CHILEANJAR
CHILEAN JOURNAL of AGRICULTURAL RESEARCH

SCIENTIFIC NOTE

WEED DYNAMICS IN WHEAT-CANOLA INTERCROPPING SYSTEMS

Muhammad Naeem[1*], Zahid Ata Cheema[1], Azraf-ul-Haq Ahmad[1], Abdul Wahid[2], Muhammad Kamaran[1], and Muhammad Arif[1]

Weeds cause huge losses due to their competition with crops. Intercropping of wheat (*Triticum aestivum* L.) with canola (*Brassica napus* L.) under different spatial arrangements was evaluated for their effects on weeds and interaction between the crops at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan, during 2009-2010. The treatments included wheat (line sowing), canola (line sowing), wheat (broadcast method), one row of wheat + one row of canola (30 cm apart), two rows of wheat + two rows of canola (45 cm apart), four rows of wheat + four rows of canola (75 cm apart) and mixed cropping of wheat + canola (broadcast method). The results revealed that all intercropping treatments significantly affected weed density and dry weight over component sole crop of wheat. Mixed cropping of wheat + canola suppressed dry weight of *Phalaris minor* Retz., *Chenopodium album* L., *Rumex dentatus* L., and *Coronopus didymus* L. by 94, 77.2, 77.4, and 92%, respectively, over sole crop of wheat. The other intercropping treatments like one row of wheat + one row of canola, two rows of wheat + two rows of canola, and four rows of wheat + four rows of canola generally suppressed total dry weight of weeds by 81, 74, and 76%, respectively. Four rows of wheat + four rows of canola gave the highest land-equivalent ratios 1.37 and net benefit Rs 93 543 followed by two rows of wheat + two rows of canola. It is suggested that wheat-canola intercropping system in agro ecological conditions of Faisalabad could enhance land-equivalent ratio > 1 (over-yielding) by suppressing weeds.

Key words: Intercropping, *Brassica napus*, *Triticum aestivum*, weeds.

Wheat (*Triticum aestivum* L.) is used as one of the key food source all over the world including Pakistan, it is cultivated on an area of 8805 thousand hectares with 23.31 million tones total production; while canola (*Brassica napus* L.) is being grown on an area of about 0.142 million hectares with 0.076 million tones total seed production (Government of Pakistan, 2010-2011). The factors such as low nutrient use efficiency, less rainfall/irrigation, waterlogged and salt affected soils and late sowing are limiting crop yield, but one of them, very serious and less attended is weed infestation (Montazeri *et al*., 2005). Zand *et al*. (2007) illustrated that 30% grain yield losses are associated with weed infestation. The extensive use of herbicides in modern agriculture to control weeds has given rise to concerns about herbicide residues in the environment and the fast increase of herbicide resistance. Worldwide, over 383 weed species have now been reported to have developed resistance to important herbicides (Heap, 2012). The emergence of herbicide resistant weed species is therefore threatening sustainable farming production and has resulted in enlarged economic loss and related environmental problems.

Intercropping considered to be an important agronomic practice which can be used for decreasing the reliance on synthetic herbicides in weed control (Banik *et al*., 2006) as it generates beneficial biological interactions between crops, increasing grain yield, stability and more efficient utilization of available resources that ultimately results in reducing weed pressure (Kadziuliene *et al*., 2009). Various intercrop treatments (e.g., wheat-canola and wheat-canola-pea [*Pisum sativum* L.]) tended to generate greater weed suppression compared with component sole crops, indicating synergism among crops within intercrops with regard to weed suppression (Szumigalski and Van Acker, 2005). Khorramdel *et al*. (2010) conducted an experiment with following treatments i.e. canola and wheat alone, one row of canola + one row of wheat (1:1), two rows of canola + two rows of wheat (2:2), three rows of canola + three rows of wheat (3:3) and four rows of canola + four rows of wheat (4:4). Data on weed density and DM revealed that the maximum and minimum values of weeds DM were observed in wheat alone and four rows of canola + four rows of wheat, respectively. There are two probable causes for the decline of weed biomass in intercropping systems i.e. some species release allelopathic compounds which limit the occurrence of weed (Wanic *et al*., 2004) and intercropping provides an efficient utilization of available resources (Eskandari and Ghanbari, 2009; Olorunmaiye, 2010). The main principle of better resource use in

