RELATIONSHIPS BETWEEN VEGETATIVE GROWTH, GRAIN YIELD AND GRAIN PROTEIN CONTENT IN SIX WINTER BARLEY CULTIVARS

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The relationship between the protein content of grain, plant grain yield and yield components (number of ears per plant, number of grains per ear, and 1000-grain weight) was determined for six cultivars of winter barley, four six-rowed (*Hordeum vulgare* L.) and two two-rowed (*H. distichon* L.), grown in Granada (Spain) during 1979, 1980 and 1981. Each cultivar was grown with two levels of nitrogen fertilizer (25 and 40 kg/ha) applied both at seeding and as a top-dressing. Protein content of the grain, grain yield and number of ears per plant varied significantly with genotype, level of nitrogen fertilizer applied at seeding and year. Protein content of the grain was positively correlated with plant grain yield. Both factors were correlated principally with the number of ears per plant, and to a lesser extent with grains per ear and grain weight. The protein content and grain yield depended on the crop dry weight or biomass during the vegetative period (source capacity) which was in turn, related to the leaf area index.

Key words: Barley, protein content, grain yield, *Hordeum vulgare* L., *Hordeum distichon* L.

[Rapports entre la croissance végétative, le rendement grainier et la teneur en protéines du grain chez six cultivars d'orge.]
Titre abrégé: Croissance de l'orge et paramètres de rendement.
Nous avons déterminé les rapports entre la teneur en protéines du grain, le rendement grainier des plants et les paramètres du rendement (nombre d'épis par plante, nombre de grains par épi et poids de 1000 grains) chez six cultivars d'orge d'hiver: quatre à six range (*Hordeum vulgare* L.) et deux à deux rangs (*H. distichon* L.). Les essais ont été menés à Granada (Espagne) en 1979, 1980 et 1981. Pour chaque cultivar, on utilisait deux taux d'épandage d'engrais azoté (25 et 40 kg/ha). L'engrais était ajouté au moment de l'ensemencement et aussi comme fumure en couverture. La teneur en protéines du grain, le rendement grainier et le nombre d'épis par plante variaient de façon significative avec le génotype, le taux d'épandage d'engrais à l'ensemencement et l'année de l'essai. Nous avons par ailleurs observé une corrélation positive entre la teneur en protéines du grain et le rendement grainier des plantes. Ces deux paramètres étaient principalement liés au nombre d'épis par plante et, à un degré moindre, au nombre de grains par épi et au poids du grain. La teneur en protéines et le rendement grainier dépendaient du poids sec des plantes (biomasse) pendant la période végétative, ce dernier dépendant pour sa part de l'indice foliaire.

Mots clés: Orge, teneur en protéines, rendement grainier, *Hordeum vulgare* L., *H. distichon* L.

The amount of nitrogen applied to cereals is usually the factor that establishes the yield and the protein content in the grain due to its high mobility in the soil and ease of absorption by the roots. The responses of cereals to nitrogen depend to a great extent on seasonal factors (Engelstad and Terman 1966).

The relationship between nitrogen application and yield and protein content is complex and at times apparently contradictory. For genotypes, the correlation between grain yield and protein content is strongly negative; within genotypes this correlation can be positive, negative or close to zero, depending on the level of soil fertility and climatic conditions (Kramer 1979). A gradual increase in available nitrogen can produce a drop in the protein content of the grain, even though the yield increases (a dilution effect). This occurs when environmental conditions are favorable; the main effect of nitrogen application is an increase in grain yield (Andersen 1977). However, when climatic factors are unfavorable (severe water deficit principally), the main effect of nitrogen is an increase in protein content. At intermediate water availability nitrogen can increase both yield and protein content (Terman et al. 1969). An additional supply of nitrogen causes both grain yield and protein content to increase over a wide range of nitrogen applications (Walker 1975). However, differences may be found in the protein contents of cultivars with the same grain yield, due mainly to differences in the efficiency with which the genotypes can take up nitrogen from the soil and/or the rate at which they use it for grain protein production (Andersen 1977).

