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Influence of nitrogen fertilizer on grain yield of barley *(Hordeum vulgare* L.) under irrigated conditions

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Abstract

A field study was conducted from 1998 to 2000 in Ciudad Real (Spain) to analyze the productive response of the barley (*Hordeum vulgare* L.) crop to different nitrogen-fertilizer strategies. The effect of N dose and its partitioning between sowing-time and top-dressing at tillering state on grain yield and yield components was evaluated, as well as the contribution of each one of these parameters to the final yield by means of a correlation and regression study, and path coefficient analysis. The specific climatic conditions of each growing season had a very marked effect on barley crops, and grain yields and yield components significantly differed every year. No significant differences in yield were found between 100 and 150 kg N ha^{-1} doses, but yield was significantly reduced by applying 200 kg N ha^{-1}. The evolution of grain yield according to N fertilizer was properly fitted to a quadratic function, with the maximum value corresponding to about 120 kg N ha^{-1}. It is not advisable to exceed this dose because this is of no benefit to the plant and implies a risk of environmental contamination. The highest yield was obtained by applying two thirds of the total N fertilizer at seeding time, whereas a single application of N fertilizer as a top-dressing resulted in a significant reduction in barley grain yield. In these field conditions, grain yield mainly depended on the number of ears per square meter, being the 1000-kernel weight the most stable yield component.

Key words: yield components, N-fertilizer partitioning, N-fertilizer application time.

Resumen

Influencia de la fertilización nitrogenada sobre el rendimiento de la cebada (Hordeum vulgare L.) cultivada en regadío

Entre 1998 y 2000 se realizó un estudio de campo en Ciudad Real (España) para analizar la respuesta productiva de la cebada (*Hordeum vulgare* L.) a distintas estrategias de fertilización nitrogenada. Se evaluó la influencia de la dosis de nitrógeno y su fraccionamiento entre fondo y cobertera en ahijado sobre la producción de grano y los componentes del rendimiento, y se analizó la contribución de cada uno de ellos en la cosecha final mediante un estudio de correlaciones y regresiones y mediante análisis por coeficientes de sendero. Las condiciones climáticas específicas de cada campaña tuvieron un efecto muy marcado sobre el cultivo de la cebada, obteniéndose cada año cosechas de grano y componentes del rendimiento significativamente diferentes. No se produjeron diferencias en el rendimiento al aportar 100 ó 150 kg N ha^{-1}, mientras que se redujo significativamente con 200 kg ha^{-1}. La evolución del rendimiento frente al nitrógeno se ajustó satisfactoriamente a una función cuadrática con un máximo en torno a 120 kg N ha^{-1}, dosis que no debe superarse por no beneficiar al cultivo y suponer un riesgo de contaminación para el medio ambiente. La mejor producción se obtuvo aportando las dos terceras partes del nitrógeno fertilizante en fondo, mientras que una única aplicación en cobertera redujo de forma significativa el rendimiento de la cebada, por lo que se desaconseja esta práctica. En las condiciones del ensayo, la cosecha dependió fundamentalmente del número de espigas por metro cuadrado, siendo el peso de mil granos el componente del rendimiento más estable.

Palabras clave: componentes del rendimiento, fraccionamiento del N fertilizante, época de aplicación del N fertilizante.

Introduction

Cereals are among the key crops of the agricultural economy of Castilla-La Mancha, together with vineyards and olive groves. At present, barley is the most sown and one of most economic importance cereal in the region, explaining the need to optimize cultivation techniques.

Crop production systems are often based on the use of large amounts of nitrogen (N) fertilizer, frequently in larger amounts than the plants require (Segura *et al.*,

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1999) and without taking into account the residual N remaining in the soil, its mineralisation capacity or the amount of nutrients that can be added with the irrigation water (Murillo *et al.*, 2000). Therefore, as well as not benefiting the crops in any way, this can also pollute groundwaters with nitrates. In fact, some areas of Castilla-La Mancha have been declared to be at risk of this type of pollution, Western Mancha and Campo de Montiel, in which the main or only water supply in 49 towns are underground waters (Junta de Comunidades de Castilla-La Mancha, 2001).

On the other hand, nitrogen fertilization has an important effect on the final harvest, therefore if this element is not available in sufficient amount, yield is impaired. The results of trials with increasing doses of N show that a typical response curve presents an initial rise followed by a peak and then a gradual decline in yield. Several studies have aimed to determine this optimum dose with varied results. For example, while the Instituto Técnico y de Gestión Agrícola (ITGA, 1999) of Navarra reported this to be 163 kg N ha^{-1}, Webb *et al.* (1998) found it to be 143 kg ha^{-1} and Conry (1995) found no differences in yields obtained with doses higher than 125 kg N ha^{-1}.