[1]University of Agriculture, Department of Agronomy, Faisalabad-38040, Pakistan.
[*]Corresponding author (mnaeemuaf35@gmail.com).
[2]University of Agriculture, Department of Botany, Faisalabad-38040, Pakistan.
Received: 23 November 2011.
Accepted: 25 June 2012.

intercropping is that if crops differ in the way they utilize environmental resources when grown together, they can complement each other and make better combined use of resources than when they grow as exclusively (Ghanbari-Bonjar, 2000). Wheat contains different types of allelochemicals, namely, phenolic acids, hydroxamic acids, vanillic acid, para-coumaric acid, syringic acid, and ferulic acid having allelopathic and weed suppressing ability (Wu *et al*., 2000; 2001).

Al-Khatib *et al*. (1999) reported that canola used as green manure crop suppressed many grassy and broadleaf weeds due to their content of volatile glucosinolates and their breakdown products such as isothiocyanates, nitriles, epithinitriles, and ionic thiocyanates (Vaughn and Boydston, 1997). These are the most common and potent germination inhibitors and can be used as promising bio-herbicides (Vaughn, 1999). The objective of this study was to investigate weeds growth under wheat-canola combinations and their influence on crop yields.

MATERIALS AND METHODS

Soil and site

The experiment was conducted at Agronomic Research Area, University of Agriculture, Faisalabad (31.25° N and 73.09° E), Punjab, Pakistan, during the winter of 2009-2010 to evaluate weed dynamics under wheat-canola intercropping systems. The experiment was carried in a randomized complete block design (RCBD) with four replicates in plots measuring 6.0 m × 2.4 m. The experimental soil belongs to Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification) and Haplic Yermosols in FAO classification scheme.

Experimental material and details

Wheat cv. Sehar-2006 and intercrop canola hybrid Hiola-401 were planted at same time on a well prepared seed bed using a single row hand drill on 26 November 2009. Sole crop of wheat and canola were sown in 30 cm spaced rows. Wheat and canola seed were used at 125 and 5 kg ha^{-1} respectively for drill sowing and 150 kg ha^{-1} for wheat sown by broadcast method. Nitrogen and P in the form of urea and diammonium phosphate were applied at 120 and 110 kg ha^{-1}, respectively. Half of 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 given 20 d after sowing and following irrigations were adjusted according to the climatic conditions and need of the crop.

The treatments included wheat and canola alone (line sowing), wheat alone (broadcast method), one row of wheat + one row of canola (30 cm apart), two rows of wheat + two rows of canola (45 cm apart), four rows of wheat + four rows of canola (75 cm apart) and mixed cropping of wheat + canola (broadcast method).

Measurements

Data regarding individual and total weed density and dry weight in a unit area was recorded with the help of quadrate measuring 0.5 m × 0.5 m randomly used at two places in each experimental unit. Weeds were allowed to dry under shade for 10 d, then oven dried at 70 °C and their dry weight was recorded. Wheat and canola crop was harvested and threshed manually in second week of April 2010 from individual treatment plots; grain yield was weighed in kilograms and expressed as t ha^{-1}. Yield of wheat and canola were recorded by standard sampling techniques.

Land equivalent ratio (LER)

Land equivalent ratio was calculated by the formula:

$$\mathrm{LER} = \frac{\textit{Yield of intercrop A}}{\textit{Yield of pure stand}} + \frac{\textit{Yield of intercrop B}}{\textit{Yield of pure stand}}$$

Economic analysis

Economic analysis was performed to determine the most economical treatment.

Statistical analysis

Data collected for different parameters were subjected to Fisher's ANOVA technique. Least significant difference (LSD) test at 0.05 probability level was used to compare differences among the treatment means (Steel *et al*., 1997).