An increase in nitrogen application generally increases the number of ears (Thorne and Watson 1955; Leyshon et al. 1980) and number of grains per ear (Kirby and Jones 1977; Dale and Wilson 1978), and reduces the 1000-grain weight (Reisenauer and Dickson 1961; Needham and Boyd 1976). It also stimulates vegetative growth (Briggs 1978) which determines the amount of nitrogen that can be taken up and controls the quantity that can be translocated to the grain. This fact has great importance for hot, dry conditions (which shorten the ripening time of the grain) where it has been shown that assimilation during the period before anthesis contributes substantially to the grain yield (Austin et al. 1980; Ramos et al. 1982).

The present study describes the relationships between the crude protein content, grain yield and yield components for six winter barley cultivars grown with two levels of nitrogen applied at two different times, over 3 yr under the cultivation conditions that exist in southern Spain.

MATERIALS AND METHODS

The experiments were carried out in an area representative of the cereal-growing region of the province of Granada (southern Spain) during 1979, 1980 and 1981. Six winter barley cultivars were tested, four six-rowed (Astrix, Monlon, Albacete and Hâtif de Grignon) and two two-rowed (Pallas and Logra). The crops were seeded at a rate of 120 kg/ha at the end of November in a fine loamy, carbonatic, thermic, Calcixerollic Xerochrept soil. Cultivars were harvested at the end of June.

The experimental area measured approximately 3000 m^2 and was divided into 24 plots of 100 m^2 (four per cultivar) separated by pathways 1 m wide. The treatments consisted of two levels of nitrogen fertilizer applied at seeding (25 and 40 kg N/ha applied as ammonium sulphate) and two more applied as a top-dressing (25 and 40 kg N/ha as ammonium nitrosulphate). The statistical design was an unreplicated $2 \times 2 \times 6$ factorial in each of the 3 yr. This design was chosen since no statistical variations in the interaction between cultivar and nitrogen treatments were observed in 1978 in a similar replicated study with three of the cultivars. Different plot sides in close proximity having similar levels of available nitrogen were used each year.

At each sampling time the number of plants per unit of surface area was determined using a wooden quadrat and 20–30 plants per plot were collected at random. Later, in the laboratory, six representative plants per plot were selected to establish the means of the primary values for calculating growth indexes: dry weight of leaves, stems and ears (material dried at 70–80°C for 24 h); and foliar area (using a photoelectronic planimeter LI-COR 3000 Portable Area Meter). This was repeated at intervals of about 15 days during the principal stages of development as laid out on Feekes' scale modified by Large (1954) and adapted for barley by Briggs (1978). From the last sample, taken at harvest, the following parameters were also recorded: number of ears per plant (mean of 20 plants per plot), number of grains per ear (mean of 20 plants per plot), and 1000-grain weight. Grain yield per plant was calculated as the product of these three parameters.

The growth indexes were calculated in acordance with Warren Wilson (1981). The total nitrogen of the grain dry matter was determined using a modified Kjeldahl method (Lachica et al. 1973). Crude protein content was calculated as percent Kjeldahl-N × 5.7 on a dry matter basis.

Analysis of variance and correlation techniques were used to analyze the data. Since there was no replication the second-order interaction (years × cultivars × N treatment) was used to test for significance. Differences between means were compared by using the least significant different test (Steel and Torrie 1982).

RESULTS AND DISCUSSION

Grain protein content, grain yield and the number of ears per plant varied significantly with genotype, year and nitrogen treatment at seeding (Tables 1 and 2). The other two yield components, number of grains per ear and 1000-grain weight, varied significantly with the cultivar only.

Genotype Effects

The six-rowed cultivars had more grains per ear and higher 1000-grain weight which explain the greater yield per plant compared with the two-rowed cultivars, which had only one statistically higher yield component — the number of ears per plant (Table 3). This is a typical result when two-rowed and six-rowed barley cultivars are compared, due to the higher tillering capacity of the two-rowed type, while the six-rowed one presents a greater grain-bearing capacity per tiller (Riggs and Kirby 1978). Cultivars with the greatest number of ears per plant (Pallas, Logra and Albacete) had the lowest protein content, as discussed below.

Nitrogen Treatment Effects

The 40-kg/ha rate of nitrogen applied at seeding increased protein content and grain yield significantly compared with the 25-kg/ha rate (Table 4). The yield increase was due to more ears per plant, the only yield component which varied significantly with the treatment tested. Application of nitrogen fertilizer as a top-dressing at the middle of shooting did not increase protein content (Table 4). Grain yield was increased when nitrogen was applied at seeding at high rates but not when applied at low rates. Top-dressed nitrogen increased the number of ears per plant but not the number of grains per ear or 1000-grain weight.

