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Land Equivalent Ratio as a Reference for Relative Crowding Coefficient and Aggressivity of Intercropped Plant Species

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ABSTRACT

The authors have proposed formulas which relate land equivalent ratio (LER) with either relative crowding coefficient (k) or aggressevity (A) of intercropped plant species and have examined the proposed formulas using numerical example and the results of a practical experiment. The practical experiment was carried out in two successive seasons under plastic greenhouse using indeterminate tomato spaced at 25 and 50 cm intercropped with climbing snap bean at three ratios, i.e., 1:1, 1:2 and 2:1 tomato: snap bean, respectively. Examination of the proposed formulas proved that the formulas deduction is correct. Results of the intercropping experiment revealed that land equivalent ratios (LERs), relative crowding coefficients (ka and kb) and aggressevity (Aa and Ab) indicated that tomato was the dominant crop and snap bean was the dominated one. Also, both LER and K showed that there was yield advantage. In addition, LER indicated that yield advantage was, mostly, due to tomato. The highest total LER were found with 1 tomato : 2 bean in the first season(1.235) and with 2 tomato : 1 bean in the second season (1.127). Positive correlations were found in both investigated seasons between the relative crowding coefficient (K) and total land equivalent ratio (LER) of the combined intercrops.

Key words: Land equivalent ratio, Relative crowding coefficient, Aggressivity, Modified formulas, Intercropping, Tomato, Snap bean.

Introduction

Intercropping can be defined as growing of two or more crops on the same area of ground. The main goal of intercropping is to produce a greater yield on a given piece of land by making better use of growth resources that would otherwise not be utilized by a sole crop. Land equivalent ratio (LER) is used as measure for land use efficiency of intercropped plants. It can be defined as the relative land area under sole crops that is required to produce the yields achieved in intercropping (Willey, 1979). Beside of yield advantage due to intercropping, it also offers the opportunity to guard against market risk and/or avoid infection with plant diseases as well as it improves soil fertility (Li *et al*, 2003; Zhang and Li, 2003). Many studies have demonstrated yield advantage and complementary effects for intercropping legumes with other vegetable crops in open field included tomato with cowpea (Olasantan,1991), chili with bean (Costa and Perera, 1998,),potato with bean (Sharaiha and Saoub, 2004), some winter vegetable crops with broad bean (Mahdi *et al*, 2011) and squash with broad bean (Abd El-Lateef and Hafez, 2012) . In addition, Abd El-Gaid *et al* (2014) found a significant positive yield response of tomato due to the investigated intercropping systems with green bean plants .They also found that the highest LER value was found with 1 tomato: 3 common bean plants.

The terms relative crowding coefficient and aggressevity are competitive functions between intercropped species. The term relative crowding coefficient (k) of plant species was proposed by Hall (1974). It gives a measure of whether that species has produced more, or less yield than expected .If a species has a coefficient less than, equal to or greater than one, it means it has produced less yield, the same yield or more yield than expected yield. To determine if there is a yield advantage of intercropping, the product of the coefficient is formed (K= ka * kb). If K greater than, equal or less than one, there is a yield advantage, no difference or yield disadvantage, respectively. Aggressivity (A) was proposed by McGilchrist (1965) .It gives a simple measure of how much the relative yield increase in species a is greater than that for species b. An aggressevitiy value of zero indicates that both component species are equally competitive. Both species a and b have the same numerical value but the sign of the dominant species is positive and that of the dominated one is negative. The greater the numerical value the bigger the difference in competitive abilities and the bigger the difference between actual and expected yields. No one has tried to find a relation between land equivalent ratio and either relative crowding coefficient or aggressevity.

Therefore, modified formulas were proposed for calculating relative crowding coefficient and aggressevity taken in consideration land equivalent ratio as a reference. Tomato is an important vegetable crop and it is a widespread under greenhouse. Snap bean is a popular legume crop as well as it improves soil fertility. Indeterminate tomato and climbing snap bean were chosen to be intercropped under greenhouse to examine the

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proposed formulas using intercropping results and to increase crop diversity under greenhouse as well as to study the effect of intercropping on yield advantage.

Material and Methods

The formulas proposed by Hall (1974) for calculating relative crowding coefficient and by McGilchrist (1965) for calculating aggressevity of intercropped plant species were modified by the authors to relate land equivalent ratio with either relative crowding coefficient or aggressivity. This led us to examine the proposed formulas using data obtained practically, Thus, two intercropping experiments were carried out using indeterminate tomato at two planting spaces (25 and 50 cm apart within the row) and climbing snap bean

Intercropping patterns:

1- Sole tomato.
2- Sole snap bean.
3- 1 tomato: 1snap bean.
4- 1 tomato: 2 snap bean.
5- 2 tomato: 1 snap bean.

