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Vegetative growth of winter barley in relation to environmental conditions and grain yield

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SUMMARY

The object of this study was to investigate the vegetative growth in six barley varieties grown in southern Spain (Granada) during 1979, 1980 and 1981. The results showed that crop dry weight (CDW) was dependent on environmental factors (mean temperature, rain, and radiation) which were the determinants of the two CDW components, leaf area index (LAI) and leaf area ratio (LAR). However, the effects of these climatic factors on crop growth rate (CGR) and on its components, mean leaf area index ($\overline{\text{LAI}}$) and net assimilation rate (NAR), were partially obscured by ontogenetic drift. In addition, a highly significant relationship was demonstrated between CDW (when the LAI reaches its maximum value) and grain yield. This suggests that the pre-anthesis period has a great influence in the determination of grain yield variation in hot, dry areas, where photosynthesis is very limited after ear emergence.

INTRODUCTION

In a previous paper (Ramos, García del Moral & Recalde, 1982) it was shown that the vegetative period has a decisive influence on grain yield variation of barley crops, under environmental conditions that lead to a shorter post-anthesis period. The object of this study was to investigate the vegetative growth in six winter barley varieties grown in Granada (southern Spain) during 1979, 1980 and 1981. Measurements of crop dry weight (CDW), leaf area index (LAI), leaf area ratio (LAR), crop growth rate (CGR), mean leaf area index ($\overline{\text{LAI}}$) and net assimilation rate (NAR) have been used to determine the relationships between dry weight accumulation and climatic conditions.

MATERIALS AND METHODS

Full details of the experimental area, varieties, soil, sowing and harvest are given by Ramos *et al.* (1982).

Two levels of nitrogen fertilizer were applied to each variety both at sowing and as a top-dressing, resulting in four separate treatments: 25+25, 25+40, 40+25 and 40+40 kg N/ha (in each pair of N rates, the first is applied at sowing and the second as top-dressing). The design was a 2×2 factorial over the six varieties, with a total of 24 plots.

During all 3 years samples of between 480 and 720 plants (20–30 plants per plot) were collected from one experimental field of 2400 m^2, completely at random. Later in the laboratory 144 representative plants (6 per plot) were selected to estimate the means of the primary values. This was repeated at intervals of about 15 days during the principal developmental stages until anthesis, on the Feekes' scale as modified by Large (1954) and adapted for barley by Briggs (1978). In 1979, five samples were collected from 5 March (Feekes stages 5–6) to 24 April (anthesis); in 1980, six samples from 13 February (Feekes stages 1–3) to 23 April (anthesis); and finally, five samples from 23 February 1981 (Feekes stages 3–4) to 20 April (anthesis). On each date the following primary values were obtained: (*a*) total dry matter, excluding roots (W) and separate dry weight values of leaves, tillers and ears (after drying at 70–80 °C to constant weight); (*b*) leaf lamina area (A) by using a photoelectronic planimeter LI-COR 3000 portable Area Meter (the assimilatory surfaces of organs other than the leaves were not taken into account); (*c*) number of plants grown per unit area (N) by using a wooden quadrat.

The values of each growth index were calculated as:

$$\text{CDW} = \text{LAI} \times \frac{1}{\text{LAR}};$$

$$NW = NA \times \frac{W}{A}$$

(Warren Wilson, 1981).

