Nitrogen fertilizer application and competitive balance between spring wheat (*Triticum aestivum* L.) and volunteer oilseed rape (*Brassica napus* L.)

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ABSTRACT. We investigated the effect of nitrogen fertilizer on the competitive balance between spring wheat (*Triticum aestivum* L.) and volunteer oilseed rape (*Brassica napus* L.). The nature of the response of the species was also studied through evaluations of canopy structure and N absorption. Wheat and weed were sown in the field in monocultures and mixtures, receiving each of three nitrogen fertilizer levels (0, 40 and 100 kg/ha N). Aerial biomass production and N content were determined at four times during the experiment. Light interception and plant height were measured twice and relative leaf area was periodically evaluated using a point quadrat method. Nitrogen fertilizer increased biomass yield of both wheat and oilseed rape, but significantly altered the competitive balance between the two species. The crop was more competitive than the weed at low soil N availability. However, they were equally competitive at the highest N fertilizer level; significant crop losses due to weed competition were observed only under this situation. Total light interception was greater under the 100 kg/ha N fertilized (87%) than under the unfertilized treatment (40%). Observations of the structure and development of the canopies showed that the crop had access to relatively more light at low than at high soil N when in competition with volunteer oil seed rape. The oilseed rape N absorption was significantly lower in crop-weed mixtures than in monocultures for any N fertilizer treatment, but crop N absorption was only reduced at high N fertilizer doses. Soil fertility manipulation has to be considered part of wheat's integrated weed management programs.

RESUMEN. La fertilización con nitrógeno y el balance competitivo entre trigo (*Triticum aestivum* L.) y poblaciones espontáneas de colza (*Brassica napus* L.): Se investigó el efecto de la fertilización nitrogenada sobre el balance competitivo entre trigo (*Triticum aestivum* L.) y colza (*Brassica napus* L.). Los mecanismos de respuesta a la competencia fueron estudiados a través de evaluaciones en la estructura del canopeo y la absorción de N de cada especie. En un experimento a campo se sembró trigo y colza en monoculturas y en mezclas con tres niveles de fertilización nitrogenada (0, 40 y 100 kg/ha N). Se evaluó la producción de biomasa aérea y el contenido de N de ambas especies en cuatro momentos del ciclo de trigo. La intercepción de radiación y la altura de las plantas se midió dos veces durante el experimento y el área foliar de trigo y maleza fue determinada periódicamente en parcelas puntuales por medio de un instrumento óptico. La aplicación de N aumentó la producción de biomasa de trigo y la maleza al mismo tiempo que modificó el balance competitivo entre ambas especies. El trigo fue más competitivo que la maleza en condiciones de baja disponibilidad de N. En cambio, fue igualmente competitivo a la dosis más alta de N, disminuyendo significativamente el rendimiento del cultivo. La radiación interceptada fue mayor con dosis de 100 kg/ha N (87%) que aquellas sin fertilizar (40%). El análisis de la estructura y desarrollo del canopeo reveló que el trigo tuvo acceso a una mayor cantidad de radiación en competencia con la colza en bajas dosis de N. La cantidad de N absorbida por la maleza fue significativamente menor en las mezclas con trigo que en sus monoculturas en las tres dosis ensayadas. Sin embargo, la absorción de N por el trigo sólo se redujo en la dosis más alta. Estos resultados sugieren que la manipulación de la fertilidad edáfica debería ser considerada en el diseño de estrategias integradas para el manejo de malezas.

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INTRODUCTION

Weed competition effects on crops are one of the most important causes of yield losses (Eussen 1982; Koch et al. 1982; van Heemst 1985). Since the appearance of herbicides in the 1950s, much effort has been invested to reduce the effects of weeds through their use, especially in developed countries (Le Baron 1991). Relatively little effort has been invested in effective non chemical control practices supported on studies of crop weed interactions (Liebman & Dyck 1993), although it is now recognized that continuous herbicide use may cause contamination of the environment and herbicide resistance in weeds (Kropff & Lotz 1992; Wyse 1992; Mortimer & Maxwell 1994). Therefore, there is an increasing need to improve the understanding of weed interference processes for developing integrated weed management systems, where crop management techniques may be considered effective parts of weed control methods (Ghersa et al. 2000).

Several wheat (*Triticum aestivum* L.) management techniques have been evaluated for their effect on weeds. Attention has been concentrated in crop practices such as cultivar selection, plant arrangement and density. Differences in competitive ability among wheat cultivars have been reported (e.g., Valenti et al. 1983; Challaiah et al. 1986; Satorre & Guglielmini 1990; Satorre & Snaydon 1992; Lanning et al. 1997) and the reduction of weed yield when increasing crop density has been also studied (e.g., Cousens et al. 1985; Satorre & Arias 1990; Hashem et al. 1998). Some research has shown that fertilizer use can greatly modify the competitiveness of either crops or weeds in weed control programs, but this depends on: 1) the factor(s) for which crop and weed compete, and 2) the relative response of crop and weed to applied nutrients (Satorre 1988). The available information on wheat crops suggests that fertilizer increase the competitive ability of the crop relative to the weed (e.g., Naylor 1972; Valenti et al. 1983; Valenti & Wicks 1992), though sometimes there may be no effect (Wells 1979; Henson & Jordan 1982) and, in other cases, fertilizer application has increased the competitive ability of the weed (Rerkassem et al. 1980; Carlson & Hill 1986; Satorre & Snaydon 1992; Sindel & Michael 1992). Differential responses between crop and weed to applied fertilizer should be considered in rational weed control decision making, particularly in low input crop production systems. This would require a thorough understanding of the nature of crop–weed balance under various soil fertility conditions.