Indeterminate tomato transplants and climbing snap bean seeds were planted under plastic greenhouse at Marriott Experimental Station of the Desert Research Center in the first week of November of 2008 and 2009, respectively. All recommended agricultural practices for protective agriculture were followed. A split plot design was used where tomato spacing treatments were randomly distributed in the main plots and intercropping patterns were arranged in the subplots.

Data Recorded:

1- Proof of the proposed formulas by the authors for calculating relative crowding coefficient and aggressivity in relation to LER and examination of the formulas using numerical example were introduced.
2- Yield of tomato per plant, per plot and per square meter.
3- Yield of snap bean per plant, per plot and per square meter.
4- Land equivalent ratio (LER) for tomato, bean and combined intercrops were calculated according to Willey (1979) as follow :

LER for tomato = Intercrop yield of tomato / sole crop yield of tomato.
LER for bean = Intercrop yield of bean/sole crop yield of bean.
Total LER = LER for tomato + LER for bean.

5- The actual magnitude of yield advantage or yield disadvantage of either tomato or bean was calculated.
6- Calculation of the relative crowding coefficients and aggressivity of tomato and snap bean using the author's formulas and those of Hall (1974) and McGilchrist (1965) was carried out.

The proposed formulas by the authors are:

a- Relative crowding coefficient (k) for 1 a : 1 b intercropping pattern:

$$ka = \frac{LERa}{1-LERa} \quad \text{(equation1)}$$

$$kb = \frac{LERb}{1-LERb} \quad \text{(equation 2)}$$

For other intercropping ratios:

$$ka = \frac{LERa*Zba}{(1-LERa)*Zab} \quad \text{(equation 3)}$$

$$kb = \frac{LERb*Zab}{(1-LERb)*Zba} \quad \text{(equation 4)}$$

Relative crowding coefficient of the combined intercrops (K) = ka*kb

Where: ka and kb are the relative crowding coefficients for species a and b.

Zab and Zba are planting proportions of species a and b

b- Aggressivity Aa and Ab for species a and b, respectively:

For 1 species a : 1 species b intercropping pattern :

$$Aa = LERa - LERb \quad \text{(equation5)}$$

$$Ab = LERb - LERa \quad \text{(equation 6)}$$

For other intercropping ratios:

$$Aa = \frac{LERa}{Zab} - \frac{LERb}{Zba} \quad \text{(equation 7)}$$

$$Ab = \frac{LERb}{Zba} - \frac{LERa}{Zab} \quad \text{(equation 8)}$$

All data were subjected to analysis of variance according to Thomas and Hills (1975).

Results and Discussions

1- Proof of the authors' formulas for calculating relative crowding coefficients and aggressivity in relation to land equivalent ratio (LER): The symbols used here are:
Yaa= sole yield of species a.
Ybb= sole yield of species b.
Yab= intercrop yield of species a (in combination with b).
Yba = intercrop yield of species b (in combination with a).
Zab= planting proportion of species a in combination with b.
Zba= planting proportion of species b in combination with a.
ka = relative crowding coefficient for species a .
kb = relative crowding coefficient for species b.
Aa = Aggressivity for species a.
Ab= Aggressivity for crop b.

a – Relative crowding coefficients (ka, kb and K) :

For intercropping pattern 1 species a: 1 species b:

Since $ka = \frac{Yab}{Yaa-Yab}$ (Hall, 1974) Then $ka = \frac{Yab}{Yaa*\left(1-\frac{Yab}{Yaa}\right)}$ $ka = \frac{Yab}{Yaa} * \frac{1}{1-\frac{Yab}{Yaa}}$

Since LER for species a = $\frac{Yab}{Yaa}$ Then, $ka = LERa * \frac{1}{1-LERa}$

Then ka= $\frac{LERa}{1-LERa}$ (equation 1)

Similarly

$kb = \frac{LERb}{1-LERb}$ (equation 2)

For other intercropping ratios:

Since $ka = \frac{Yab}{Yaa-Yab}$ Then, $ka = \frac{Yab*Zba}{Yaa*\left(1-\frac{Yab}{Yaa}\right)*Zab}$ $ka = \frac{Yab}{Yaa} * \frac{Zba}{\left(1-\frac{Yab}{Yaa}\right)*Zab}$

Since LER for species a = $\frac{Yab}{Yaa}$ Then, ka= $LERa * \frac{Zba}{(1-LERa)*Zab}$

Then ka= $\frac{LERa*Zba}{(1-LERa)*Zab}$ (equation 3)

Similarly kb= $\frac{LERb*Zab}{(1-LERb)*Zba}$ (equation 4)

Relative crowding coefficient of the combined intercrops (K) = ka*kb
Where: ka and kb are the relative crowding coefficients for species a and b

b- Aggressivity (A):

