

# Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering

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## Abstract

For increasing land use efficiency and weed suppression intercropping plays a pivotal role. A field experiment was carried out on wheat (*Triticum aestivum* L. emend. Fiori and Paol)–chickpea (*Cicer arietinum* L.) mono- and intercropping with various weeding (0, 1, or 2 hand-weeding operations) and row spacing (20- or 30-cm) treatments in the eastern plateau region of India over consecutive five winter seasons (1997/2001). The experimental design was a randomized complete block with eighteen treatments replicated thrice. Significant ( $P \leq 0.05$ ) differences were observed in yield and economics with and without weeding treatments. Chickpea yield was significantly reduced by wheat when intercropped. However, total productivity and land use efficiency were higher under the intercropping system as compared to monocrops of either species. There was a significant reduction in weed density and biomass for the intercropping system over both monocrops. Wheat facilitated an increase in nodule number and dry weight in chickpea under intercropping over monocrops, moreover, root length of chickpea was greater when intercropped. These findings suggest that intercropping wheat and chickpea increase total productivity per unit area, improve land use efficiency and suppress weeds, a menacing pest in crop production. Considering the experimental findings, wheat–chickpea (30 cm) with two weedings may be recommended for yield advantage, higher net income, more efficient utilization of resources, and weed suppression as a biological control in eastern plateau region of India.

**Keywords:** Wheat/chickpea monocropping; Wheat–chickpea intercropping; Additive series; Complementarity; Weed smothering; Row spacing; Inter-specific competition; Economics

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## 1. Introduction

Wheat (*Triticum aestivum* L. emend. Fiori and Paol), the most important cereal in the world, and chickpea (*Cicer arietinum* L.), the third most important pulse crop play a vital role in global agricultural economy (FAO, 2003). In the eastern plateau region of India, the most commonly grown winter cereal and pulse crops are also wheat and chickpea; however, because the fragile, whimsical nature of weather and degraded soil configuration offer little opportunity for stable agricultural production, monocropping cannot ensure stability of production (Banik et al., 2000).

Again, at adequate density, the yield of uniformly distributed crop plants can be optimised by suppressing weeds (Johri et al., 1992; Weiner et al., 2001) and deploying nutrients (Midya et al., 2005; Scott et al., 1987). It is generally accepted that yield increases when wheat rows are narrowly spaced. This, however,

is not always supported by the literature (Crabtree and Rupp, 1980; Teich et al., 1993; McLeod et al., 1996; Lafond and Gan, 1999; Hiltbrunner et al., 2004).

Intercropping has gained interest because of potential advantages it offers over yielding, i.e. improved utilization of growth resources by the crops and improved reliability from season to season. When a legume is grown in association with another crop (intercropping), commonly a cereal, the nitrogen nutrition of the associated crop may be improved by direct nitrogen transfer from the legume to cereal (Giller and Wilson, 1991). Legumes, with their adaptability to different cropping patterns and their ability to fix nitrogen, may offer opportunities to sustain increased productivity (Jeyabal and Kuppaswamy, 2001). Therefore, productivity normally is potentially enhanced by the inclusion of a legume in a cropping system (Maingi et al., 2001). Legume intercrops are also potential sources of plant nutrients that complement/supplement inorganic fertilizers (Banik and Bagchi, 1994; Ofori and Stern, 1987).

In addition, legume intercrops are included in cropping systems because they reduce soil erosion (Giller and Cadisch, 1995) and suppress weeds (Exner and Cruse, 1993). Harsh

environmental conditions under eastern plateau (Banik et al., 2006), which is detrimental to crop plants, may be congenial for weeds, the menacing pest in crop production. Use of herbicides in any crop mixture is a risky endeavour and not an eco-friendly approach. Biological, and cultural weed control are important components of Integrated Weed Management. Of late, researchers are confronted with the complex problem of weed management by ecological means, giving due consideration to minimal use of chemicals with least disturbance to the environment. Weed management in intercropping, however, has hardly been studied to date (Altieri and Liebman, 1986; Moody and Shetty, 1979; Midya et al., 2005).

Very little research attention has been given to biological weed control using crop mixtures in winter crops in the eastern plateau area. The major objective of this study was therefore, to investigate the wheat–chickpea intercropping as a biological weed control measure in the sub-tropical, mid-uplands of the plateau region of India. Another objective of the study was also to examine the complementarity of the intercropping system root penetration depth and nodulation pattern of chickpea as influenced with the association of wheat and complex crop–weed interaction under the intercropping system.

## 2. Materials and methods

### 2.1. Experimental site

The experiments were conducted at Agricultural Experimental Farm, Indian Statistical Institute, Giridih, India (24°1'32"N; 86°3'12"E; elev. 280.4 m) in the eastern plateau region of India. Initial soil samples were collected using a screw auger to a 15–20 cm depth. Organic carbon and available N, P and K were analyzed adapting a method outlined by Jackson (1973). The soil of the study area was well-drained sandy loam (Alfisol) with a pH of 5.6 (1:2 soil and water suspension), electrical conductivity 0.30 dS m<sup>-1</sup> (1:2 soil and water suspension) and organic carbon level of 0.40% and available N, P and K were 140, 10 and 100 kg ha<sup>-1</sup>, respectively.