These nitrogen effects have been indicated previously by several authors. Thus, Dubetz and Wells (1965) found that yield responses of a two-rowed malting barley grown in a greenhouse were due primarily to increased tillering. Similar results for wheat were reported by Spratt and Gasser (1970) for growth chamber conditions and by Campbell et al. (1977) for field conditions. Reisenauer and Dickson (1961) showed that high rates of nitrogen at seeding increased the yield and protein content but decreased grain size of malting barley. Likewise, low doses of nitrogen are usually most effective on grain yield and protein content of barley when applied at sowing time or at very early growth stages, as indicated by Andersen (1977).

Year Effects

Crude protein content and grain yield were statistically lower in 1979 than in 1980 or 1981 (Table 5) probably due to less growing season precipitation in 1979 than in 1980 and 1981 (60, 133 and 156 mm, respectively). In effect, available soil moisture appears as one of the most important factors regulating yield-protein content relationships in cereal crops (Terman et al. 1969). In a study at Lethbridge, Alberta barley protein content was highly dependent on available soil water before seeding and, into a lesser extent, on the growing season precipitation (Bole and Pitman 1980). The only yield component that in-

Table 1. Mean values of protein content, grain yield and yield components for each cultivar, nitrogen treatment and year

	Protein content (%)			Grain yield (g)			Ears/ plant			Grains/ ear			1000-grain wt (g)		
Cultivar†	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981
Two-rowed															
Pallas	6.4	9.8	10.5	1.4	3.1	3.0	2.3	3.5	3.6	21.0	25.0	23.4	29.4	35.4	36.5
Logra	6.1	8.7	9.9	1.6	3.2	2.9	2.0	3.7	3.3	21.3	22.8	22.0	36.1	37.6	39.1
Six-rowed															
Astrix	7.0	10.5	10.3	2.4	3.8	3.7	1.6	3.1	2.8	36.4	30.0	27.4	40.2	40.4	48.9
Monlon	7.0	11.3	11.3	2.1	3.8	3.7	1.5	2.9	2.7	30.6	33.0	31.3	43.4	40.3	44.7
Albacete	6.4	9.3	10.6	2.2	4.0	3.7	2.1	3.6	3.6	26.4	30.7	28.2	40.4	35.7	37.6
H. Grignon	8.0	11.9	10.5	2.4	4.5	4.0	1.9	2.9	2.9	28.9	31.3	29.2	43.2	49.6	48.1
Treatment‡															
Ns1 + Nt1	7.0	10.2	9.7	2.0	3.3	3.2	1.8	3.0	2.9	28.0	28.8	26.8	39.2	39.3	42.7
Ns1 + Nt2	6.6	10.0	10.7	2.1	3.6	3.4	2.1	3.2	2.9	26.5	28.1	26.7	38.7	39.7	43.4
Ns2 + Nt1	6.6	10.6	11.2	1.7	3.8	3.6	1.8	3.4	3.3	26.0	27.6	26.8	38.0	40.9	42.4
Ns2 + Nt2	7.2	10.3	10.5	2.2	4.1	3.8	2.0	3.5	3.4	29.3	30.7	27.3	39.3	39.5	41.4

† Mean of four treatments.

‡ Mean of six cultivars.

Ns1 = 25 kg N/ha at seeding; Ns2 = 40 kg N/ha at seeding; Nt1 = 25 kg N/ha as a top-dressing; Nt2 = 40 kg N/ha as a top-dressing.

Table 2. Summary of the analysis of variance of protein content, grain yield and yield components for six barley cultivars and four nitrogen treatments for the years 1979, 1980 and 1981

		Mean squares				
Sources of variation	df	Protein content (%)	Grain yield (g)	Ears/ plant	Grains/ ear	1000-grain wt (g)
Cultivars (C)	5	7.11**	2.36**	1.35**	206.03**	273.69**
Years (Y)	2	104.30**	20.40**	13.31**	22.73	10.35
Treatments (T)	3	2.53*	0.91**	0.57**	18.76	1.05
Ns	1	6.37**	1.87**	1.51**	14.09	1.50
Nt	1	0.01	0.56	0.18	20.64	0.12
NsNt	1	1.21	0.29	0.01	21.54	1.52
C×Y	10	0.81	0.07	0.09	20.77	7.80
C×T	15	0.41	0.17	0.07	15.00	6.75
Y×T	6	0.33	0.24	0.15	3.07	4.36
Error	30	0.83	0.15	0.06	9.74	6.39
Total	71	–	–	–	–	–