Various species of Cruciferae are among the most noxious weeds of spring wheat crops. Cruciferae species are densely distributed in the main wheat producing areas of Argentina, and high crop losses have been reported because of these weeds (Satorre & Arias 1990; Leaden 1995). Moreover, some *Brassica napus* (L.) genotypes are important cultivated oilseed plants, and their wild forms and volunteer plants are recognized as highly competitive weeds that can seriously reduce wheat yield (Hanf 1983; Jensen 1991). This paper presents data from a field experiment with wheat and volunteer oilseed rape (*B. napus*) as a weed. The objectives of this research were to evaluate the effect of different N fertilizer applications on crop and weed competitive balance and to identify the mechanisms involved in the differential response of both component species to soil N availability when in competition.

MATERIALS AND METHODS

The study was conducted during 1992 at the experimental unit of the Plant Production Department, Universidad de Buenos Aires (34°35'S; 58°29' W, 25 m.a.s.l.) on a silty clay loam (Vertic Argiudol) soil. The experimental area was sown with wheat as a cover crop two months before the experiment, to deplete soil N levels. Just before planting the experiment, the wheat was cut 2 cm above ground with a lawn-mower and the plant material was disposed away from the experimental site. Afterwards, the area was rototilled twice to form the seedbed.

Wheat as the crop and oilseed rape as the weed, were sown on 23 July in a split plot design in three complete blocks. Nitrogen fertilizer applications (the equivalent of 0, 40 and 100 kg/ha N) constituted main plots. Additive mixtures of crop and weed density (1:1) and monocultures of the crop and weed constituted subplots. Urea fertilizer (46-0-0) was hand applied before sowing and incorporated in the soil with the second pass of the rototiller.

Each experimental unit consisted of 13 crop rows, 0.15 m apart and 5 m long. Spring wheat seeds (cv. Marcos Juárez INTA) were placed by hand in rows and oilseed rape seeds (collected from a field grown plot of the commercial hybrid Iciola 41) were broadcast immediately after the crop was sown. Crop and weed seeds were lightly covered with a handrake. Crop and weed emerged simultaneously and both components were thinned to 330 plants/m² closely after emergence; other spontaneous weed species were handweeded periodically from all treatments. Plant density was set high to assure full competition between crop and weed and to avoid any effect of density on competition indexes (Satorre 1988). Meteorological data (max. and min. air temperature and precipitation) were obtained from a weather station located 500 m from the experimental field. Climatic variables for the period 1986–1999 at this site were used to compare the experimental conditions with prevailing conditions in the area. Crops were rainfed but no water deficit was evident at any time during the experiment. Insecticide (Dimethoate) was used to control aphids.

Canopy structure was evaluated weekly with a point quadrat procedure using an optical device as described by Beaumer & de Wit (1968) and Ghersa & Martínez Ghersa (1991). Seven point quadrats were randomly assigned to each of six positions around each experimental unit, i.e., 42 point quadrats at an angle of 45° were recorded per subplot at each of the 10 weeks observation period. Relative leaf area of wheat (*Rw*) and of *B. napus* (*Rb*) were calculated as:

$$Rw = \frac{Nw}{42} \quad \text{and} \quad Rb = \frac{Nb}{42} \quad ,$$

where *Nw* and *Nb* are the number of point quadrats intercepting crop and weed leaves, respectively. This method estimates how the light resource is partitioned among components in mixtures.

The photosynthetically active radiation (*PAR*) was measured at ground level and above the crop using a 1 m long linear photon flux sensor (LI 191 S, Licor Inc., Lincoln NE, USA). Canopy light interception was calculated as the ratio of the difference between *PAR* above and at ground level to above measured radiation. *PAR* at ground level was measured by inserting the linear sensor parallel to randomly chosen central interrows of each plot. Measurements were taken on clear sunny days during the 2 h period around solar noon, at day 54 and day 76 after sowing. Crop and weed plant height were also measured 75 and 106 days after sowing.

A decimal code was used to periodically register crop (Zadoks et al. 1974) and weed phenology (Lancashire et al. 1991). Above-ground biomass was harvested at four occasions. One 0.21 m² sample area was harvested from each subplot at the terminal spikelet initiation stage (60 days), booting (80 days) and anthesis (90 days) and 0.42 m² sample plots were taken at crop maturity (130 days). In all samples, plant material of each species was separated, oven-dried at 70 °C and weighed. Once weighed, all plant fractions were ground in a hammer mill and total N concentration was determined by Kjedahl digest combustion. At crop maturity grain yield was also determined.