### 2.2. Field experiments and experimental design

Experiments were conducted during the winter seasons of five consecutive years (1997–2001). Each experiment had 18 treatments arrangement with three replications in a randomized complete block design. Wheat and chickpea were grown as monocrops or intercropped in alternate rows. Row spacing treatments were 20- or 30-cm rows, each with or within-row seed space of 10-cm, and there were three hand-weeding treatments (unweeded, one weeding, or two weedings). Each plot was 6 m × 3 m.

### 2.3. Cultural practices

Land preparation was carried out by tractor ploughing followed by harrowing. The fertilizer schedule was 60:40:40 kg N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O ha<sup>-1</sup> for monocropped and intercropped wheat

and 20:40:20 (N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O) for monocropped chickpea. Proportionate fertilizers were also applied to intercropped chickpea along the rows. Two-thirds of nitrogen in the form of urea (46-0-0) and the whole amount of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in the form of single super phosphate (0-16-0) and muriate of potash (0-0-60) respectively, were applied as basal and remaining one-third nitrogen was topdressed 22 days after sowing (DAS) at crown root initiation stage of wheat. The total amount of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in the form of urea, SSP and MOP was applied as basal in chickpea. The crops were raised with two lifesaving irrigations only at 22 DAS and 45 DAS. Recommended agronomic package of practices was followed (Mohsin et al., 1986). Weeding operations were accomplished at 20 and 40 DAS depending on the weeding treatments.

Planting took place on 16, 10, 12, 20 and 14 November 1997 to 2001, respectively.

Wheat grain was harvested on 8, 2, 5, 10 and 7 April, 1997 to 2001, respectively, and chickpea grain was harvested on 12, 7, 10, 25, 15 April, 1997 to 2001, respectively. Harvesting was done manually with the help of sickles leaving border rows (single row from each side).

### 2.4. Observations and data analysis

Five chickpea plants from each chickpea monocrop and intercrop plot were dug up at 50 days after emergence (before flowering, which occurred approximately 55 DAS). Nodules were removed from roots and counted and dry mass was measured (Ghosh, 2004). Length and dry weight of roots also were recorded. Major weeds infesting the crops were identified and data pertaining to weed population and dry matter were recorded prior to crop harvest. For dry weight determination, the samples were oven-dried at 70 °C temperature to a constant weight.

Land equivalent ratio was calculated as follows (Willey, 1979):

$$LER = (LERa + LERb) = \left\{ \left( \frac{Yab}{Yaa} \right) + \left( \frac{Yba}{Ybb} \right) \right\}$$

where LERa and LERb are the partial LER of crop wheat and chickpea, respectively.

Competitive ratio was calculated by following the formula as advocated by Willey and Rao (1980):

$$CR = CRa + CRb \quad CRa = \left[ \left( \frac{LERa}{LERb} \right) \times \left( \frac{Zba}{Zab} \right) \right],$$

where CRa is the competitive ratio for intercrop wheat.

Relative crowding coefficient (*K*) was calculated following the formula (DeWit, 1960):

$$K = Kab \times Kba \\ = \left[ \frac{(Yab \times Zba)}{\{(Yaa - Yab) \times Zab\}} \right] \times \left[ \frac{(Yba \times Zab)}{\{(Ybb - Yba) \times Zba\}} \right],$$

where Kab and Kba are relative crowding coefficient for wheat and chickpea intercrop, respectively, aggressivity (*Yab*) was cal-

culated (McGilchrist, 1965) as:

$$Y_{ab} = \left[ \left\{ \frac{Y_{ab}}{(Y_{aa} \times Z_{ab})} \right\} - \left\{ \frac{Y_{ba}}{(Y_{bb} \times Z_{ba})} \right\} \right],$$

where  $Y_{ab}$  is the aggressivity of intercrop wheat, whereas, wheat equivalent yield was calculated (Chetty and Reddy, 1987) as, Wheat equivalent yield = Yield of Chickpea  $\times$  (Price of Chickpea/Price of Wheat), and Actual yield loss (Banik, 1996) was calculated as:

$$\begin{aligned} \text{AYL} &= \text{AYL}_a + \text{AYL}_b \\ &= \left[ \left\{ \frac{(Y_{ab}/Z_{ab})}{(Y_{aa}/Z_{aa})} \right\} - 1 \right] + \left[ \left\{ \frac{(Y_{ba}/Z_{ba})}{(Y_{bb}/Z_{bb})} \right\} - 1 \right]. \end{aligned}$$

where  $\text{AYL}_a$  and  $\text{AYL}_b$  are the partial yield loss of intercrop wheat and chickpea, respectively.

$Y_{ab}$  representing the yield of intercrop a (wheat) in combination with b (chickpea),  $Y_{ba}$  the yield of intercrop b (chickpea) in combination with a (wheat).  $Z_{ab}$  representing the sown proportion of intercrop a (wheat) in combination with b (chickpea) and  $Z_{ba}$  the sown proportion of intercrop b (chickpea) in combination with a (wheat).

