by taking 10 spikes of wheat and 10 siliques of canola selected randomly from each plot and then their averages were calculated. Number of fruiting branches and number of siliques per plant was counted by taking averages of 10 plants from each experimental unit. Spike lengths of 10 randomly selected spikes were measured from base of the spike to the apex by using a measuring tape and then their averages calculated. Both the crops were harvested at maturity, tied into bundles in respective plots and biological yield of each treatment was recorded with the help of hand held weighing balance. The crop was harvested in second week of April, 2010 from individual treatment plots, tied into bundles and allowed to sun-dry in respective plots. Each bundle in experimental plot was manually beaten with stick to determine seed yield, which was then converted into t ha^{-1}. A random sample of seeds was taken from each plot and 1000 seeds were counted and weighed. The yield of wheat and canola were recorded by employing standard sampling procedures. Harvest index was calculated as ratio between economic yield to biological yield and presented in percentage.

Land Equivalent Ratio (LER)

Land Equivalent Ratio was calculated by the formula given by Willey (1979) as:

$$\text{Total LER} = \text{LER (wheat)} + \text{LER (canola)}$$

Where, LER (wheat) = Grain yield of wheat grown as intercrop/Grain yield of wheat in monoculture.

LER (canola) = Seed yield of canola grown as intercrop/Seed yield of canola in monoculture.

Economic and Dominance Analysis

Economic and marginal analysis was carried out to find out the most economical and cost-effective treatment of different wheat-canola intercropping combinations. The production expenses of both crops comprised the cost of seed bed preparation, fertilizer, seed, sowing, irrigation, harvesting and threshing charges. The gross revenue was assessed by using the prevalent average market values for both the grain and straw of the wheat and canola crops in Pakistan Rupees. Then, the total costs from the gross income were subtracted to get net income, while benefit-cost ratio (BCR) was calculated by dividing the gross income with total costs. Marginal analysis was performed on the basis of total variable costs and principal market prices of wheat and canola crop following the method established by CIMMYT (1988).

Statistical Analysis

Data collected for various traits subjected to Fisher's analysis of variance. Least significant difference test at 0.05 probability level was used to evaluate differences among the treatments means (Steel *et al.*, 1997).

Results

All the yield and yield related traits of wheat and canola were influenced significantly by different wheat-canola intercropping treatments except 1000-grain weight of wheat, which was found to be non-significant (Table 2 and 3). Number of fertile tillers per m^2 and number of grains per spike are important yield contributing traits of wheat and differed significantly by intercropping treatments as compared to component sole crop of wheat. Higher number of fertile tillers per m^2 (312.75) were recorded in pure stand of wheat and minimum (196.25) in one row of wheat alternating with one row of canola. Likewise, number of grains per spike was significantly higher in pure stand of wheat than intercropping treatments. Row intercropping treatments gave similar number of grains per spike, while mixed intercropping resulted in a higher number of grains per spike compared with one wheat row alternating with one canola row and two wheat rows alternating with two canola rows. Spike length was influenced significantly by different intercropping treatments over its pure stand. A maximum spike length (10.5 cm) was measured in wheat planted alone which was at parity with mixed intercropping of wheat + canola but all intercropping treatments gave statistically equal spike length (Table 2).

Among various yield contributing traits, 1000-grain weight of wheat was not influenced significantly by any of the intercropping treatments, while significant effect of intercropping was observed on 1000-seed weight of canola as compared to canola planted alone except four row of wheat alternating with four rows of canola. Pure stand of canola and four rows of wheat alternating with four rows of canola gave statistically higher 1000-seed weight of canola over one row of wheat alternating with one row of canola and mixed intercropping of wheat + canola (Table 2 and 3). Number of fruiting branches per plant, number of siliques per plant and number of seeds per silique varied significantly by different intercropping treatments compared with component sole crop of canola. Pure stand of canola, two wheat rows alternating with two canola rows and four wheat rows alternating with four canola rows resulted statistically equal number of fruiting branches and siliques per plant but significantly higher over one wheat row alternating with one canola row and mixed intercropping of wheat + canola. A greatest number of seeds per silique (26.50) were recorded in canola planted alone and minimum (20.25) was observed in mixed intercropping of wheat + canola. Row intercropping treatments gave statistically equal number of seeds per silique but significantly lower compared with canola planted alone. Four rows of wheat alternating with four rows of canola resulted higher number of seeds per silique over mixed intercropping of wheat + canola (Table 3).