Analyses of variance were performed for all variables at each sampling date, except for relative leaf area measurements that were analyzed considering sampling time as a factor. Crop and weed biomass data were transformed to decimal logarithms to homogenize variance. Aggressivity (*AG*) indices (McGilchrist & Trenbath 1971), which consider the effect of competition on both the crop and the weed, were calculated as:

$$AG = \frac{RCY - RWY}{RCY + RWY} \, ,$$

according to the modification introduced by Satorre (1988), where *RCY* and *RWY* are the ratios of the biomass yield per unit area of crop and weed in mixtures to their biomass yield in monocultures, respectively. When $AG > 0$ the crop is more competitive than the weed, and if $AG < 0$ the weed is more competitive than the crop; $AG = 0$ means that crop and weed were equally competitive. Analyses of variance were also performed on *AG* values.

Results

Climatic variables

Monthly average temperature and precipitation registered during the experiment and calculated from a 14-years data series are shown in Table 1. Monthly precipitation val-

Table 1. Monthly mean temperature and precipitation values in 1992 and 1986–1999 for the period of the experiment. Probabilities of 1992 values in a normalized distribution estimated from the 1986–1999 data series are also presented.

Tabla 1. Temperatura media mensual y valores de precipitación de 1992 y de la serie 1986–1999 para el período comprendido por el experimento. Se presentan los valores de probabilidad normalizados de 1992 estimados a partir de la serie 1986–1999.

	Temperature (°C)						Precipitation (mm)					
	Jul	Aug	Sep	Oct	Nov	Dec	Jul	Aug	Sep	Oct	Nov	Dec
1992	8.7	12.7	14.4	18.1	18.3	23.2	46.5	78.1	67.5	135.8	89.1	138.6
1986–1999	11.3	13.4	14.7	17.7	20.7	23.7	50.8	72.4	57.1	115.6	110.7	131.5
Probability	0.04	0.27	0.38	0.69	0.01	0.34	0.45	0.54	0.65	0.65	0.38	0.54

ues were close to the used series average for all months during the experiment but, registered temperatures tended to be lower than the 1986–1999 average values. However, temperature deviations were greater at the beginning and at the end of the crop growing cycle (i.e., July and November) and were low during the active crop and weed growth periods (Table 1).

Crop and weed yield

Nitrogen fertilizer increased biomass yield of both crop and weed ($P < 0.05$). Mean biomass of wheat in monocultures varied between 334 and 962 g/m^2 at maturity for 0 and 100 kg/ha N, respectively, while weed biomass in monoculture increased from 110 to 516 g/m^2 for 0 and 100 kg/ha N, respectively (Figure 1a,b). Weed competition consistently reduced wheat dry matter in the early stages at the 100 kg/ha N treatment (Figure 1a). At maturity, there were no significant differences in wheat dry matter in monocultures and weed infested plots in the two low soil N treatments ($P > 0.05$). In contrast, weed competition reduced crop biomass by 35% in the 100 kg/ha N treatment. Looking at the effect of the crop on the weed, wheat competition significantly ($P < 0.01$) reduced weed biomass in mixtures. Biomass reduction of the weed was higher ($P < 0.01$) than that experienced by the crop, particularly from the crop boot stage at the low soil N level treatments (0 and 40 kg/ha N), i.e., weed biomass reduction averaged 78% at low soil N availability, while at high soil N weed biomass reduction only averaged 49% (Figure 1b).

There were significant differences ($P < 0.05$) among treatments for the aggressivity of the crop relative to the weed at anthesis (Table 2). Aggressivity indices reflected the change in competitive balance under the various soil N conditions. When 100 kg/ha N was applied, wheat and volunteer oilseed rape had almost the same competitive ability, since the aggressivity value (0.207) was not significantly different from zero. However, when 0 or 40 kg/ha N was applied, the crop was significantly more competitive than the weed ($AG = 0.769$ and 0.731, respectively).

Crop grain yield was affected by N application and weed competition in a similar way as crop biomass at maturity, i.e., grain yield was almost unaffected by weed competition at 0 and 40 kg/ha N but it was reduced by 44% due to weed competition when 100 kg/ha N was applied (Table 2).

Table 2. Log$_{10}$ transformed wheat yield at harvest (g/m^2) in monocultures and mixtures with crop aggressivity indexes (AG) at anthesis. Arithmetic values are presented between brackets. SE for individual values of wheat yield and crop AG are presented ($n = 3$).

Tabla 2. Valores transformados logarítmicamente (Log$_{10}$) del rendimiento de trigo (Wheat yield; g/m^2) en monoculturas y mezclas e índices de agresividad del cultivo (AG) en antesis. Los valores aritméticos son presentados entre paréntesis. SE: Error estándar de los valores individuales para el rendimiento de trigo y del índice de agresividad del cultivo ($n = 3$).