For intercropping pattern,1 species a:1 species b:

Since Aa = $\frac{Yab}{Yaa} - \frac{Yba}{Ybb}$ (McGilchrist,1965)

Since LERa = $\frac{Yab}{Yaa}$ and LERb = $\frac{Yba}{Ybb}$

Then, $Aa = LERa - LERb$ (equation5)

Since *Ab*= $\frac{Yba}{Ybb} - \frac{Yab}{Yaa}$

Then, *Ab* = $LERb - LERa$ (equation 6)

For other intercropping ratios:

Aa= $\frac{Yab}{Yaa*Zab} - \frac{Yba}{Ybb*Zba}$ Then $Aa = \left(\frac{Yab}{Yaa} * \frac{1}{Zab}\right) - \left(\frac{Yba}{Ybb} * \frac{1}{Zba}\right)$

Since $LERa = \frac{Yab}{Yaa}$ and $LERb = \frac{Yba}{Ybb}$

Then $Aa = \left(LERa * \frac{1}{Zab}\right) - \left(LERb * \frac{1}{Zba}\right)$

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Then $Aa = \frac{LERa}{Zab} - \frac{LERb}{Zba}$ (equation 7)

Similarly

$Ab = \frac{LERb}{Zba} - \frac{LERa}{Zab}$ (equation 8)

It may be worth to mention that the proposed formulas led to deduce the following facts:

1. If the intercropped species have equal LER value, it will result in ka = kb in case of 1 species a : 1 species b or $ka*(Zab)^2 = kb*(Zba)^2$ in case of other intercropping ratios.
2. In case of 1 species a: 1 species b intercropping pattern, the higher LER of a certain species, the dominant one. In case of other intercropping ratios, the higher LER/ species proportion, the dominant one.
3. If aggressivity of the two intercropped species equal zero (equally competitive), it means that both species have the same LER value (LERa=LERb) in case of 1a: 1b intercropping pattern and vice versa; or LERa / Zab= LERb / Zba in case of other intercropping ratios and vice versa.

Numerical example:

Table (1) represented a proposed numerical example of the yield of intercrops a and b which were intercropped using different intercropping patterns just to examine the authors' formulas and the deduced facts. At first, Land equivalent ratios were calculated. Then, both relative crowding coefficient and aggressevity values were calculated using the authors' formulas and those of Hall (1974) for relative crowding coefficient and McGilchrist (1965) for aggressivity. Calculations revealed that the authors' formulas gave the same values obtained by Hall (1974) and McGilchrist (1965) formulas as well as the deduced facts are correct.

THUS, the authors' formulas were deduced correct and land equivalent ratio could be used as a reference for relative crowding coefficient and aggressevity.

Table 1: Numerical example to examine the authors' formulas and deduced facts.

Intercropping pattern	Yield (kg/plot	LER a, b and a + b	$k*Z^2$	ka,kb and K	LER/Z	Aa and Ab
			Species a			
1A : 3B	50	0.3333	0.0937	1.5000	[1]1.3332	0.1333
1A : 2B	80	0.5333	0.2539	2.2857	[1]1.6000	0.4004
1A : 1B	100	[1]0.6666		2.0000		0.0666
2A : 1B	120	0.8000[a]	0.8887[a]	2.0000	1.2001*	0.0000*
3A : 1B	130	0.8666	1.2187	2.1666	¯1.1554	-0.0444
Sole crop a	150					
			Species b			
1A : 3B	45	0.9000	1.6875	3.0000	¯1.2000	-0.1333
1A : 2B	40	0.8000[a]	0.8887[a]	2.0000	¯1.2001	-0.4004
1A : 1B	30	¯0.6000		1.5000		-0.0666
2A : 1B	20	0.4000	0.1481	1.3333	1.2001*	0.0000*
3A : 1B	15	0.3000	0.0803	1.2857	[1]1.2000	0.0444
Sole crop b	50					
		Species a+b		Species a*b		
1A : 3B		1.2333		4.5000		
1A : 2B		1.3333		4.5714		
1A : 1B		1.2666		3.0000		
2A : 1B		1.2000		2.6666		
3A : 1B		1.1666		2.7857		

LER a, b, and a + b stand for land equivalent ratios of species a ,b and a+b, espectively.
*ka, kb and K stand for relative crowding coefficients of species a, b and a*b, respectively.*
Aa and Ab stand for aggressivity of species a and b, respectively.
$k*Z^2$ stands for the product of relative crowding coefficient of species and its square proportion (calculated for first fact).
[1] and ¯ stand for the dominant and dominated species indicated by higher and lower LER, respectively, with 1 a: 1 b intercropping ratio as well as higher and lower LER/Z with other intercropping ratios (second fact).
LER/Z stands for land equivalent ratio divided by the proportion of the plant species (calculated for the second and third facts).
**stands for equal competition of both intercropped species with the ratio 2species a : 1b indicated by equal LER/Z value or aggressivity equal zero (third fact).*

