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Suppressing weed biomass as influenced by seeding rate in wheat/faba bean intercropping system

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Abstract

The effect of seeding rate (sr), sulphur fertilization and intercropping on weed suppression in wheat (*Triticum aestivum* L.)/faba bean (*Vicia faba* L; bean) intercropping system is not well investigated. Field experiments were carried out to study the effects of wide sr (0-650 wheat seeds/m^2; not in all experiment) in addition to the other aforementioned cultural practices on weed suppression or weed biomass. Without the application of herbicide, weeds were suppressed well at the higher wheat sr under both the conventional and organic management system. However, in three other conventional experiments when herbicide was applied these benefits were reduced substantially. Averaged across wheat sr in one-experiment weed biomasses found were 185 g/m^2 and 36 g/m^2 for without and with bean treatment respectively. However, for the combined effects of wheat sr and bean treatment, compared to the sole crop with the highest wheat sr, intercropping was poorer than sole crop in controlling weeds, in several but not all experiments. Nevertheless in one experiment at 10-wheat seeds/m^2, weed biomass were 336 g/m^2 and 53 g/m^2 for the wheat sole crop and intercrop (40-bean seeds/m^2) respectively. Thus, illustrating the practical benefits of using both sr and intercropping to suppress weeds at the lower densities. Sulphur fertilization had less effect on weed biomass. In general, this research suggests that weeds have the capacity to reduce crop resource use at the lower densities. Consequently, it is necessary to control weeds by manipulating sr and/or intercropping to allow more resources to be intercepted by the crop.

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Introduction

Weeds are unwanted plants that compete with the crops for growth resources, thereby reducing the crop biomass and may affect crop seed yield substantially (Welsh *et al.,* 1997a; 1997b; Murphy *et al.* 2008). Wheat (*Triticum aestivum* L.) seed yields have been reported to be reduced by 31.5% (Mennan and Zandstra, 2005), 63% (Mason *et al.*, 2007) or 19.6% (Qasem, 2007) by competition with weeds in different investigations. Weeds had also been shown to increase the susceptibility of faba bean (*Vicia faba* L.; bean) to infection by chocolate spot (*Botrytis fabae*), thereby indirectly reducing seed yields (Sahile *et al.,* 2008). The competitive effects of weeds on crops can be managed by several methods including the use of herbicides (Qasem, 2007) or by non-chemical agronomic manipulations, such as seeding rate (sr) (Mennan and Zandstra, 2005; Mason *et al.*, 2007), fertilization (Blackshaw *et al.,* 2005; Qasem, 2007) and intercropping (Haymes and Lee, 1999; Banik *et al.,* 2006). For wheat, chemical control of weeds is the most prevalent (Zand *et al.,* 2010). However, low-input growers require other efficient weed management methods such as choosing appropriate sr and/or intercropping. For instance, Mason *et al.* (2007) under organic management employed sr to control weeds in cereals. Similarly, it was demonstrated that wheat/bean intercrop suppressed weeds better than their component sole crops (Bulson *et al.*, 1997; Haymes and Lee, 1999). However, the suppressive ability of wheat/bean intercrop was investigated in only a few investigations. Thus, further knowledge of the competitive ability of this intercrop against weeds is necessary.

The literature indicate that weeds compete substantially with the crops for nutrients such as nitrogen (N) (Blackshaw *et al.,* 2003; 2005; Yin *et al.,* 2005), phosphorus (Yin *et al.,* 2005) and potassium (Yin *et al.,* 2005). For instance, it was reported that N fertilization improved crop competitiveness against weeds (Qasem, 2007; Zand *et al.,* 2010). Sulphur (S) is one of the important macronutrients that is increasingly becoming critical for crop production (Scherer, 2001; Salvagiotti and Miralles, 2008; Salvagiotti *et al.,* 2009). The effect of S fertilization on productivity of wheat/bean intercrop under organic system had been investigated (Gooding *et al.,* 2007). However, whether S fertilization has effects on weed suppression or weed biomass in wheat/bean intercropping system is not clear. Thus, the effects of S fertilization on weed biomass need to be investigated.

