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Environmental Resource Consumption in Wheat (*Triticum aestivum*) and Bean (*Vicia faba*) Intercropping: Comparison of Nutrient Uptake and Light Interception

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Abstract

Wheat (*Triticum aestivum*) and bean (*Vicia faba* L.) sole crops and their mixture in three planting pattern (M_1: alternate-row intercrop, M_2: within-row intercrop, M_3: mixed intercrop) were used to investigate the amount of resource consumption in terms of PAR interception and nutrient uptake. The experiment was carried out as randomized complete block design with four replications. The results showed that intercropping systems had a significant effect on environmental resources consumption, where intercropping systems had more nutrient uptake and light interception compared to sole crops, suggesting the complementarity effect of intercropping components in resources consumption. The ability of wheat and bean was different in intercropping systems in absorbing nutrients because of their differences in root morphology and cation exchange capacity.

Keywords: cereals, competitive ratio, legume, photosynthetically active radiation, root CEC

Introduction

Efficient utilization of environmental resources is one of the most important advantages of intercropping, defining as the growing of two or more crop species simultaneously in the same field during a growing season (Ofori and Stern, 1987). The underlying principle of better resource use in intercropping is that if crops differ in the way they utilize environmental resources when grown together they can complement each other and make better combined use of resources than when they are grown separately (Willey, 1990). Environmental resource use is considered as the biological basis for obtaining yield advantage (Willey, 1979).

Solar radiation is a major resource determining growth and yield of component crops in intercropping, particularly when other resources (e.g. water and nutrients) are not severely limiting crop growth. Willey (1990) concluded that spatial complementarity of light use in intercropping occurs because of canopy differences. Watiki *et al.* (1993) who worked with maize-cowpea intercrops stated that an increase of radiation interception by the intercrops caused an increase in dry weight. There is an increasing requirement that nutrient uptake and utilization by crop plants should be as efficient as possible. Additionally, recent studies have shown greater uptake where intercropping has produced a yield advantage (Chowdhury and Rosario, 1994; Abraham and Singh, 1992).

It is important for agronomists to find ways to improve either or both the absorption and conversion efficiencies of intercrops. The success of intercrops, relative to sole crops, might be determined by various agronomic practices which affect the nature of the interaction between the species, and so affect their use of limiting resources. Such practices include relative density of component crops, supplies of limiting resources and the intimacy with which crops are intercropped (Ghanbari-Bonjar and Lee, 2003).

The present experiment deals with the intimacy of intercropping, i.e. planting pattern. The experiment was designed to quantify the benefits of intercropping in terms of (i) nutrient uptake and also (ii) photosynthetically active radiation (PAR) interception.

Materials and methods

A field experiment was conducted during the 2002-2003 growing season on Prescott field on Wye College farm, University of London, Kent, UK (51°11′ N, 0°57′ E, altitude 40-50 m above sea level). The soil series is classified as a well drained calcareous silt loam with pH 8.0 and 4.5% organic matter content. The mean chemical concentration of N, P, K, Ca and Mg were 2.06, 40.16, 175.67, 3153.15 and 61.4 mg.kg^{-1}, respectively. The field has previously produced a crop of forage maize.

Five treatments (two monocultures and three mixtures of wheat and bean) were included in the experiment as showed in Tab. 1. The experimental design was a randomized complete block (RCB) with four replications.

The intercrop composition was based on the replacement design (Snaydon, 1991), in which total population

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Tab. 1. The description of experimental treatments

Treatment	Description
B	Sole bean
W	Sole wheat
M_1	Alternate-row intercrop
M_2	Within-row intercrop
M_3	Mixed intercrop

of intercrop components were half of their sole crops. The plots size was 10.2 m^2 (1.7 m×6 m) and were drilled longitudinally. Treatments were separated by a 2 m buffer zone. The site of experiment was ploughed to 0.2-0.3 m depth after the removal of forage maize, followed by harrowing in the early autumn prior to drilling the trial. Wheat and bean were sown to a depth of approximately 3 and 5 cm, respectively by hand in October 20. Seed rates of 48 and 480 seeds of wheat and bean, respectively, per m^2 were sown to allow for thinning down to an approximate plant population of 32 and 400 plants per m^2. The wheat cultivar Maris Widgeon was selected because of popularity of this taller cultivar with organic growers. It also was hypothesized that long straw might reduce competitive shading by the beans. All wheat's seeds were treated with Panactine® for protection against important seed-borne diseases. The bean cultivar chosen was Punch.