Uptake of soil N is moderate during the first phases of crop growth, but continues up to harvest and is maximum during anthesis (McTaggart and Smith, 1995). According to Baethgen *et al.* (1995), relatively small amounts of available nitrogen must be ensured for the establishment of the barley crop and the initial development of tillering. The additional N could be applied at the end of this period. According to the ITGA (2000), there is no point in using N before sowing because it serves no purpose at all, and can only be of interest in fertilizer complexes provided that it does not exceed 25-30 kg N ha^{-1}. According to Cochet and Moynier (1994), if N losses are important one single N input can be applied at the stage of ear 1 cm high. In malting barleys, Conry (1995) recommends a single application of N at seeding time, while Molina (1989) and the Servicio de Investigación y Tecnología Agraria of Castilla-La Mancha (SITA, 1998) recommend a total of 100-120 kg N ha^{-1} divided into equal parts between seeding and top-dressing at tillering stage.

Strict nitrogen fertilizer doses cannot be established since the requirements for this element of cereals in general and of barley in particular depend on factors such as variety, climate, soil or crop system. However, guidelines can be established to take into account the importance of total N amount, its partitioning and application time. The aim of this work was to determine the productive response of an irrigated barley crop to different nitrogen fertilizer regimes.

Material and methods

The experiments were conducted over three years (1998-2000) on «La Entresierra» farm, belonging to the Junta de Comunidades de Castilla-La Mancha, in Ciudad Real, Spain (3º56' W, 39º0' N, altitude 640 m). For crop rotation, three adjacent plots of similar shape and size were used.

It was used a loam-sandy (81% sand, 9% lime, 10% clay), slightly basic (pH=8.1), non-saline (EC=0.30 dS m^{-1}) soil, with low contents of total N (0.1%, Kjeldahl) and phosphorus (13 ppm, Olsen), very high levels of potassium (415 ppm, ammonium acetate) and normal contents of organic matter (2.1%).

The 'Beka' variety was chosen owing to its importance and influence among cereal growers in Castilla-La Mancha. Sowing was done by a steady trickle in rows 20 cm apart with a mean seed dose of 160 kg ha^{-1} (420 seeds per m^2), corresponding in the field to around 350 plants m^{-2}.

The crop was irrigated by a total cover sprinkler system. The irrigation period was variable and depended on climatic conditions and crop development, ranging from full tillering to dough development. The irrigation program was established so that the plants received a total amount of water (net irrigation + effective rainfall) of around 80% crop evapotranspiration (ETc), since this reduction has been shown not to significantly affect barley yield (Martín de Santa Olalla *et al.*, 1992; Moreno *et al.*, 2000) and can mean a considerable saving of water during dry seasons. The ETc was determined in an adjacent barley irrigation experiment with the methodology described by Moreno *et al.* (2000).

Fertilization consisted of 100 kg P_2O_5 ha^{-1} applied before sowing in an 18% superphosphate form, and the differential doses of N applied by hand in the form of 40% urea at seeding time and 33.5% ammonium nitrate as a top dressing at tillering stage. According to López Bellido (1991), one of the most problematic aspects associated with phosphorus fertilizer is its fixation by the soil, that can result in efficiencies of less than 20% or even less in soils with a basic pH. It is, therefore, recommendable to apply a larger amount of phosphorus fertilizer than that indicated by crop extractions, as 11 kg of P_2O_5 per ton of grain (FAO, 1986) and soil level, in an attempt to increase fertilizer solubility. The high levels of assimilable potassium in the soil make it recommendable not to use potassium fertilizer.

A split plot statistical design with four repetitions was used, considering the total N doses as the main plots (0, 100, 150 and 200 kg ha^{-1}) and its partitioning between seeding and top-dressing at tillering as the subplots [the total N dose at seeding (S), two thirds at seeding and one third as a top-dressing (2S1T), one third at seeding and two-thirds as a top-dressing (1S2T) and the total N dose as a top-dressing (T)], resulting in a total of 64 subplots of 2.4 x 17 m (42 m^2) separated by rows of 0.5 m. The experimental field was surrounded by a perimeter 10 m wide to prevent any interference from outside.

After reaching commercial maturity and before harvesting, a sample of 0.20 m^2 was randomly cut to ground level with scissors in each elemental plot; the ear was separated from the chaff, and the number of ears and kernels were counted after manual threshing. After drying in a forced ventilation oven, each component was weighed on a conventional balance with 0.1 g precision.