The main objectives of the present research is to investigate the effects of seeding rate and bean treatment on weed biomass suppression in wheat/ bean intercropping under a range of conditions. ii A second objective was to investigate the effects of sulphur fertilization on weed biomass as influenced by wheat seed rate and bean treatment.

Materials and methods

Study area

The experiments reported in this paper were carried out at the University of Reading's Crop Research Unit, Sonning, Berkshire, United Kingdom (0° 56′ W, 51° 27′ N). Further characteristics of the experimental site were discussed elsewhere (Yahuza, 2012a).

Experimental designs, treatments and crop management

Experiment 1 (autumn-sown conventional experiment, 2005-2006) was a complete factorial combination of five wheat seed rates (wsr) (0, 10, 50,100, 200 seeds/m^2) with or without 40 seeds/m^2 of bean randomized in four blocks with wsr as the main plot factor and bean treatment as the split-plot factor. However, in addition the design was complicated by a further factor, sulphur (S). The S treatment main plots had an area 10m x 20m. The S treatment were with and without 40 kg SO_4 /ha. For the S treatment, Nitram (ammonium nitrate granules, (34.5%N)) was applied to blocks 1 and 3 at 264 kg/ha, equivalent to 91 kg N/ha at 169 days after sowing (DAS), at GS 30 (Zadoks *et al.,* 1974). This was carried out by spraying the fertilizer onto the crops. Similarly, Nitram was applied to blocks 2 and

4 at 178 kg/ha in addition to double top (ammonium sulphate) at 116 kg/ha, which was equivalent in total to 92 kg N/ha and 35 kg SO_4/ha. Glyphosate (*N*-(phosphonomethyl)glycine) was sprayed on 2 August 2005 before establishment. Note that in this experiment no herbicide was sprayed after establishment. Further details on crop management for Experiment 1 and the subsequent experiments were presented in an earlier paper (Yahuza, 2012b).

Experiment 2 (autumn-sown organic experiment 2005-2006), was similar to Experiment 1 in design, except that this experiment was managed organically. For the S treatment, on Wednesday 19 April 2006, Thiovit Jet, which is 80% S was applied to block 2 and 4 by spraying directly onto the crop. This was applied at a rate of 20 kg/ha, which was equivalent to 16 kg S/ha. It was equivalent to 40 kg SO_4/ha.

Experiment 3 consist of spring wheat (cv. Paragon) sr (0, 30, 75, 200, 400 and 650) seeds/m^2 with or without 40 seeds/m^2 spring bean (cv. Hobbit) randomized in four blocks in a split-plot with wsr as the main plot and the bean treatment as the subplot factor. The crops were sprayed with 3.3 litres BASF 'Claymore' (pendimethalin) per ha in 200 litres of water on 11 March 2006 (pre-emergence of the bean). At 84 DAS, 177 kg/ha of Nitram fertilizer was applied. This was equivalent to 60 kg N/ha.

Experiment 4 consist of five wheat (cv Mallaca) sr (0, 25, 75, 150, 400 seeds/m^2) with or without 30 seeds/m^2 bean (cv Clipper) treatment as affected by three bean sowing dates (BSD; Yahuza, 2012b). The experiment was laid-out in a randomized complete block design replicated in 3 blocks. Note that the bean sowing date factor was nested within the bean treatment (Yahuza, 2012b). The first sowing (SSWB) was carried out on 30 October 2006. The second bean was drilled on 22 November 2006 (SB23DAW). The last bean sowing was Wednesday 6 December 2006 (SB37DAW). For weed control, on 3 November 2006 pendimethalin was sprayed on pure wheat plots and SSWB intercrop at a rate of 3.3 l/ha in 200 litres of water (pre-emergence of the bean). Similarly, pendimethalin was applied to SB23DAW intercrop on Wednesday 29 November 2006 at a rate of 3.3 l/ha in 200 litres of water (pre-emergence of the beans). In addition, SB37DAW were sprayed with pendimethalin on 8 December 2006 at a rate of 3.3 l/ha in 200 litres of water (pre-emergence of the bean). At GS 31, 250 kg/ha of Nitram fertilizer was applied. This was equivalent to 86 kg N/ha.