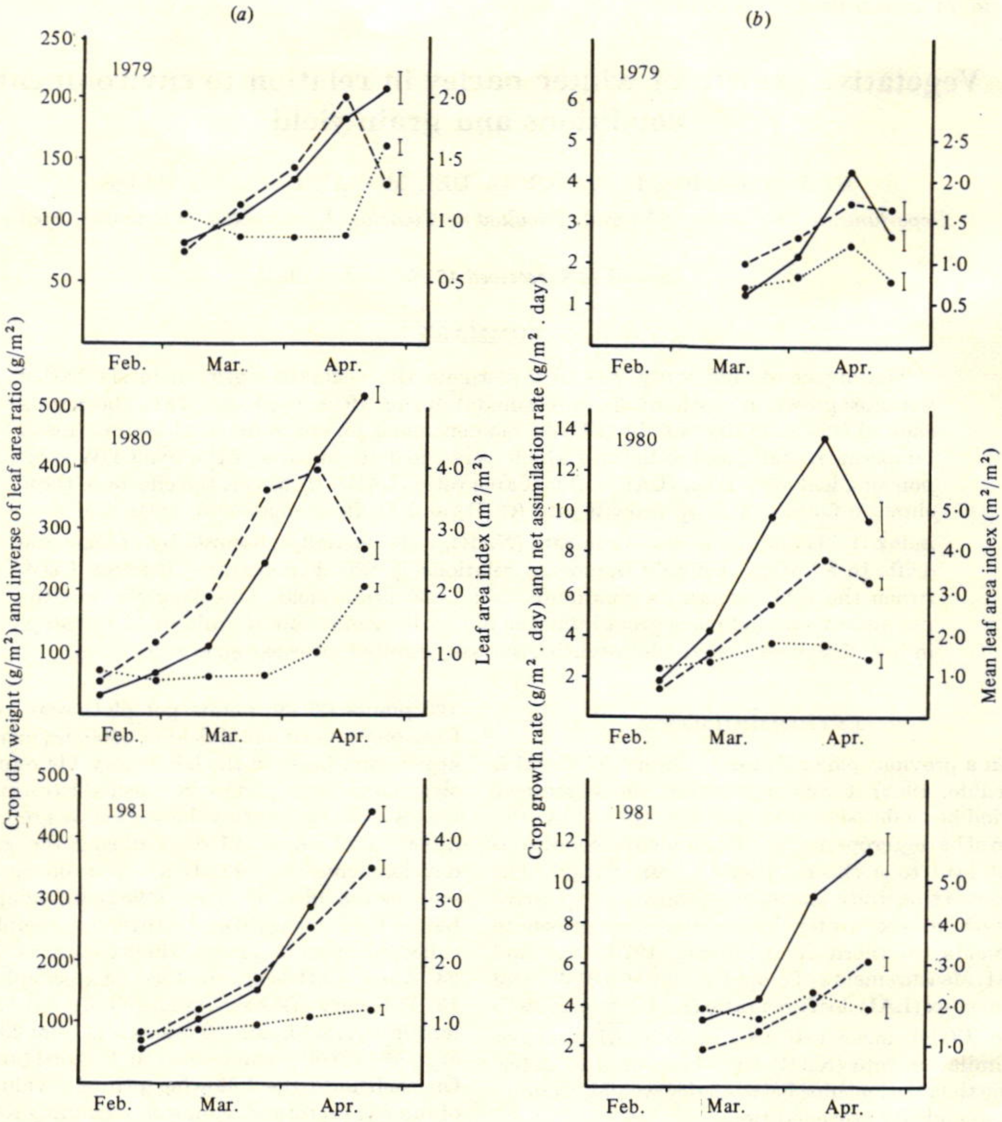

Fig. 1. Annual changes in value of (*a*) CDW (●—●), LAI (● - - - ●) and 1/LAR (●.....●); and (*b*) CGR (●—●), LAI (● - - - - ●) and NAR (●.....●). The standard error (I) shown for each index is a mean for the whole vegetative period.

$$\mathrm{CGR} = \overline{\mathrm{LAI}} \times \mathrm{NAR};$$

$$N \times \frac{W_2 - W_1}{t_2 - t_1} = N \times \frac{A_2 - A_1}{\ln A_2 - \ln A_1} \times \frac{(W_2 - W_1)(\ln A_2 - \ln A_1)}{(t_2 - t_1)(A_2 - A_1)}$$

(Williams, 1946; Watson, 1958).

RESULTS

Changes in growth indexes

Figure 1(*a*) shows the values of CDW (g/m^2), LAI (m^2/m^2) and 1/LAR (g/m^2) throughout the pre-anthesis period. It is worth noting that in 1981, CDW and LAI progressively increased until anthesis, whereas 1/LAR remained relatively stable. However, in 1979 and 1980 LAI started to

Table 1. *Correlation coefficients (simple, partial and multiple) and regression equations between CDW, LAI, 1/LAR and climatic conditions during the pre-anthesis period in the 3 years combined (16 data)*

