Producing organic wheat with high grain protein content: the significance of intercropping and the need for diagnostic tools

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Abstract

Grain quality of wheat is one of the major concerns of organic farming production. Cereal-legume intercropping may be of significance in this regard as it enhances the yield productivity and the grain protein content (GPC) of the intercropped wheat. However, fitted tools are needed for the diagnosis and management of such interspecific canopies. Our main objectives were i) to analyse the effect of intercropping and N-management on organic farming performances and ii) to analyse the relationships between N-status indicators and GPC of intercropped wheat. These objectives were assessed in winter pea–wheat intercrops in 2007 and 2009 in western France. Our study confirmed the significance of intercropping in the production of wheat with high GPC. We showed that tools for diagnosis, fitted for sole crops to manage grain yield and GPC (N nutrition index, chlorophyll meter), can be used on intercropped wheat.

Introduction

Organic farming may be a way to improve the sustainability of agroecosystems by limiting the use of non-renewable resources and chemical inputs. However, the yield and the quality of crops are often lower in organic farming than in conventional agriculture. Two major constraints explain the low and variable yields and GPC of organic arable systems which are a deficient N nutrition (Berry et al. 2002) and weeds competition (Bond & Grundy 2001). Intercropping, the simultaneous growing of two or more species in the same field, is gaining interest in Europe in the context of organic farming. Intercropping is known to enhance productivity compared to sole cropping (Jensen 1996). Moreover, a higher GPC in the intercropped cereal has also been observed when compared to sole crops (Jensen 1996). These advantages are assumed to be linked to the complementary use, in time and space, of resources by the intercropped species (Jensen 1996). According to Gooding *et al.* (2007), the effect of intercropping on the GPC of wheat is a result of i) the low competitiveness of legumes for mineral N compared to the cereals and ii) the competition for light between the species, limiting the intercropped cereal biomass compared to sole crops.

However, the performances of organic cereal-legume intercrops are highly variable, and there is a lack of diagnostic and management tools for such interspecific canopies. Indeed, tools used to establish the N status of crops were built for sole cropped wheat and must be tested before widespread use in intercropping. The aim of this study is i) to analyse the effect of intercropping and N-management on organic farming performances and ii) to analyse the relationships between N-status indicators and GPC of intercropped wheat.

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Materials and methods

Tab.1: Treatments, experimental conditions and N fertilisation

Reference of experiment	Year of harvest	Crop design	Treatments	Planned densities (gm^{-2}) Pea	Wheat	Stage of wheat at the date of N-fertilisation (ZGS)	Time of N-fertilisation	Rate of N-fertilisation (kg N ha^{-1})
A	2007	W100	A-SC N0	—	330	—	—	0
		W100	A-SC N	—	330	ZGS30	15 March 2007	570
		P50W50	A-IC1	45	165	—	—	0
		P30W70	A-IC2	27	231	—	—	0
		P50W50	A-IC3	45	165	ZGS32	13 April 2007	380
		P30W70	A-IC4	27	231	ZGS32	13 April 2007	380
B	2009	W100	B-SC N0	—	330	—	—	0
		W100	B-SC N	—	330	ZGS30	7 April 2009	40
		P50W50	B-IC5	45	165	—	—	0
		P30W70	B-IC6	27	231	—	—	0
		P50W50	B-IC7	45	165	ZGS30	7 April 2009	40
		P30W70	B-IC8	27	231	ZGS30	7 April 2009	40
		P50W50	B-IC9	45	165	ZGS32	28 April 2009	40
		P30W70	B-IC10	27	231	ZGS32	28 April 2009	40

W100: wheat sole crop; P30W70 and P50W50: substitutive intercrops of pea and wheat; SC and IC: sole cropped and intercropped design, respectively, with or without N-fertilisation; ZGS: Zadoks growth stage scale.

Field experiments were carried out in 2007 (Exp A) and 2009 (Exp B) (organic farming in western France). Winter wheat (*Triticum aestivum* L., cv Apache) was grown as a sole crop and as an intercrop with winter peas (*Pisum sativum* L., cv Lucy) (Table 1). Pests were not controlled and no irrigation was provided. Crops were grown without and with N-fertilisation (chicken feather meal: high levels in Exp A and moderate levels in Exp B) (Table 1). At the end of the winter, the soil contained about 98 and 112 kg N ha^{-1} in the 0-75 cm layer in 2007 and 2009, respectively. Crops were sown on 02/11/2006 and 19/11/2008 (randomised complete block design; *n*=4) and were harvested near the flowering of wheat (observed on 10/05/2007 and 25/05/2009) and at maturity (on 04/07/2007 and 10/07/2009).