Experiment 5 was based on a conventional response surface (Yahuza, 2012b), and was laid down in a randomized complete block design. The experiment consists of complete factorial combination of five wheat (cv. Mallaca) sr (0, 25, 100, 200, 400 wheat seeds/m^2) and five bean (cv. Clipper) sr (0, 5, 20, 40, 80 bean seeds/ m^2) randomized in 3 bocks. On 7 November 2007 the experiment was sprayed with pendimethalin at a rate of 3.3 litres per ha in 200 litres of water. Similarly, at GS 30, 348 kg/ha of Nitram was applied per hectare. This was equivalent to 120 kg N per ha.

Weed biomass assessment

The weed biomass was collected from destructive samples taken from 1m x 0.5m area with a quadrat at maturity of the crops (Yahuza, 2012b). Four rows were included for sole crop plot and eight for the intercrops and the plants were cut at the soil surface. Samples were separated into the components, weighed, placed in dishes labelled and packed in ovens and dried at a temperature of 85^{o}C for 48 hours. After drying, the samples were weighed. In Experiments 1 and 2, the assessment was carried out 293 DAS. On the other hand, in Experiment 3, the weed biomass was determined at 152 DAS. Similarly, in Experiments 4 and 5 the weed biomass was assessed 287 and 270 DAS respectively.

Statistical analyses

In general, data were analysed using GENSTAT (Genstat 8.1 release, Rothamsted UK). Generally, the following were considered in the analysis of variance (ANOVA). For the analyses of weed biomass, plots with no crop sowing were included in the analyses.

Thus, in the tables means at 0-wheat seeds/m^2 for wheat sole crop and intercrop represents weed biomass of the uncropped plots (control) and weed biomass of the bean sole crop plots respectively. For each of Experiments 1, 2 and 3, the analyses were done using the General ANOVA. The treatment structure was pol (wsr; 3) x bean treatment with all interactions. The block structure was replications/wsr/bean with all interactions. In Experiment 4 similar procedures used for Experiments 1, 2 and 3 were employed, except for the further complication of the BSD factor. The variables were analysed using the General ANOVA with the treatment structure given as pol (wsr; 3) x (bean/BSD). This means that the BSD factor was nested within the bean treatment. The block structure was the replications. However, as stated earlier in this paper means presented are averages across the three BSD. In Experiment 5, the analytical procedure differs slightly from that of the previous experiments because the bean seed rate (bsr) was also varied. The variables were analysed using the General ANOVA with the treatment structure given as pol (wsr; 3) x pol (bsr; 3). The block structure was the replications. Later intercrop weed biomass for each experiment were compared with the wheat sole crop at maximum wsr to evaluate whether intercrops reduced weed biomass better than the sole crops.

Results

Effects of wheat seed rate and intercropping on weed biomass in Experiment 1

In Experiment 1, intercropping significantly reduced weed biomass compared to the wheat sole crop. The effect of bean treatment was highly significant ($P < 0.001$). Averaged across wsr, weed biomass were 185.1 g/m^2 and 36.3 g/m^2 for 0 and 40-bean seeds/m^2 respectively (SED 14.87, DF 15). The effect of wsr on weed biomass was highly significant ($P < 0.001$) and this deviated from linearity ($P = 0.002$ for the cubic wsr effects). For the effects of wheat seed rate, weed biomass were 249.8 g/m^2, 158.4 g/m^2 , 42.9 g/m^2 , 64.2 g/m^2 and 38.3 g/m^2 for 0, 10, 50, 100 and 200 wheat seeds/m^2 respectively (SED 26.99, DF 12). There were significant interaction between wsr and intercropping ($P = 0.009$ for the cubic wsr x bean effect). For the interactive effect, at 10 wheat seeds/m^2 intercropping significantly reduced weed biomass (Table 1). However, as indicated in Table 1 at 50-wheat seeds/m^2 or more both the wheat sole crops and total intercrops effectively controlled weeds as no significant differences were found (SED 35.79, DF 25.41). Compared with wheat sole crop at 200-wheat seeds/m^2, intercropping reduced weed biomass by as much as 81% (Table 1).