Data were analyzed using the Analysis of Variance (ANOVA) technique following normal procedure (Gomez and Gomez, 1984). Combined analyses were done to identify the temporal effect on the treatments as advocated by Gomez and Gomez (1984).

### 3. Results

#### 3.1. Grain and seed yield

Mean grain yield of wheat and chickpea (Table 1) was higher in monocrops as compared to intercrops. Highest mean wheat grain yield (2902 kg ha<sup>-1</sup>) was obtained under monocrop wheat at 20 cm spacing weeded twice (Table 1). Highest seed yield of chickpea (1400 kg ha<sup>-1</sup>) was recorded under monocropping at 30 cm spacing weeded twice. Among intercropping systems, highest mean grain yield of wheat (2533 kg ha<sup>-1</sup>) was obtained at 20 cm spacing with two weedings, whereas highest chickpea yield (887 kg ha<sup>-1</sup>) was registered when wheat–chickpea (30 cm) was weeded twice. Uncontrolled weeds caused severe reduction in grain yield for both crop species. Monocropping produced lowest grain yield of unweeded wheat at 30 cm spacing (1604 kg ha<sup>-1</sup>) and unweeded monocrop chickpea at 20 cm spacing (466 kg ha<sup>-1</sup>). There was 42.6% reduction in grain yield of unweeded monocropped wheat when grown at 20 cm spacing as compared to when monocropped wheat was sown at same spacing and weeded twice. The reduction in grain yield of wheat was 54% when intercropped with chickpea at 20 cm spacing without weeding. Whereas 12.7% grain yield depression was noted under wheat–chickpea at 20 cm spacing with two hand-weedings. There was 59.4% reduction in grain yield under unweeded monocropped chickpea at 30 cm spacing as compared to the treatment where monocropped chickpea at same spacing weeded twice.

Table 1

Grain yield (kg ha<sup>-1</sup>) of wheat and chickpea as affected by row spacing, weeding management and intercropping system (data are the means of three replicates)

Treatments	1997		1998		1999		2000		2001		Pooled	
	Wheat	Chickpea	Wheat	Chickpea	Wheat	Chickpea	Wheat	Chickpea	Wheat	Chickpea	Wheat	Chickpea
T1	1911		1320		1913		1658		1529		1666	
T2	1667		1422		1703		1667		1561		1604	
T3	2783		1577		2657		2529		2256		2360	
T4	2478		1697		2493		2327		2709		2341	
T5	3057		2009		3233		3109		3100		2902	
T6	2679		2253		3017		2716		2689		2671	
T7		504		389		523		497		419		466
T8		584		474		672		567		541		568
T9		833		620		942		780		789		793
T10		958		718		1138		941		983		948
T11		1250		842		1441		1239		1133		1181
T12		1312		1022		1735		1513		1417		1400
T13	1470	321	1111	185	1527	234	1350	215	1217	204	1335	232
T14	1327	356	1190	241	1550	275	1453	259	1350	253	1374	277
T15	2126	487	1435	306	2054	435	2142	304	1833	358	1918	378
T16	1935	521	1524	312	2125	511	2035	356	1854	435	1895	427
T17	2653	768	1833	521	2908	763	2563	845	2709	697	2533	719
T18	2432	833	2154	578	2766	965	2425	935	2435	1124	2442	887
S.E. ( $\pm$ )	21.36	11.58	16.35	8.87	28.63	8.33	22.32	8.76	16.85	10.09	39.48	31.06
LSD ( $P=0.05$ )	44.30	24.02	33.91	18.40	59.38	17.28	46.29	18.17	34.95	20.93	78.17	61.50

T1 = Monocrop wheat at 20 cm spacing without weeding. T2 = Monocrop wheat at 30 cm spacing without weeding. T3 = Monocrop wheat at 20 cm spacing with one-weeding. T4 = Monocrop wheat at 30 cm spacing with one-weeding. T5 = Monocrop wheat at 20 cm spacing with two-weeding. T6 = Monocrop wheat at 30 cm spacing with two-weeding. T7 = Monocrop chickpea at 20 cm spacing without weeding. T8 = Monocrop chickpea at 30 cm spacing without weeding. T9 = Monocrop chickpea at 20 cm spacing with one-weeding. T10 = Monocrop chickpea at 30 cm spacing with one-weeding. T11 = Monocrop chickpea at 20 cm spacing with two-weeding. T12 = Monocrop chickpea at 30 cm spacing with two-weeding. T13 = Wheat–chickpea at 20 cm spacing without weeding. T14 = Wheat–chickpea at 30 cm spacing without weeding. T15 = Wheat–chickpea at 20 cm spacing with one-weeding. T16 = Wheat–chickpea at 30 cm spacing with one-weeding. T17 = Wheat–chickpea at 20 cm spacing with two-weeding. T18 = Wheat–chickpea at 30 cm spacing with two-weeding.

