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# Effect of seed rate on the seed yields in wheat/faba bean intercropping system: estimates of intercrop performance using three different indices

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## Abstract

For wheat (*Triticum aestivum* L.) / faba bean (bean; *Vicia faba* L.) intercropping system, the analyses of intercrop benefits had hitherto been restricted to the land equivalent ratio (LER) despite the fact that the index has its disadvantages. In the research reported here, based on the LER, crop performance ratio (CPR) and monetary advantage (MA) indices, seed yield intercrop performance were assessed from results and values obtained after yields response to seed rate were quantified using meaningful equations. Based on the results, a maximum LER of 2.20 and a maximum CPR of 1.61 were found. In two experiments LER >1.0 but CPR <1.0 were obtained, indicating that the total intercrop (wheat + bean) were less efficient than the component sole crops. Estimates of intercrop benefits using the MA agreed with estimates based on the LER, probably because the former is a derivative of the latter. However, estimates of seed yield intercrop performance using fitted data did not consistently agree with estimates based on actual results. For the majority of the experiments, it was concluded that wheat/bean intercropping system is beneficial, and growers may wish to adopt the cropping system.

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## Introduction

## Introduction

Various indices have been developed for comparing the performance of the intercrops compare to their component sole crops (Hiebsch and McCollum, 1987; Francis, 1989; Vandermeer, 1989; Fukai, 1993). Specifically, the land equivalent ratio (LER) (Willey, 1979, 1985; Yahuza, 2011a), crop performance ratio (CPR; Harris *et al.,* 1987; Azam-Ali *et al.,* 1990) and monetary advantage index (MA) (Ghosh, 2004; Dhima *et al.,* 2007) are some of the indices available for such evaluation purposes. In calculating the LER, the two sole crop yields are given the value of 1 (Willey, 1985) which helps indicate the relative competitive abilities of the component crops and also shows the relative value of any intercropping yield advantage (Willey, 1979). If the value is greater than unity, the intercrop is more efficient and vice versa (Vandermeer, 1989). However, a major limitation of LER is that the index is not able to identify the physiological or physical processes responsible for any differences that may occur between the intercrops and sole crops (Harris *et al*., 1987). This is because the index does not present the absolute or relative biological efficiencies of the system in terms of the amount of biomass or yield fixed relative to the energy captured during the season (Azam-Ali and Squire, 2002). Despite the drawbacks, the LER remains the most widely- used index among researchers. For instance, the practical benefits of wheat (*Triticum aestivum* L.)/faba bean (bean; *Vicia faba* L.) intercropping system were demonstrated in the United Kingdom (UK) previously (Hongo, 1995; Haymes and Lee, 1999), but none of these investigations made comparison between the evaluations that were based on LER with other indices that may have different interpretation of any intercrop advantage that were found.

Harris *et al.* (1987) first proposed the concept of crop performance ratio (CPR) to assess the performance of intercrops compare to the component sole crops. They developed the index because of the limitation of the LER mentioned earlier. Consequently, unlike the LER, the literature indicate that the CPR is the appropriate index for calculating the biological advantage of intercrop compare to the component sole crops, because the index calculates the efficiency with which resources such as radiation are used to produce dry matter (Harris *et al.*, 1987; Azam Ali *et al.*, 1990). Similar to the LER, a value of CPR greater than 1 indicates an intercrop advantage and a CPR less than 1 an intercrop disadvantage (Azam-Ali and Squire, 2002). However, unlike the LER, the partial CPR cannot be summed to get the total intercrop CPR (Yahuza, 2011a). This suggests that the total intercrop CPR has to be calculated separately even though the partial CPR values might have been calculated for the component crops. Moreover, unlike the LER, similar calculations, but with several different variables instead of yield, can be made to evaluate variables such as light interception, radiation use efficiency, harvest index, transpiration, nutrient uptake, yield components and tiller number using the CPR approach (Harris *et al.,* 1987; Azam-Ali and Squire, 2002). Therefore, the most important advantage of the CPR concept is that it can be extended to analyze the capture or use of any resource by an intercrop compare with its component sole crops (Azam-Ali and Squire, 2002). To my knowledge, this index had rarely been used in analysing intercrop performance in wheat/bean intercropping system. Thus, it is important that the CPR be used alongside the LER in evaluating intercrop performance in wheat/bean intercropping system, since each of these two indices have different interpretation of intercrop performance.

Irrespective of the indices that was used to assess intercropping advantages, there may be need to indicate some monetary values for intercropping if at least one of the component crops is a cash crop (Ghosh, 2004; Yahuza, 2011a). Such economic evaluation is needed in addition to whatever analyses carried out on yield (Willey, 1979). In general, the calculation of MA assumes that the appropriate economic assessment of intercropping should be in terms of increased value per unit area (Willey, 1985). Thus, it is obvious that for wheat /bean intercropping system, analysis based on MA is important given that the two crops are mainly cash crops (Nix, 2009; Yahuza, 2011b). Although, Dhima *et al.* (2007) used the MA recently and indicated that intercropping was beneficial, previous experiments on wheat/bean intercropping system have rarely used the approach. Consequently, for wheat/bean intercropping system, it is necessary that the MA be used in addition to the LER and CPR in order to compare the performance of intercrop compare to their component sole crops.

From the foregoing, it is clear there is a need to use more than one index for analysing any given intercropping system before wider conclusion can be reached as to whether the system is beneficial or not. Obviously, for wheat/bean intercropping system that has not been widely accepted by the growers, this type of comparisons appears to be necessary in order to attract potential growers (Yahuza, 2011a; b). Thus, in contrast to one or two year's trials of the previous investigations (Hongo, 1995; Bulson *et al.,* 1997; Haymes and Lee, 1999), evidence from at least three-year field trials may be necessary. In addition, though wheat/bean intercropping system has been investigated under both conventional (Hongo, 1995; Haymes and Lee, 1999) and organic systems (Pristeri *et al.,* 2006), and/or winter-sown versus spring-sown (Bulson *et al.,* 1997; Haymes and Lee, 1999), only a few investigations have compared the performance of this intercrop under these contrasting conditions simultaneously. Indeed, as far as I am aware there has not been any research on this intercrop combination that has compared the performance of the intercrops to their component sole crops under contrasting growth conditions of conventional versus organic which were established in the same season simultaneously. Thus, for this intercrop combination; comparison based on evaluations using each of the three indices mentioned previously under different contrasting growth condition is important in order to give the prospective growers the choice to choose the system that is more beneficial.

The literature indicate that it is possible to calculate intercrop performance based on fitted data after regression of yields against density using biologically meaningful yield-density equations (Oyejola, 1983; Dolman, 1985). Indeed, establishing yield-density relationship using equations such as a hyperbolic asymptotic model (Willey and Heath, 1969) have been shown to be an important preliminary requirement in the analyses of intercropping data (Dolman, 1985; Yahuza, 2011c). For instance, Dolman (1985) applied hyperbolic asymptotic equation to evaluate intercrop performance consisting of crops of vegetative yields, and used the fitted data in determining the performance of intercropping based on evaluations using the LER. However, in general this vital step in the analyses of results from intercropping research is rarely followed (Yahuza, 2011c). Therefore, it is not surprising that for wheat/bean intercropping system this approach has not been used previously in the evaluation of intercrop performance irrespective of the index involved (Yahuza, 2011a). Thus, in addition to evaluations based on actual results, it is necessary to evaluate intercrop performance for this intercrop combination based on fitted data.

For the present investigations on wheat/bean intercropping system, in Yahuza (2012), the seed yields were analysed using competition approach by applying equations to quantify the data as was applicable. Since this intercrop combination has not been well studied previously, here the objectives were i. To evaluate performance of intercrops compare to the component sole crops in response to seed rate using the LER, CPR and MA based on results and fitted data. ii. To compare the intercrops to the component sole crops under the contrasting growth conditions for which details were given in Yahuza (2012).