RESULTS AND DISCUSSION

Weed flora of the experimental site consisted of little seed canary grass (*Phalaris minor* L.), lamb's-quarters (*Chenopodium album* L.), broadleaf dock (*Rumex dentatus* L.) and swine cress (*Coronopus didymus* L.) while other weeds were less in number. Table 1 presented the data on individual and total weed density and dry weight. Data pertaining to total weed density showed that all intercropping treatments significantly affected weed density over component sole crop of wheat. The suppression of total weed density in mixed cropping of wheat + canola plots were significantly higher i.e. 81% as compared to sole crop of wheat sown by drill method. The other intercropping treatments like one row of wheat + one row of canola, two rows of wheat + two rows of canola and four rows of wheat + four rows of canola generally suppressed total weed density by 77, 72.9, and 72% respectively. Wheat alone sown by broadcast method was also significantly depressed the total weed density by 60% as compared to wheat alone sown by drill method. The reduction in total weed density in intercropping treatments was more with the development of the crop, possibly due to more crop canopy and their synergistic allelopathic effects. These findings are supported by Szumigalski and Van Acker (2005), that intercropping of wheat with canola tended to provide

Table 1. Effect of wheat-canola intercropping systems on total and individual weed density and dry biomass production of common wheat weeds.

	Total weed data		Little seed canary grass (*Phalaris minor* Retz.)		Lamb's-quarters (*Chenopodium album* L.)		Broadleaf dock (*Rumex dentatus* L.)		Swine cress (*Coronopus didymus* L.)	
Treatments	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight
	m^{-2}	$g\ m^{-2}$	m^{-2}	$g\ m^{-2}$	m^{-2}	$g\ m^{-2}$	m^{-2}	$g\ m^{-2}$	m^{-2}	$g\ m^{-2}$
Wheat alone (line sowing)	473.00a	26.80a	18.50a	5.03a	19.00b	3.20a	11.00a	0.62b	314.00a	10.80a
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Wheat alone (broadcast method)	189.00c	8.45c	4.75c	0.98bc	11.50de	1.50d	10.50ab	0.76a	108.50b	2.60bc
	(60.0%)	(-68%)	(-74.3%)	(-84%)	(-39.5%)	(-53%)	(-4.55%)	(22.5%)	(-65.5%)	(-76%)
Canola alone (line sowing)	225.00b	17.30b	18.00a	3.45ab	21.50a	3.20a	11.00a	0.76a	80.50c	3.08b
	(52.4%)	(-35%)	(-2.7%)	(-39%)	(-13.2%)	(0%)	(0%)	(23%)	(-74.4%)	(-71%)
One row of wheat + one row of	108.00e	5.10e	4.75c	0.67bc	12.75d	2.10c	7.50b	0.33d	54.50e	1.11c
canola (30 cm apart)	(77.2%)	(-81%)	(-74.3%)	(-93%)	(-32.9%)	(-34%)	(-31.8%)	(-46%)	(-82.6%)	(-90%)
Two rows of wheat + two rows	128.00d	6.47d	2.00d	0.56c	16.00c	2.55b	13.00a	0.41cd	56.50e	2.73bc
of canola (45 cm apart)	(72.9%)	(-76%)	(-89.2%)	(-94%)	(-15.8%)	(-20%)	(-18.2%)	(-33%)	(-82%)	(-75%)
Four rows of wheat + four rows	131.00d	7.10d	8.25b	1.69bc	13.50d	1.52d	10.00ab	0.46c	64.00d	1.52bc
of canola (75 cm apart)	(72.3%)	(-74%)	(-55.4%)	(-67%)	(-28.9%)	(-53%)	(-9.09%)	(-25.8%)	(-79.6%)	(-86%)
Mixed cropping of wheat +	89.50f	2.80f	2.50d	0.50c	10.00e	0.73e	2.00c	0.14e	48.00f	0.88c
canola (broadcast method)	(81%)	(-90%)	(-86.5%)	(-94%)	(-47.4%)	(-77.2%)	(-81.8%)	(-77.4%)	(-84.7%)	(-92%)
LSD at 5% probability Level	9.55	0.89	1.63	2.90	2.25	0.37	3.13	0.09	5.30	1.90

In parenthesis percentage decrease in density and dry weight of weeds as compared to control; LSD: Least significant difference.
Means in a column not sharing a common letter differ significantly by Fisher's protected LSD at 5% probability level.

greater weed suppression as compared with component sole crop, indicating some kind of synergism among them because wheat and various species of brassicaceae have allelopathic potential in weed suppression (Al-Khatib *et al*., 1997; Wu *et al*., 2000).