### 3.2. Relative yield loss and competition functions

The land equivalent ratio value (Fig. 1a) for all the intercropped treatments was greater than unity. Maximum land equivalent ratio (1.548) was recorded under wheat–chickpea (30 cm) weeded twice followed by wheat–chickpea (20 cm) weeded twice (1.482). Intercropped wheat had always greater competitive ratio as compared to intercropped chickpea (Fig. 1b). Positive aggressivity values (Fig. 1c) for wheat (0.0025–0.0035) also were recorded under intercropping systems. Relative crowding coefficient values (Fig. 1d) for wheat were greater than one, whereas, it was less than one for chickpea except in case of chickpea under wheat–chickpea (20- and 30-cm) with the two weeding treatment. Kab values were numerically higher than Kba values. The products of relative crowding coefficient values ( $K$ ) which were always more than one (Fig. 1d), maximum value (17.404) was recorded under wheat–chickpea (30 cm spacing) when weeded twice.

Minimum relative yield loss (8.55%) and maximum relative yield loss (19.88%) for wheat was observed under wheat–chickpea at 30-cm spacing with one hand-weeding and unweeded wheat–chickpea at 20-cm spacing, respectively. Whereas, in case of chickpea, minimum and maximum values (Fig. 1e) were recorded under unweeded wheat–chickpea (30-cm) spacing and wheat–chickpea (20-cm) spacing weeded twice, respectively.

The mean data of partial Actual Yield Loss (AYL) of wheat and chickpea were negative indicating yield loss due to intercropping when per plant yield was considered (Fig. 1f). Maximum actual yield loss value was observed (−0.726) under wheat–chickpea at 20 cm spacing with two weedings (Fig. 1f).

### 3.3. Numbers and dry weight of nodules

Nodule numbers increased with increasing row spacing from 20 to 30 cm (Table 2). Significantly higher nodule numbers were registered for weeded monocrops, irrespective of row spacing (Table 2). However, in intercropping treatments, the variation between unweeded and both weeding treatments was not significant. Under intercropping treatments higher nodule numbers were produced as compared to monocropped chickpea (Table 2). Among the intercropping treatments, highest number of nodules (41.9) in chickpea was recorded in wheat–chickpea at 30 cm spacing weeded twice. Dry weight of nodules also followed the same trends (Table 2).

### 3.4. Depth of penetration of roots and dry weight of roots

There was no significant effect of spacing on depth of penetration of roots. Root length was shortest under unweeded monocropped chickpea sown at 20 cm spacing (Table 2). Root length increased as the number of weeding operation increased. Additionally, root length was higher under intercropping as compared to monocrops. The longest roots were recorded under the intercropping system of wheat–chickpea (30 cm) weeded twice.

Table 2

Average number and weight of nodules per plant (g), root weight per plant (g) and root length (cm) of chickpea as affected by different treatments (mean of 5 years and three replicates)

Treatments	Number of nodules	Weight of nodules (g)	Length of root (cm)	Dry weight of root (g)
T7	11.4	0.066	14.6	0.591
T8	12.5	0.072	15.4	0.679
T9	18.8	0.109	16.4	0.788
T10	21.3	0.124	16.7	0.820
T11	27.3	0.159	18.7	1.038
T12	35.0	0.204	19.3	1.101
T13	14.3	0.083	15.9	0.733
T14	18.2	0.107	16.4	0.788
T15	20.6	0.120	17.2	0.875
T16	22.5	0.131	17.5	0.908
T17	37.3	0.217	19.4	1.125
T18	41.9	0.244	20.5	1.234
S.E. ( $\pm$ )	1.35	0.017	1.24	0.08
LSD ( $P=0.05$ )	2.80	0.04	2.57	0.17

T7 = Monocrop chickpea at 20 cm spacing without weeding. T8 = Monocrop chickpea at 30 cm spacing without weeding. T9 = Monocrop chickpea at 20 cm spacing with one-weeding. T10 = Monocrop chickpea at 30 cm spacing with one-weeding. T11 = Monocrop chickpea at 20 cm spacing with two-weeding. T12 = Monocrop chickpea at 30 cm spacing with two-weeding. T13 = Wheat–chickpea at 20 cm spacing without weeding. T14 = Wheat–chickpea at 30 cm spacing without weeding. T15 = Wheat–chickpea at 20 cm spacing with one-weeding. T16 = Wheat–chickpea at 30 cm spacing with one-weeding. T17 = Wheat–chickpea at 20 cm spacing with two-weeding. T18 = Wheat–chickpea at 30 cm spacing with two-weeding.

### 3.5. Effect on weed flora, density and biomass

The major weed flora of the experimental site comprised of grassy weeds: *Cynodon dactylon*; *Avena ludoviciana*; Sedge: *Cyperus rotundus*; and broad leaf weeds: *Chenopodium album*, *Medicago denticulata*, *Melilotus indica*, *Melilotus alba*, *Anagallis arvensis*, *Coronopus dedymus*. The proportion of broadleaf weeds was greater than grassy weeds.