**Materials and methods**

This research was carried out at the University of Reading's Crop Research Unit, Sonning, Berkshire, UK ($0^{o}$ 56΄ W, $51^{o}$ 27΄ N). Site attributes, experimental design and treatments as well as crop management were well detailed in Yahuza (2012), and in there references were made to earlier publications for further details, so are not repeated here. Briefly, Experiments 1 to 4 were based on additive designs (Jolliffe, 2000) whilst Experiment 5 was based on response surface design (Connolly, 1987). All the Experiments were conventionally-managed except Experiment 2, which was organically-managed. However, similar to Yahuza (2012), here Experiment 1 was referred to as the conventional experiment, and was compared with Experiment 2 that was organically-managed, since the two experiments had similar designs, drilled and harvested same day, and received similar agronomic treatment as was permissible under organic management (in the case of Experiment 2). All the experiments were established in the winter except Experiment 3, which was spring-sown. However, Experiment 1, which was autumn-sown, was compared with Experiment 3 that was spring-sown, since the two experiments were established in the same cropping year and was both conventionally-managed (Yahuza, 2012). In addition, all analyses of variance (ANOVA) and regression analyses were detailed in Yahuza (2012). Although these analyses are not repeated here, they serve as the background of the present paper, so readers will find Yahuza (2012) a useful reference in understanding the present paper.

*Some abbreviations used in this paper explained*

In some cases sr, wsr, bsr refers to the seed rate, wheat seed rate and bean seed rate respectively. Similarly, WP, BP refers to wheat partial and bean partial LER/CRP respectively. In addition, occasionally (particularly in the tables) seed yield, wheat sole crop, wheat intercrop, bean sole crop, bean intercrop and the total intercrop are referred to simply as the SY, WSC, WIC, BSC, BIC and TIC respectively. Similarly, on a few instances (particularly in the tables) the results are refereed to as the WSC SY, WIC SY, BSC SY, BIC SY for the wheat sole crop, wheat intercrop, bean sole crop and bean intercrop seed yields respectively. As for the results, abbreviations used for the fitted yields (particularly in the tables) include the fitted data (FD), fitted WSC SY (FWSSY), fitted WIC SY (FWISY), predicted wheat sole crop asymptotic yield (PWSASY), fitted BSC SY (FBSSY), and fitted BIC SY (FBISY).

*Estimating intercrop performance*

Intercrop performance was evaluated based on the LER, CPR and MA indices. The LER, CPR and MA were calculated according to the procedures described by Willey (1985), Harris *et al.* (1987) and Ghosh (2004) respectively. For the results, the wheat partial values (for CPR or LER) were calculated using the maximum wheat sole crop yield for standardization. However in the case of bean, there was only one sole crop in most experiments (30 or 40 seeds/m$^2$), so the same sole crop was used for all treatments. However, in Experiment 5 the maximum yielding bean sole crop was chosen.

*Estimating intercrop performance based on the land equivalent ratio*

For the evaluations using the LER, first wheat and bean partial LER were calculated using equations 1 and 2 respectively.

$$L_{wheat} = \frac{WY_i}{WS_s} \qquad 1$$

$$L_{bean} = \frac{BY_i}{BY_s} \qquad 2$$

This allows the total intercrop LER to be calculated using equation 3

$$LER = \left(\frac{WY_i}{WY_s}\right) + \left(\frac{BY_i}{BY_s}\right) \qquad 3$$

In equations 1-3, WY and BY refer to wheat and bean yields respectively. The subscript i, refers to the intercrop and the subscript s the sole crop.

With regard to calculating the LER from fitted data after the yield-density equations were applied (Dolman, 1985; Yahuza, 2011c), the approach was similar as was described in respect of the results. However, in some cases concerning the bean, results were used again. Thus, for the wheat, the predicted asymptotic yield of the wheat sole crop (i.e.$1/b_w$) (Dolman, 1985; Yahuza, 2011c; 2012) was used for standardization. Hence, wheat partial LER was calculated using equation 4 to determine the LER based on fitted data. Fitted bean LER values were also determined based on either linear or quadratic response to wsr (Yahuza, 2012).

$$L_{wheat} = \frac{WY_i}{\left(1/b_w\right)} \qquad 4$$

Where $WY_i$ refers to the fitted wheat intercrop yield and $1/b_w$ refers to the predicted asymptotic yield of the wheat sole crop (Yahuza, 2012).

*Estimating intercrop performance based on the crop performance ratio*

Similar procedures used for LER were used in the case of the evaluation of intercrop performance based on the CPR. The CPR was calculated according to the procedures described by Harris *et al.* (1987) and Azam-Ali *et al.* (1990). Here the proportion-sown area was 50% (0.5) wheat and 50% (0.5) bean for each of the experiments. This was because for the intercrops a row of wheat was usually followed by a row of bean except in Experiment 5 where the two components crops were sown in the same row. Here it was still assumed that the proportional sown area was still 50% wheat and 50% bean.

Therefore, the yield per unit area of wheat in the intercrop ($WY_i$) was divided by the proportion ($P_{iw}$), of wheat in the intercrop to give the yield per unit area sown to wheat. This quantity was then expressed as a fraction of wheat in the sole plot, $WY_s$ to give crop performance ratios (CPR). Similar calculations were also done for the bean, thus allowing the total intercrop crop performance ratio (TCPR) to be calculated. Hence, the wheat CPR, bean CPR and total intercrop CPR were calculated using equations 5, 6 and 7 respectively. It should be pointed out that unlike the partial LERs, the partial CPR for wheat (equation 5) and bean (equation 6) cannot be summed to get the total intercrop CPR (equation 7; Azam-Ali and Squire, 2002).

$$CPR_{wheat} = \frac{WY_i}{P_{iw} WY_s} \qquad 5$$

$$CPR_{bean} = \frac{BY_i}{P_{ib} BY_s} \qquad 6$$

$$TCPR_{wheat+bean} = \frac{WY_i + BY_i}{P_{iw} WY_s + P_{ib} BY_s} \qquad 7$$

In equations 5-7 $WY_i$ and $WY_s$ are wheat yields per unit area (g/m$^2$) in the intercrop and sole crop respectively, and $P_{iw}$ is the proportional sown area of wheat in the intercrop (which was 0.5). Similarly, $BY_i$ and $BY_s$ are bean yields per unit area (g/m$^2$) in the intercrop and sole crop respectively, and $P_{ib}$ is the proportional sown area of bean in the intercrop (which was 0.5). Moreover, similar to the LER, the CPR for each of the component as well as the total intercrop was calculated based on the fitted data.

*Estimating intercrop performance based on the monetary advantage*

The monetary values for the seed yields were obtained from the national estimates by Nix (2009). In order to reduce variation between years, the estimated price of each of wheat and bean for the 2009/10 marketing year as given by Nix (2009) was used for all the winter experiments irrespective of the year of establishment and cropping system involved, and whether conventionally or organically managed. However, a different estimate (but still the 2009/10 marketing year) was used for the spring experiment. Nix estimated that the average winter wheat (milling) wheat for the marketing year 2009/10 was 147 UK pounds sterling (£147) per metric tonne whilst the estimate for the spring wheat was £145 per metric tonne. On the other hand, the winter bean estimated price was £165 per metric tonne whilst estimate for the spring bean was £175 per metric tonne. Note that the seed yields were converted to tonnes per hectare before the MA was calculated. In addition, it should be pointed out that 1 United states of America dollars = £ 0.62 as at 28 February 2011. Hence, for both the winter and spring sowing, bean had greater premium price than the wheat. Therefore, it was assumed that MA will be greater in circumstances that bean yield was not substantially reduced. Consequently, based on the LER estimates, the MA was calculated using equation 8 as described by several workers (Willey, 1985; Ghosh, 2004; Dhima *et al.,* 2007; Yahuza, 2011a). Similar to the LER and CPR, the evaluations was carried using the results and fitted data.

$$MA_{LER} = \left[ TIV \left( \frac{LER - 1}{LER} \right) \right] \quad 8$$

Where TIV = total intercrop value (UK pound sterling (£)), and LER is the land equivalent ratio.