Data revealed that all intercropping treatments significantly reduced total weed dry weight over component sole crop of wheat sown by drill method (Table 1). Of all the intercropping treatments i.e. mixed cropping of wheat + canola appeared relatively more effective with 90% inhibition in total weed dry weight. While, other intercropping treatments like one row of wheat + one row of canola, two rows of wheat + two rows of canola and four rows of wheat + four rows of canola generally suppressed weed dry weight by 90, 85, and 86%, respectively. This weed control in wheat-canola intercropping systems might be due to either their shading effect/interference (allelopathy + competition) or better utilization of available resources than their component sole crops and Wanic *et al*. (2004) said that some species release allelopathic compounds which limit the occurrence of weeds, while Eskandari and Ghanbari (2009) revealed that intercropping provides an efficient utilization of available resources.

Little seed canary grass frequently grows during the winter season in wheat crop and several other winter crops. Little seed canary grass density and dry weight influenced significantly by different wheat-canola intercropping systems and was lowest in mixed cropping of wheat + canola sown by broadcast method, i.e. 86.5 and 94% respectively over component sole crop of wheat sown by drill method. Dry weight of little seed canary grass was also significantly lower in wheat alone sown by broadcast method where inhibition was up to 84% over control (Table 1). Mixed cropping of wheat + canola was better than other intercropping systems because both crops interact closely with each other and suppressed weeds by releasing different types of allelochemicals and better utilization of available resources. Kamunya *et al*. (2008) exposed that effects of plant-plant interactions like interference positively effects on pest suppression.

Lamb's-quarters is an important weed of wheat. All wheat-canola intercropping systems significantly affected density and dry weight of lamb's-quarters as compared to component sole crop of wheat. Mixed cropping of wheat + canola suppressed lamb's-quarters density and dry weight by 47.4 and 77.2% respectively, while other intercropping treatments like one row of wheat + one row of canola and four rows of wheat + four rows of canola suppressed lamb's-quarters density by 32.9 and 28.9% and dry weight by 34 and 53% respectively (Table 1). This weed suppression in all intercropping treatments and broadcasted sole crop of wheat may be due to their allelopathic interference and shading effect. Khorramdel *et al*. (2010) supported this work and revealed that row intercropping of wheat with canola results in lowest amounts of relative frequency for lamb's-quarters with 36.4-62.8%.

Among the broad-leaf weeds, broadleaf dock is one of major concern in irrigated wheat fields in Pakistan as it is highly competitive and can cause drastic yield reduction under heavy infestation (Siddiqui and Bajwa, 2001). Broadleaf dock density and dry weight influenced significantly by different wheat-canola intercropping systems and was lowest in mixed wheat-canola intercropping systems as it reduced its density by 81.8% and dry weight by 77% over component sole crop of wheat. It might be due to valuable biological relations between wheat and canola that results in more efficient utilization of available resources and reducing weed pressure. This weed suppression may be due to their allelopathic interference or canopy shading. Olorunmaiye (2010) revealed that greater crop yield and less weed growth might be achieved if intercrops are more effective than sole crops in usurping resources from weeds or suppressing growth of weeds through allelopathy and Ibeawuchi (2007) also revealed that intercropping suppresses weeds, reduces pest, disease infestation and gives yield advantage over time.

Swine-cress is an annual or biennial herb that occurs locally in waste and cultivated places. Its density and dry weight was significantly lower in all intercropping treatments, sole crop of wheat sown by broadcast method and sole crop of canola. Mixed cropping of wheat + canola reduced swine cress density and dry weight by 84.7 and 92% respectively (Table 1). This reduction in density and dry weight by all wheat-canola intercropping systems may be due to development of the crop, possibly due to more crop canopy and their synergistic allelopathic effects. These findings are confirmed by Wanic *et al*. (2004), who revealed that some species release allelopathic compounds which limit the occurrence of weeds and Eskandari and Ghanbari (2009) said that intercropping provides an efficient utilization of available resources by the crop plants. Broadcasted sole crop of wheat also suppressed swine cress density and dry weight up to 65.5 and 76% respectively (Table 1).

The grain yield is the collective influence of various parameters of plant growth and yield components. Intercropping of wheat with canola significantly reduce yield of wheat as compared to component pure stand of wheat (Table 2). The higher grain yield (4.02 t ha^{-1}) was recorded in component sole crop of wheat sown by drill method and lowest (2.03 t ha^{-1}) was recorded in one row of wheat + one row of canola. The reduction of yield in case of different wheat-canola intercropping systems may be due to dominant plant height of canola causing over shading, more nutrient use efficiency and light competition with wheat. Olowe and Adeyemo (2009) supported these findings and revealed that depending on crops mixed, competition for light, water and nutrients, or allelopathic effects that may occur between mixed crops may reduce yields.