Maximum dry matter of weeds ( $186.5 \text{ g m}^{-2}$ ) and highest weed population ( $220 \text{ m}^{-2}$ ) was recorded under the unweeded wheat monocrop (30 cm) (Figs. 2 and 3). Monocropped chickpea had significantly less weed population and dry matter as compared to monocropped wheat. Intercropping system significantly reduced the weed population (Fig. 3) and biomass (Fig. 2) as compared to the monocropping. There was significant reduction of weed population and weed biomass under intercropping system of unweeded wheat–chickpea at both row spacing as compared to monocropping of wheat with one weeding treatment, but comparable with sole chickpea weeded once. There was 69.7% reduction in weed biomass and 70% in weed population under the intercropping treatment of wheat–chickpea at 20 cm spacing without weeding treatment as compared to unweeded monocrop wheat at 20 cm spacing; whereas, the corresponding values were 34.6 and 38%, respectively, for unweeded monocropped chickpea at 20 cm spacing. The reduction of weed biomass and density under wheat sown at 20 cm spacing with one weeding and two weedings was 45.2, 44.7 and 72.7, 73.1%, respectively; whereas, in the case of monocropped chickpea with 20-cm row spacing the reduction in weed biomass and

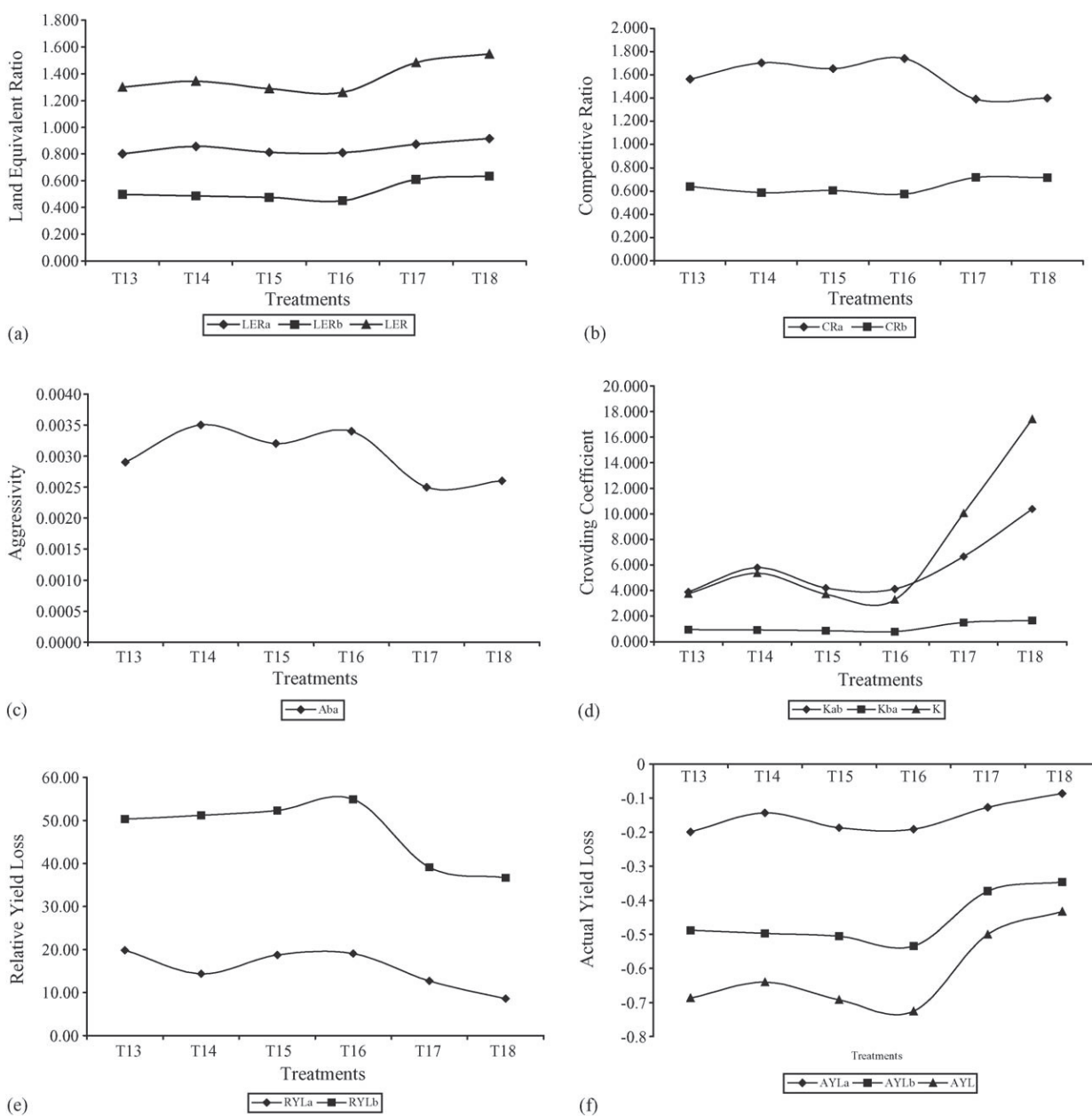


Fig. 1. (a) Land equivalent ratio (LER) in wheat–chickpea intercropping system (mean 5 years and 3 replicates). T13 = wheat–chickpea at 20 cm spacing without weeding. T14 = wheat–chickpea at 30 cm spacing without weeding. T15 = wheat–chickpea at 20 cm spacing with one-weeding. T16 = wheat–chickpea at 30 cm spacing with one-weeding. T17 = wheat–chickpea at 20 cm spacing with two-weeding. T18 = wheat–chickpea at 30 cm spacing with two-weeding. (b) Competitive ratio in wheat–chickpea intercropping system (mean of 5 years and 3 replicates). T13 = wheat–chickpea at 20 cm spacing without weeding. T14 = wheat–chickpea at 30 cm spacing without weeding. T15 = wheat–chickpea at 20 cm spacing with one-weeding. T16 = wheat–chickpea at 30 cm spacing with one-weeding. T17 = wheat–chickpea at 20 cm spacing with two-weeding. T18 = wheat–chickpea at 30 cm spacing with two-weeding. (c) Aggressivity in wheat–chickpea intercropping system (mean of 5 years and 3 replicates). T13 = wheat–chickpea at 20 cm spacing without weeding. T14 = wheat–chickpea at 30 cm spacing without weeding. T15 = wheat–chickpea at 20 cm spacing with one-weeding. T16 = wheat–chickpea at 30 cm spacing with one-weeding. T17 = wheat–chickpea at 20 cm spacing with two-weeding. T18 = wheat–chickpea at 30 cm spacing with two-weeding. (d) Relative crowding coefficient in wheat–chickpea intercropping system (mean of 5 years and 3 replicates). T13 = wheat–chickpea at 20 cm spacing without weeding. T14 = wheat–chickpea at 30 cm