**Results**

*Performance of the seed yields as evaluated using the land equivalent ratio*

In Experiment 1 as regards the seed yields the total intercrop LER did not show an advantage for intercropping, except at 200 wheat seeds/m² where intercropping was slightly beneficial (Table 1a). See the Materials and Methods section for explanations on the abbreviations used in Table 1a and all the subsequent tables. It is not surprising that intercrops at lower wsr performed less well, since the sole crop wheat yield was greatest at this density of 200-wheat seeds/m². The low total intercrop LER values obtained can be attributed to the poor performance of the wheat in the intercrop as is indicated by the wheat partial LER (Table 1a). However, when predicted asymptotic yield of the WSC was used for standardization, there was no benefit for intercropping across wsr (Table 1b). This is sensible given that as was seen in Yahuza (2012), for this experiment, wheat SY response to wsr was linear despite the variability as was indicated by the significant quadratic effects from the ANOVA.

In Experiment 2, for the SY the total intercrop LER suggested advantages for intercropping across wsr (Table 2a). Although wheat partial LER values were low, the partial LER values of the bean facilitated the higher total intercrop LER values obtained (Table 2a). The chocolate spot (*Botrytis fabae*) infections of the beans (data not presented) were responsible for the greater performance of the intercrop bean compared to bean sole crop. The extremely high bean partial LER found was not surprising, given that the bean intercrop were less infected by the disease compared to the sole bean (Table 2a). Using the fitted data to calculate the LER gave similar results (Table 2b). However, as shown in Table 2b, the estimates based on fitted data indicate that the estimates based on the results were slightly reduced. Nevertheless, one way of overcoming this extremely high LER estimate due to disease would have been to use plant population density (p) instead of wsr. However, in this experiment p may not have provided different results since the disease outbreak occur at the reproductive stages even though the final plant densities were taken earlier (data not provided).

In Experiment 3 with respects to the SY, for all treatments the LER indicated positive benefits for intercropping across all wsr (Table 3a). The better performance of intercrop can be attributed mainly to the wheat as is indicated by the wheat partial LER values > 0.5 except at 30-wheat seeds/m² (Table 3a). On the other hand, bean partial LER values were greater than wheat at the two lower wsr; thus facilitating benefit of intercropping despite the low wheat partial LER values (Table 3a). As is indicated in Tables 3b that estimates using fitted data were similar to that based on results is not surprising given that in this experiment the PWSASY that was used for standardization, was closer to the maximum yield obtained from the results. This further indicates that the equations used to quantify the SYs for the wheat and bean respectively for this experiment as described in Yahuza (2012) had described the data well.

**Table 1a.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the SY results, and determined using the maximum yield for standardization in Experiment 1, to show that there was no benefit for intercropping except at 200-wheat seeds/m².

| Wheat seed rate (seeds/m²) | WSC SY (g/m²) | WIC SY (g/m²) | WP LER | BSC SY (g/m²) | BIC SY (g/m²) | BP LER | TIC LER |
|---|---|---|---|---|---|---|---|
| 10 | 102 | 22 | 0.04 | 208 | 151 | 0.73 | 0.77 |
| 50 | 326 | 55 | 0.11 | | 136 | 0.65 | 0.77 |
| 100 | 425 | 120 | 0.24 | | 153 | 0.74 | 0.98 |
| 200 | 490 | 179 | 0.37 | | 139 | 0.67 | 1.03 |

For the beans, no significant effect of wsr. Mean for all plots = 157 g/m².

**Table 1b.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the fitted SY (as was applicable), and determined using the predicted WSC asymptotic yield for standardization in Experiment 1, to show that there was no benefit for intercropping.

| Wheat seed rate (seeds/m²) | FWSSY (g/m²) | FWISY (g/m²) | PWSASY (g/m²) | WP LER based on PWSASY | BP LER | TIC LER based on FD |
|---|---|---|---|---|---|---|
| 10 | 112 | 15 | 604 | 0.02 | 0.73 | 0.75 |
| 50 | 321 | 65 | | 0.11 | 0.65 | 0.76 |
| 100 | 420 | 113 | | 0.19 | 0.74 | 0.93 |
| 200 | 495 | 181 | | 0.30 | 0.67 | 0.97 |

For both the WSC and WIC, see Yahuza (2012) for fitted equation. For the beans, see Table 1a for the results that was used (no fitting).

**Table 2a.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the SY results, and determined using the maximum yield for standardization in Experiment 2, to show that there was benefit for intercropping across wsr, largely facilitated by the beans.

| Wheat seed rate (seeds/m²) | WSC SY (g/m²) | WIC SY (g/m²) | WP LER | BSC SY (g/m²) | BIC SY (g/m²) | BP LER | TIC LER |
|---|---|---|---|---|---|---|---|
| 10 | 104 | 34 | 0.05 | 49 | 47 | 0.97 | 1.01 |
| 50 | 347 | 95 | 0.14 | | 66 | 1.35 | 1.49 |
| 100 | 375 | 157 | 0.24 | | 63 | 1.29 | 1.52 |
| 200 | 660 | 243 | 0.37 | | 90 | 1.84 | 2.20 |

**Table 2b.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the fitted SY (as was applicable), and determined using the predicted WSC asymptotic yield for standardization in Experiment 2, to show that there was benefit for intercropping.

| Wheat seed rate (seeds/m²) | FWSSY (g/m²) | FWISY (g/m²) | PWSASY (g/m²) | WP LER based on PWSASY | FBISY (g/m²) | BP LER | TIC LER based on FD |
|---|---|---|---|---|---|---|---|
| 10 | 77 | 23 | 1016 | 0.02 | 50 | 1.01 | 1.04 |
| 50 | 294 | 96 | | 0.09 | 58 | 1.18 | 1.28 |
| 100 | 456 | 160 | | 0.16 | 68 | 1.40 | 1.55 |
| 200 | 630 | 242 | | 0.24 | 89 | 1.82 | 2.05 |

For both the WSC and WIC, see Yahuza (2012) for fitted equation. For the BIC, fitted equation was linear. BSC SY = 49 g/m² (no fitting).

**Table 3a.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the SY results, and determined using the maximum yield for standardization in Experiment 3, to show that there was benefit for intercropping across wsr.

| Wheat seed rate (seeds/m²) | WSC SY (g/m²) | WIC SY (g/m²) | WP LER | BSC SY (g/m²) | BIC SY (g/m²) | BP LER | TIC LER |
|---|---|---|---|---|---|---|---|
| 30 | 334 | 221 | 0.35 | 241 | 212 | 0.88 | 1.23 |
| 75 | 481 | 380 | 0.60 | | 181 | 0.75 | 1.35 |
| 200 | 568 | 453 | 0.71 | | 107 | 0.44 | 1.15 |
| 400 | 613 | 508 | 0.80 | | 114 | 0.47 | 1.27 |
| 650 | 639 | 566 | 0.89 | | 93 | 0.39 | 1.27 |

**Table 3b.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the fitted SY, and determined using the predicted WSC asymptotic yield for standardization in Experiment 3, to show that there was benefit for intercropping across wsr.

| Wheat seed rate (seeds/m²) | FWSSY (g/m²) | FWISY (g/m²) | PWSASY (g/m²) | WP LER based on PWSASY | FBISY (g/m²) | BP LER based on FD | TIC LER based on FD |
|---|---|---|---|---|---|---|---|
| 30 | 335 | 228 | 660 | 0.35 | 213 | 0.88 | 1.23 |
| 75 | 475 | 360 | | 0.55 | 172 | 0.71 | 1.26 |
| 200 | 576 | 473 | | 0.72 | 126 | 0.52 | 1.24 |
| 400 | 615 | 523 | | 0.79 | 103 | 0.43 | 1.22 |
| 650 | 632 | 545 | | 0.83 | 92 | 0.38 | 1.21 |

For the WSC, WIC, BSC and BIC, see Yahuza (2012) for fitted equations. The FBSSY = 241 g/m².