Photosynthetically active radiation (PAR) was measured between 12-14 hours on occasions (Tab. 2). A Sun fleck ceptometer (model SF-80T) was used to measure above the plant canopy and the soil surface at 5 randomly selected locations within each plot. Mean values for each plot were then used to calculate the percentage of PAR intercepted by plant canopy as follows:

$$\% \mathbf{PAR_i=[1\text{-}(PAR_b/PAR_a)]\times 100}$$

where the subscript i designates intercepted PAR, and subscripts a and b designate Par above and below the plant canopy, respectively.

Tab. 2. Dates of PAR interception measurement

Date	Operation
April 4	1st PAR measurement
April 25	2nd PAR measurement
May 14	3rd PAR measurement
May 30	4th PAR measurement
June 19	5th PAR measurement
July 11	6th PAR measurement

At harvest time, plants were cut to 2 cm above the soil surface and separated by hand into wheat and bean. Plants were dried in the oven at 70°C for 48 h and weighed. Total N of above ground whole plant biomass in different cropping system was determined, using the Kjeldahl's method. Ca, Mg and K were measured using Atomic absorption and phosphorus was measured by Spectrophotometrically means.

The competitive ability of bean for nutrients to wheat was evaluated by calculating the competitive ratio of bean with respect to wheat (RC_b) or competitive ratio of wheat with respect to bean (RC_w) (Willey, 1979):

$$\mathbf{CR_b=(Y_{ab}/Y_{aa}\div Y_{ba}/Y_{bb})\times Z_{ab}/Z_{ba}}$$

in which:

CR_b: competitive ratio of bean with respect to wheat
Y_{ab}: Nutrient uptake by bean in intercropping
Y_{aa}: nutrient uptake by bean in sole crop
Y_{ba}: nutrient uptake by wheat in intercropping
Y_{bb}: nutrient uptake by wheat in sole crop
Z_{ab}: part of intercropping allocated to bean
Z_{ba}: part of intercropping allocated to wheat

Since the CR values of the two crops will in fact the reciprocal of each other, it will often be sufficient to consider the values of only one (Willey, 1990). This ratio value gives the exact degree of competition, by indicating the number of times in which the dominant species is more competitive than the recessive species.

The analysis of variance of the data was carried out, using MSTATC software. Treatment mean differences were separated by the least significant difference (LSD) test at 5% probability level.

Results and discussion

The percentage of PAR interception was significantly ($P<0.0001$) affected by cropping system. The men of PAR interception averaged over sampling dates by intercrop treatments and sole cropped bean were significantly ($P<0.05$) higher than that for sole cropped wheat. The mean percentage of PAR interception for intercrop treatments and sole bean were similar (Tab. 3).

The mean PAR interception averaged over cropping system increased up to 242 DAS (Tab. 3). The intercrops intercepted more PAR that that for wheat sole crop treatment. As concluded by Keating and Carberry (1993) wheat and bean can differ in PAR interception because of differences in their vertical arrangement of foliage and canopy architecture and can therefore intercept more PAR compared to sole crops.