Plot harvesting was done with a special experimental harvester. The water content of the kernels was determined with a digital humidity gauge, Burrows Mod. 700, Seedburo Equipment Company, Chicago (Illinois), and the data were obtained as kilogrammes per hectare. Both yield and 1000-kernel weight were referred to 12% standard humidity.

The data from three years of experiments were compiled, thus it allows to maximize the number of observations and, therefore, the accuracy of the results (from n=64 to n=192). Analysis of variance was applied to the data obtained for each parameter and the degree of significance and the minimum significant difference (msd) at 5% were determined. To clarify the relationships between grain yield and its components [number of ears per square metre (EM2), number of kernels per ear (KPE) and 1000-kernel weight (KW)], correlations and regressions were studied, and path coefficient analysis, described by García del Moral *et al.* (1991a), was performed.

Results

Nitrogen fertilizer dose effects

The main effect of the N dose was decisive on all the parameters measured and the results were significant at $P \leq 0.001$ (Table 1).

No significant differences were found ($P \leq 0.5$) between the yields from the 100 and 150 kg N ha^{-1} doses, but there were differences between the 200 and 0 kg N ha^{-1} doses. The treatment without N supply was the least productive (Table 2).

Figure 1 shows that yield properly fits to a quadratic function ($P \leq 0.001$), with a peak at 123 kg N ha^{-1}.

The yield component results (Table 2) showed that EM2 behaved in a similar way to yield and was minimum without N supply, with no significant differences when applying 100 or 150 kg N ha^{-1} and decreasing with 200 kg N ha^{-1}.

The smallest value of KPE was always recorded in the treatment that never received N fertilizer, with significant differences compared to the other treatments, while the statistical analysis revealed an absence of

Table 1. Summary of the analysis of varience (F calculated) of the grain yield and its components in barley according to N fertilizer dose and its partitioning between seeding and top-dressing. Years 1998 to 2000

Sources of variation	Degrees of freedom	F calculated			
		Grain yield	Ears per m^2	Kernels per ear	1000-kernel weigth
Year	2	111.16***	256.95***	45.40***	31.60***
N Dose	3	305.85***	156.76***	204.91***	66.65***
Year × N Dose	6	11.45***	7.65***	23.80***	8.80***
Error a	27	1.38	1.43	1.22	1.31
Partitioning (P)	3	21.68***	3.33*	31.47***	3.66*
Year × P	6	1.21	1.48	4.31***	6.41***
N Dose × P	9	2.52*	2.04*	2.29*	1.25
Year × N Dose × P	18	2.35**	2.44**	4.44***	2.75***
Error b	108				

*,**,***: Significant at 0.05, 0.01 and 0.001, respectively.

Table 2. Grain yield and yield components in barley according to N fertilizer dose and its partitioning between seeding and top-dressing. Years 1998 to 2000

Treatment	Parameter			
	Grain yield (kg ha^{-1})	Ears per m^2	Kernels per ear	1000-kernel weight (g)
N Dose (kg ha^{-1})				
0	2,139 c	488 c	13.3 b	35.6 c
100	4,860 a	751 a	16.9 a	38.6 a
150	4,837 a	771 a	16.8 a	37.6 b
200	3,895 b	662 b	16.6 a	35.9 c
Partitioning				
S	3,988 b	660 ab	16.2 a	36.8 ab
2S1T	4,244 a	688 a	16.3 a	37.1 a
1S2T	4,073 b	672 ab	16.0 a	37.1 a
T	3,604 c	652 b	15.0 b	36.5 b
Mean	3,978	668	15.9	36.9

Partitioning: The total dose at seeding (S), two thirds at seeding and one third as a top-dressing (2S1T), one third at seeding and two-thirds as a top-dressing (1S2T) and the total dose as a top dressing (T). For each parameter and treatment (fertilizer dose and partitioning between seeding and top-dressing), different letters differ at $P \leq 0.05$.

differences between treatments fertilized with N at $P \leq 0.05$.

The last yield component, KW, was impaired by both 200 kg N ha^{-1} dose and no nitrogen fertilizer. The highest value corresponded to 100 kg N ha^{-1}.

Nitrogen fertilizer partitioning effects

The analysis of variance (Table 1) reveals the large influence of N fertilizer partitioning on grain yield and number of kernels per ear ($P \leq 0.001$), as well as on the number of ears and kernel weight ($P \leq 0.05$).