Seed yields of canola was also significantly reduced by different wheat-canola intercropping systems except four rows of wheat + four rows of canola where it was statistically at par with sole crop of canola. The higher seed yield of canola (1.72 t ha^{-1}) was recorded in its pure stand and lowest (0.95 t ha^{-1}) was observed in mixed cropping of wheat + canola (Table 2). The lowest seed yield of canola in mixed cropping of wheat + canola might be due to vigorous competition between both crops for resources because of no distinct row arrangement and more competitive ability of wheat than canola and it also revealed that when wheat was grown in association with canola it competes well than other crops (Ali, 1999).

Land equivalent ratio (LER) was also higher in all intercropping treatments that results in over-yielding over pure stand of wheat and canola. Maximum LER (1.37) (Table 2), net benefits (Rs 93 543, Tables 3 and 4) and marginal rate of return (3076.11%, Table 3) was obtained in case of four rows of wheat + four rows of canola just by spending Rs 4241 ha^{-1} over sole crop of wheat and canola sown by drill method. The other intercropping treatment i.e. two rows of wheat + two rows of canola was also economical with Rs 87 907 net benefits (Tables 3 and 4). The highest LER showed that intercropping generates a greater yield on a certain piece of land by make use of resources that would otherwise not be utilized by component sole crops. It may be due to override positive effect of intercropping on weed suppression that resulted in efficient utilization of resources by the crop plants. These findings are in accord with Ali *et al*. (2000), who stated that intercropping of wheat and canola gave maximum LER, net return and benefit cost ratio.

Table 2. Yields of wheat and canola from intercrops and Land Equivalent Ratio (LER).

Treatments	Wheat yield	Canola yield	LER
	—— t ha^{-1} ——		
Wheat alone (line sowing)	4.02	-	-
Wheat alone (broadcast method)	3.92	-	-
Canola alone (line sowing)	-	1.72	-
One row of wheat + one row of canola (30 cm apart)	2.03	1.13	1.16
Two rows of wheat + two rows of canola (45 cm apart)	2.14	1.29	1.28
Four rows of wheat + four rows of canola (75 cm apart)	2.09	1.47	1.37
Mixed cropping of wheat + canola (broadcast method)	2.52	0.95	1.18

CONCLUSIONS

It is concluded that wheat-canola intercropping system in agro ecological conditions of Faisalabad could suppresses weeds and reduces pest infestation through interference as compared with sole component crops and gives yield advantage over time. Meanwhile, four rows of wheat + four rows of canola appeared to be a productive practice both in terms of weed suppression and higher net benefits and marginal rate of return over sole cropping of either component crops.

Table 3. Dominance and marginal analysis.

Treatments	Total cost that vary	Net benefits	Marginal costs	Marginal net benefits	Marginal rate of return
	———	——— Rs	———	———	%
Wheat alone (line sowing)	0	85 945	-	-	-
Wheat alone (broadcast method)	0	83 719	-	-	D
Canola alone (line sowing)	0	62 253	-	-	D
Mixed cropping of wheat + canola (broadcast method)	3994	84 008	-	-	D
Four rows of wheat + four rows of canola (75 cm apart)	4241	93 543	247	7598	3076.11
Two rows of wheat + two rows of canola (45 cm apart)	4241	87 907	-	-	D
One row of wheat + one row of canola (30 cm apart)	4241	79 605	-	-	D

Exchange rate: 1 US dollar = 55.49 Indian rupees (Rs).

Table 4. Economic analysis of wheat-canola intercropping systems.