Tab. 3. Effect of different cropping system on percentage of PAR interception by crop canopies

Cropping system	163 DAS	182 DAS	201 DAS	222 DAS	242 DAS	260 DAS	Mean
B	76.7 a	89.2 a	98.2 a	99.2 a	93.0 a	68.2 c	87.4 a
M_1	72.2 b	85.2 b	91.5 b	96.5 a	96.5 a	87.7 a	88.3 a
M_2	72.5 b	82.7 b	91.0 b	96.2 a	95.0 a	87.7 a	87.5 a
M_3	72.0 b	84.7 b	90.75 b	95.5 a	96.0 a	87.2 a	87.7 a
W	46.2 c	53.0 c	60.7 c	63.7 b	71.5 b	72.0 b	61.2 b
Mean	67.9	79.0	86.4	90.2	90.4	80.6	82.4

B=sole bean; M1: alternate-row intercrop; M2: within-row intercrop; M3: mixed intercrop; W = sole wheat
DAS=Day after seeding
LSD for main effect of cropping system=1.51

Wheat and bean reached their PAR interception at 260 DAS and 222 DAS respectively (Tab. 3). Therefore solar radiation which would be otherwise wasted due to poor growth of wheat early in the season and bean leaf senescence at the end of the season can be utilized more efficiently by wheat-bean intercropping. Thus intercrop canopies can intercept PAR more effectively than sole crops. So as concluded by Watiki *et al.* (1993) and Keating and Carberry (1993), intercropping leads to an increase in the total amount of PAR captured and would PAR seem to play a relatively important role in determining total intercrop productively.

Total magnesium (Mg) uptake was significantly ($P<0.001$) affected by cropping system (Tab. 4). Mg uptake by intercrops was significantly greater than for sole wheat and except for M_2 were also significantly greater than that of sole bean (Tab. 4). There were no significant differences between intercrops for Mg uptake. The mean Mg uptake by intercrop plots was 3.04 and 1.11 times that of sole wheat and sole bean plots, respectively.

Calcium (Ca) uptake also was significantly ($P<0.0001$) affected by cropping systems. Intercrops and sole bean showed significantly greater Ca uptake than for sole wheat (Tab. 4). In general Ca uptake by intercrop treatments tended to be greater than for sole bean (Tab. 4), though this was not significant. The mean of Ca uptake by intercrops were 9.7 and 1.06 times greater than those of wheat and sole bean, respectively.

Potassium (K) uptake was significantly ($P<0.0001$) influenced by cropping system. Intercrops and sole bean treatments absorbed more K than wheat sole cropped (Tab. 4). Mostly there was no significant difference between intercrops and bean sole crop. The mean potassium uptake averaged over three intercrops was 3.7 and 1.02 times greater than those of sole wheat and sole bean, respectively.

Phosphorus (P) uptake was significantly affected by cropping system ($P<0.0001$). The amount of P captured by intercrops and bean sole crop treatments was significantly ($P<0.05$) greater than that for sole wheat (Tab. 4). The mean of total P uptake by intercrops was 2.93 times greater than that of sole wheat. There was no significant difference between P uptake in intercrops and sole bean.

Tab. 4. Effect of different cropping system on nutrient uptake (kg ha^{-1})

Cropping system	Mg	Ca	K	P	N
B	12.55 b	39.89 a	204.7 ab	33.29 a	281.7 a
M_1	14.02 a	43.97 a	214.9 a	34.46 a	301.8 a
M_2	13.95 ab	43.5 a	202.8 b	32.31 a	292.0 a
M_3	14.19 a	40.37 a	204.6 ab	32.10 a	295.4 a
W	4.58 c	4.36 b	55.76 c	11.23 b	41.95 b
Mean	11.86	34.42	176.58	28.68	242.59

B=sole bean; M_1: alternate-row intercrop; M_2: within-row intercrop; M_3: mixed intercrop; W=sole wheat; Different letters in each column indicates significance at P ≤0.05 %.

Total Nitrogen uptake was significantly ($P<0.0001$) affected by cropping system. All of intercrops took up significantly ($P<0.05$) larger than amounts of N than sole wheat (Tab. 4). The N uptake by intercrops appeared greater than for sole bean but was statistically not significant. There were no significant ($P<0.05$) differences between intercrops. The mean nitrogen uptake averaged over three intercrops was 7.0 and 1.05 times greater than those sole wheat and sole bean, respectively.