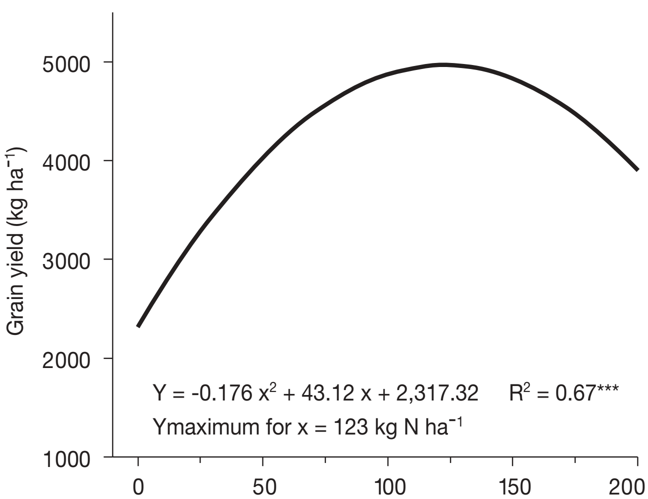

Figure 1. Evolution of grain yield in barley according to N fertilizer dose for data from the three years of experiments (n = 192). *** Significant at $P \leq 0.001$.

The obtained results (Table 2) indicate that a single application of N fertilizer as a top-dressing results in a decrease in barley grain yield, while no significant differences were found when a single dose was applied at seeding or partitioned 1/3 at seeding and 2/3 as a top-dressing. The other studied partitioning, 2S1T, was the most productive.

Figure 2 shows that all the partitionings of the 100 and 150 kg N ha^{-1} doses exceeded the field average (3,978 kg ha^{-1}), grain yield was impaired by applying the total N fertilizer as a top-dressing and the low yield was obtained without N fertilizer.

The statistical analysis (Table 2) reveals a similarity ($P \leq 0.05$) between the yield components in all the treatments that received nitrogen input at seeding time and the negative effect of a single application of N fertilizer as a top-dressing. For EM2, there were only differences between the 2S1T and T partitionings, the most and the least productive, respectively, whereas the smallest grain filling was obtained when a single dose of N fertilizer was applied either at seeding or as a top-dressing.

Year effects

It is interesting to observe the great influence of the year factor, since grain yields and yield components

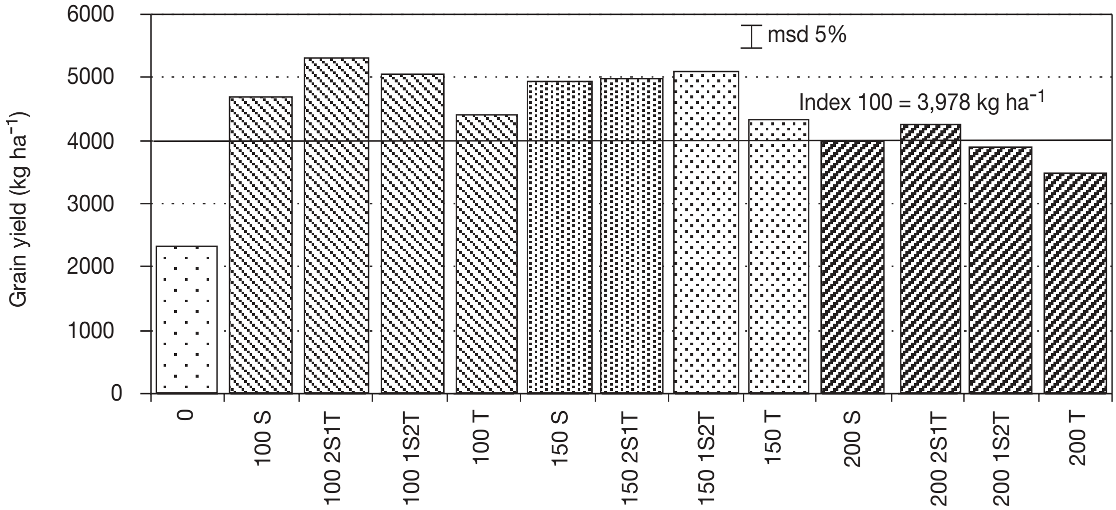

Figure 2. Average grain yield (kg ha^{-1}) in barley according to N fertilizer dose and its partitioning. Years 1998 to 2000.

were significantly differents each year (Table 1). The climatic model from 1998 to 2000 considerably varied from year to year (Table 3), and although the crop was under irrigated conditions, these differences resulted in a great variation in both grain yield and all of its parameters.

Interaction effects

The analysis of variance (Table 1) reveals that the effect of the *N* dose × partitioning interaction was significant ($P \leq 0.05$) for all the parameters measured except for KW.