Effects of wheat seed rate and intercropping on weed biomass in Experiment 2

In Experiment 2 intercropping significantly reduced weed biomass ($P = 0.001$). Averaged across wsr, weed biomass were 216 g/m^2 and 55 g/m^2 for 0 and 40-bean seeds/m^2 respectively (SED 21.6, DF 15). The effects of wsr on weed biomass deviated from linearity ($P = 0.022$ for the cubic wsr effect). There was highly significant interactive effect detected between the wsr and bean treatment ($P = 0.001$ for the linear wsr x bean effect). For the interactive effects, compared to the wheat sole crop, intercropping significantly reduced weed biomass across wsr except at 200 wheat seeds/m^2 where the wheat sole crop also controlled weeds well (Table 2; SED 45.2, DF 26.98).

Compared with the wheat sole crop at 200-wheat seeds/m^2, the intercrops were less able to control weeds than the sole crops as indicated by the negative values seen in Table 2. Bean in this experiment was attacked by chocolate spot disease (*Botrytis fabae*; data not presented) during the reproductive stage. Since most bean plants were defoliated, the weeds became more vigorous, hence the similarities in weed biomass observed in the intercrop treatments compared to the sole crops at the maximum wsr (Table 2). Indeed earlier weed samples taken before the crops were diseased suggests that the intercrops were better in suppressing weeds than the sole crop (data not presented).

Table 1. Effects of wheat seed rate and intercropping on weed biomass, and comparison of reduction of weed biomass with the wheat sole crop at 200-wheat seeds/m^2 in Experiment 1.

Wheat seed rate (seeds/m^2)	Weed biomass sole wheat plots (g/m^2)	Weed biomass intercrop plots(g/m^2)	Weed biomass reduction due to intercropping (g/m^2)	Weed biomass reduction due to intercropping (%)
0	458.7	40.9	23.5	36.5
10	287.2	29.6	34.8	54.0
50	55.1	30.7	33.7	52.3
100	60.2	68.2	-3.8	-5.9
200	64.4	12.2	52.2	81.1
SED wsr	26.99	DF	12	
SED wsr x bean treatment	35.79	DF	25.41	

Table 2. Effects of wheat seed rate and intercropping on weed biomass and comparison of reduction of weed biomass with the wheat sole crop at 200 seeds/m^2 in Experiment 2 .

Wheat seed rate (seeds/m^2)	Weed biomass (g/m^2) sole wheat plots	Weed biomass (g/m^2) intercrop plots	Weed biomass reduction due to intercropping (g/m^2)	Weed biomass reduction due to intercropping (%)
0	424	128	-116	-180
10	336	53	-41	-64
50	153	54	-42	-65
100	155	25	-13	-20
200	12	14	-2	-3
SED wsr	29.6	DF	12	
SED wsr x bean treatment	45.2	DF	26.98	

Table 3. Effects of wheat seed rate and intercropping on weed biomass and comparison of reduction of weed biomass with the wheat sole crop at 650 seeds/m^2 in Experiment 3.

Wheat seed rate (seeds/m^2)	Weed biomass sole wheat plots (g/m^2)	Weed biomass intercrop plots (g/m^2)	Weed biomass reduction due to intercropping (g/m^2)	Weed biomass reduction due to intercropping (%)
0	383.6	129.1	-126	-4065
30	29.9	19.5	-16	-529
75	10.0	3.8	-0.7	-22
200	6.6	4.8	-1.7	-55
400	15.4	4.2	-1.1	-36
650	3.1	2.5	0.6	19
SED wsr	24.4	DF	15	
			27.78	
SED wsr x bean	29.85	DF		