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 3. Means of all values of protein content, yield and yield components for each cultivar for the years 1979, 1980 and 1981

Cultivar	Protein content (%)	Grain yield (g)	Ears/ plant	Grains/ ear	1000-grain wt (g)
Two-rowed					
Pallas	8.90*c*	2.50*b*	3.11*a*	23.73*b*	33.80*b*
Logra	8.23*d*	2.54*b*	3.02*a*	22.04*b*	37.58*b*
Six-rowed					
Astrix	9.28*b*	3.28*a*	2.50*b*	31.24*a*	43.15*a*
Monlon	9.87*a*	3.20*a*	2.36*b*	31.61*a*	42.81*a*
Albacete	8.76*c*	3.31*a*	3.09*a*	28.46*a*	37.92*b*
H. Grignon	10.12*a*	3.61*a*	2.55*b*	29.81*a*	46.95*a*

a-d Means followed by same letter within each column do not differ significantly at the 0.05 level using the least significant difference test.

creased significantly during 1980 and 1981 was the number of ears per plant. This agrees with the findings of Dubetz and Wells (1965) that this component showed the greatest response to available soil water in Betzes barley.

Relationships Between Grain Protein Content, Plant Grain Yield and Yield Components

The results presented above show that a relationship exists between grain production and protein content of the grain. To inves-

Table 4. Means of all values of protein content, yield and yield components for each nitrogen treatment for the years 1979, 1980 and 1981

Nitrogen treatment†	Protein content (%)	Grain yield (g)	Ears/ plant	Grains/ ear	1000-grain wt (g)
Ns1 + Nt1	8.94*b*	2.85*c*	2.57*d*	27.85*a*	40.40*a*
Ns1 + Nt2	9.10*b*	2.86*c*	2.72*c*	27.10*a*	40.61*a*
Ns2 + Nt1	9.44*a*	3.02*b*	2.81*b*	26.81*a*	40.41*a*
Ns2 + Nt2	9.30*a*	3.39*a*	2.99*a*	29.10*a*	40.04*a*

† See Table 1 for explanation of nitrogen treatments.

a-d Means followed by same letter within each column do not differ significant at the 0.05 level using the least significant difference test.

Table 5. Means of all values for each year of protein content, yield and yield components

Year	Protein content (%)	Grain yield (g)	Ears/ plant	Grains/ ear	1000-grain wt (g)
1979	6.82*b*	2.00*b*	1.92*b*	27.42*a*	38.78*a*
1980	10.27*a*	3.70*a*	3.27*a*	28.80*a*	39.85*a*
1981	10.50*a*	3.52*a*	3.13*a*	26.92*a*	41.77*a*

a-d Means followed by same letter within each column do not differ significantly at the 0.05 level using the least significant difference test.

tigate the nature of this relationship, correlations were calculated between protein content, grain yield and yield components for each cultivar, treatment and year. The coefficients of correlation obtained (Table 6) showed (a) a high degree of correlation between protein content and grain yield, and (b) that the correlations between protein content or grain yield with yield components depended on the factors which were considered. For this reason we studied the effects of genotype, treatment and year both separately and with the data grouped in first and second order interactions.

If only the genotype were considered (Table 6a), protein content (P) and grain yield (GY) appear negatively correlated with the number of ears per plant (NEP), and positively related to the number of grains per ear (GE) and 1000-grain weight (GW). This indicates that cultivars with the greatest number of ears per plant had the lowest GY and P, and suggests that a compensating effect could be involved in the use of plant assimilates to produce seeds (Evans and Wardlaw 1976), i.e. when plant nutrients are limiting, increases in the numbers of ears occur at the expense of grain production.