Table 3. Temperature and relative humidity data during the months of the barley crop. Years 1998 to 2000

	Month	Temperature (° C)					No. days with temperature			Relative humidity (%)
		Mean		Absolute						
		Max.	Min.	Mean	Max.	Min.	≤ 0°C	≥ 30°C	≥ 35°C	
1998	January	11.2	1.1	6.1	15.5	–4.5	14	0	0	82
	February	15.5	2.6	9.0	22.0	–1.5	5	0	0	74
	March	20.2	3.0	11.6	24.0	–3.0	5	0	0	58
	April	16.7	3.8	10.2	27.0	–2.0	6	0	0	68
	May	21.4	8.6	15.0	29.5	2.5	0	0	0	68
	June	30.9	13.3	22.1	36.5	7.5	0	17	8	47
1999	January	12.2	–1.8	5.2	17.5	–6.0	24	0	0	73
	February	14.1	–2.2	6.0	21.5	–8.5	20	0	0	61
	March	17.7	1.6	9.7	24.5	–3.0	9	0	0	60
	April	21.5	4.6	13.1	28.5	–2.0	2	0	0	52
	May	27.3	8.9	18.1	36.5	3.0	0	13	1	49
	June	32.2	12.6	22.4	38.5	8.0	0	21	8	42
2000	January	9.2	–3.5	2.9	16.0	–8.5	27	0	0	79
	February	18.2	0.1	9.2	22.0	–3.5	16	0	0	66
	March	19.3	0.9	10.1	26.0	–4.5	8	0	0	55
	April	16.2	4.0	10.1	22.5	–3.0	3	0	0	69
	May	25.4	9.5	17.4	36.0	1.5	0	6	1	64
	June	32.8	13.1	22.9	38.5	4.0	0	23	11	39

Data from the weather station of the Centro de Mejora Agraria «El Chaparrillo» (Ciudad Real).

Table 4. Correlation coefficients (n = 192) between grain yield and yield components in barley. Years 1998 to 2000

	EM2	KPE	KW
Grain yield	0.91***	0.69***	0.45***
Ears per m^2 (EM2)		0.38***	0.23***
Kernels per ear (KPE)			0.33***
1000-kernel weight (KW)			

EM2: ears per m^2. KPE: kernels per ear. KW: 1000-kernel weight. *** Significant at 0.001.

The year factor always showed interactions ($P \leq 0.001$) with the N dose applied, while year × partitioning (P) had no effect on both grain yield and EM2. However, for the other parameters, this interaction was significant ($P \leq 0.001$).

With reference to year × *N* dose × P interaction, the statistical analysis reveals significant differences at $P \leq 0.01$ for grain yield and EM2, and at $P \leq 0.001$ for KPE and KW.

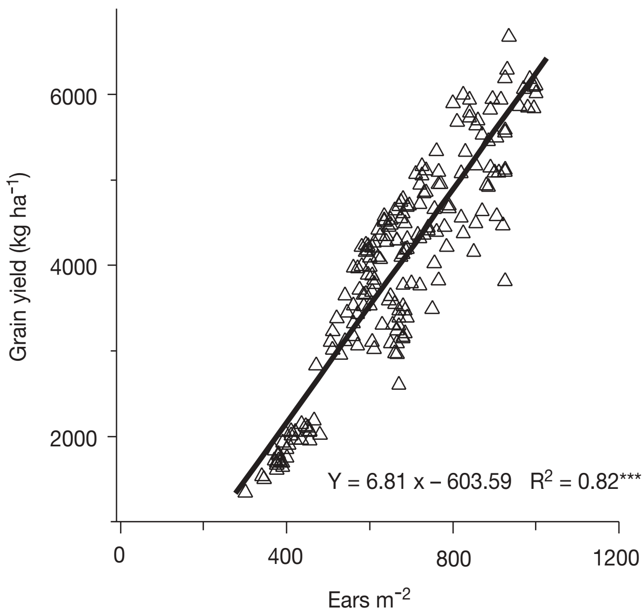

Figure 3. Linear regression (n = 192) between grain yield and ears per m^2 in barley. *** Significant at $P \leq 0.001$.

Yield component analysis

A strong positive correlation was observed between grain yield and both EM2 (r=0.91***) and KPE (r=0.69***), and a moderate correlation between grain yield and KW (r=0.45***) (Table 4).

Figure 3 shows the regression obtained between grain yield (dependent variable) and EM2 (independent variable), revealing a good linear dependence.