Effects of wheat seed rate and intercropping on weed biomass in Experiment 3

In Experiment 3, in general, weed biomass was comparatively lower than it was in Experiments 1 and 2 (Table 3). Intercropping significantly reduced weed biomass. Averaged across wsr, weed biomass were 74.8 g/m^2 and 27.3 g/m^2 for 0 and 40-bean seeds/m^2 respectively (SED 9.89, DF 18). The effect of wsr was highly significant ($P < 0.001$) and this deviated from linearity ($P < 0.001$ for the cubic wsr effect). There was significant interaction between wsr and bean treatment ($P < 0.001$), which also deviated from linearity ($P < 0.001$ for the cubic wsr x bean effect). For the interactive effects weed biomass did not differ between the wheat sole crops and the intercrops except that weed biomass at 0 wheat seeds/m^2 (bean sole crop plot) was significantly lower than the control (Table 3; SED 29.85, DF 27.78). Compared with the intercrop, wheat sole crop was better at controlling weeds than the intercrop at 650 wheat seeds/m^2 (Table 3). The negative values seen in the table indicates that wheat sole crop at 650 seeds/m^2 was more competitive with the weeds than the intercrop.

Effects of wheat seed rate and intercropping on weed biomass in Experiment 4

In Experiment 4 intercropping significantly reduced weed biomass ($P < 0.001$). Averaged across wsr, for the mean effects of intercropping, weed biomass were 309 g/m^2 and 102 g/m^2 for 0 and 30-bean seeds/m^2 respectively (SED 58.1, DF 38). The effect of wsr on weed biomass was not significant ($P > 0.05$). There was a significant interactive effect detected between wsr and bean treatment ($P = 0.007$ for linear wsr x bean treatment). For the interactive effects as indicated in Table 4, weed biomass was significantly reduced by intercropping at 25-wheat seeds/m^2 (SED 129.8, DF 38). Bean sole crop also reduced weed biomass significantly. When compared with the wheat sole crop at 400-wheat seeds/m^2, the intercrops were not consistently better at controlling weeds than the former (Table 4).

Effects of wheat seed rate and intercropping on weed biomass in Experiment 5

In Experiment 5, wsr had significant effect on weed biomass ($P < 0.001$ for cubic wsr effect). Bean seed rate also had a significant linear effect on weed biomass ($P = 0.027$), and there was significant linear wsr x linear bsr interactive effect detected ($P = 0.053$). Averaged across bsr, weed biomass were 634 g/m^2, 291 g/m^2, 86 g/m^2, 411 g/m^2 and 23 g/m^2 for 0, 25, 100, 200 and 400 wheat seeds/m^2 respectively (SED 49.5, DF 47). This indicates that compared to the control, weed biomass was significantly reduced across wheat seed rates. Similarly, averaged across wsr, weed biomass were 258 g/m^2, 224 g/m^2, 255 g/m^2, 183 g/m^2 and 155 g/m^2 for 0, 5, 20 , 40 and 80 bean seeds/m^2 respectively (SED 49.5, DF 47). Compared to the control, weed biomass was significantly reduced at 80-bean seeds/m^2.

For the interactive effects of wsr and bsr, at 400-wheat seeds/m^2, wheat sole crop control weeds more effectively than the intercrops and bean sole crop (Table 5; SED 110. 7, DF 47). As indicated by the negative values, compared to the wheat sole crop with the maximum wsr, wheat sole crop was more competitive with the weeds than the bean sole crops and the intercrops (Table 5). In this experiment, birds destroyed bean plants indiscriminately (data not given), thus the fact that the wheat sole crop at the maximum density control weeds biomass better was not surprising.

Effects of sulphur fertilization, wheat seed rate and intercropping on weed biomass

The weed biomass data in Experiments 1 and 2 that were treated with sulphur were reanalysed with sulphur included in the ANOVA. In Experiment 1 sulphur did not have a significant effect on weed biomass ($P > 0.05$). Weed biomass did not respond significantly to the interactive effect between wheat seed rate and sulphur treatment ($P > 0.05$). Similarly, weed biomass did not respond significantly to the interactive effects of sulphur treatment and intercropping ($P > 0.05$), and weed biomass did not respond to the interactive effects of wheat seed rate, sulphur treatment and bean treatment ($P > 0.05$).