The nutrient uptake in terms of Mg, Ca, K, P and N in intercropping was higher than the mean for sole crops. Greater nutrient uptake is usually presumed to be possible because of some complementary exploration of the soil profile by the components crops (Ahlawat *et al*., 1985) or fuller use of resources over time (Willey, 1990). Higher total nutrient uptake has been reported by several authors (Bulson *et al*., 1997; Chowdhury and Rosario, 1994; Wahua, 1983). The greater nutrient uptake has very often claimed to be associated yield advantages (Willey, 1990; Chowdhury and Rosario, 1994).

Competitive ratio value gives the exact degree of competition, by indicating the number of times in which he dominant species is more competitive than the recessive species (Ghanbari-Bonjar, 2000). The competitive ratio of been with respect to wheat (CR_b) for Mg was significant ($P<0.05$) greater than 1.0 (Tab. 5). The mean CR_b averaged over three intercrops for Mg uptake was 1.20, indicating that concerning Mg uptake bean was 1.20 times more competitive than wheat. The CR_b for Ca uptake also was greater than 1.0 but statistically non significant ($P>0.05$) (Tab. 5). The mean CR_b for Ca averaged over three intercrops for Ca uptake was 1.17 indicating that concerning Ca uptake, bean was 1.17 times more competitive than the wheat.

The competitive ability of wheat with respect to bean (CR_w) for K and P uptake significantly ($P=0.0016$ and $P<0.05$, respectively) was always greater than 1.0 (Tab. 5). The mean CR_w averaged over intercrops for K and P was 1.16 and 1.35, respectively. Indicating that concerning K and P uptake, wheat was 1.16 and 1.35 times more competitive than bean.

Tab. 5. Effect of different cropping system on intercrop competition for nutrient

Cropping system	*CR_b for Mg	CR_b for Ca	**CR_w for K	CR_w for P
M_1	1.14 b	1.05 a	1.32 a	1.51 a
M_2	1.37 a	1.21 a	1.13 b	1.23 b
M_3	1.29 ab	1.24 a	1.02 b	1.31 ab
Mean	1.27	1.17	1.16	1.30

M1: alternate-row intercrop; M2: within-row intercrop; M3: mixed intercrop
* competitive ability of bean with respect to wheat (CRb); ** competitive ability of wheat with respect to bean (CRw); Different letters in each column indicates significance at P ≤0.05 %.

Bean was more competitive than wheat for Ca and Mg (Tab. 5). The roots of legumes generally have a root cation exchange capacity (CEC) about twice that of cereal roots. A plant root surface having high CEC might absorb relatively more divalent cations such as Ca and Mg, than a plant root from a cereal, with a low root CEC (Haynes, 1980). However, wheat was more competitive than bean for P and K absorption (Tab. 5). This was in line with expectation, since legumes are known to be poor competitors for phosphorus and potassium when intercropped with cereals because of their root morphology and cation exchange capacity of root surface (Francis, 1989; Martin and Snaydon, 1982). Concerning competition for nitrogen in wheat-bean intercropping, the bean component is capable of fixing atmospheric N_2 under favorable condition. So it seems important that the biological nitrogen fixation by the bean component should be considered, but in the present experiment, there was no way to designate the amount of N derived from fixation and absorption from the soil. Therefore, CR for N was not accounted.

Conclusions

In general, it was concluded that environmental resource consumption, especially PAR interception and nutrient uptake in intercropping system was better than sole crop, suggesting that intercrop components have "complementarity effect" in environmental resource obtaining which is result of different morphological and physiological characteristics of intercrop components. Wheat and bean has different ability to absorb cations because of different CEC of their root. The results of this experiment could provide some quantitative evidence for the hypothesis that greater environmental resources consumption (such as PAR and soil moisture) by intercrops is a primary cause of yield advantages.

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