**Table 4.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the SY results, and determined using the maximum yield for standardization in Experiment 4, to show that there was benefit for intercropping across wsr.

| Wheat seed rate (seeds/m$^2$) | WSC SY (g/m$^2$) | WIC SY (g/m$^2$) | WP LER | BSC SY (g/m$^2$) | BIC SY (g/m$^2$) | BP LER | TIC LER |
|---|---|---|---|---|---|---|---|
| 25 | 274 | 120. | 0.20 | 392 | 336 | 0.86 | 1.06 |
| 75 | 434 | 167 | 0.28 | | 400 | 1.02 | 1.30 |
| 150 | 396 | 282 | 0.48 | | 260 | 0.66 | 1.14 |
| 400 | 588 | 304 | 0.52 | | 236 | 0.60 | 1.12 |

In Experiment 4 as regards seed yields, for all the intercrop combinations the LER suggest advantages for intercropping at all wsr (Table 4). The better performance of the total intercrop can be attributed to the higher partial LER values of the bean compared to the lower ones for wheat (Table 4). However, as was pointed out in Yahuza (2012), in this experiment the SY was estimated from a smaller area. Estimates based on smaller area may be prone to greater errors than estimates from larger area. Indeed, as was indicated in Yahuza (2012) no equation was applied to quantify the SYs in this experiment, since no definite pattern was found. Hence, for this experiment, performance indices were not estimated based on fitted data.

In Experiment 5, as regards seed yields the total intercrop LER suggest advantages for intercropping with higher sr for wheat and/or bean (Table 5a). The benefits of intercropping were greater at 20-bean seeds/m$^2$ or more (Table 5a). Nevertheless, the higher partial LER values of the wheat found in this experiment were due to the indiscriminate bird damage to the beans (data not presented), that led to similarities in seed yields between the wheat sole crops and intercrops (Yahuza, 2012). Thus, it was not surprising that for this experiment, as for the evaluations of LER based on the results, similar trends were found when the fitted data were used (Table 5b). Nevertheless, estimates based on fitted data in most cases reduced the estimates based on the results.

*Performance of the seed yield as evaluated using the crop performance ratio*

In Experiment 1, evaluations based on the CPR showed that the wheat in the intercrop struggled with respect to seed yields (Table 6). Thus, the wheat in the intercrop performed less efficiently compared to the wheat sole crop (Table 6). On the other hand, bean in the intercrop performed better compared to the sole crop (Table 6). However, the total intercrop was not efficient compare to the sole crops (Table 6). This poor performance can be attributed to the under performance of the wheat in the intercrop compared to the WSC as is indicated by the wheat CPR values (Table 6). However, as was the case with the LER, when the PWSASY was used for standardization, estimates based on fitted data reduced the estimates based on results (Table 6).

In Experiment 2, with respect to seed yields, evaluations based on the CPR indicate that the wheat in the intercrop struggled compare to the sole crop (Table 7). On the other hand, bean in the intercrop was more efficient than the bean sole crop (Table 7). Nevertheless, due to the poorer performance of the wheat in the intercrop, the total intercrop CPR was low (Table 7). Similar to Experiment 1, based on fitted data, the CPR estimates based on results were reduced (Table 7). In addition, for this experiment, unlike, the LER, neither the estimates based on results nor that based on the fitted data indicate benefit for intercropping (Table 7).

**Table 5a.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the SY results, and determined using the maximum yield for standardization in Experiment 5, to show that there was benefit for intercropping mainly at 20 bean seeds/m² or more.

| Wheat seed rate (seeds/m²) | Bean seed rate (seeds/m²) | WSC SY (g/m²) | WIC SY (g/m²) | WP LER | BSC SY (g/m²) | BIC SY (g/m²) | BP LER | TIC LER |
|---|---|---|---|---|---|---|---|---|
| 25 | 5 | 270 | 221 | 0.30 | 9 | 22 | 0.09 | 0.39 |
| 100 | 5 | 723 | 624 | 0.85 | 9 | 18 | 0.07 | 0.92 |
| 200 | 5 | 682 | 674 | 0.92 | 9 | 6 | 0.02 | 0.94 |
| 400 | 5 | 734 | 701 | 0.96 | 9 | 20 | 0.08 | 1.03 |
| 25 | 20 | 270 | 309 | 0.42 | 91 | 45 | 0.18 | 0.60 |
| 100 | 20 | 723 | 511 | 0.70 | 91 | 109 | 0.43 | 1.12 |
| 200 | 20 | 682 | 552 | 0.75 | 91 | 120 | 0.47 | 1.22 |
| 400 | 20 | 734 | 755 | 1.03 | 91 | 18 | 0.07 | 1.10 |
| 25 | 40 | 270 | 153 | 0.21 | 215 | 273 | 1.07 | 1.28 |
| 100 | 40 | 723 | 464 | 0.63 | 215 | 331 | 1.30 | 1.93 |
| 200 | 40 | 682 | 692 | 0.94 | 215 | 98 | 0.38 | 1.33 |
| 400 | 40 | 734 | 681 | 0.93 | 215 | 98 | 0.38 | 1.31 |
| 25 | 80 | 270 | 129 | 0.18 | 255 | 358 | 1.40 | 1.58 |
| 100 | 80 | 723 | 475 | 0.65 | 255 | 106 | 0.42 | 1.06 |
| 200 | 80 | 682 | 550 | 0.75 | 255 | 153 | 0.60 | 1.35 |
| 400 | 80 | 734 | 520 | 0.71 | 255 | 201 | 0.79 | 1.50 |

In Experiment 3 evaluations based on the CPR, indicate that wheat in the intercrop was more efficient than the sole crop except at 30-wheat seed/m² (Table 8). On the other hand, as suggested by the CPR estimate, bean in the intercrop performed better than the sole crop only at 75 seed/m² or lower (Table 8). Evaluations based on the CPR indicate that the total intercrop was more efficient than the sole crops except at 30-wheat seeds/m² where the performance approximately equates to that of WSC (Table 8). Based on fitted data, similar trends were found (Table 8). However, as was the case with the earlier experiments, when the PWSASY was used for standardization, the CPR estimates based on fitted data reduced the estimates based on results (Table 8).

In Experiment 4, the evaluations of intercrop performance based on CPR indicate that wheat in the intercrop struggled and was more efficient than the sole crop only at 400-wheat seeds/m² (Table 9). On the other hand, bean in the intercrop performed well than the sole crop at all intercrop combinations as indicated by the bean partial CPR estimates (Table 9). The evaluations based on CPR also indicate that the total intercrop performed more efficiently than the sole crops except at 25-wheat seeds/m² (Table 9). However, in this experiment CPR was not estimated using fitted data, since no equation was applied to quantify the SYs (Yahuza, 2012).

In Experiment 5 as regards seed yields, the evaluation of intercrop performance based on the CPR, indicate that wheat in the intercrop was more efficient than the sole crop except at 25-wheat seeds/m² (Table 10). It was clear that the partial CPR for the bean tended to be greater with increase in bsr, particularly at the lowest wsr (Table 10). Nevertheless, as depicted in Table 10, evaluations based on the CPR showed that the total intercrop was generally advantageous except at 25-wheat seeds/m². This suggests that the intercrops were more efficient than the component sole crops. This can be attributed to the positive wheat partial CPR values (Table 10). Similar to the earlier experiments, for this experiment, in most cases, CPR estimates based on fitted data reduced the estimates based on results (Table 10).