spacing without weeding. T15 = wheat–chickpea at 20 cm spacing with one-weeding. T16 = wheat–chickpea at 30 cm spacing with one-weeding. T17 = wheat–chickpea at 20 cm spacing with two-weeding. T18 = wheat–chickpea at 30 cm spacing with two-weeding. (e) Relative yield loss in wheat–chickpea intercropping system (mean of 5 years and 3 replicates). T13 = wheat–chickpea at 20 cm spacing without weeding. T14 = wheat–chickpea at 30 cm spacing without weeding. T15 = wheat–chickpea at 20 cm spacing with one-weeding. T16 = wheat–chickpea at 30 cm spacing with one-weeding. T17 = wheat–chickpea at 20 cm spacing with two-weeding. T18 = wheat–chickpea at 30 cm spacing with two-weeding. (f) Actual yield loss in wheat–chickpea intercropping system (mean of 5 years and 3 replicates). T13 = wheat–chickpea at 20 cm spacing without weeding. T14 = wheat–chickpea at 30 cm spacing without weeding. T15 = wheat–chickpea at 20 cm spacing with one-weeding. T16 = wheat–chickpea at 30 cm spacing with one-weeding. T17 = wheat–chickpea at 20 cm spacing with two-weeding. T18 = wheat–chickpea at 30 cm spacing with two-weeding.

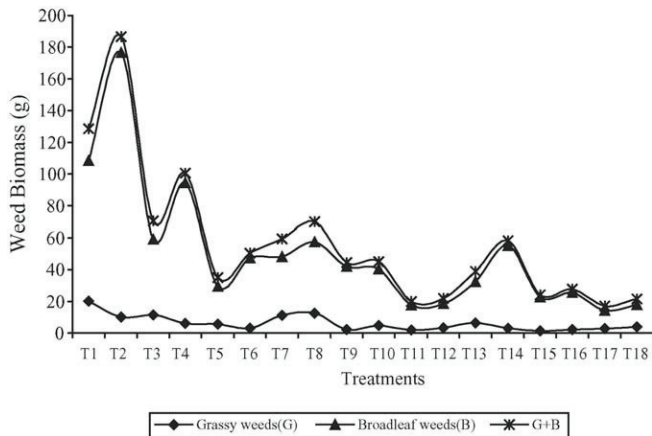


Fig. 2. Weed biomass (g) as affected by row spacing, weeding management and intercropping treatments (mean of 5 years and 3 replicates). T1—Monocrop wheat at 20cm spacing without weeding. T2—Monocrop wheat at 30cm spacing without weeding. T3—Monocrop wheat at 20cm spacing with one-weeding. T4—Monocrop wheat at 30cm spacing with one-weeding. T5—Monocrop wheat at 20cm spacing with two-weeding. T6—Monocrop wheat at 30cm spacing with two-weeding. T7—Monocrop chickpea at 20cm spacing without weeding. T8—Monocrop chickpea at 30cm spacing without weeding. T9—Monocrop chickpea at 20cm spacing with one-weeding. T10—Monocrop chickpea at 30cm spacing with one-weeding. T11—Monocrop chickpea at 20cm spacing with two-weeding. T12—Monocrop chickpea at 30cm spacing with two-weeding. T13—wheat–chickpea at 20cm spacing without weeding. T14—Wheat–chickpea at 30cm spacing without weeding. T15—Wheat–chickpea at 20cm spacing with one-weeding. T16—Wheat–chickpea at 30cm spacing with one-weeding. T17—Wheat–chickpea at 20cm spacing with two-weeding. T18—Wheat–chickpea at 30cm spacing with two-weeding.

weed density was 25, 42.4 and 66.7, 71.7%, respectively. On the contrary, unweeded wheat–chickpea intercrop (20-cm) reduced weed biomass 44.8% as compared to wheat at 20 cm spacing weeded once. So, the unweeded intercropping treatment was found to be superior over one weeding treatment for weed control in wheat. Narrow row spacing (20-cm) in all the treatments was found to be effective as wide spacing (30-cm), whether intercropped or monocropped. Intercropping treatments where weeding was done registered lower weed populations and dry matter (Figs. 2 and 3).