The N status of both sole cropped (SC) and intercropped (IC) wheat was assessed at flowering by calculating the N nutrition index (NNI) (Justes *et al.* 1997). The NNI of IC wheat was calculated as the ratio between the measured concentration of N in the shoot of IC wheat and critical Nc determined from the total aboveground dry matter of the intercrop (DMic = IC wheat DM + IC pea DM; as proposed by Cruz & Soussana (1997) for mixed crops) as per Justes et *al.*'s (1997) equation for wheat: if DMic < 1.55 t ha^{-1}, Nc = 5.35 %; if DMic > 1.55 t ha^{-1}, Nc = 5.35 x $(DMic)^{-0.442}$. As proposed by Prost & Jeuffroy (2007), SPAD readings for wheat were taken at flowering (ZGS65) with a chlorophyll meter (SPAD 502, Minolta). The SPAD index was calculated as the ratio of the SPAD reading on one treatment to that of the SC N-fertilised treatment in the same experiment, after checking that the NNIs of this treatment were equal to 1 to confirm that it had a non-limiting N status. Analysis of variance was performed (α=5 %) and the means were compared using Tukey's HSD tests (α=5 %) (R software).

Results and discussion

Total grain yield of unfertilised or N-fertilised intercrops (varying from 400 to 666 gm^{-2}) was rarely significantly different from that of unfertilised or N-fertilised SC (varying from 400 to 632 gm^{-2}). This was consistent with the previous results which demonstrated that N-fertilisation did not increase the total grain yield of intercrops (Jensen 1996; Naudin *et al.* 2010). With the exception of B-IC5, unfertilised and N-fertilised intercrops resulted in an insignificant difference in the grain yield of wheat than the unfertilised SC wheat (from 343 to 617 gm^{-2}) (Table 1). With the exception of A-IC2, the GPC of unfertilised or N-fertilised IC wheat (varying from 8.1 to 11.5%) was always higher than that of unfertilised SC wheat (7.3%). Moreover, as shown by Naudin *et al.* (2010), the GPC of N-fertilised IC wheat was not significantly different from that of N-fertilised SC wheat, irrespective of the level of N-fertilisation (above 11% and 9% in Exp A and Exp B, respectively). In Exp A, intercropping increased the NNI of wheat (varying from 0.45 to 0.74) in comparison with unfertilised SC wheat (0.38), but the NNI of IC wheat (with or without N-fertilisation) remained significantly lower than that of N-fertilised SC wheat (0.97). In Exp B, the NNI of wheat was not significantly different, irrespective of crop design or N-fertilisation, and never exceeded 0.65. Irrespective of the treatment, weed dry matter was not significantly different. Thus, weeds are not the cause of differences between the yields or the GPC of wheat.

Tab.2: Grain yield and grain protein content of SC and IC wheat at maturity; N status of wheat and weeds dry matter at wheat flowering.