**Table 5b.** The land equivalent ratios for the wheat, bean and total intercrop calculated based on the fitted SY (as was applicable), and determined using the predicted WSC asymptotic yield for standardization in Experiment 5, to show that there was benefit for intercropping mainly at 20 bean seeds/m² or more.

| Wheat seed rate (seeds/m²) | Bean seed rate (seeds/m²) | FWSSY (g/m²) | FWISY (g/m²) | PWSASY (g/m²) | WP LER based on PWSASY | BSC SY (g/m²) | BIC SY (g/m²) | BP LER | TIC LER based on FD |
|---|---|---|---|---|---|---|---|---|---|
| 25 | 5 | 336 | 295 | 842 | 0.35 | 9 | 22 | 0.09 | 0.44 |
| 100 | 5 | 612 | 559 | | 0.66 | 9 | 18 | 0.07 | 0.73 |
| 200 | 5 | 709 | 658 | | 0.78 | 9 | 6 | 0.02 | 0.81 |
| 400 | 5 | 770 | 721 | | 0.86 | 9 | 20 | 0.08 | 0.93 |
| 25 | 20 | 336 | 253 | | 0.30 | 91 | 45 | 0.18 | 0.48 |
| 100 | 20 | 612 | 519 | | 0.62 | 91 | 109 | 0.43 | 1.04 |
| 200 | 20 | 709 | 629 | | 0.75 | 91 | 120 | 0.47 | 1.22 |
| 400 | 20 | 770 | 704 | | 0.84 | 91 | 18 | 0.07 | 0.91 |
| 25 | 40 | 336 | 214 | | 0.25 | 215 | 273 | 1.07 | 1.32 |
| 100 | 40 | 612 | 474 | | 0.56 | 215 | 331 | 1.30 | 1.86 |
| 200 | 40 | 709 | 595 | | 0.71 | 215 | 98 | 0.38 | 1.09 |
| 400 | 40 | 770 | 682 | | 0.81 | 215 | 98 | 0.38 | 1.19 |
| 25 | 80 | 336 | 162 | | 0.19 | 255 | 358 | 1.40 | 1.60 |
| 100 | 80 | 612 | 404 | | 0.48 | 255 | 106 | 0.42 | 0.90 |
| 200 | 80 | 709 | 536 | | 0.64 | 255 | 153 | 0.60 | 1.24 |
| 400 | 80 | 770 | 642 | | 0.76 | 255 | 201 | 0.79 | 1.55 |

For both the WSC and WIC, see Yahuza (2012) for fitted equations. For the beans, no fitting results were used.

*Performance of seed yield as evaluated using the monetary advantage*

In Experiment 1, the evaluations of intercrop performance based on the MA for the seed yields showed an increase farm income by intercropping but only at 200-wheat seeds/m² (Table 11a). However, for this experiment, similar to the LER estimate, the MA estimates based on the fitted data indicate no financial benefit for intercropping (Table 11b). As explained earlier, this is sensible given that though the asymptotic equation was fitted to the wheat SY data, the response was mainly linear (Yahuza, 2012). Moreover, this contrast between the MA estimates based on the results and the fitted data is not surprising, since the MA is a derivative of the LER.

**Table 6.** The crop performance ratio for the wheat, bean and total intercrop calculated based on the SY results, and the fitted data in Experiment 1 to show that there was no benefit for intercropping across wsr.

| Wheat seed rate (seeds/m²) | WP CPR | BP CPR | TIC CPR | WP CPR based on PWSASY | BP CPR based on FD | TIC CPR based on FD |
|---|---|---|---|---|---|---|
| 10 | 0.09 | 1.45 | 0.50 | 0.05 | 1.45 | 0.41 |
| 50 | 0.22 | 1.31 | 0.55 | 0.22 | 1.42 | 0.49 |
| 100 | 0.49 | 1.47 | 0.78 | 0.37 | 1.40 | 0.65 |
| 200 | 0.73 | 1.34 | 0.91 | 0.60 | 1.34 | 0.79 |

For the SYs used for calculating the CPR, see Tables 1a and 1b for the yields based on results and FD respectively.

**Table 7.** The crop performance ratio for the wheat, bean and total intercrop calculated based on the SY results, and the fitted data in Experiment 2, to show that there was no benefit for intercropping across wsr.

| Wheat seed rate (seeds/m²) | WP CPR | BP CPR | TIC CPR | WP CPR based on PWSASY | BP CPR based on FD | TIC CPR based on FD |
|---|---|---|---|---|---|---|
| 10 | 0.10 | 1.94 | 0.23 | 0.05 | 2.00 | 0.14 |
| 50 | 0.29 | 2.70 | 0.45 | 0.19 | 2.37 | 0.29 |
| 100 | 0.48 | 2.57 | 0.62 | 0.31 | 2.78 | 0.43 |
| 200 | 0.74 | 3.67 | 0.94 | 0.48 | 3.63 | 0.62 |

For the SYs used for calculating the CPR, see Tables 2a and 2b for the yields based on results and FD respectively.

**Table 8.** The crop performance ratio for the wheat, bean and total intercrop calculated based on the SY results, and the fitted data in Experiment 3, to show that there was benefit for intercropping except at 30-wheat seeds/m².

| Wheat seed rate (seeds/m²) | WP CPR | BP CPR | TIC CPR | WP CPR based on PWSASY | BP CPR based on FD | TIC CPR based on FD |
|---|---|---|---|---|---|---|
| 30 | 0.69 | 1.76 | 0.98 | 0.69 | 1.77 | 0.98 |
| 75 | 1.19 | 1.50 | 1.27 | 1.09 | 1.43 | 1.18 |
| 200 | 1.42 | 0.89 | 1.27 | 1.43 | 1.05 | 1.33 |
| 400 | 1.59 | 0.94 | 1.41 | 1.58 | 0.85 | 1.39 |
| 650 | 1.77 | 0.77 | 1.50 | 1.65 | 0.76 | 1.41 |

For the SYs used for calculating the CPR, see Tables 3a and 3b for the yields based on results and FD respectively.

In Experiment 2, the evaluation of intercrop performance based on MA showed improvement in farm income by intercropping across all wsr, even though it was greater at the higher wsr (Table 12a). The analyses of MA based on the fitted data, indicate similarities with the MA estimates based on the results (Table 12b). In this experiment, the fact that the MA estimates indicates benefits for intercropping across wsr, was as explained previously in respect of the comparatively high partial LER estimates of the bean. Since the MA is a derivative of the LER, the positive MA estimates across all wsr is not surprising.

**Table 9.** The crop performance ratio for the wheat, bean and total intercrop calculated based on the SY results, and determined using the maximum yield for standardization in Experiment 4, to show that there was benefit for intercropping.

| Wheat seed rate (seeds/m²) | WSC SY (g/m²) | WIC SY (g/m²) | WP CPR | BSC SY (g/m²) | BIC SY (g/m²) | BP CPR | TIC CPR |
|---|---|---|---|---|---|---|---|
| 25 | 274 | 120. | 0.41 | 392 | 336 | 1.71 | 0.93 |
| 75 | 434 | 167 | 0.57 | | 400 | 2.04 | 1.16 |
| 150 | 396 | 282 | 0.96 | | 260 | 1.33 | 1.11 |
| 400 | 588 | 304 | 1.03 | | 236 | 1.20 | 1.10 |

**Table 10.** The crop performance ratio for the wheat, bean and total intercrop calculated based on the SY results, and the fitted data in Experiment 5, to show that there was benefit for intercropping except at 25-wheat seeds/$m^2$.

| Wheat seed rate (seeds/$m^2$) | Bean seed rate (seeds/$m^2$) | WP CPR | BP CPR | TIC CPR | WP CPR based on PWSASY | TIC CPR based on FD |
|---|---|---|---|---|---|---|
| 25 | 5 | 0.60 | 0.17 | 0.49 | 0.70 | 0.58 |
| 100 | 5 | 1.70 | 0.14 | 1.30 | 1.33 | 1.05 |
| 200 | 5 | 1.84 | 0.05 | 1.38 | 1.56 | 1.21 |
| 400 | 5 | 1.91 | 0.16 | 1.46 | 1.71 | 1.35 |
| 25 | 20 | 0.84 | 0.35 | 0.72 | 0.60 | 0.54 |
| 100 | 20 | 1.39 | 0.85 | 1.25 | 1.23 | 1.14 |
| 200 | 20 | 1.50 | 0.94 | 1.36 | 1.50 | 1.37 |
| 400 | 20 | 2.06 | 0.14 | 1.56 | 1.67 | 1.32 |
| 25 | 40 | 0.42 | 2.14 | 0.86 | 0.51 | 0.89 |
| 100 | 40 | 1.26 | 2.60 | 1.61 | 1.13 | 1.47 |
| 200 | 40 | 1.89 | 0.77 | 1.60 | 1.41 | 1.26 |
| 400 | 40 | 1.86 | 0.77 | 1.58 | 1.62 | 1.42 |
| 25 | 80 | 0.35 | 2.81 | 0.98 | 0.39 | 0.95 |
| 100 | 80 | 1.29 | 0.83 | 1.17 | 0.96 | 0.93 |
| 200 | 80 | 1.50 | 1.20 | 1.42 | 1.27 | 1.26 |
| 400 | 80 | 1.42 | 1.58 | 1.46 | 1.52 | 1.54 |

For the SY used for calculating the CPR, see Tables 5a and 5b for the yields based on results and FD respectively.