2- Effect of tomato spacing intercropped with bean on tomato yield:

Results concerned with the effect of tomato spacing intercropped with bean on tomato yield presented in Table (2) revealed that tomato yield / plant was at 50 cm planting space significantly higher than that at 25 cm .The increment amounted to 59 and 52 per cent in the first and second seasons, respectively, Such result indicated that the intra-specific competition within tomato plants spaced at 25 cm was higher than that within tomato plants spaced at 50 cm. As for the effect of intercropping pattern on the yield / plant, Table (2) showed that it was significantly increased as bean proportion was increased which indicated that the intra-competition within tomato plants was less than the inter-specific competition with bean plants (Willey, 1979). Tomato plants may, also, made better use of growth resources and got more benefit from the fixed Nitrogen with high proportion of bean plants than did with low proportion.

Table 2: Effect of tomato spacing intercropped with bean on tomato yield.

Intercropping pattern	Yield kg / tomato plant			Yield kg / plot			Yield (kg / M)		
	25 cm	50 cm	Mean	25 cm	50 cm	Mean	25 cm	50 cm	Mean
T : B	First Season								
1T:1B	7.21	10.91	9.06	115.4	92.2	103.8	28.85	23.05	25.95
1T:2B	9.56	15.77	12.67	102.3	83.6	93.0	25.57	20.90	23.25
2T:1B	5.96	9.69	7.83	140.0	112.7	126.3	35.00	28.17	31.57
Sole tomato	5.54	8.65	7.10	178.4	138.4	158.4	44.6	34.60	39.60
Mean	7.07	11.26		134.02	106.7		33.55	26.67	
L.S.D. 0.05 Spacing	0.69			4.1			1.03		
Intercropping	0.55			3.0			0.75		
Interaction	0.77			4.3			1.08		
T : B	Second Season								
1T:1B	7.35	11.71	9.53	117.6	102.6	110.1	29.40	25.65	27.52
1T:2B	9.71	15.23	12.47	103.9	80.7	92.3	25.97	20.17	23.07
2T:1B	6.68	9.55	8.12	142.3	112.2	127.3	35.57	28.05	31.82
Sole tomato	6.18	9.10	7.64	177.8	145.4	161.6	44.45	36.35	40.40
Mean	7.48	11.40		135.4	110.2		33.85	27.55	
L.S.D.0.05 Spacing	0.36			4.3			1.08		
Intercropping	0.22			2.5			0.62		
Interaction	0.31			3.6			0.90		

The highest yield of tomato/ plant in the two seasons was obtained with 1 tomato : 2 bean intercropping pattern. Interaction results revealed that the highest yield of tomato/ plant was obtained with intercropping pattern 1 tomato : 2 bean combined with spacing tomato at 50 cm .As for tomato yield per plot and per square meter, Table (2) cleared that tomato yield was increased as tomato spacing was decreased and as its proportion was increased in the intercropping pattern due to increasing number of plants. Similar results were obtained using tomato with cowpea (Olasantan,1991), chili with bean (Costa and Perera,1998), potato with bean (Sharaiha and Saoub,2004), some winter vegetable crops with broad bean (Mahdi *et al*, 2011) and tomato with garlic (Nassef and Abd El-Gaid, 2012) . In addition, Abd El-Gaid, *et al* (2014) found a significant positive yield response of tomato due to the investigated intercropping systems with green bean plants; and the highest yield was found with 1 tomato:3 common bean plants .

3- Effect of tomato spacing intercropped with bean on bean yield:

The effect of tomato spacing intercropped with bean on bean yield presented in Table (3) showed that bean yield / plant was 33 per cent higher in the first season at tomato spacing 25 cm compared with spacing 50 cm. Such superiority may be due to the beneficial effect of tomato plants spaced at 25 cm on the micro climate, especially on raising temperature surrounding bean plants. However, in the second season, bean yield /plant was 19 per cent higher at tomato spacing 50 cm than that at 25 cm which may be due to higher light intensity with tomato spacing 50 cm than that with 25 cm.