In Experiment 2, weed biomass did not respond to sulphur treatment ($P > 0.05$). Weed biomass did not respond significantly to the interactive effect of wsr and sulphur treatment ($P > 0.05$), and there was no interaction detected between wheat seed rate, sulphur treatment and bean treatment on weed biomass ($P > 0.05$).

Table 4. Effects of wheat seed rate and intercropping on weed biomass and comparison of reduction of weed biomass with the wheat sole crop at 400 seeds/m² in Experiment 4 .

Wheat seed rate (seeds/m²)	Weed biomass sole wheat plots (g/m²)	Weed biomass intercrop plots (g/m²)	Weed biomass reduction due to intercropping (g/m²)	Weed biomass reduction due to intercropping (%)
0	690	166	-84	-102
25	405	61	21	26
75	202	52	30	37
150	168	119	-37	-45
400	82	112	-30	-37
SED wsr	79.5	DF	38	
SED wsr x bean	129.8	DF	38	

Table 5. Effects of wheat seed rate and intercropping on weed biomass and comparison of reduction of weed biomass compared with the wheat sole crop at 400 seeds/m² in Experiment 5.

Wheat seed rate (seeds/m²)	Bean seed rate (seeds/m²)	Weed biomass intercrop plots (g/m²)	Weed biomass reduction due to intercropping (g/m²)	Weed biomass reduction due to intercropping (%)
0	5	630	-624	-10400
25	5	285	-279	-4650
100	5	119	-113	-1883
200	5	58	-52	-867
400	5	27	-21	-350
0	20	721	-715	-11917
25	20	377	-371	-6183
100	20	97	-91	-1517
200	20	43	-37	-617
400	20	37	-31	-517
0	40	429	-423	-7050
25	40	343	-337	-5617
100	40	87	-81	-1350
200	40	34	-28	-467
400	40	21	-15	-250
0	80	488	-482	-8033
25	80	176	-170	-2833
100	80	73	-67	-1117
200	80	16	-10	-167
400	80	25	-19	-317
Wheat seed rate (seeds/m²)	**Bean seed rate (seeds/m²)**	**Weed biomass sole wheat plots (g/m²)**		
0	0	900		
25	0	273		
100	0	55		
200	0	56		
400	0	6		
SED wsr	49.5	DF	47	
SED wsr x bsr	110.7	DF	47	

Discussion

The findings of the present research indicate that weed biomass can be well curtailed at higher wheat sr. For instance in Experiment 1 it was interesting to see that weed biomass was reduced drastically at 200-wheat seeds/m^2 compared to weed biomasses found at the lower sr (Table 1). In agreement with the results obtained here, the possibility of manipulating sr to suppress weeds had been demonstrated previously (Korres and Froud-Williams, 2002; Mennan and Zandstra, 2005; Mason *et al.*, 2007). The fact that in Experiment 1, even in comparison with the maximum wheat sole crop sr of 200-wheat seeds/m^2, intercropping reduced weed biomass by as much as 81% (Table 1), illustrates the efficacy of combining both sr and intercropping in managing weeds. For wheat/bean intercrop earlier findings suggests that the intercrops can effectively control weeds (Bulson *et al.*, 1997; Haymes and Lee, 1999); the finding of the present research concurs. Unlike the Haymes and Lee as well as Bulson *et al.* study, in the present study I had compared effects of wsr and intercropping on weeds under both the conventional and organic management system. Even though herbicide was not applied to Experiment 1, which was treated conventionally after establishment, here the conventional experiment (Experiment 1) was able to suppress weeds better than the organic experiment (Experiment 2). The N fertilizer application to the conventional experiment might have improved the crops competitive ability against weeds (Qasem, 2007; Zand *et al.,* 2010). Given that synthetic fertilizers are not allowed under organic management (Welsh *et al.,* 1997a ; b; Lammerts van Bueren *et al.,* 2002; Mason *et al.*, 2007), it would not have been possible for the organically managed crop to benefit from such treatments.