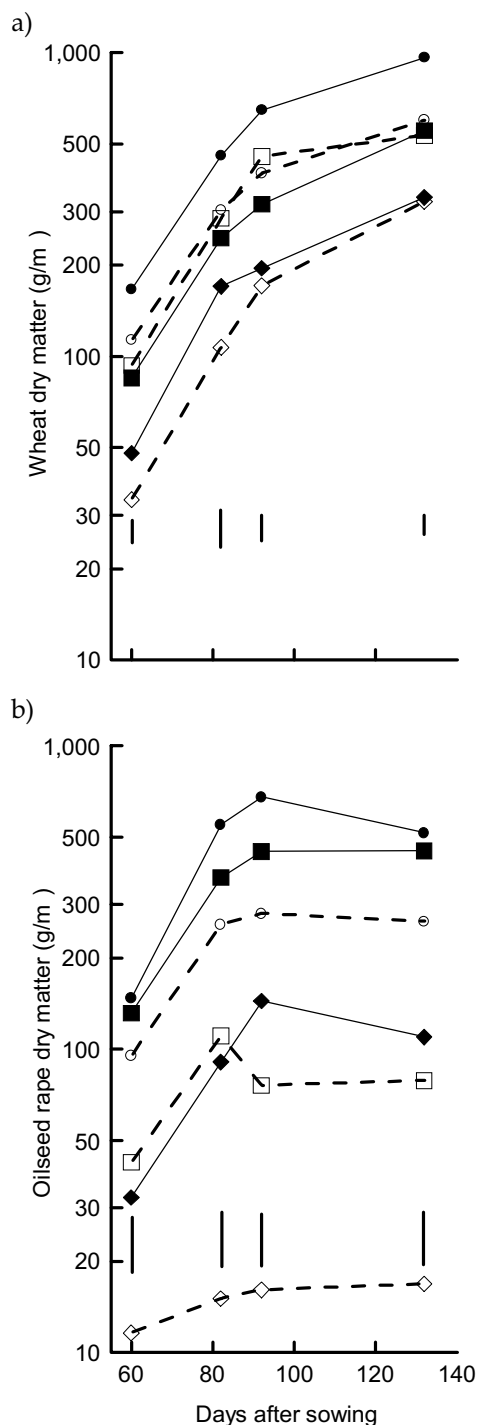| N level (kg/ha)	Wheat yield (g/m^2)		AG at anthesis
	Monoculture	Mixture	
0	2.141 (138)	2.134 (136)	0.769
40	2.358 (228)	2.289 (195)	0.731
100	2.649 (446)	2.402 (252)	0.207
SE	0.048		0.089

a)

b)

Figure 1. Plant dry matter of a) wheat and b) volunteer oilseed rape and in competition with others species at three nitrogen fertilizer levels (0, 40 and 100 kg/ha N). Vertical lines indicate SE for individual values at each sampling date (*n* = 3).

Figura 1. Materia seca de a) trigo y b) colza en competencia con tres niveles de fertilización nitrogenada (0, 40 y 100 kg/ha N). Las líneas verticales indican el EE de los valores individuales para cada momento de muestreo (*n* = 3).

Canopy structure and light use

Crop and weed canopies developed simultaneously. However there were slight phenological differences between the species. Volunteer oilseed rape plants began to flower at the booting stage of wheat and total wheat growth period until maturity was 20 days longer than the weed growth period.

Intercepted radiation in monocultures and mixtures increased ($P < 0.05$) with N application at both sampling dates: the amount of light intercepted by mixtures canopy 54 and 76 days after sowing varied from 22% and 40% in unfertilized plots to 85% and 92% in 100 kg/ha N treatments, respectively (Table 3).

The relative leaf area of crop and weed directly intercepting light was significantly different among treatments (Figure 2a–c). Nitrogen application affected the relative leaf area of crop and weed in monocultures and mixtures. Crop and weed monocultures in the 0 kg/ha N treatment reached maximum relative leaf area values of 79% and 40%, respectively, while on plots with 100 kg/ha N fertilizer application, maximum values of relative leaf area in monoculture were 98% for the crop and 93% for the weed. Moreover, the relative leaf area of the weed when in competition with the crop was significantly ($P < 0.01$) lower at 0 kg/ha N than at 100 kg/ha N treatments, i.e., the weed had access to relatively less light at low than at high soil N levels when in competition with the crop (Figure 2a–c).

Crop and weed height were increased ($P < 0.05$) by N fertilizer application. Competition from volunteer oilseed rape did not affect wheat height at any fertilizer treatment. However, weed height was significantly reduced ($P < 0.001$) by crop competition 106 days after sowing at 0 and 40 kg/ha N. Weed height was almost unaffected at 100 kg/ha N (Table 3).