However, considering the effect of either treatment or year, the relationships between NEP and GY or P appear significantly positive (Table 6b,c); i.e. when NEP increased as a result of nitrogen treatment or year effects, GY and P also increased. This is probably due to an increase in the source capacity of the crop (number of tillers and leaves) as a consequence of treatment and year influences, which could have increased the nitrogen and carbohydrates for repartition to the grains. In effect, as Kramer (1979) has already pointed out, the major source of protein for cereal grains is the nitrogenous pool present in the vegetative tissues of the crop before the period of grain filling is initiated; the remaining amount is absorbed from the soil during grain development. In wheat about 2/3 or more of the protein which is stored in the grain at maturity is present at anthesis; a good correlation exists between the amount of N and dry matter accumulation, as shown by Austin et al. (1977). When soil N is severely depleted by heading time, N uptake may be insufficient to sustain the rate of protein storage in the grain, and remobilization of protein in the plants may occur (Evans and Wardlaw 1976), often to a similar extent to that of carbohydrates reserves, causing both to be positively related to the crop dry matter produced during vegetative growth.

Therefore, genotype exercises a negative influence on the relationships between NEP and GY or P, whereas treatment and year influence these relationships positively. In order to verify the relative importance of these factors, similar correlations were calculated by grouping the data in first-order interactions (Table 6d,e,f). If treatment effect is removed (cultivar × year, Table 6d), the number of ears per plant appears positively related to grain yield or protein content, because the positive influence of year dominates the negative influence of genotype. Nevertheless, if the strong effect of year is eliminated (cultivar × treatment, Table 6e), the negative cultivar influence is greater than the positive treatment influence and NEP is negatively related to GY and P. On the other hand, when genotype

Table 6. Coefficients of power correlation between the values of protein content, grain yield and its components for cultivars, nitrogen treatments and years

	P	GW	GE	NEP		P	GW	GE	NEP
	(a) Cultivar (n=*6*)					*(b) Nitrogen treatment* (n=*4*)			
GY	0.7305	0.8420*	0.8897*	−0.6411	GY	0.6032	−0.9187	0.7409	0.9224
NEP	−0.8186*	−0.8527*	−0.8014	–	NEP	0.7799	−0.6959	0.4753	–
GE	0.7955	0.7644	–	–	GE	−0.0851	−0.8721	–	–
GW	0.7784	–	–	–	GW	−0.3542	–	–	–
	(c) years (n=*3*)					*(d) cultivar × year* (n=*18*)			
GY	0.9930	0.7319	0.3239	0.9998*	GY	0.9143**	0.5457*	0.4994*	0.6537**
NEP	0.9928	0.7312	0.3248	–	NEP	0.7184**	−0.1466	−0.2477	–
GE	0.2096	−0.4076	–	–	GE	0.3133	0.5714*	–	–
GW	0.8074	–	–	–	GW	0.4341*	–	–	–
	(e) treatment × year (n=*12*)					*(f) cultivar × treatment* (n=*24*)			
GY	0.9615**	0.5970*	0.2410	0.9895**	GY	0.5941**	0.7107**	0.8233**	−0.2579
NEP	0.9745**	0.5940*	0.1494	–	NEP	−0.5186*	−0.6971**	−0.6369**	–
GE	0.0493	−0.4021	–	–	GE	0.6191**	0.6856**	–	–
GW	0.6835*	–	–	–	GW	0.6498**	–	–	–
	(g) cultivar × treatment × year (n=*72*)								
GY	0.8249**	0.4860**	0.5103**	0.6603**					
NEP	0.6335**	−0.1599	−0.2089	–					
GE	0.3081*	0.4284**	–	–					
GW	0.3660*	–	–	–					

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 7. Mean values of protein content (P) and grain yield (GY) at harvest and crop dry weight (CDW) and leaf area index (LAI) during the vegetative period, for each cultivar and year, and coefficients of power correlation between them