The grain yield of wheat was significantly higher in its pure stand compared with all intercropping treatments, while it was not influenced significantly by any of the intercropping treatments (Table 4). Seed yield of canola was also significantly higher in its pure stand as compared to different intercropping treatments except four rows of wheat alternating with four rows of canola. Row intercropping gave similar seed yield of canola, while mixed intercropping of wheat + canola sown by broadcast method gave statistically lower seed yield over four rows of wheat alternating with four rows of canola. A higher seed yield of canola (1.72 t ha^{-1}) was recorded in its pure stand (Table 4). Biological yield of wheat and canola were influenced significantly by different wheat-canola intercropping treatments over their pure stand (Table 2 and 3). Pure stand of wheat gave higher biological yield i.e., 16.25 t ha^{-1}, while minimum (8.96 t ha^{-1}) was resulted from two rows of wheat alternating with two rows of canola (Table 2). In case of canola higher biological yield (10.83 t ha^{-1}) was observed in four rows of wheat alternating with four rows of canola that was statistically at par with its pure stand. Mixed intercropping of wheat + canola gave minimum biological yield (6.25 t ha^{-1}) of canola that was statistically at par with one row of wheat alternating with one row of canola (Table 3). Sole stand of wheat and canola crop gave higher harvest index, while smaller harvest index for both wheat and canola crop were observed in mixed intercropping of wheat + canola intercropping system (Table 2 and 3).

Economic analysis showed that all wheat-canola intercropping systems gave higher net benefits.

Table 1: Weather data of the study period

Month	Average monthly temperature (°C)	Average monthly relative humidity (%)	Total rainfall (mm)
November-09	18.2	64.7	0.02
December-09	14.5	64.4	0.0
January-10	11.1	82.3	0.03
February-10	15.7	62.7	0.43
March-10	23.5	57.5	0.28
April-10	30.0	53.0	0.04

Source: Agricultural meteorology cell, Department of Crop Physiology, University of Agriculture, Faisalabad

Table 2: Effect of wheat-canola intercropping systems on yield and related parameters of wheat

Treatments	Number of fertile tillers m^{-2}	Spike length (cm)	Number of grains per spike	1000-grain weight (g)	Biological yield (t ha^{-1})	Harvest index (%)
T1	312.75 a	10.50 a	55.75 a	37.70	16.25 a	24.74 a
T2	196.25 e	9.50 bc	47.25 c	36.85	10.21 bc	23.88 ab
T3	237.50 c	9.50 bc	47.50 c	37.83	8.96 c	22.60 b
T4	221.00 d	9.13 c	48.25 bc	37.62	11.67 b	19.88 c
T5	244.00 b	9.80 abc	50.50 b	37.45	11.15 b	17.91 d
LSD $p \leq 0.05$	4.16	0.96	2.89	NS	1.53	1.94

Where T1= Sole crop of wheat; T2 = One row of wheat alternating with one row of canola (30 cm apart one wheat row); T3 = Two rows of wheat alternating with two rows of canola (45 cm apart two wheat rows); T4 = Four rows of wheat alternating with four rows of canola (75 cm apart four wheat rows); T5 = Mixed intercropping of wheat + canola

Means in a column not sharing a common letter differ significantly by Fisher's protected Least Significant Difference at 5 % probability Level

NS = Non significant

Table 3: Effect of wheat-canola intercropping systems on yield and related parameters of canola

Treatments	Number of fruiting branches per plant	Number of siliques per plant	Number of seeds per silique	1000-seed weight (g)	Biological yield (t ha^{-1})	Harvest index (%)
T1	11.75 a	213.25 a	26.50 a	3.22 a	9.90 ab	17.38 a
T2	7.25 b	143.75 b	22.75 bc	2.84 c	7.29 cd	15.67 b
T3	10.75 a	211.25 a	21.25 bc	2.90 bc	8.23 bc	15.50 b
T4	10.25 a	212.00 a	23.75 b	3.16 ab	10.83 a	15.20 b
T5	5.50 b	105.25 c	20.25 c	2.67 c	6.25 d	13.57 c
LSD $p \leq 0.05$	2.26	3.11	2.72	0.27	1.90	1.27

Where T1= Sole crop of canola; T2 = One row of wheat alternating with one row of canola (30 cm apart one wheat row); T3 = Two rows of wheat alternating with two rows of canola (45 cm apart two wheat rows); T4 = Four rows of wheat alternating with four rows of canola (75 cm apart four wheat rows); T5 = Mixed intercropping of wheat + canola

Means in a column not sharing a common letter differ significantly by Fisher's protected Least Significant Difference at 5 % probability Level

Table 4: Effect of wheat-canola intercropping systems on economic yield and land equivalent ratios of wheat and canola