Regarding the effect of intercropping pattern on bean yield / plant, Table (3) cleared that it was, generally, increased as tomato proportion was increased which indicated that the inter-competition with tomato plants was less than the intra-competition within bean plants. Also, tomato plants at higher proportion may improve the micro-climate for bean plants especially raising temperature as compared with low proportion. Interaction results showed that the highest yield of bean / plant was obtained with spacing tomato at 50 cm combined with intercropping pattern 1 tomato: 1 bean in the first season or combined with 2 tomato : 1 bean in the second season. Regarding bean yield per plot and per square meter, it was, generally, higher with tomato spaced at 25 cm than that with 50 cm. Increasing proportion of bean in the intercropping pattern resulted in increasing its yield per plot and per square meter due to increasing number of plants per unit area; sole bean gave the highest yield per plot or per square meter. Yield results of both tomato and bean may indicate the presence, to some extent, of complementary effects between both species. Similar results were obtained by using tomato with cowpea (Olasantan,1991), chili with bean (Costa and Perera, 1998),pepper and eggplant with bean (El-Gizy,2001), potato with bean (Sharaiha and Saoub, 2004), some winter vegetable crops with broad bean (Mahdi *et al*, 2011) and tomato with green bean (Abd El-Gaid *et al*,(2014).

4- Effect of tomato spacing intercropped with bean on land equivalent ratio:

Land equivalent ratio (LER) is used as a measure for land use efficiency of intercropped plants on land area basis. If total LER (LER of crop a + LER of crop b) greater than one, it means that there is a yield advantage. Obtained data presented in Table (4) showed that the actual LER of tomato was higher with tomato spaced at 50 cm than that with 25 cm. No significant differences, due to tomato spacing, were obtained with either LER of bean or total LER.

As for the effect of intercropping pattern on land equivalent ratio of tomato and bean, the highest LER of tomato was found with 2 tomato : 1 bean and those of bean were obtained with 1 tomato : 2 bean intercropping patterns in both investigated seasons as shown in Table (4) and Fig (1). The highest total LER were found with1 tomato : 2 bean in the first season(1.235) and with 2 tomato: 1 bean in the second season (1.127).This mean that the highest LER advantage (yield advantage on land area basis) were 0.235 and 0.127 in the first and second season, respectively. Table (4) and Fig (1) showed, also, that yield advantage came mostly from tomato. In other words, tomato yielded 0.259yield advantage and bean yield - 0.024 yield disadvantage and the simple addition of both advantages thus gave 0.235total yield advantage in the first season. Whereas the corresponding values in the second season were 0.115, 0.012 and 0.127 LER advantage of tomato, bean and tomato +bean, respectively.

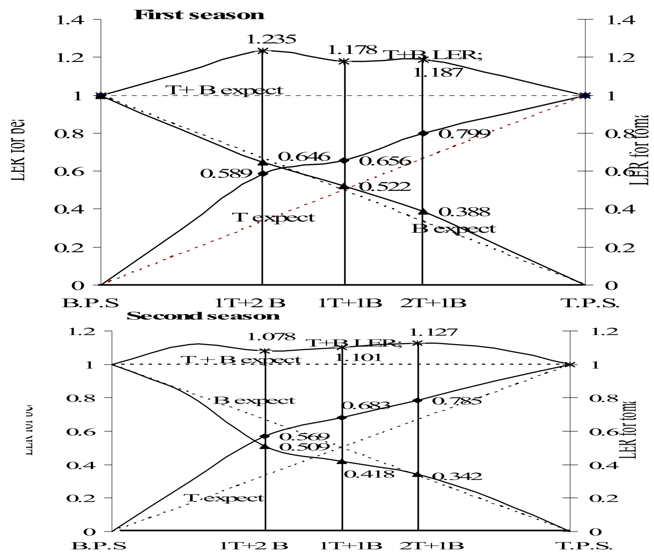
It may be worth to mention that the higher LER advantage (yield advantage) of tomato compared to bean indicated that tomato was the dominant crop and bean was the dominated one. Also, Table (4) and Fig (1) showed that LERs advantage for tomato was greater than those for bean and values of both crops were positive in the first season which indicated that LER for each crop was greater than those expected . This means that the beneficial effect of bean on tomato was greater than the beneficial effect of tomato on bean and the competition between tomato and bean plants followed, to some extent, mutual cooperation category in the first season (Willey, 1979). Whereas in the second season, the corresponding values were positive for tomato and negative for bean which indicated that the competition followed the compensation category and tomato only got benefit from bean. LERs results are in compatible with those of yield previously discussed (Tables 2 and 3). Similar results were obtained by El-Gizy (2001) using pepper or eggplant with bean, Abou-Hussein *et al* (2005) using head lettuce and green onion with green been, Abd El-Lateef and Hafez,(2012) using squash with broad bean and Abd El-Gaid *et al* (2014) using tomato with green bean.

Table 3: Effect of tomato spacing intercropped with bean on bean yield.