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Remarks
Wheat yield,	4020.8	3916.7	-	2031.3	2135.4	2083.3	2520.8	kg ha^{-1}
Adjusted wheat yield	3619	3525	-	1828	1922	1875	2269	10% less than actual yield to equate with farmers level
Income	85945	83719	-	43418	45645	44531	53883	Wheat: Rs 950 40 kg^{-1}
Canola yield	-	-	1729.3	1123.0	1291.8	1479.3	947.8	kg ha^{-1}
Adjusted canola yield	-	-	1556.3	1010.7	1162.6	1331.3	853.0	10% less than actual yield to equate with farmers level
Income	-	-	62253	40428	46503	53253	34119	Canola: Rs 1600 40 kg^{-1}
Gross income	85945	83719	62253	83846	92148	97784	88002	Rs ha^{-1}
Canola seed value	-	-	-	3500	3500	3500	3500	Canola seed rate 5 kg ha^{-1} seed cost Rs 700 kg^{-1}
Sowing charges	-	-	-	741	741	741	494	Intercrop drill sowing charges Rs 741 ha^{-1} Broadcast charges Rs 494 ha^{-1}
Cost that vary	0	-	-	4241	4241	4241	3994	Rs ha^{-1}
Net benefits	85945	83719	62253	79605	87907	93543	84008	Rs ha^{-1}

T_1: Wheat alone (line sowing), T_2: wheat alone (broadcast method), T_3: canola alone (line sowing), T_4: one row of wheat + one row of canola (30 cm apart), T_5: two rows of wheat + two rows of canola (45 cm apart), T_6: four rows of wheat + four rows of canola (75 cm apart), T_7: mixed cropping of wheat + canola (broadcast method).
Exchange rate: 1 US dollar = 55.49 Indian rupees (Rs).

ACKNOWLEDGEMENTS

I wish to thank Z.A. Cheema, A.H. Ahmad and A. Wahid for providing the assistance and guidance for conducting this experiment and smooth execution of this manuscript. I would also like to acknowledge the contributions of M. Kamran and M. Arif for their assistance in the field.

Dinámica de malezas en sistemas de intercultivo trigo-canola. Las malezas causan grandes pérdidas debidas a competencia con los cultivos. El intercultivo de trigo (*Triticum aestivum* L.) con canola (*Brassica napus* L.) bajo diferentes arreglos espaciales se evaluó por sus efectos en malezas e interacción entre los cultivos en el Área de Investigación Agronómica, Universidad de Agricultura, Faisalabad, Paquistán, durante 2009-2010. Los tratamientos incluyeron trigo (siembra lineal), canola (siembra lineal), trigo (siembra al voleo), una hilera de trigo + una hilera de canola (separadas 30 cm), dos hileras de trigo + dos hileras de canola (separadas 45 cm), cuatro hileras de trigo + cuatro hileras de canola (separadas 75 cm) y cultivo mixto de trigo + canola (siembra al voleo). Los resultados revelaron que todos los tratamientos de intercultivo afectaron significativamente densidad y peso seco de la maleza sobre el cultivo de trigo solo. El cultivo mixto de trigo + canola redujo el peso seco de *Phalaris minor* Retz., *Chenopodium album* L., *Rumex dentatus* L., y *Coronopus didymus* L. en 94; 77,2; 77,4; y 92%, respectivamente, sobre el cultivo de trigo solo. Los otros tratamientos de intercultivo como una hilera de trigo + una hilera de canola, dos hileras de trigo + dos hileras de canola, y cuatro hileras de trigo + cuatro hileras de canola generalmente redujeron peso seco total de las malezas en 81, 74, y 76%, respectivamente. Cuatro hileras de trigo + cuatro hileras de canola dieron las relaciones equivalente tierra más altas de 1,37 y beneficio neto de Rs 93 543 seguido por dos hileras de trigo + dos hileras de canola. Se sugirió que el sistema de intercultivo trigo-canola en condiciones agroecológicas de Faisalabad pudo aumentar la relación equivalente tierra > 1 (sobre-producción) al suprimir las malezas.

Palabras clave: cultivo intercalado, *Brassica napus*, *Triticum aestivum*, malezas.

LITERATURE CITED

Al-Khatib, K., and R.A. Boydston. 1999. Weed control with Brassica green manure crops. p. 255-270. *In* Narwal, S.S. (ed.) Allelopathy update. Vol. 2. Basic and applied aspects. Oxford & Ibh Publishing, New Delhi, India.

Ali, Z. 1999. Agro-economics of different canola-based wheat intercropping systems. MSc (Hons.) thesis. University of Agriculture, Department of Agronomy, Faisalabad, Pakistan.

Ali, Z., M.A. Malik, and M.A. Cheema. 2000. Studies on determining a suitable canola-wheat intercropping pattern. International Journal of Agriculture and Biology 2(1-2):42-44.

Banik, P., A. Midya, B.K. Sarkar, and S.S. Ghose. 2006. Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. European Journal of Agronomy 24:325-332.