	Harvest		Growth stages									
	P	GY	1-3		4-5		6-7		8-9		10 (anthesis)	
Year			CDW	LAI	CDW	LAI	CDW	LAI	CDW	LAI	CDW	LAI
						Pallas						
1979	6.4	1.4	31.4	0.4	65.2	1.0	118.9	1.2	122.9	1.7	265.2	1.0
1980	9.8	3.1	38.4	0.9	85.2	1.6	214.6	3.1	285.4	3.2	529.6	2.8
1981	10.5	3.0	38.9	0.6	100.2	1.5	258.4	2.2	297.1	1.8	314.3	1.9
						Logra						
1979	6.1	1.6	29.1	0.5	71.5	0.9	120.7	1.1	141.6	1.7	291.2	1.1
1980	8.7	3.2	31.8	0.7	73.0	1.3	146.1	2.3	335.2	3.3	396.0	2.0
1981	9.9	2.9	49.1	0.7	148.2	1.3	205.7	1.6	263.4	1.3	288.2	1.1
						Astrix						
1979	7.0	2.4	41.2	0.5	87.4	0.8	104.4	1.4	223.2	2.5	250.4	1.7
1980	10.5	3.8	62.7	1.2	123.1	2.1	250.7	3.9	405.3	4.1	573.5	2.8
1981	10.3	3.7	51.4	0.6	124.2	2.0	257.8	3.4	556.0	4.2	689.3	2.6
						Monlon						
1979	7.0	2.1	32.1	0.3	75.2	0.7	101.0	1.2	199.3	2.0	228.3	1.4
1980	11.3	3.8	66.5	1.3	116.5	2.1	349.9	5.1	486.8	4.8	637.5	2.8
1981	11.3	3.7	53.2	0.8	98.2	1.3	203.3	2.7	533.4	3.7	651.4	2.5
						Albacete						
1979	6.4	2.2	38.2	0.3	72.8	0.7	116.6	1.4	209.1	2.2	239.4	1.4
1980	9.3	4.0	78.2	1.5	137.8	2.4	317.2	4.8	485.6	4.0	603.8	3.1
1981	10.6	3.7	53.0	0.7	85.2	1.2	195.5	2.7	402.2	3.4	464.8	2.4
						H. Grignon						
1979	8.0	2.4	21.6	0.2	45.9	0.4	91.1	1.2	231.9	2.6	251.2	1.4
1980	11.9	4.5	80.0	1.2	137.9	2.0	210.1	2.6	464.3	4.0	524.4	2.4
1981	10.5	4.0	50.5	0.6	145.3	2.0	297.3	2.9	633.8	3.3	691.3	2.1
	*r*P-CDW		0.7009**		0.6768**		0.8164**		0.8687**		0.7894**	
	*r*GY-CDW		0.7756**		0.7047**		0.7876**		0.9612**		0.8217**	
	*r*P-LAI		0.6896**		0.7061**		0.7747**		0.6282**		0.7532**	
	*r*GY-LAI		0.7031**		0.7162**		0.8485**		0.7773**		0.8615**	
	*r*CDW-LAI		0.8589**		0.8509**		0.8970**		0.8067**		0.4794*	

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

is removed (treatment × year, Table 6f), the same relationships showed a large positive effect.

It can be concluded that the relative importance of each factor decreased in the following order: years > genotypes > nitrogen treatments. For this reason, considering the total of cultivars × nitrogen treatments × years (Table 6g), grain yield and protein content appear positively correlated with the number of ears per plant. In addition, it can also be seen that GY and P were related to the number of grains per ear and, to a lesser extent, 1000-grain weight.

Influence of the Vegetative Period on Protein Content and Grain Production per Plant

The number of ears, the principal determinant in the variations observed in protein content and grain production, is fixed during the vegetative period. For this reason, it would appear reasonable to correlate protein content and grain yield with several growth indexes which describe the crop's development during this period, i.e. biomass or crop dry weight (CDW (g/m^2)) and leaf area index (LAI (m^2/m^2)). Protein content and grain yield were both highly correlated with crop dry weight and leaf area index in all growth stages until anthesis (Table 7). The highest correlation coefficients were obtained with crop dry weight when leaf area index reached its maximum values, i.e. 10–15 days before anthesis (Feekes stages 8–9, last leaf visible and ligule of last leaf just visible, respectively). In addition, crop dry weight and leaf area index were closely related. These results agree with the fact that yield in cereals is often closely related to leaf area index at anthesis (Simpson 1968; Khalifa 1973) or to the total aboveground dry matter when leaf area reaches its maximum value (Evans and Hough 1984). Under these conditions, yield is largely determined by the yield capacity, which is in turn determined by the extent of canopy growth or nitrogen uptake, and is often related to the maximum leaf area index attained (Evans and Wardlaw 1976).

Therefore, in our area variations in protein content and grain yield depend widely on the crop dry weight during the vegetative period (source capacity), which depends in turn on the leaf area index. As suggested by Austin et al. (1977), these relationships could occur because both carbon assimilation and nitrate reduction depend on energy from photosynthesis, which is not only required to sustain the growth of roots, but also to ensure continued nitrate uptake. Thus, in hot dry areas an early application of nitrogen fertilizers is very important, because of its positive effects on the source capacity of the crop and therefore on protein content and grain yield in barley.

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