In Experiment 3, the MA evaluations based on the result showed intercropping improved income across all wsr (Table 13a). However, unlike the previous experiments there was no consistent income improvement with increase in wsr (Table 13a). The evaluation of MA based on the fitted data also indicate that intercropping was beneficial, even though similar to the earlier experiments, the MA estimates based on the results were reduced (Table 13b).

**Table 11a.** Monetary advantage based on the total intercrop LER as determined using the SY results for Experiment 1, to indicate that intercropping was not advantageous over sole cropping except at 200-wheat seeds/$m^2$.

| Wheat seed rate (seeds/$m^2$) | WSC value (£) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER | TIC MA (£) |
|---|---|---|---|---|---|---|
| 10 | 150 | 32 | 343 | 249 | 0.77 | -84 |
| 50 | 479 | 81 | | 224 | 0.77 | -93 |
| 100 | 625 | 176 | | 252 | 0.98 | -9 |
| 200 | 720 | 263 | | 229 | 1.03 | 16 |

**Table 11b.** Monetary advantage based on the total intercrop LER and calculated based on the fitted SYs (as was applicable) and determined using the predicted WSC asymptotic yield for standardization in Experiment 1, to indicate that intercropping was not beneficial.

| Wheat seed rate (seeds/m²) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER based on FD | MA based on FD (£) |
|---|---|---|---|---|---|
| 10 | 21 | 343 | 249 | 0.75 | -88 |
| 50 | 95 | | 224 | 0.76 | -102 |
| 100 | 166 | | 252 | 0.93 | -33 |
| 200 | 265 | | 229 | 0.97 | -15 |

**Table 12a.** Monetary advantage based on the total intercrop LER as determined using the SY results for Experiment 2, to indicate that intercropping was advantageous over sole cropping across wsr.

| Wheat seed rate (seeds/m²) | WSC value (£) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER | TIC MA (£) |
|---|---|---|---|---|---|---|
| 10 | 153 | 50 | 81 | 78 | 1.02 | 3 |
| 50 | 510 | 140 | | 109 | 1.49 | 82 |
| 100 | 551 | 231 | | 104 | 1.52 | 115 |
| 200 | 970 | 357 | | 148 | 2.20 | 276 |

**Table 12b.** Monetary advantage based on the total intercrop LER and calculated based on the fitted SYs (as was applicable) and determined using the predicted WSC asymptotic yield for standardization in Experiment 2, to indicate that intercropping was beneficial.

| Wheat seed rate (seeds/m²) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER based on FD | TIC MA based on FD (£) |
|---|---|---|---|---|---|
| 10 | 33 | 81 | 82 | 1.03 | 4 |
| 50 | 141 | | 95 | 1.28 | 51 |
| 100 | 236 | | 113 | 1.55 | 124 |
| 200 | 355 | | 147 | 2.06 | 258 |

In Experiment 4, for the seed yields, evaluation of intercrop performance based on MA showed that intercropping can improve farm income and benefits were greatest at the intermediate wsr of 75-wheat seeds/m² (Table 14). However, the fact that for this experiment the LER was not calculated using the fitted data, the MA was not calculated using the fitted data. Nevertheless, the comparatively higher MA estimates found in this experiment can be ascribed to the fact that bean intercrop seed yields were not reduced much compare to the other experiments. In addition, bean had greater premium price than the wheat as was explained in the materials and methods.

In experiment 5, the evaluation of MA based on results showed that income improvement was possible mainly when bsr was 20 seeds/m² or more (Table 15a). The comparatively, higher MA estimates found in this experiment can be ascribed mainly to the wheat intercrop largely due to the damages done to beans as was explained earlier in respect of the LER estimates. Thus, it was not surprising that the MA calculated based on fitted data, showed similar trend as that calculated based on the results (Table 15b). However, for this experiment , as was the case with the earlier experiments, in most cases the MA calculated based on fitted data reduced the estimates based on the results.

**Table 13a.** Monetary advantage based on the total intercrop LER as determined using the SY results for Experiment 3, to indicate that intercropping was advantageous over sole cropping across wsr.

| Wheat seed rate (seeds/m²) | WSC value (£) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER | TIC MA (£) |
|---|---|---|---|---|---|---|
| 30 | 484 | 320 | 422 | 370 | 1.22 | 126 |
| 75 | 697 | 551 | | 316 | 1.34 | 222 |
| 200 | 824 | 657 | | 187 | 1.15 | 111 |
| 400 | 888 | 737 | | 199 | 1.27 | 197 |
| 650 | 926 | 821 | | 163 | 1.27 | 210 |

**Table 13b.** Monetary advantage based on the total intercrop LER and calculated based on the fitted SYs and determined using the predicted WSC asymptotic yield for standardization in Experiment 3, to indicate that intercropping was advantageous.

| Wheat seed rate (seeds/m²) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER based on FD | TIC MA based on FD (£) |
|---|---|---|---|---|---|
| 30 | 331 | 421 | 373 | 1.23 | 132 |
| 75 | 522 | | 301 | 1.26 | 169 |
| 200 | 686 | | 220 | 1.24 | 174 |
| 400 | 758 | | 180 | 1.22 | 168 |
| 650 | 790 | | 161 | 1.21 | 163 |

**Table 14.** Monetary advantage based on the total intercrop LER as determined using the SY results for Experiment 4, to indicate that intercropping was beneficial particularly at the intermediate wsr.

| Wheat seed rate (seeds/m²) | WSC value (£) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER | TIC MA (£) |
|---|---|---|---|---|---|---|
| 25 | 403 | 176 | 647 | 554 | 1.06 | 42 |
| 75 | 638 | 245 | | 660 | 1.30 | 211 |
| 150 | 582 | 415 | | 429 | 1.14 | 105 |
| 400 | 864 | 447 | | 389 | 1.12 | 89 |

## Discussion

The main thrust of the present research was to demonstrate the benefit of wheat/bean intercrop compare to the component sole corps. Here results were evaluated using the LER (Vandermeer, 1989), CPR (Harris *et al.*, 1987) and MA (Willey, 1985). The basis for choosing these indices was because each one has different interpretation (Azam-Ali and Squire, 2002; Yahuza, 2011a). For agronomic purposes in most cases, intercrop performance is evaluated using the LER (Willey, 1985). However, the literature showed that the CPR is better suited to describe physical or physiological basis of intercropping performance compared to the component sole crops (Azam-Ali and Squire, 2002). Thus, these indices are important in comparing the performance of wheat/bean intercrop compare to the component sole crops. This is because this intercrop combination has not been widely adopted yet, suggesting that further information is needed to attract prospective growers (Yahuza, 2011b). In the UK, the benefits of wheat/bean intercropping systems based on evaluations using the LER are well-documented (Haymes and Lee, 1999; Bulson *et al.*, 1997; Pristeri *et al.*, 2006; Gooding *et al.*, 2007). However, in most cases intercropping aimed at improving productivity in terms of seed yields or biomass yields through more efficient use of growth resources such as solar radiation (Marshall and Willey, 1983; Tsubo and Walker 2002; Awal *et al.*, 2006), water (Gao *et al.*, 2009) or nutrients (Schmidtke *et al.*, 2004; Hauggard-Nielsen *et al.,* 2009). This clearly indicate the limitation of the LER in appropriately evaluating the performance of intercropping compare to sole cropping, given the interpretation of the index (Azam-Ali and Squire, 2002). My investigations had succeeded in using three different indices in analysing the performance of intercrops compare to the component sole crops.