The interrelationships between the yield components were slight and positive. The analysis of regression (Table 5), considering all yield components as yield predictive variables, shows that EM2 explains the 82.5% of the yield variability, and the 96.3% together with KPE. The typical error of the estimation has been included as an additional source of information about the goodness of the fit.

The path coefficient analysis (Table 6) indicates a reduction in the relative importance of EM2 on grain yield compared to the simple correlation analysis, although EM2 remains as the most important component, followed by KPE, that also had a reduced effect. KW had almost no direct effect on yield.

Figure 4 shows the relationships between grain yield and its components. The U variable introduced in the diagram corresponds to all the residual factors that affect yield independently from the considered variables.

Table 5. Regression analysis (n = 192) of grain yield and yield components in barley. Years 1998 to 2000

Model	Predictive variables	Coefficients	Typical error	R^2
1	(Constant)	–603.59	157.97	0.825***
	EM2	6.86	0.23	
2	(Constant)	138.30	138.30	0.963***
	EM2	0.114	0.11	
	KPE	9.24	9.24	
3	(Constant)	–7,303.47	185.26	0.989***
	EM2	5.55	0.063	
	KPE	217.65	5.25	
	KW	111.67	5.32	

EM2: ears per m^2. KPE: kernels per ear. KW: 1000-kernel weight. R^2 = Pearson's determination coefficient. *** Significant at 0.001. Dependent variable: Grain yield. Introduced variables: EM2, KPE, KW. Predictive variables: EM2, KPE, KW. Excluded variables: None.

Table 6. Path coefficient analysis of grain yield and yield components (n = 192) in barley. Years 1998 to 2000

Multiple correlation coefficient	R	0.989***
Ears per m² vs. grain yield		
Direct effect	P_{14}	0.734***
Indirect effect via:		
— Kernels per ear	r_{12} P_{14}	0.135
— Kernel weight	r_{13} P_{34}	0.039
Correlation	r_{14}	0.908***
Kernels per ear vs. *grain yield*		
Direct effect	P_{24}	0.355***
Indirect effect via:		
— Ears per m²	r_{12} P_{14}	0.278
— Kernel weight	r_{23} P_{34}	0.055
Correlation	r_{24}	0.688*
Kernel weight vs. *grain yield*		
Direct effect	P_{34}	0.170***
Indirect effect via:		
— Ears per m²	r_{13} P_{14}	0.168
— Kernels per ear	r_{23} P_{24}	0.116
Correlation	r_{34}	0.454***
Residual effects, U	P_{U4}	0.106

*, ***: Significant at 0.05 and 0.001, respectively. The r and P refer to path-coefficient analysis of direct and indirect effects among four characters, indicated by subscripts: 1 = ears per m², 2 = kernels per ear, 3 = kernel weight, 4 = grain yield.

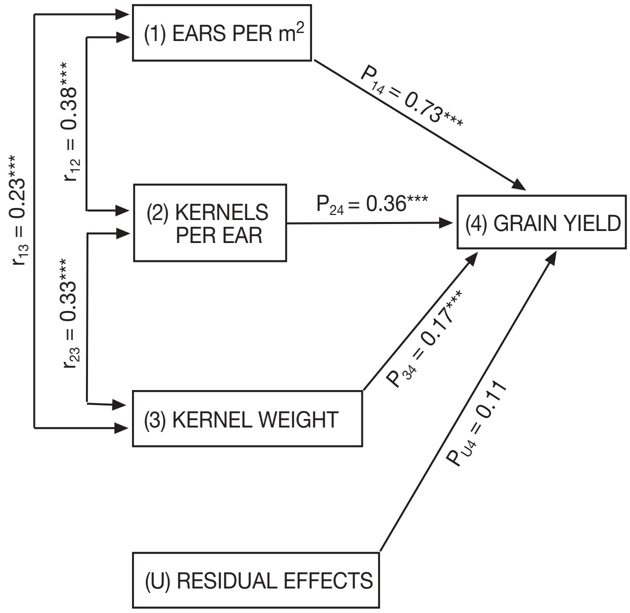

Figure 4. Path-diagram showing the relationships between grain yield and yield components in barley. The double-headed arrows indicate mutual associations determined by simple correlation coefficients (r) and the single-headed arrows represent direct effects established by path coefficients (P). *** Significant at 0.001.

Discussion

The significant differences ($P \leq 0.001$) found in the yields of the different years demonstrate the great influence of the year factor, so the climatic conditions led to very variable results in yield and all its components each year. This agrees with García del Moral *et al.* (1985), who maintain that the response of cereals to N fertilizer depends largely on seasonal variations conditioned by environmental factors.