Nitrogen use by crop and weed

The crop and the weed absorbed more N ($P < 0.05$) at all growth stages when 100 kg/ha N was applied (Table 4). At nil or low (40 kg/ha) N applications, total N absorbed by the crop in monocultures and in mixtures did not significantly differ. However, volunteer oilseed rape plants absorbed significantly less N in mixtures than in weed monocultures. When 100 kg/ha N was applied, the crop and the

weed, in competition, tended to absorb similar amounts of N from the soil, despite the fact that the weed absorbed significantly more N than the crop at booting when in monoculture (Table 4). The ratio between the biomass produced and the N absorbed by plants (N use efficiency) tended to be greater in wheat than in rape at low soil N availability (Table 5).
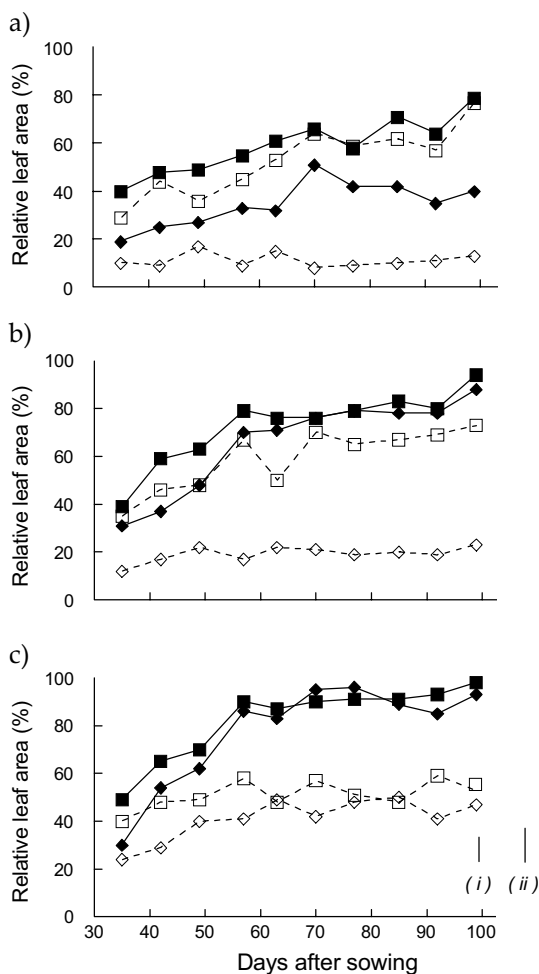

Figure 2. Relative leaf area (%) of wheat and volunteer oilseed rape in monocultures (solid lines with solid symbols) and mixtures (dashed lines with empty symbols) at three nitrogen fertilizer levels: a) 0, b) 40 and c) 100 kg/ha N. Vertical lines indicate SE for individual values considering all the samples throughout the experiment ($n = 30$): (i) wheat and (ii) volunteer oilseed rape.

Figura 2. Area foliar relativa (%) de trigo y colza en monoculturas (línea llena y símbolos llenos) y mezclas (líneas punteadas con símbolos vacíos) con tres niveles de fertilización nitrogenada: a) 0, b) 40 y c) 100 kg/ha N. Las líneas verticales indican el EE de los valores individuales para los diez momentos evaluados ($n = 30$): (i) trigo y (ii) colza.

DISCUSSION

Nitrogen was the main factor limiting crop and weed growth in either monocultures or mixtures. This is suggested by the fact that N application from 0 to 100 kg/ha N increased most plant attributes of both wheat and oilseed rape. Although light became a more important competition factor and N may have become less important when N fertilizer dosage was increased, it appears that N uptake and use regulated crop and weed growth, and their relative contribution to the total leaf area and biomass produced in mixtures.

Wheat plants had almost the same ability to capture N as the weed, since the pattern of N absorption in monocultures was similar between species (Table 4). However, N use efficiency was slightly greater in wheat than in oilseed rape at all soil N levels (Table 5). When no N fertilizer was applied, competition effects from oilseed rape on wheat were low (Figure 1a). Overall low levels of light interception were attained and the crop intercepted most of the incident radiation (Figure 2 and Table 3). Clements et al. (1929) and Donald (1963) first pointed out that some species may reduce their ability to compete for light when in competition for a limiting soil factor such as N. However, the nature of such responses in wheat-weed mixtures have been rarely explored (Exley & Snaydon 1992; Satorre & Snaydon 1992). In the case of some Cruciferae species, it is recognized that they are generally adapted to high N environments. For example, Liebman & Robichaux (1990) demonstrated that CO_2 net assimilation is greatly reduced in two weedy species of mustard (*B. hirta* Moench and *B. kaber* (DC) L.C. Wheeler) when leaf N content is lowered, affecting their performance in mixtures.