Intercropping pattern	Yield g / plant			Yield kg / plot			Yield (kg / M)		
	25 cm	50 cm	Mean	25 cm	50 cm	Mean	25 cm	50 cm	Mean
T : B	First Season								
1T:1B	1011	1507	1259	23.33	18.14	20.73	5.83	4.60	5.18
1T:2B	985	862	924	30.15	21.39	25.77	7.54	5.34	6.44
2T:1B	1092	859	976	16.79	13.87	15.33	4.20	3.47	3.83
Sole bean	941	719	830	44.01	35.24	39.63	11.0	8.81	9.91
Mean	1007	756		28.58	22.16		7.15	5.54	
L.S.D. 0.05 Spacing	40			1.48			0.37		
Intercropping	26			0.62			0.15		
Interaction	NS			0.87			0.22		
T : B	Second Season								
1T:1B	631	714	673	15.13	17.14	16.14	3.78	4.29	4.04
1T:2B	582	649	616	18.59	20.77	19.68	4.65	5.19	4.92
2T:1B	739	949	844	13.31	13.22	13.27	3.33	3.31	3.32
Sole bean	544	661	603	43.05	35.63	39.34	10.76	8.91	9.84
Mean	624	743		22.52	21.69		5.63	5.42	
L.S.D. 0.05 Spacing	NS			1.60			0.40		
Intercropping	NS			1.10			0.28		
Interaction	NS			NS			NS		

Table 4: Effect of tomato spacing intercropped with bean on Land equivalent ratio:

Tomato spacing	Intercropping pattern T : B	Tomato			Bean			T + B		
		LER	Exp LER	LER advantage	LER	Exp LER	LER advantage	LER	EXP LER	LER advantage
		First season								
25 cm	1T : 1B	0.647	0.50	0.147	0.530	0.50	0.030	1.177	1.00	0.177
	1T : 2B	0.573	0.33	0.243	0.685	0.67	0.015	1.258	1.00	0.258
	2T : 1B	0.785	0.67	0.115	0.382	0.33	0.052	1.167	1.00	0.167
Mean		0.668	0.50	0.167	0.532	0.50	0.032	1.198	1.00	0.198
50 cm	1T : 1B	0.666	0.50	0.166	0.515	0,50	0.015	1.182	1.00	0.182
	1T : 2B	0.604	0.33	0.274	0.607	0.67	-0.063	1.211	1.00	0.211
	2T : 1B	0.814	0.67	0.144	0.394	0.33	0.064	1.208	1.00	0.208
Mean		0.694	0.50	0.194	0.505	0.50	0.005	1.199	1.00	0.199
1T : 1B		0.656	0.50	0.156	0.522	0.50	0.022	1.178	1.00	0.178
1T : 2B		0.589	0.33	0.259	0.646	0.67	-0.024	1.235	1.00	0.235
2T : 1B		0.799	0.67	0.129	0.388	0.33	0.057	1.187	1.00	0.187
LSD.0.05 Spacing		0.014			NS			NS		
Intercropping		0.012			0.014			0.020		
Interaction		0.017			0.021			0.029		
		Second Season								
25 CM	1T : 1B	0.661	0.50	0.161	0.355	0.50	-0.145	1.017	1.00	0.017
	1T : 2B	0.584	0.33	0.254	0.432	0.67	-0.238	1.016	1.00	0.016
	2T : 1B	0,800	0.67	0.130	0.309	0.33	-0.021	1.110	1.00	0.110
Mean		0.681	0.50	0.181	0.364	0.50	-0.136	1.046	1.00	0.046
50 CM	1T : 1B	0.705	0.50	0.205	0.481	0.50	-0.019	1.186	1.00	0.186
	1T : 2B	0.555	0.33	0.225	0.583	0.67	-0.087	1.138	1.00	0.138
	2T : 1B	0.771	0.67	0.101	0.371	0.33	0.041	1.142	1.00	0.142
Mean		0.677	0.50	0.177	0.481	0.50	-0.019	1.158	1.00	0.158
1T : 1B		0.683	0.50	0.183	0.418	0.50	-0.082	1.101	1.00	0.101
1T : 2B		0.569	0.33	0.239	0.509	0.67	-0.161	1.078	1.00	0.078
2T : 1B		0.785	0.67	0.115	0.342	0.33	0.012	1.127	1.00	0.127
LSD 0.05 Spacing		NS			0.041			NS		
Intercropping		0.011			0.050			0.045		
Interaction		0.015			0.071			0.069		



T.P.S and B.P.S stand for pure stand of tomato and bean, respectively.
------ Stands for expected LER for tomato, bean and total (tomato + bean).
—— Stands for actual LER for tomato, bean and total (tomato + bean) .
T and B stand for tomato and bean.

Fig. 1: Effect of tomato intercropped with bean on land equivalent ratio.