### 3.6. Economic feasibility

Wheat equivalent yield (Table 3) was significantly higher ( $P=0.05$ ) when intercropped as compared to respective monocrops. Highest wheat equivalent yield ( $3943 \text{ kg ha}^{-1}$ ) was achieved under wheat–chickpea (30 cm) weeded twice. Unweeded intercropping treatments also recorded significantly higher ( $P=0.05$ ) wheat-equivalent yield as compared to unweeded monocropped wheat sown at 20 cm or chickpea sown at 30 cm spacing (Table 3).

Monetary advantages of all the intercropping systems were positive clearly indicating the yield advantages of intercropping over monocropping (Table 3). Significantly higher gross return (Euro  $647 \text{ ha}^{-1}$ ) was achieved under wheat–chickpea (30 cm) weeded twice. Lowest net return of (Euro  $24 \text{ ha}^{-1}$ ) was obtained under unweeded monocropped chickpea (20 cm)

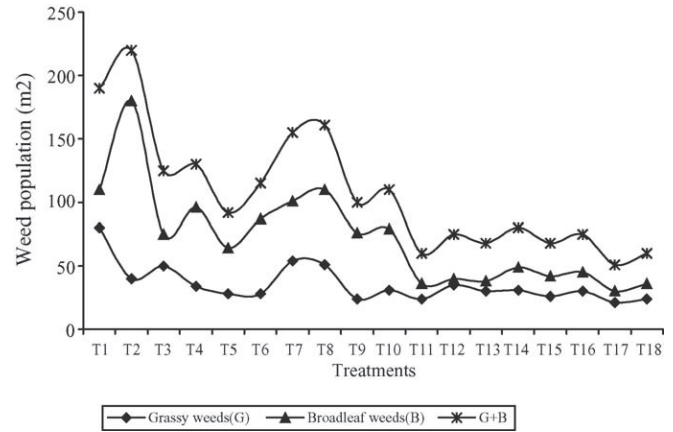


Fig. 3. Weed population ( $\text{m}^{-2}$ ) as affected by row spacing, weed management and intercropping treatments (mean of 5 years and 3 replicates). T1—Monocrop wheat at 20cm spacing without weeding. T2—Monocrop wheat at 30cm spacing without weeding. T3—Monocrop wheat at 20cm spacing with one-weeding. T4—Monocrop wheat at 30cm spacing with one-weeding. T5—Monocrop wheat at 20cm spacing with two-weeding. T6—Monocrop wheat at 30cm spacing with two-weeding. T7—Monocrop chickpea at 20cm spacing without weeding. T8—Monocrop chickpea at 30cm spacing without weeding. T9—Monocrop chickpea at 20cm spacing with one-weeding. T10—Monocrop chickpea at 30cm spacing with one-weeding. T11—Monocrop chickpea at 20cm spacing with two-weeding. T12—Monocrop chickpea at 30cm spacing with two-weeding. T13—Wheat–chickpea at 20cm spacing without weeding. T14—Wheat–chickpea at 30cm spacing without weeding. T15—Wheat–chickpea at 20cm spacing with one-weeding. T16—Wheat–chickpea at 30cm spacing with one-weeding. T17—Wheat–chickpea at 20cm spacing with two-weeding. T18—Wheat–chickpea at 30cm spacing with two-weeding.

Table 3  
Economics of wheat–chickpea intercropping systems (mean of 5 years and three replicates)

Treatments	Wheat-equivalent yield ( $\text{kg ha}^{-1}$ )	Cost of Cultivation (Euro $\text{ha}^{-1}$ )	Gross return (Euro $\text{ha}^{-1}$ )	Net return (Euro $\text{ha}^{-1}$ )
T1	1666	119	267	148
T2	1604	116	256	140
T3	2360	163	380	218
T4	2341	159	379	219
T5	2902	206	479	273
T6	2671	203	435	232
T7	789	102	125	24
T8	961	96	159	63
T9	1342	129	215	86
T10	1604	123	259	135
T11	1999	151	319	169
T12	2369	145	378	233
T13	1727	192	275	82
T14	1842	186	293	107
T15	2558	225	406	181
T16	2617	218	418	200
T17	3750	269	612	343
T18	3943	262	647	385
S.E. ( $\pm$ )	48.21		4.43	2.49
LSD (0.05)	94.97		8.73	4.91

Average procurement price per kg of wheat grain = Euro 0.142; wheat straw = Euro 0.015; chickpea grain = Euro 0.24; chickpea dry stalk = Euro 0.007.