It appeared that when 100 kg/ha N was applied, belowground competition was partially relieved and the weed was able to take up more N from the soil, particularly at early stages of weed growth (Table 4). Under that condition, weed height and relative leaf area increased and the volunteer oilseed rape plants were able to intercept as much light as the crop (Figure 2). The overall competitive ability of the crop was, therefore, partially reversed by the manipulation of soil fertility, from $AG = 0.769$ to $AG = 0.207$ (Table 2). Sev-

Table 3. Light interception (%) of crop and weed in monocultures (Mono.) and mixtures at day 54 and day 76 after sowing, and plant height at harvest (106 days after sowing). SE for individual values of wheat and rape at each sampling date are presented ($n = 3$).

Tabla 3. Intercepción de luz (%) por parte del cultivo (Wheat) y de la maleza (Rape) en monoculturas (Mono.) y en mezclas a los 54 y 76 días después de la siembra y altura de las plantas a la cosecha (106 después de la siembra). SE: Error estándar de los valores individuales de trigo y maleza para cada muestreo ($n = 3$).

N level	Light interception (%)								Height (cm) 106 days			
	54 days				76 days							
	Wheat		Rape		Wheat		Rape		Wheat		Rape	
(kg/ha)	Mono.	Mixture	Mono.	Mixture	Mono.	Mixture	Mono.	Mixture	Mono.	Mixture	Mono.	Mixture
0	18	22	11	22	40	40	19	40	60	58	56	40
40	50	51	46	51	63	67	59	67	75	69	90	57
100	63	85	72	85	81	92	83	92	85	90	98	102
SE	5.9		9.6		4.8		8.3		3.5		7.7	

eral other studies with wheat and weeds have also reported that N application increased the effects of shoot competition (Aspinall 1960; Bulmer 1987; Satorre & Snaydon 1992). In accordance with our results, Liebman (1989) also found that high doses of N fertilizer applied to barley-pea intercrops increased white mustard cv. Kirby (*Brassica hirta* Moench) competitiveness while the weed was strongly suppressed at low soil N conditions (Liebman 1989; Liebman & Robichaux 1990). The wheat crop also absorbed more N when 100 kg/ha N was applied than in either the 0 or 40 kg/ha N treatments, but this had only a low impact on crop height and relative leaf area (Figure 2 and Tables 3 and 4).

It is not surprising that biomass production of both species in this experiment increased when high N levels were applied, since both are crops known to be very responsive. However, the effect of N on the competitive balance of the species was not previously evident. The results clearly suggest that reversal of the competitive balance between wheat and oilseed rape among the different soil N conditions was related to the weeds ability to modify its access to light.

The reversal of weed competitive ability explained the interaction found for crop yield between N fertilizer application and weed control condition, i.e., crop losses due to weed competition were negligible at low soil N lev-

Table 4. Nitrogen utilization (g/m²) by crop and weed in monocultures (Mono.) and mixtures at three dates during crop development: terminal spikelet (60), boot (82) and anthesis (92 days after sowing). SE for individual values of wheat and rape at each sampling date are presented ($n = 3$).

Tabla 4. Utilización de nitrógeno (g/m²) por el cultivo (Wheat) y la maleza (Rape) en monoculturas (Mono.) y mezclas en tres estados de desarrollo de trigo: espiguilla terminal (60), bota (82) y antesis (92 después de la siembra). SE: Error estándar para valores individuales de trigo y maleza para cada momento ($n = 3$).

N level (kg/ha)		Nitrogen utilization (g/m²)					
		Wheat			Rape		
		60 days	82 days	92 days	60 days	82 days	92 days
0	Monoculture	0.99	2.35	2.11	0.72	1.20	1.90
	Mixture	0.66	1.56	1.96	0.25	0.19	0.20
40	Monoculture	1.89	2.87	3.81	3.20	4.81	5.73
	Mixture	1.79	2.69	4.24	0.82	1.59	0.86
100	Monoculture	3.64	7.61	8.71	3.98	9.75	9.82
	Mixture	2.95	4.04	4.60	2.58	3.98	3.71
SE		0.29	1.04	1.11	1.48	1.36	1.21

Table 5. Nitrogen use efficiency expressed as dry matter produced/nitrogen utilized (g/g). Data for crop and weed in monocultures and mixtures at three crop development stages: terminal spikelet (60), boot (82) and anthesis (92 days after sowing). SE for individual values of wheat and rape at each sampling date are presented ($n = 3$).

Tabla 5. Eficiencias de uso del nitrógeno expresado como materia seca producida/nitrógeno utilizado (g/g) correspondientes a monoculturas mezclas de trigo (Wheat) y colza (Rape) en tres estados del desarrollo del cultivo espiguilla terminal (60), bota (82) y antesis (92 después de la siembra). SE: Error estándar de los valores individuales de trigo y maleza para cada momento ($n = 3$).