5- Effect of tomato spacing intercropped with bean on relative crowding coefficient and aggressivity:

Both relative crowding coefficient and aggressivity of the intercropped tomato and bean plants were calculated using the authors formulas and those of Hall (1974) and McGilchrist (1965) respectively, for more examination of the proposed formulas. Calculations using both formulas not only gave the same values but also gave the same least significant differences. Again, authors can state that land equivalent ratio could be used as a reference for relative crowding coefficient and aggressivity. Obtained data presented in Table (5) showed that all values of the relative crowding coefficients for tomato (kt) were higher than those of bean (kb) which indicated that tomato was the dominant crop and bean was the dominated one. Generally, both kt and kb were higher when tomato were spaced at 50 cm than at 25 spacing which indicated that yield advantage was higher with spacing 50 cm than with spacing 25 c m. The highest value for the product of kt and kb (K) was obtained

Table 5: Effect of tomato spacing intercropped with bean on relative crowding coefficient and aggressivity.

Tomato spacing	Intercropping pattern	Relative crowding coefficient			Aggressivity	
		kt	kb	K =kt*kb	At	Ab
	T : B	Frist Season				
25 CM	1T : 1B	1.832	1.128	2.066	0.117	-0.117
	1T : 2B	2.689	1.088	2.924	0.693	-0.693
	2T : 1B	1.823	1.234	2.249	0.033	-0.033
Mean		2.115	1.150	2.413	0.281	-0.281
50 cm	1T : 1B	1.996	1.061	2.117	0.151	-0.151
	1T : 2B	3.051	0.772	2.356	0.903	-0.903
	2T : 1B	2.193	1.298	2.846	0.041	-0.041
Mean		2.413	1.044	2.440	0.365	-0.365
1T : 1B		1.914	1.095	2.092	0.134	-0.134
1T : 2B		2.870	0.930	2.640	0.798	-0.798
2T : 1B		2.008	1.266	2.548	0.037	-0.037
LSD .0.05 Spacing		0.169	NS	NS	0.047	0.047
Intercropping		0.130	0.063	0.232	0.041	0.041
Interaction		0.184	0.089	0.219	0.067	0.067
	T : B	Second Season				
25 CM	1T : 1B	1.953	0.551	1.077	0.306	-0.306
	1T : 2B	2.812	0.380	1.069	1.106	-1.106
	2T : 1B	2.004	0.895	1.794	0.273	-0.273
Mean		2.256	0.609	1.313	0.562	-0.562
50 CM	1T : 1B	2.397	0.927	2.222	0.225	-0.225
	1T : 2B	2.494	0.699	1.743	0.791	-0.791
	2T : 1B	1.690	1.180	1.994	0.044	-0.044
Mean		2.194	0.935	1.986	0.353	-0.353
1T : 1B		2.175	0.739	1.650	0.266	-0.266
1T : 2B		2.653	0.540	1.406	0.949	-0.949
2T : 1B		1.847	1.037	1.894	0.159	-0.159
LSD 0.05 Spacing		0.113	NS	NS	0.032	0.032
Intercropping		0.081	0.060	0.183	0.029	0.029
Interaction		0.114	0.075	0.164	0.046	0.046

with 2 T: 1B intercropping pattern. It amounted to 2.548 and 1.894 in the first and second season, respectively. As for aggressivity, Table (5) showed that all values of tomato were positive and those of bean were negative indicating that tomato was the dominant crop and bean was the dominated one. Aggressivity of both crops were higher with tomato spaced 50 cm than with 25 cm in the first season and vise versa in the second season . The highest aggressivity value was obtained with 1 T : 2 B intercropping pattern in both investigated seasons which indicated that there were bigger differences in the competitive abilities of tomato and bean plants, i.e., bigger differences between the actual and expected yield with that intercropping pattern (Willey, 1979). Similar results were obtained by Mohamed *et al* (1984) and Langat *et al* (2006).

Results of both relative crowding coefficient and aggressevity were in compatible with those of land equivalent ratio. This may be confirmed with the positive correlations found between the relative crowding coefficient (K) and total land equivalent ratio (LER) of the combined intercrops in both investigated seasons. A linear correlation coefficients (r) of 0.85 and 0.98 were obtained in the first and the second seasons, respectively. The corresponding coefficients of determination (r^2) were 0.73 and 0.97, which indicated that 73 and 97 per cent of the variation in land equivalent ratio in the first and second seasons, respectively, were related to the relative

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crowding coefficient. The regression coefficients were 0.095 and 0.145 for the two seasons, respectively, which indicated that for each increase of one unit of the relative crowding coefficient, land equivalent ratio correspondingly increased by 0.095 and 0.145 in the first and second seasons, respectively.