Eskandari, H., and A. Ghanbari. 2009. Intercropping of maize (*Zea mays*) and cowpea (*Vigna sinensis*) as whole-crop forage: Effect of different planting pattern on total dry matter production and maize forage quality. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 37:152-155.

Ghanbari-Bonjar, A. 2000. Intercropped wheat and bean as a low-input forage. PhD thesis. Wye College, University of London, Kent, UK.

Government of Pakistan. 2010-2011. Economic survey 2010-2011. p. 20-21. Economic Advisor's Wing, Finance Division, Islamabad, Pakistan.

Heap, I. 2012. International Survey of Herbicide Resistant Weeds. Online. Available at http://www.weedscience.com/ (accessed 21 June 2012).

Ibeawuchi, I.I. 2007. Intercropping - A food production strategy for the resource-poor farmers. Nature and Science 5:46-59.

Kadziuliene, Z., L. Sarunaite, I. Deveikyte, S. Maiksteniene, A. Arlauskiene, L. Masilionyte, *et al*. 2009. Qualitative effects of pea and spring cereals intercrop in the organic farming systems. Agronomy Research 7:606-611.

Kamunya, S.M., F.N. Wachira, J. Lang'at, W. Otieno, and V. Sudoi. 2008. Integrated management of root knot nematode (*Meloidogyne* spp.) in tea (*Camellia sinensis*) in Kenya. International Journal of Pest Management 54:129-136.

Khorramdel, S., L. Rostami, A. Koocheki, and J. Shabahang. 2010. Effects of row intercropping wheat (*Triticum aestivum* L.) with canola (*Brassica napus* L.) on weed number, density and population. p. 411-414. Proceedings of 3rd Iranian Weed Science Congress. Vol. 1. Weed biology and ecophysiology, Babolsar, Iran. 17-18 February 2010.

Montazeri, M., E. Zand, and M.A. Baghestani. 2005. Weeds and their control in wheat fields of Iran. Advances in Agronomy 58:57-93.

Olorunmaiye, P.M. 2010. Weed control potential of five legume cover crops in maize/cassava intercrop in a Southern Guinea savanna ecosystem of Nigeria. Australian Journal of Crop Science 4:324-329.

Olowe, V.I.O., and A.Y. Adeyemo. 2009. Enhanced crop productivity and compatibility through intercropping of sesame and sunflower varieties. Annals of Applied Biology 155:285-291.

Siddiqui, I., and R. Bajwa. 2001. Variation in weed composition in wheat fields of Lahore and Gujranwala divisions. Pakistan Journal of Biological Sciences 4:492-504.

Steel, R.G.D., J.H. Torrie, and D.A. Dickey. 1997. Principles and procedures of statistics: A biometrical approach. 3rd ed. p. 172-177. McGraw Hill Book, Columbus, Ohio, USA.

Szumigalski, A., and R. Van Acker. 2005. Weed suppression and crop production in annual intercrops. Weed Science 53:813-825.

Vaughn, S.F. 1999. Glucosinolates as natural pesticides. p. 81-94. *In* Cutler, H.G., and S.J. Cutler (eds.) Biologically active natural products: Agrochemicals. CRC Press, Boca Raton, Florida, USA.

Vaughn, S.F., and R.A. Boydston. 1997. Volatile allelochemicals released by crucifer green manures. Journal of Chemical Ecology 23:2107-2116.

Wanic, M., M. Kostrzewska, and M. Jastrzebska. 2004. Role of intercrop sowing in weeds control for spring barley in cereal crops rotation. Fragmenta Agronomica 1:85-102.

Wu, H., T. Haig, J. Pratley, and D. Lemerle. 2000. Distribution and exudation of allelochemicals in wheat (*Triticum aestivum*). Journal of Chemical Ecology 26:2141-2154.

Wu, H., J. Pratley, D. Lemerle, and T. Haig. 2001. Allelopathy in wheat (*Triticum aestivum* L.) Annals of Applied Biology 139:1-9.

Zand, E., M.A. Baghestani, S. Soufizadeh, A. Eskandari, R. PourAzar, and M. Veysi. 2007. Evaluation of some newly registered herbicides for weed control in wheat (*Triticum aestivum* L.) in Iran. Crop Protection 26:1349-1358.