N level (kg/ha)		Nitrogen use efficiency (g/g)					
		Wheat			Rape		
		60 days	82 days	92 days	60 days	82 days	92 days
0	Monoculture	48.3	72.9	92.6	45.3	73.0	75.3
	Mixture	50.8	69.0	87.4	47.5	76.8	82.8
40	Monoculture	45.9	85.3	83.6	42.4	74.5	80.7
	Mixture	52.8	80.2	88.4	52.3	70.5	88.6
100	Monoculture	45.8	80.7	87.4	39.0	61.1	70.5
	Mixture	38.4	77.5	87.0	38.9	67.0	76.5
SE		2.8	3.2	3.5	2.2	7.1	4.2

els but were high when N level in the soil was increased. This result has implications for weed management, particularly since most wheat producers will tend to reach high crop yields by applying N fertilizer or choosing fertile fields for their crops. On one hand, the return from weed control will be higher at high N availability than at low N availability, promoting the use of herbicides when N fertilizer is applied. On the other hand, weed control thresholds and weed density tolerance are reduced by the increase of relative weed competitive ability at high N availability, suggesting the need to control volunteer oilseed rape at a lower weed density in high-N fields than in low-N fields. Since weed control condition and N availability interact for crop grain yield, there is no simple economic substitution of one crop management technique by the other, i.e., within the range of conditions explored in this experiment, more N would continuously need to be applied to compensate for yield losses due to the weed as wheat yield potential increases from almost 1 ton/ha to 2.5 ton/ha (no compensation appeared to be possible above that yield, since weed relative competitive ability increases significantly; Table 2). Under low-input, low-yield management systems (i.e., low N fertilizer use) the expected high relative wheat competitive ability may prevent yield losses from the weed and reduce the use of herbicides. From these results, it may also be suggested that changes in weed abundance may be promoted by the increase in crop fertilizer management in the main wheat producing areas, i.e., *B. napus* populations as weeds would become more important with the increase of N fertilizer use in the crops; while they will remain as dominated poor competitors in low-N, low-input wheat crops. However, more research is needed to confirm this hypothesis.

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REFERENCES

ASPINALL, D. 1960. An analysis of competition between barley and white persicaria. II Factor determining the course of competition. *Ann. Appl. Biol.* **48**:637–654.

BEAUMER, K & CT DE WIT. 1968. Competitive interference of plant species in monoculture and mixed stands. *Neth. J. Agric. Sci.* **16**:103–122.

BULMER, R. 1987. Aspects of agroecology of *Bromus sterilis*. Ph.D. Thesis. University of Reading. United Kingdom.

CARLSON, HL & JE HILL. 1986. Wild oat competition with spring wheat: effects of nitrogen fertilization.

Weed Sci. **34**:29–33.

CHALLAIAH; OC BURNSIDE; GA WICKS & VA JOHNSON. 1986. Competition between winter wheat (*Triticum aestivum*) and cultivars and downy brome (*Bromus tectorum*). *Weed Sci.* **34**:689–693.

CLEMENTS, FE; JE WEAVER & H HANSON. 1929. *Plant competition - An analysis of community functions.* Carnegie Institution of Washington Publication. Washington, USA.

COUSENS, R; F POLLARD & RAP DENIER. 1985. Competition between *Bromus sterilis* and winter cereals. *Aspects of Applied Biology* **9**:67–74.

DONALD, CM. 1963. Competition among crop and pasture plant. *Adv. Agron.* **15**:1–118.

EUSSEN, JHH. 1982. The ecology of pests: Weeds. *Prot. Ecol.* **4**:213–221.

EXLEY, DM & RW SNAYDON. 1992. Effects of nitrogen fertilizer and emergence date on root and shoot competition between wheat and blackgrass. *Weed Res.* **32**:175–182.

GHERSA, CM & MA MARTÍNEZ GHERSA. 1991. A field method for predicting yield losses in maize caused by johnsongrass (*Sorghum halepense*). *Weed Technol.* **5**:279–285.

GHERSA, CM; RL BENECH ARNOLD; EH SATORRE & MA MARTÍNEZ GHERSA. 2000. Advances in weed management strategies. *Field Crops Res.* **67**:95–104.

HANF, M. 1983. *The arable weeds of Europe with their seedlings and seeds.* Basf United Kingdom Limited, United Kingdom.

HASHEM, A; SR RADOSEVICH & ML ROUSH. 1998. Effect of proximity factors on competition between winter wheat (*Triticum aestivum*) and italian ryegrass (*Lolium multiflorum*). *Weed Sci.* **46**:181–190.

VAN HEEMST, HDJ. 1985. The influence of weed competition on crop yield. *Agricultural Systems* **18**:81–93.

HENSON, JF & LS JORDAN. 1982. Wild oat (*Avena fatua*) competition with wheat (*Triticum aestivum* and *Triticum durum*) for nitrate. *Weed Sci.* **30**:297–300.

JENSEN, PK. 1991. Weed size hierarchies in Denmark. *Weed Res.* **31**:1–7.

KOCH, W; ME BESHIR & R UNTERLADSTATTER. 1982. Crop loss due to weeds. Pp. 103–111 in: *Proceedings FAO/ International Weed Science Society Expert Consultation on improving weed management within the developing countries.* Food and Agricultural Organization of the United Nations. Rome, Italy.