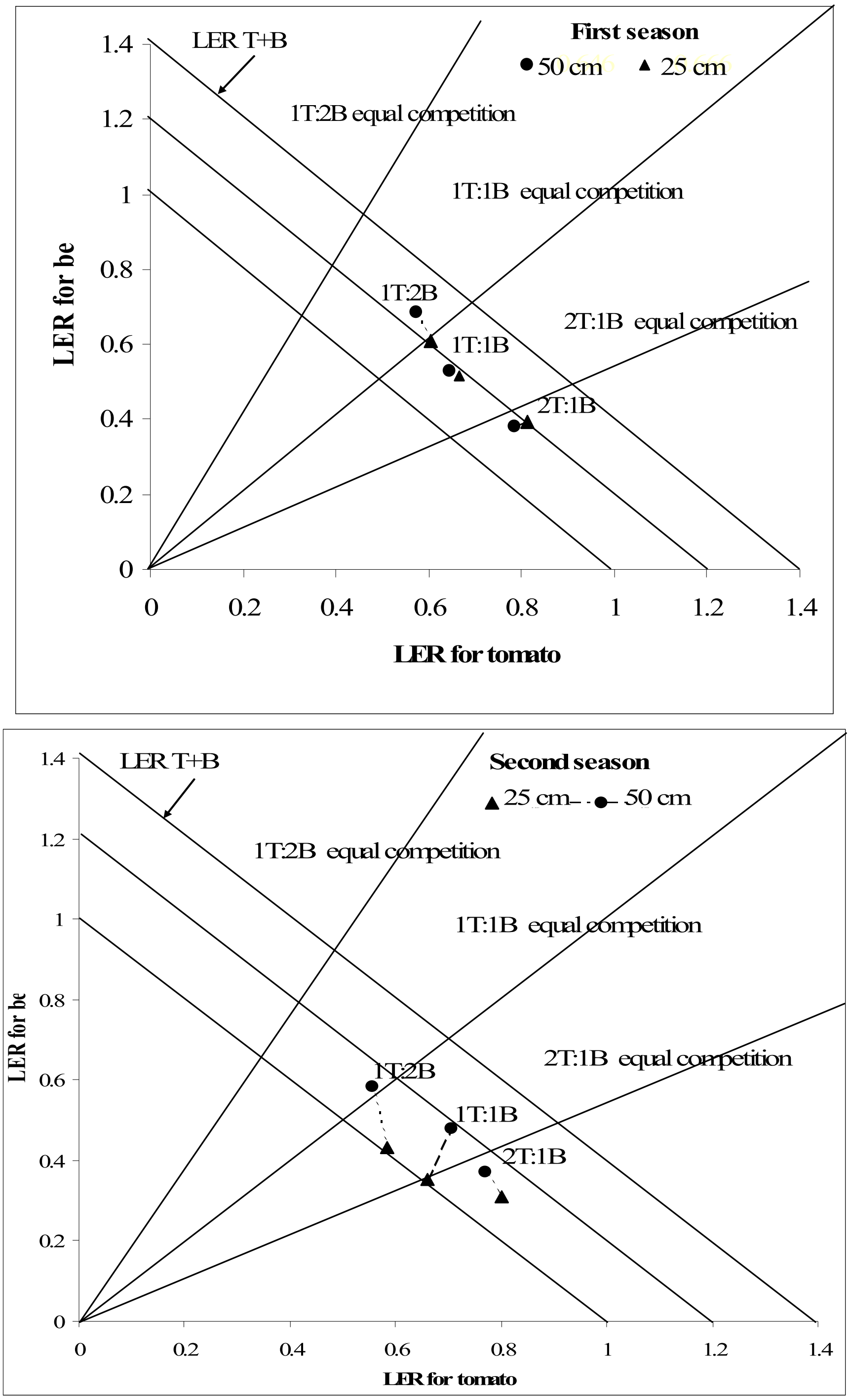

Fig. 2: Effect of tomato spacing intercropped with bean on land equivalent ratio.

It can be concluded from the previous investigated competitive functions, *i.e.,* land equivalent ratio (LERt and LERb), relative crowding coefficient (kt and kb) and aggressively (At and Ab), that for any combination, all the three functions indicated that tomato was the dominant crop and bean was the dominated one. Also, both k products (K) and total LER values showed which combination did or did not give a yield advantage, but the aggressively values were not able to do this. In addition, relative crowding coefficients did not give a simple indication of the actual magnitude of any yield advantage. From this point of view, the LER values were considered preferable. Therefore, it is appreciated to throw more light upon LER and represent LER of tomato, LER of bean and total LER values in a figure easy to read as illustrated in Fig. (2). LER of tomato and LER of bean were plotted on the X and Y axes, respectively, and the total LER value was then shown by the diagonal lines which join those axes. Fig. (2) clearly showed the actual level of intercropping advantage for any given combination and the proportions of each component which produced this. As an added refinement, the diagonal lines rising from the origin were added to indicate the expected yields of the investigated intercropping patterns at which both component crops are equally competitive. All points of each intercropping pattern were located between the corresponding diagonal line of expected yield and tomato axis which indicated that tomato was the dominant crop and bean was the dominated one. These results were true with all investigated intercropping patterns in both seasons.

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