Although low winter temperatures delay shoot development, they usually favour tillering since they reduce leaf development and, therefore, competition (García del Moral and Ramos, 1989). On the other hand, the environmental conditions during grain filling are often considered as the cause of reduced barley yield. High temperatures (30-35ºC), even during short periods of time, have a strong effect on the structure of the mature barley grain, reducing its final weight (Wallwork *et al.*, 1998). Moreover, they also limit production by accelerating leaf senescence, which reduces the grain filling period without affecting the rate of grain development (Savin and Nicolas, 1999).

Climatic data recorded during the crop cycle, excluding rainfall due to the irrigated conditions, indicate that the year 2000 had the most favourable climate for barley growth, with a cold winter and moderate temperatures in May, the month in which grain filling occurs. Good prospects for yield in 1999 were affected by the high temperatures recorded in May (13 days with a temperature above 30ºC) combined with low environmental humidity. The year 1998, with mild winter temperatures and late frosts, was the least likely to produce good yields.

The optimum N fertilizer doses to maximize barley yield are in agreement with those reported by Molina (1989) and the Servicio de Investigación y Tecnología Agraria of Castilla-La Mancha (SITA, 1998), which recommend inputs of 100-120 kg N ha^{-1}. Vialles (1994) recommends a maximum supply of 130 kg N ha^{-1} with wheat as preceding crop, but 10-30 units less with other ones. However, Webb *et al.* (1998) obtained the optimum economic results with 143 kg N ha^{-1} and the ITGA with 163 kg N ha^{-1} (ITGA, 1999), deducing that, even with these high levels of fertilizer, the declining part of the N-yield function was not reached.

According to Baethgen *et al.* (1995), relatively small amounts of available N must be ensured for the crop establishment and the initial development of tillering.

The additional N could be applied at the end of this period, since the N requirements before tillering are less than 10% of the total. In this way, the ITGA (1998) recommends a dose of N fertilizer for short cycle barleys with preceding cereal crop to be around 100-110 kg N ha^{-1} partitioned 30-40 at seeding time and 70 at top-dressing. This means 1/3 at seeding and 2/3 at top-dressing, equivalent to the 100 1S2T treatment. The ITGA (2000) suggests not applying more than 25-30 kg N ha^{-1} before sowing.

However, Molina (1989) and the SITA of Castilla-La Mancha (SITA, 1998) recommend dividing the N inputs into equal parts between sowing-time and top-dressing at the initial tillering. Bouthier (1994) is of the same opinion for malting barley sowed in winter, but for malting barley sowed in spring recommends not to fertilize within tillering in order to keep its quality potential. García del Moral *et al.* (1982) found N applied at sowing time to have the greatest effect on yield.

The results obtained in this experiment suggest a total of 100-120 kg N ha^{-1} partitioned 2/3 at sowing time and the rest at top-dressing within tillering, avoiding in all cases a single application of N as a top-dressing. The use of ureic N at sowing time, due to its slower effect and its greater retention by the soils, would give a suitable supply of N that is completed with the ammonium N applied during tillering, the period when the potential number of ears is determined. Hence, this would also ensure enough N availability during the stem elongation and the anthesis, when N requirements are maximum (McTaggart and Smith, 1995).

The increased grain yield with N supply usually occurs by increasing EM2 (Molina, 1989; Alvarez, 1992). This study shows a similar response of both yield and EM2 to the N dose.

KPE was significantly greater in treatments receiving N fertilizer. According to Dale and Wilson (1978), an increased N dose generally increases KPE, while deficiencies of this element can induce important reductions in this parameter, estimated by these authors to be around 40-60%. In this experiment, KPE of the control treatment was approximately the 80% of that obtained with N fertilizer, meaning a reduction of 20%.

Grain filling was found to be impaired by both no application of N fertilizer and doses above 100 kg N ha^{-1}. The negative reaction of kernel weight to N is a complex process. It has been suggested that N establishes an inverse relationship between KPE and KW, since the increasing kernel number leads to competition for limited resources. Nevertheless, there is no clear evidence for a consistent relationship between these two yield components, since in some cases N reduces grain filling without increasing the number of kernels, while in other cases this last parameter increases or decreases without affecting the final weight (García del Moral, 1982).

It can be deduced from the study of the interactions of the main factors that, with the exception of KW, the partitioning of N fertilizer produces different results depending on the total N dose applied. In the same way, the year × N dose interaction found in all the measured parameters revealed that the specific conditions of each season resulted in different grain yields and yield components in the different treatments.