Treatments	Economic yield (t ha^{-1})		Land equivalent ratio (LER)		
	Wheat	Canola	Wheat	Canola	Total
Sole crop of wheat	4.02 a	-	-	-	-
Sole crop of canola	-	1.72 a	-	-	-
One row of wheat alternating with one row of canola (30 cm apart one wheat row)	2.03 b	1.13 bc	0.50	0.66	1.16
Two rows of wheat alternating with two rows of canola (45 cm apart two wheat rows)	2.14 b	1.29 bc	0.53	0.75	1.28
Four rows of wheat alternating with four rows of canola (75 cm apart four wheat rows)	2.09 b	1.47 ab	0.52	0.85	1.37
Mixed intercropping of wheat + canola	2.52 b	0.95 c	0.63	0.55	1.18
LSD $p \leq 0.05$	0.56	0.37	-	-	-

Four rows of wheat alternating with four rows of canola proved better with higher net income (107492) and higher benefit cost ratio (2.76) compared with other intercropping treatments and sole cropping of wheat and canola; whereas one row of wheat alternating with one row of canola and canola sown as pure stand seemed uneconomical (Table 5).

Marginal analysis also showed that four rows of wheat alternating with four rows of canola was the best treatment with highest (2732%) marginal rate of return (MRR). Moreover, sole plantation of wheat, two rows of wheat alternating with two rows of canola and mixed intercropping of wheat + canola also gave 1383, 821 and 584% MRR, respectively, whereas sole crop of canola and one row of wheat alternating with one row of canola were uneconomical either due to higher cost and relatively less net benefits (Table 6).

Discussion

Yield and yield components of wheat and canola were significantly affected by different wheat-canola intercropping systems (Table 2 and 3). The higher grain

Table 5: Effect of wheat-canola intercropping systems on net income and benefit-cost ratio

Treatments	Total expenses	Gross income	Net income	Benefit cost ratio (BCR)
	Rs.ha^{-1}			
Sole wheat	55242	136121	80879	2.46
One row of wheat alternating with one row of canola (30 cm apart one wheat row)	59373	139706.6	80333	2.35
Two rows of wheat alternating with two rows of canola (45 cm apart two wheat rows)	60406	148585.3	88179	2.46
Four rows of wheat alternating with four rows of canola (75 cm apart four wheat rows)	61113	168605.1	107492	2.76
Mixed intercropping of wheat + canola	59870	143647	83777	2.40
Sole canola	52689.35	98268.5	45579	1.87

Table 6: Effect of wheat-canola intercropping systems on dominance and marginal analysis

Treatments	Total Cost that vary	Net benefits	Marginal Costs	Marginal net benefits	Marginal rate of return %
	(Rs. ha^{-1})				
Sole canola	-	45579	-	-	-
Sole wheat	2553	80879	2553	35300	1383
One row of wheat alternating with one row of canola (30 cm apart one wheat row)	6684	80333	4131	-	D
Mixed intercropping of wheat + canola	7180	83777	497	2898	584
Two rows of wheat alternating with two rows of canola (45 cm apart two wheat rows)	7717	88179	536	4402	821
Four rows of wheat alternating with four rows of canola (75 cm apart four wheat rows)	8424	107492	707	19313	2732

yield of wheat planted alone could be attributed to higher yield components *viz.* number of fertile tillers per m^2 and number of grains per spike compared with wheat-canola intercropping combinations. While, lower yield of wheat and canola in their intercropping systems might be due to competition for resources and allelopathic effects on each other. Olowe and Adeyemo (2009) reported that depending on crops mixed, competition for light, water and nutrients, or allelopathic effects that may occur between mixed crops may reduce yields. Tahir *et al.* (2003b) showed a higher competitive ratio for canola than wheat, indicating that in intercropping system canola was more competitive than wheat when grown in association with each that resulted in lower yield of wheat. Khan *et al.* (2005) asserted that intercropping of wheat with rapeseed in 1:1 ratio resulted in minimum yield advantage over wheat alone. Seed yield of the canola crop is related to several yield components such as number of fruiting branches per plant, number of siliques per plant and 1000-seed weight which are affected by various agronomic practices that are practiced during the production of a crop. So any increase or decrease in above mentioned components result in increase or decrease of yield. A higher seed yield of canola was observed in its pure stand that might be due to less competitive environment among crop plants of same species. A greater reduction in seed yield of canola under mixed intercropping system of wheat with canola lacking distinct row arrangement appear to be due to higher competition between both crops and more competitive capability of wheat than canola (Table 3). In our study, four rows of wheat alternating with four rows of canola gave seed yield similar to pure stand of canola. Canola + one row of wheat intercropping system gave higher canola seed yield compared with other canola based intercropping systems (Tahir *et al.*, 2003a). A maximum seed yield was observed in canola planted alone which differed significantly by other intercropping treatments (Ali *et al.*, 2000).