(Table 3). There were significant differences in net returns with weeding treatments and no weeding treatments, irrespective of species. Wheat–chickpea (30 cm) with no weeding treatment secured significantly higher net return over unweeded monocropped wheat at both row spacing, monocropped wheat at 30 cm spacing weeded once, and chickpea monocrops, the 30 cm spacing weeded twice (Table 3). All weeded intercrop treatments registered significantly higher net returns over other treatments. Wheat–chickpea (30 cm) weeded twice recorded significantly higher net return over other weeded intercropping treatments, which were not different from each other. Highest gross return (Euro 647 ha<sup>-1</sup>) and net return (Euro 385 ha<sup>-1</sup>) were secured by wheat–chickpea (30 cm) weeded twice. Unweeded monocrops recorded the least return (Table 3).

## 4. Discussion

### 4.1. Yield and yield equivalent

Higher grain yield of monocropped wheat and chickpea relative to intercropping treatments may be due to the less disturbance in the habitat in homogeneous environment of monocropping systems (Grime, 1977). Fluctuations in weather parameters affected the grain yield over years. Stiff competition by the weeds resulted less grain yield under the unweeded treatment. Higher wheat-equivalent yield when intercropped compared to respective monocrops was due to higher total productivity because intercropping exploited resources more efficiently (Midya et al., 2005). It may be due to the legume affect of chickpea on nitrogen nutrition of wheat or facilitative interaction in wheat–chickpea intercrops (Zhang and Li, 2003; Li et al., 2004). Highest wheat equivalent yield achieved under wheat–chickpea at 30 cm spacing with two weedings was due to least population of weeds and less inter-specific and intra-specific competition as compared to other intercropping systems.

### 4.2. Competition functions

Higher LER in intercropping treatments indicated yield advantage over monocropping due to better land utilization. Advantage from wheat–legume intercropping system has been reported previously (Banik, 1996).

Relative crowding coefficient, aggressivity, actual yield loss values indicated wheat as dominant species in a crop mixture situation. Greater competitive ability of wheat to exploit resources in association with chickpea has been reported by other researchers (Li et al., 2002). The advantages accrued from intercropping systems, as evident from competitive functions, is due to better utilization of growth resources under cereal–legume intercropping system (Ofori and Stern, 1987). Land productivity measured by land equivalent ratio and monetary gain showed some advantages of mixed cropping of cereals and legumes (Yunusa, 1989; Mandal et al., 1990).

### 4.3. Weed density and weed biomass

Less weed dry matter and density registered under intercropping may be due to the weed suppressing capability

of intercropping over monocropping. Intercrops may demonstrate advantages on weed control over sole crops both by producing greater crop yield and less weed growth through usurping resources from weeds and also by suppressing weed growth through allelopathy (Yih, 1982). Intercrops may also provide yield advantages without suppressing weed growth below levels observed in component monocrops by using resources that are not exploited by weeds and convert resources to harvestable materials more efficiently than monocrops (Liebman and Elizabeth, 1993). Less weed production under monocropped chickpea over monocropped wheat may be due to better weed smothering efficiency of pulse crops (Sheaffer et al., 2002; Midya et al., 2005). Less weed biomass production and weed density under intercropping system is due to higher inter-specific competition combined with complementarity between intercrop species that improve the crop stand competitive ability towards weeds (Nielson et al., 2003).

### 4.4. Nodule number and dry weight

Higher number of nodules and greater nodule dry weight under intercropping also may be due to complementarity effect; where association of cereal with legume; encourages legume component to fix more amount of nitrogen (Giller and Wilson, 1991). Effective nodules are the sites of symbiotic nitrogen fixation. Higher number of effective nodules under intercropping system over pure stand of legume is an indication that more atmospheric nitrogen fixation in the crop mixture (Maingi et al., 2001). So, more nitrogen fixation may be due to more numbers of nodule formations (Thompson, 1977). Higher number of nodule may also be due to the “facilitative interaction” of intercropping (Zhang and Li, 2003; Li et al., 2004).

### 4.5. Depth of penetration of roots and root dry matter

Higher depth of penetration of chickpea root under intercropping system may be due to the spatial complementarity where the component crops avoid the area of resources that is already depleted or being depleted by other crops. Deeper rooting component may be forced more deeper in the presence of a shallow rooting component under intercropping system (Whittington and O'Brien, 1968).

### 4.6. Economics

Higher net return is achieved with greater productivity. Highest returns were obtained from wheat–chickpea at 30 cm spacing weeded twice due to greater productivity under this treatment with comparable cost of cultivation. Higher gross and net return under intercropping was due to higher total productivity under mixed stand with relative less input investment.

## 5. Conclusions

For monocrops total productivity was lower, but weed density and biomass was greater. Narrow spacing under both

monocropping and intercropping reduced weed population and density. There was reduction in yield under intercropping over monocropping due to competition. However, results obtained from competition functions and economics indicated overall advantage accrued from intercropping.

Since, inter-specific competition coupled with complementarity increases crop stand ability to smother weeds, intercropping systems were found to be beneficial in terms of weed management. In particular, intercropping of wheat and chickpea with a 30 cm row spacing weeded twice was found to be the most effective under experimental condition, for better economics, land use efficiency and for smothering weeds.

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