**Table 15a.** Monetary advantage based on the total intercrop LER as determined using the SY results for Experiment 5, to indicate that intercropping was beneficial mainly at 20 bean seeds/m² or more.

| Wheat seed rate (seeds/m²) | Bean seed rate (seeds/m²) | WSC value (£) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER | Total intercrop MA (£) |
|---|---|---|---|---|---|---|---|
| 25 | 5 | 397 | 325 | 15 | 36 | 0.39 | -571 |
| 100 | 5 | 1063 | 917 | 15 | 30 | 0.92 | -82 |
| 200 | 5 | 1003 | 991 | 15 | 10 | 0.94 | -62 |
| 400 | 5 | 1079 | 1030 | 15 | 33 | 1.03 | 34 |
| 25 | 20 | 397 | 454 | 150 | 74 | 0.60 | -356 |
| 100 | 20 | 1063 | 751 | 150 | 180 | 1.12 | 102 |
| 200 | 20 | 1003 | 811 | 150 | 198 | 1.22 | 184 |
| 400 | 20 | 1079 | 1110 | 150 | 30 | 1.10 | 103 |
| 25 | 40 | 397 | 225 | 355 | 450 | 1.28 | 147 |
| 100 | 40 | 1063 | 682 | 355 | 546 | 1.93 | 592 |
| 200 | 40 | 1003 | 1017 | 355 | 162 | 1.33 | 291 |
| 400 | 40 | 1079 | 1001 | 355 | 162 | 1.31 | 277 |
| 25 | 80 | 397 | 189 | 421 | 591 | 1.58 | 286 |
| 100 | 80 | 1063 | 698 | 421 | 175 | 1.06 | 52 |
| 200 | 80 | 1003 | 809 | 421 | 252 | 1.35 | 275 |
| 400 | 80 | 1079 | 764 | 421 | 332 | 1.50 | 364 |

Here results showed intercropping to be beneficial in terms of both the LER and CPR (in some of the experiments). Therefore, wheat/bean intercropping system has the capacity to improve the efficiency of resource use compare to sole cropping. Haymes and Lee (1999) reported a maximum LER value of up to 1.4 previously in the UK. In my research, though the maximum LER values obtained in Experiments 3 (Table 3a) and 4 (Table 4) compared well to the value reported by Hames and Lee (1999), in some of the experiments greater values were found while in Experiment 1 (Table 1a) lower value was obtained. For instance in Experiments 2 and 5 maximum LER values found were 2.20 (Table 2a) and 1.93 (Table 5a) respectively. However, it should be pointed out that the circumstance that led to such high LER values in both Experiments 2 and 5 were due to a reduction in inter-specific competition between wheat and bean plants in the intercrop. Thus, in agreement with Vandermeer (1989), it was not surprising that there was over estimation of partial LER values for the beans (in Experiment 2) and over estimation of partial LER values for the wheat (in Experiment 5). This led to comparatively higher LER values found in each of the two experiments compare to published values (Hongo, 1995; Hames and Lee, 1999; Pristeri *et al.,* 2006). Nevertheless, it was interesting that for each of the two experiments these extremely high benefits of intercropping as analysed based on LER were substantially reduced when CPR was used for evaluation (Tables 6 and 7). The implication of the different results obtained when the LER and CPR were used for evaluations in Experiments 1 and 2 indicates that the two indices should be used jointly when judging the efficiencies of wheat/bean intercrop compare to the component sole crops particularly under contrasting production systems. For instance, whilst an LER of 1.1 indicates that 10% more land will be required if sole crops of the crops intercropped were sown (Willey, 1985), a CPR value of 1.1 indicates that the intercrop was 10 % more efficient than the sole crop in using resource to produce yield (Azam-Ali *et al.,* 1990). In addition, except in Experiments 1 and 2 where the maximum LER was obtained at 200-wheat seeds/m², in most cases the maximum LER values where obtained at 100-wheat seeds/m² or lower in combination with the beans at 40 or 30 bean seeds/m². This indicates that the recommended sr for the wheat/bean intercrops is substantially lower than that for each of the sole crops. In agreement with my results, based on the analyses using the LER, previous investigations have also indicated greater benefits of this intercrop at sr that was substantially lower than that for the component sole crops (Hongo, 1995; Bulson *et al.,* 1997).

Whilst the present study confirms earlier findings of wheat/bean intercropping system as regards positive LER values in the UK (Haymes and Lee, 1999; Pristeri *et al.,* 2006; Gooding *et al.,* 2007), the CPR has rarely been used in evaluating this intercrop combination in the past. It would interest the reader that the maximum CPR estimate of 1.61 obtained in this study at 100-wheat seeds/m² /40-bean seeds/m² (Table 10) was greater than previous reports in the literature for other intercrop combinations. For instance, the maximum CPR value obtained by Harris *et al.* (1987) in their investigations was 1.21. Similarly, the maximum CPR obtained by Azam-Ali *et al.* (1990) for the seed yield in their research was 1.27. However, whilst the two studies evaluated intercrop performance based on the CPR in situations where water was the main limiting resource, here the index was used in circumstance where radiation was the main driver of productivity. Indeed, the present research disagree with Harris *et al.* (1987) who found out that maximum CPR was obtained in lower water regimes. Here, the maximum CPR estimate was obtained in Experiment 5, which was established in the 2007-2008 cropping year. As was discussed elsewhere (Yahuza, 2012), the 2007-2008 cropping year was not only wetter than the previous cropping years, but was wetter than the long-term average for the site. In any case, the results of my investigations agrees with Harris *et al.* (1987) and Azam-Ali *et al.* (1990) that the total intercrop may be more efficient than sole crop in using resources to produce yield. However, unlike their studies that showed the cereal component to be always more efficient than the legume component, here in my Experiment 4 the bean performed more efficiently than the wheat (Table 9).

One of the findings of the present research was that the maximum CPR estimates were consistently lower than the maximum LER estimates in most of the experiments. In addition, maximum CPR estimates were found at intercrop combinations that gave maximum LER estimates, except in Experiment 3. In Experiment 3, whilst the maximum CPR estimate of 1.50 was obtained at 650-wheat seeds/m² (Table 8), the maximum LER estimate of 1.35 was obtained at 75-wheat seeds/m² (Table 3a). Given that the main thrust of this research was to improve growers' lots, it was assumed intercrop combinations based on LER estimates was more valid. This indicates that irrespective of the index used, recommended wsr for intercropping with beans should not exceed 100 wheat seeds/m² regardless of the cropping systems, and/or growing seasons. The demonstration that irrespective of whether LER or CPR was used, this intercrop system is still beneficial in most of the experiments may further encourage growers to adopt the cropping system.