In wheat-canola intercropping systems, lesser number of fertile tillers per m^{-2}, spike length and number of grains per spike over sole plantation of wheat might be due to negative interaction/competition between both crops (Table 2). Khan *et al.* (2005) noted higher competitive ratio values for canola when grown in association with wheat that ultimately affect yield components of wheat. Likewise, Khan *et al.* (2012) reported a higher number of tillers in wheat as sole crop compared with wheat-canola intercropping systems.

A maximum number of fruiting branches, siliques per plant and seeds per silique were recorded in pure stand of canola might be due to less competitive environment and minimum in mixed intercropping of wheat + canola could be attributed due to competition between closely spaced plants for nutrients, light and moisture. Ali *et al*. (2000) also calculated higher number of fruiting branches and siliques per plant in pure stand of canola, while minimum in case of canola intercrop with three rows of wheat. Different wheat-canola intercropping systems did not influence the 1000-grain weight of wheat; whereas 1000-seed weight of canola was influenced significantly (Table 2 and 3). Khan *et al.* (2012) also recorded similar test weight for wheat planted alone or as intercrop, while 1000-seed weight of canola influenced significantly by different wheat-canola intercropping systems. A higher 1000-seed weight recorded in canola planted alone might be due to lesser competition, while in mixed intercropping, competition of individuals from diverse species make concurrent require of inputs that go beyond limited resources that results in lower seed weight (Ali *et al.,* 2000).

In our study, harvest index and biological yield of both wheat and canola was influenced significantly by different wheat-canola intercropping systems. In their work, Khan *et al.* (2012) observed similar harvest index for wheat planted alone or as intercrop, while for canola it was influenced significantly by different wheat-canola intercropping systems. They observed that sole plantation of canola gave higher biological yield and harvest index, while smaller was observed in 3 rows of wheat + 1 row of synthetic canola intercropping system. The reduction in biological yield and harvest index of different wheat-canola intercropping systems might be due to their interspecific competition between both crops for shared resources. Szumigalski and Van Acker (2005) revealed that reduction in biological yield of canola as a result of two or three rows of wheat is probably due to enlarged competition of both crops for growth resources, while lack of inter-specific competition among canola crop planted alone might be the reasons of their higher biological yield compared with their intercropping treatments (Tahir *et al*., 2003b; Imran *et al*., 2011).

The effectiveness of any production system is ultimately evaluated on the basis of its economics. To determine which treatment gives highest net return is based on economic analysis; relative involvement of extra costs is based on marginal analysis while Land equivalent ratio (LER) is used to measure the efficiency of any intercropping systems. A higher LER (1.37) showed that intercropping generates a greater yield on a certain piece of land by making use of resources that would otherwise not be utilize by component crops grown as pure stand. In present study, four rows of wheat alternating with four rows of canola produced higher net income, benefit cost ratio, marginal rate of return and LER compared with all other intercropping systems and sole plantation of wheat and canola crop (Table 4–6). Crop yield were comparable among intercrops and sole plantation of wheat and canola (Hummel *et al.*, 2009a) as yield improvement was observed in wheat-canola intercropping treatment i.e. mean LER higher than one (Nelson *et al.,* 2006). Intercropping resulted in enhanced use of resources, in comparison with monoculture (Sobkowicz, 2006) and 4 rows of wheat + 2 rows of hybrid canola recorded higher net income, benefit-cost ratio and marginal rate of return (Khan *et al*., 2012). A higher land equivalent ratio, area-time equivalent ratio and net benefits were observed in canola + one row of wheat compared with other intercropping systems and sole plantation of canola (Tahir *et al*., 2003a).

This work is the first effort on growing wheat and canola crop in mixed culture with no distinct row arrangement. In conclusion, wheat-canola intercropping systems under two spatial patterns reduced yield of wheat but canola crop growing in pattern of four rows of wheat alternating with four rows of canola gave almost equivalent yield over sole plantation of canola. Nevertheless, wheat-canola intercropping is pragmatic and productive practice in terms of higher net benefits and marginal rate of return over sole cropping of either component crops. Therefore, farmer should be sown wheat-canola in the pattern of four rows of wheat alternating with four rows of canola for enhanced productivity and domestic oilseed production in sub-tropical to tropical agro-ecological conditions of Pakistan.

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