The lack of any year × P effect on either grain yield or EM2 means that the pattern of differences detected between the different partitionings was independent from the year of the experiment. On the other hand, the year × N dose × P interaction implies that the treatments proposed were differently affected by the specific conditions of each season.

Analysis of the correlations between grain yield and its components reveals a strong positive relationship between yield and EM2. It agrees with García del Moral *et al.* (1991a, b), Isla and Royo (1995) and Moreno *et al.* (2000), who came to the conclusion that grain yield in barley is mainly conditioned by EM2.

The positive relation between KPE and grain yield was also observed by Rojo and García del Moral (1986), Cooper *et al.* (1994) and Baethgen *et al.* (1995), who also obtained a zero or positive relationship between grain yield and KW.

According to García del Moral and Ramos (1989) and Baethgen *et al.* (1995), the compensatory mechanisms determine that at least one component tends to be negatively correlated with another one, provided that it is permitted by the developmental conditions of the crop. In this way, it allows to stabilize the grain yield in a wide range of environments and circumstances. However, the interrelationships between the yield components presented in this study were slight and positive, since barley with limited N had not a normal development, avoiding the compensatory mechanisms. This fact had a marked influence on the observations made, masking the compensation between yield components that occurred in treatments receiving suitable N fertilizer. Indeed, by simply omitting the treatment without N supply from the statistical study, it is obtained $r_{NES\text{-}NGE} = -0.26^{**}$, $r_{NES\text{-}WTG} = -0.02$ and $r_{NGE\text{-}WTE} = 0.06$.

The analysis of regression corroborates the importance of the ear population on the final yield, attributing the 82.5% of the yield variability. In this study, the three yield components have been included as predictive variables of the yield function, although with little participation of KW. Moreno *et al.* (2000), with data from one year, obtained a determination coefficient for EM2 of 93.6%, and KWG was excluded as a factor responsible for variation in yield.

The complex interactions existing between yield and its components limit the value of a simple analysis of correlation when the relative magnitude and the degree of association of these parameters are interpreted. This is because the yield components occur successively and may therefore interact in compensatory interactions during plant development, so the magnitude reached by each of these can largely condition the subsequent yield components (García del Moral *et al.*, 1991a, b).

In the path coefficient analysis, a reduction in the relative importance of EM2 on grain yield was found compared to a simple correlation analysis, although this remains as the most influential component, followed by KPE, that also had a reduced effect. These findings agree with the results of previous studies which describe EM2 to be the parameter most responsible for variations in spring barley yield in a mediterranean environment (Shepherd *et al.*, 1987; García del Moral *et al.*, 1991a, b; Campos, 1995).

The indirect effects obtained in the path coefficient analysis indicated that the correlation coefficient between yield and KW was affected by the positive indirect effects of this component via EM2 and KPE. Hence, path analysis shows that KW had almost no direct effect on yield. This result was also obtained by García del Moral *et al.* (1991a, b) in barley, and agrees with studies by Ramos *et al.* (1982), García del Moral *et al.* (1985), Shepherd *et al.* (1987) and Campos (1995), which conclude that yield depends on EM2 and KPE.

Mean kernel weight is a highly stable characteristic in barley which could be attributed to the capacity of this crop to mobilize and redistribute the reserves stored in the stems, so that, according to García del Moral *et al.* (1991a), even under unfavourable conditions, grain growth could take place using the carbohydrate reserves assimilated during preanthesis, resulting in less variation in KW compared with EM2 or KPE.

However, Isla and Royo (1995), working with the six-rowed «Barbarrosa» variety, found the direct effect of EM2 and KW components on yield to be much greater than that of KPE, which was almost zero, and that of EM2 was 20% greater than that of KW. In this case, ear filling would be the most stable characteristic.

Since direct effects measured by path coefficients permit, in addition to identify the most important component in yield determination, to evaluate the quantitative influence of each of these parameters, we found that in our experimental conditions, the direct effect of EM2 on grain yield was double that of KPE. García del Moral *et al.* (1991a, b) obtained the same result for spring barley.

As conclusions: a) for the same variety and region, with identical cultivation techniques, barley yield varies considerably from year to year depending on the climatic conditions. b) Nitrogen fertilization has a crucial effect on irrigated barley yield, which results harmed by either shortage or excess of this element. c) N fertilizer doses of 100-120 kg N ha^{-1} are recommended, since higher inputs could have negative effects on the crop and always implies a source of environmental contamination and increases the costs to the farmers. d) The application of N fertilizer only as a top-dressing significantly reduces barley yield. e) The number of ears per square metre is the main determining factor for barley yield and the component which best explains yield variability.

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