**Table 15b.** Monetary advantage based on the total intercrop LER and calculated based on the fitted SYs and determined using the predicted WSC asymptotic yield for standardization in Experiment 5, to indicate that intercropping was beneficial mainly at 20-bean seeds/m² or more.

| Wheat seed rate (seeds/m²) | Bean seed rate (seeds/m²) | WIC value (£) | BSC value (£) | BIC value (£) | TIC LER based on PWSASY | TIC MA based on FD (£) |
|---|---|---|---|---|---|---|
| 25 | 5 | 433 | 15 | 36 | 0.44 | -605 |
| 100 | 5 | 822 | 15 | 30 | 0.73 | -308 |
| 200 | 5 | 967 | 15 | 10 | 0.81 | -237 |
| 400 | 5 | 1060 | 15 | 33 | 0.93 | -76 |
| 25 | 20 | 372 | 150 | 74 | 0.48 | -490 |
| 100 | 20 | 763 | 150 | 180 | 1.04 | 40 |
| 200 | 20 | 925 | 150 | 198 | 1.22 | 201 |
| 400 | 20 | 1035 | 150 | 30 | 0.91 | -110 |
| 25 | 40 | 314 | 355 | 450 | 1.32 | 187 |
| 100 | 40 | 697 | 355 | 546 | 1.86 | 575 |
| 200 | 40 | 874 | 355 | 162 | 1.09 | 86 |
| 400 | 40 | 1002 | 355 | 162 | 1.19 | 189 |
| 25 | 80 | 239 | 421 | 591 | 1.60 | 310 |
| 100 | 80 | 593 | 421 | 175 | 0.90 | -90 |
| 200 | 80 | 788 | 421 | 252 | 1.24 | 199 |
| 400 | 80 | 943 | 421 | 332 | 1.55 | 453 |

Azam-Ali and Squire (2002) asserted that knowledge of energy equivalents is necessary in intercrops systems, which are often composed of plants products with substantially different composition. They stated that by referring all CPR calculations to the energy equivalence of biomass in mega joules, it is possible to compare biological outputs of different species composed of organs, each with different energy values. In calculating the modified CPR, it is assumed that the carbohydrate and protein fractions have the same energy value and that there is no lipid in the seed (Azam-Ali and Squire, 2002). However, such conversion may not be necessary if none of the component crops is an oil seed crop. Indeed, since the procedures assume that protein and carbohydrates are of equal energy value it is not sensible to make any conversion if the intercrop components involved are all mainly legumes and/or cereals, except if an oil seed legumes is involved. Hence, the CPR can still be calculated from absolute yields as was demonstrated by Harris *et al.* (1987), and used in my investigations. This clearly suggest that for wheat/bean intercropping system, there cannot be any different approach in evaluating intercrop performance based on the CPR other than the method that I used.

The result of the present research had shown that for wheat/bean intercropping system, it is possible to increase farm income by up to £592 (Table 15a). In the UK, most growers of wheat are commercially oriented; therefore, in addition to physical evaluation estimate based on monetary evaluation (Willey, 1979; 1985), as was demonstrated in here is necessary. However, previous investigations on wheat/bean intercropping systems have rarely presented estimates of financial performance (Pristeri *et al.,* 2006). An exception was the study of Bulson *et al.* (1997) in an organic system that did some economic analysis based on gross margin. Gross margin is the return of the crop (yield /tonne x value /tonne) less variable input costs (Nix, 2009). In their study, calculating gross margin was easy because seeds were the only variable costs, since the experiments were organically-managed. Therefore, in this paper, in addition to the LER an economic evaluation based on land use efficiency as determined using the MA was calculated. Despite the different approaches used by the author and by Bulson *et al.* (1997), both studies suggest that this intercrop system is potentially financially advantageous compare to the component sole crops.

Dolman (1985) working with crops of vegetative yield, demonstrated the possibility of estimating intercrop performance based on fitted data as analysed using the LER. Following similar approach used by Dolman, here fitted data was used in calculating the LER, CPR and MA in addition to the analyses that were based on the results. It was interesting and sensible that Dolman (1985) assumed that the sole crop that should be used for standardization would correspond to the PWSASY as indicated by the fitted function $1/b_w$ in my research (Yahuza, 2012). To my knowledge, this approach had not been used before to evaluate wheat/bean intercropping systems. Indeed, it should be stressed that in most intercropping investigations, this important and vital step is neglected. Thus, my investigation has the credit for pioneering the use of this approach with crop of reproductive yields. It is worthy to note that even Harris *et al.* (1987) and Azam-Ali *et al.* (1990) did not use this approach in the analyses of CPR. Bulson *et al.* (1997) did not use this approach in monetary evaluation either. Indeed, one of the novel findings of this investigation was that in most cases the LER/CPR calculated based on the fitted data reduced the high estimates based on the results. See for instance Tables 1a, 2a, 3a and 5a and compare with Tables 1b, 2b, 3b and 5b respectively. Consequently, it is obvious that for the quantification of yield-density relationships in any given intercropping system as it relates to the benefits to the grower to be well understood, estimating intercrop performance using this approach is necessary.

It will be recalled that it was also the objective of the present research, to compare conventionally-managed with organically managed wheat/bean intercropping systems. Previously wheat/bean intercropping had been investigated under conventional (Haymes and Lee, 1999) and organic (Bulson, 1991; Bulson *et al.,* 1997; Pristeri *et al.,* 2006) systems in the UK, and positive benefits of intercropping based on the evaluations using the LER were reported. However, this intercrop combination had rarely been compared under the two contrasting system as was carried out in my research. In the present investigations, based on the LER estimates, the organically-managed experiment (Experiment 2; Table 2a), was more beneficial than the conventionally-managed one (Experiment 1; Table 1a). For instance whilst the organic experiment was beneficial across all wsr, the conventional experiment was only beneficial at 200-wheat seed/m$^2$. However, the fact that the organic experiment was beneficial at all wsr was due to high bean partial LER values due to factors explained previously. Thus, it was not surprising that the maximum LER values obtained in the organic experiment was greater than values reported earlier in the UK (Bulson *et al.,* 1997; Pristeri *et al.,* 2006). However, based on the evaluations using the CPR, results indicated neutral or low performance of intercropping compared to the wheat sole crop for each of the two cropping systems (Tables 6 and 7). This further illustrates the importance of using more than one index in analysing intercrop performance especially when the crop is not widely accepted by the growers. As regards monetary evaluation, compared to the organic experiment (Table 12a), the conventional experiment (Table 11a) did not increase the farm income much. The positive MA found in the organic experiment across wsr was as explained previously. However, whilst in my research the organic experiment was not repeated in subsequent years, the conventional one was. Thus, future research should compare the performance of wheat/bean intercropping system under these two contrasting condition for at least two cropping year before wider conclusion should be drawn. In any case, this research agree with Bulson *et al.* (1997) by indicating that wheat/bean intercrop is financially advantageous than the component sole crops.

Here in terms of both the LER (Table 3a) and CPR (Table 8) positive benefits were obtained in my spring-sown experiment (Experiment 3), in contrast to the winter experiment (Experiment 1) that was only beneficial at 200-wheat seeds/m² based on the evaluation using the LER (Tables 1a and 6). Only a few studies have compared wheat/bean intercropping under winter-sown and spring-sown conditions in the UK previously (Haymes and Lee, 1999; Gooding *et al*., 2007; Pristeri *et al.,* 2006). In their study, they demonstrated positive benefits for this intercrop under both winter-sown and spring-sown conditions based on evaluations using LER. In the present investigations, the maximum LER estimate of 1.35 obtained in the spring-sown experiment was greater than that obtained in Experiment 1, which was winter-sown. Thus, the present research suggests that wheat/ bean intercrop is more beneficial under the spring-sown conditions than under the winter-sown one. In agreement with my results, Haymes and Lee (1999) found out that the spring-sown wheat/bean intercropping is more beneficial than the winter-sown one. Moreover, compared with the winter-sown experiment (Table 11a), the spring-sown experiment (Table 13a) gave greater income. Although, Haymes and Lee (1999) also compared the performance of wheat/ bean intercropping system under spring-sown and winter –sown conditions previously in the UK, they did not evaluate the MA as I did. Given the additional information provided here, growers may adopt spring-sown wheat/bean intercrop rather than the winter-sown one (Yahuza, 2011b). This is interesting because the spring-sown crops might also reduce the cost of production. However, given that, the spring-sown experiment was not repeated in the subsequent years, more work is needed to compare the effects of season of sowing on the performance of this intercropping system before wider conclusions can be drawn.

## Conclusions

Despite the negative values obtained in some of the experiments (for the CPR), in terms of the LER, CPR and MA, this research showed that wheat/bean intercropping system is beneficial. Unlike the earlier studies on this intercrop combination, in the present research, the conclusion was based on evaluation using different indices with different interpretations. However, whilst here the indices were calculated from derived variables, it is recommended that future trials should calculate the indices within the replicate trials of any experiment of this nature and then subject to an ANOVA. In conclusion, given the positive advantages found in most of the experiment carried out, growers may wish to adopt wheat/bean intercropping system.

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