Several workers had highlighted the need for an integrated weed management strategy to tackle weeds by both chemical and non-chemical agronomic means (Bradley *et al.,* 2001; Blackshaw *et al.,* 2005; Chikowo *et al.,* 2009). For wheat/bean intercropping system such strategies has rarely been used. Here the results with herbicide application showed that both wsr and intercropping had lesser effects. In other words, the additional effects of sr and intercropping may not be necessary except if the amount of herbicide applied is reduced. Unlike my results, Bradley *et al.* (2001) and Barros *et al.* (2007) successfully used lower doses of herbicides in addition to non-chemical agronomic methods in controlling weeds. This implies that the 3. 3 l/ha of pendimethalin applied in Experiments 3, 4 and 5 here may not warrant additional non-chemical agronomic weed management tool. It is suggested that between 1-1.5 l/ha of the herbicide in addition to non-chemical methods such as sr or intercropping will be an effective and efficient weed management strategy.

It was thought that for the wheat sole crop, weed suppression would be greater at the maximum sr for each experiment. This was based on the earlier findings in the literature for the wheat sole crops (Korres and Froud-Williams, 2002; Mason *et al.*, 2007). It was also assumed that intercropping might offer greater weed suppression effectiveness than the sole crop at the maximum sr for each experiment (Bulson *et al.,* 1997). These assumptions were true as is demonstrated in Experiment 1 as can be seen in Table 1. However, besides Experiment 1, compared to the sole crop with the highest wheat sr, intercropping was poorer than the sole crop in controlling weeds in several experiments (Tables 2-5). It should be pointed out that here the comparisons were made with the wheat sole crop with maximum sr. Had it been that the comparisons were made between the wheat sole crop and the intercrop at each density, it might well results in a different results. Here the comparisons were made with the wheat sole crop with the maximum density since it is unlikely that growers will use the lowest sr that was used in each experiment in the present research under practical conditions.

Here, the effects of sulphur fertilization on weed biomass were not substantial in either the conventional or the organic experiments. In other word, weed suppression was unaltered by sulphur application. It is well established that weeds compete with crops for N (Blackshaw *et al.,* 2003; Blackshaw *et al.,* 2005) and other nutrients. However, similar investigations has not been done previously to investigate whether weeds compete for S which is also an important macronutrient for crop production (Salvagiotti and Miralles, 2008; Salvagiotti *et al.*, 2009) to confirm or contradict the results obtained here. Given that here the effects of S fertilization was studied in only a given cropping year, further investigations on the effects of this nutrient on weeds in wheat/bean intercropping system is necessary before wider conclusions can be drawn.

The literatures suggest that in addition to the component crops, weeds are also co-competitors for growth resources (Vandermeer, 1989; Shili-Touzi *et al.*, 2010). For instance, Baumann *et al.* (2001) asserted that weed suppression by the intercrop could be attributed to improvement in total light intercepted by the intercrop canopy. Similarly, Haymes and Lee (1999) contended that while intercrop light interception was due to vigorous canopy development, sole bean light interception was largely due to a heavy weed infestation. This implies that weeds might have effects on the estimates of radiation use efficiency (RUE) for each plot since weeds must have been intercepting light also. Elsewhere it was argued that weeds effect on RUE estimate might be through its direct effects on light interception by competing with the crops for N, which in turn reduces the crops capacity to intercept radiation (Yahuza, 2012). In such cases, RUE estimates will be so high. However, there has been little attention paid to quantify the effects of weeds biomass inclusions on the estimates of RUE. Nevertheless, the present research suggests that weeds have the capacity to reduce crop resource use at lower densities. Thus, it is necessary to control weeds to allow more radiation to be intercepted by the crop. This is possible by increasing sr to a level that will suppress weeds effectively or by growing two or more crops simultaneously.

Conclusions

In conclusion, the present research has shown that without the application of herbicide it is possible to utilize wheat sr to suppress weeds in wheat/ bean intercropping under contrasting system. However, when herbicides were applied these benefits of both seeding rate and intercropping reduces and may not be necessary. Compared to the sole crop with the highest wheat sr, intercropping was poorer than the sole crop in controlling weeds, in several but not all experiments. Sulphur fertilization had less effect on weed biomass. In conclusion, to suppress weeds well high seeding rate and/or intercropping may be necessary.

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