KROPFF, MJ & LAP LOTZ. 1992. Optimization of weed management systems: the role of ecological models of interplant competition. *Weed Technol.* **6**:462–470.

LANCASHIRE, PD; H BLEIHOLDER; T VAN DEN BOOM; P LANGELUDDEKE; R STAUSS ET AL. 1991. A uniform decimal code for growth stages of crops and weeds. *Ann. Appl. Biol.* **119**:561–601.

LANNING, SP; LE TALBERT; JM MARTIN; TK BLAKE & PL BRUCKNER. 1997. Genotype of wheat and barley affects light penetration and wild oat growth. *Agron. J.* **89**:100–103.

LEADEN, MI. 1995. *Fecha de siembra y balance de competencia entre trigo (*Triticum aestivum*) y nabón (*Raphanus sativus*). Interacciones con la densidad del cultivo y la maleza y la disponibilidad inicial de nitrógeno.* MSc Thesis, Facultad de Ciencias Agrarias, Universidad Nacional de Mar del Plata–EEA INTA Balcarce, Argentina.

LE BARON, HM. 1991. Distribution and seriousness of herbicide-resistant weed infestations worldwide. Pp. 27–44 in: JC CASELEY; GW CUSANS & RK ATKIN (eds). *Herbicide Resistance in Weeds and Crops.* Butterworths/Heinemann. London, United Kingdom.

LIEBMAN, M. 1989. Effects of nitrogen fertilizer, irrigation and crop genotype on canopy relations and yields of an intercrop weed mixture. *Agric. Ecosyst. & Environ.* **22**:83–100.

LIEBMAN, M. & RH ROBICHAUX. 1990. Competition by barley and pea against mustard: effects on resource acquisition, photosynthesis and yield. *Agric. Ecosyst. & Environ.* **31**:155–172.

LIEBMAN M & E DYCK. 1993. Weed Management. A need to develop ecological approaches. *Ecol. Appl.* **3**(1):39–41.

MCGILCHRIST, CA & BR TRENBATH. 1971. A revised analysis of plant competition experiment. *Biometrics* **27**:659–671.

MORTIMER, AM & BD MAXWELL. 1994. Selection for herbicide resistance. Pp. 1–25 in: SB POWLES & JAM HOTUM (eds). *Herbicide Resistance in Plants: Biology and Biochemistry.* CRC Press. Boca Raton, USA.

NAYLOR, REL. 1972. The nature and consequence of interference by *Alopecurus myosuroides* competition in winter cereals. Pp. 701–708 in: *Proceedings of British Crop Protection Conference - Weeds.*

RERKASSEM, K; WR STERN & NA GOODCHILD. 1980. Associated growth of wheat of wheat and annual ryegrass. III Effect of early competition on wheat. *Aust. J. Agric. Res.* **31**:1057–1067.

SATORRE, EH. 1988. *The competitive ability of spring cereals.* Ph.D. Thesis. University of Reading. United Kingdom.

SATORRE, EH & SP ARIAS. 1990. Competencia entre trigo (*Triticum aestivum* L.) y malezas. III El efecto de la densidad del cultivo y la maleza. Pp. **4**:1–10 in: *Actas del II Congreso Nacional de Trigo. AIANBA. 17–19 de octubre de 1990.* Asociación de Ingenieros Agrónomos de la zona Norte de la Provincia de Buenos Aires. Pergamino, Argentina.

SATORRE, EH & AC GUGLIELMINI. 1990. Competencia entre trigo (*Triticum aestivum* L.) y malezas. I- El comportamiento de cultivares modernos de trigo. Pp. **4**:77–87 in: *Actas del II Congreso Nacional de Trigo. AIANBA. 17–19 de octubre de 1990.* Asociación de Ingenieros Agrónomos de la zona Norte de la Provincia de Buenos Aires. Pergamino, Argentina.

SATORRE, EH & RW SNAYDON. 1992. A comparison of root and shoot competition between spring cereals

and *Avena fatua* L. *Weed Res.* **32**:45–55.

SINDEL, BM & PW MICHAEL. 1992. Growth and competitiveness of *Senecio madagascariensis* Poir. (fireweed) in relation to fertilizer use and increases in soil fertility. *Weed Res.* **32**:399–406.

VALENTI, SA & GA WICKS. 1992. Influence of nitrogen rates and wheat (*Triticum aestivum*) cultivars on weed control. *Weed Sci.* **40**:115–121.

VALENTI, SA; GA WICKS & OC BURNSIDE. 1983. Effects of nitrogen rates and its application period on weed control in three winter wheat cultivars. *Proceedings of North Central Weed Control Conference*. 77-78.

WELLS, GS. 1979. Annual weed competition in wheat crops: the effect of weed density an applied nitrogen. *Weed Res.* **19**:185–191.

WYSE, DL. 1992. Future of weed science research. *Weed Technol.* **6**:162–165.

ZADOKS, JC; TT CHANG & CF KONZACK. 1974. A decimal code for the growth stages of cereals. *Weed Res.* **14**:415–421.