	Total grain yield of crops (g m^{-2})			**Grain yield of wheat** (g m^{-2})			**GPC of wheat** (%)			**NNI of wheat**			**Weeds DM** (g m^{-2})		
	mean	±SE	HSD	**mean**	±SE	HSD	**mean**	±SE	HSD	**mean**	±SE	HSD	**mean**	±SE	HSD
A-SC N0	**400**	±38.0	b	**400**	±38.0	b	**7.3**	±0.15	c	**0.38**	±0.03	e	**67**	±28.3	---
A-SC N	**598**	±20.3	a	**598**	±20.3	a	**11.9**	±0.28	a	**0.97**	±0.03	a	**83**	±13.4	---
A-IC1	**547**	±35.5	a	**348**	±18.4	b	**8.9**	±0.27	b	**0.57**	±0.03	cd	**82**	±22.7	---
A-IC2	**400**	±35.5	b	**343**	±29.4	b	**7.1**	±0.36	c	**0.45**	±0.05	de	**75**	±25.6	---
A-IC3	**565**	±32.0	a	**359**	±7.9	b	**11.5**	±0.25	a	**0.74**	±0.04	b	**82**	±22.3	---
A-IC4	**541**	±20.8	ab	**437**	±12.2	b	**11.0**	±0.11	a	**0.70**	±0.04	bc	**90**	±7.8	---
B-SC N0	**580**	±34.9	---	**580**	±34.9	a	**7.3**	±0.32	b	**0.48**	±0.02	---	**25**	±11.3	---
B-SC N	**632**	±34.8	---	**632**	±34.8	a	**8.9**	±0.71	ab	**0.54**	±0.05	---	**23**	±7.1	---
B-IC5	**511**	±55.1	---	**398**	±39.4	b	**8.4**	±0.32	ab	**0.50**	±0.03	---	**58**	±21.7	---
B-IC6	**666**	±42.8	---	**617**	±48.6	a	**8.1**	±0.23	ab	**0.59**	±0.07	---	**28**	±18.4	---
B-IC7	**644**	±18.6	---	**510**	±24.1	ab	**9.4**	±0.18	a	**0.63**	±0.04	---	**54**	±18.3	---
B-IC8	**651**	±33.1	---	**604**	±33.7	a	**9.0**	±0.21	a	**0.65**	±0.07	---	**37**	±4.8	---
B-IC9	**649**	±20.0	---	**589**	±25.7	a	**9.1**	±0.19	a	**0.64**	±0.01	---	**28**	±10.5	---
B-IC10	**628**	±33.3	---	**594**	±36.3	a	**9.1**	±0.29	a	**0.59**	±0.06	---	**40**	±15.0	---

SC and IC: sole cropped and intercropped design, respectively, with or without N-fertilisation; GPC: grain protein content; DM: dry matter. Values are means (*n*=4). Analysis of variance (α=5 %) was carried out for each experiment, and treatments with the same letter or symbol (“---") are insignificantly different (Tukey’s HSD test; α=5 %).

The GPC of wheat at harvest was highly correlated with the NNI of wheat at flowering, irrespective of the crop design (Figure 1a). This confirms that, in a sole cropping or an intercropping system, a high N status of the wheat enhances its GPC. A negative correlation between the efficiency of accumulated N to produce grain number of wheat and the NNI confirmed that a decrease in the grain number favours grain quality by concentrating N in the grains (Figure 1b). SPAD readings may also contribute to build a good indicator of N status for IC wheat (Figure 1c), as shown by Prost & Jeuffroy (2007) in case of SC wheat. Furthermore, as the GPC of wheat was highly correlated with the SPAD index (Figure 1d), the SPAD index may be a very interesting diagnostic tool to manage the GPC of IC wheat. Moreover, as SPAD readings depend on the cultivar (Prost *et al.* 2007), the SPAD index may be more significant than the SPAD readings so as to replace the NNI. However, more experiments with additional calculations of the SPAD index similar to our study are required.

Conclusions

Our study confirms the significance of intercropping to produce high-quality wheat grains. The present study demonstrates that the tools of diagnosis, previously fitted for SC wheat to manage grain yield and GPC (namely the NNI or the SPAD index), can be used on IC wheat. Further studies are needed for testing these tools using various cultivars under various climatic conditions.

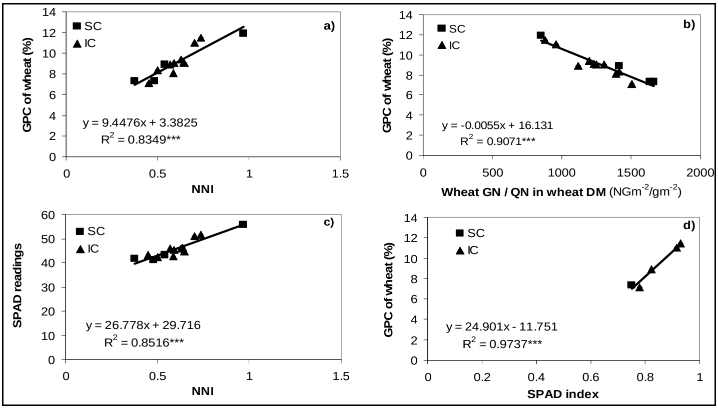

Figure 1: N status indicators and grain protein content of wheat

SC and IC: sole cropped and intercropped design, respectively, with or without N-fertilisation; GPC: grain protein content; NNI: N nutrition index; GN: grain number; QN: accumulated N in shoot; DM: dry matter. *** significant for P<0.001.

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