Simple	Partial	Multiple	Regression equation
CDW–T_{mn} = 0·76			
CDW–ΔT = −0·12	CDW–ΔT . T_{mn} = −0·61		ln CDW = 1·9 ln T_{mn} − 0·1 ΔT + 0·01 Rn + 0·001 Rad − 0·3
CDW–Rn = 0·30	CDW–Rn . T_{mn} . ΔT = 0·51	R = 0·96	
CDW–Rad = 0·77	CDW–Rad . T_{mn} . ΔT . Rn = 0·67		Fiducial limits = ±87·6
LAI–T_{mn} = 0·68			
LAI–ΔT = −0·11	LAI–ΔT . T_{mn} = −0·50		ln LAI = 1·4 ln T_{mn} − 0·07 ΔT + 0·02 Rn + 0·0008 Rad − 3·6
LAI–Rn = 0·40	LAI–Rn . T_{mn} . ΔT = 0·62	R = 0·88	
LAI–Rad = 0·65	LAI–Rad . T_{mn} . ΔT . Rn = 0·26		Fiducial limits = ±1·0
1/LAR–T_{m} = 0·53			
1/LAR–ΔT = −0·08	1/LAR–ΔT . T_{mn} = −0·33		ln 1/LAR = 0·5 ln T_{mn} − 0·06 ΔT − 0·03 Rn + 0·0006 Rad + 3·3
1/LAR–Rn = 0·01	1/LAR–Rn . T_{mn} . ΔT = −0·19	R = 0·81	
1/LAR–Rad = 0·62	1/LAR–Rad . T_{mn} . ΔT . Rn = 0·67		Fiducial limits = ±45·9

Table 2. *Correlation coefficients (simple, partial and multiple) and regression equations between CGR, $\overline{LAI}$, NAR and climatic conditions during the pre-anthesis period in the 3 years combined* (13 *data*)

Simple	Partial	Multiple	Regression equation
CGR–T_{mn} = 0·56			
CGR–ΔT = 0·21	CGR–ΔT.T_{mn} = −0·18		ln CGR = −0·01 ln T_{mn} + 0·04 ΔT + 0·02 Rn + 0·002 Rad − 2·7
CGR–Rn = 0·07	CGR–Rn.T_{mn}.ΔT = 0·28	R = 0·64	
CGR–Rad = 0·50	CGR–Rad.T_{mn}.ΔT.Rn = 0·18		Fiducial limits = ±6·2
$\overline{LAI}$–T_{mn} = 0·56			
$\overline{LAI}$–ΔT = −0·05	$\overline{LAI}$–ΔT.T_{mn} = −0·56		ln $\overline{LAI}$ = −6·0 ln T_{mn} + 0·2 ΔT + 0·03 Rn + 0·004 Rad + 6·8
$\overline{LAI}$–Rn = 0·01	$\overline{LAI}$–Rn.T_{mn}.ΔT = 0·14	R = 0·69	
$\overline{LAI}$–Rad = 0·69	$\overline{LAI}$–Rad.T_{mn}.ΔT.Rn = 0·45		Fiducial limits = ±1·4
NAR–T_{mn} = 0·36			
NAR–ΔT = 0·54	NAR–ΔT.T_{mn} = −0·34		ln NAR = −5·4 ln T_{mn} + 0·3 ΔT + 0·03 Rn + 0·02 Rad + 6·9
NAR–Rn = 0·02	NAR–Rn.T_{mn}.ΔT = 0·37	R = 0·61	
NAR–Rad = 0·20	NAR–Rad.T_{mn}.ΔT.Rn = 0·23		Fiducial limits = −1·6

decline before anthesis at 10 and 15 days respectively, while 1/LAR increased from this point, thereby increasing CDW. In addition, it has been shown that in 1980 and 1981 the maximum values of CDW and LAI were higher than during 1979 (2·6 and 2·1 times greater for CDW and 2·0 and 1·7 times greater for LAI). Maximum 1/LAR values were relatively constant from year to year.

Figure 1 (*b*) shows the values of CGR (g/m^2.day), $\overline{\text{LAI}}$ (m^2/m^2) and NAR (g/m^2.day). In 1979 and 1980, CGR and LAI increased progressively during crop development up to a maximum, which coincided in time, beyond which the values of both begin to decrease; in 1981, CGR and $\overline{\text{LAI}}$ values increased until anthesis. However, NAR was very constant during all the vegetative development thoughout the 3 years studied.

Environmental conditions

In order to investigate the influence of environmental conditions on the pre-anthesis period simple, partial and multiple correlations were calculated between growth indexes and the following climatic factors: maximum temperature (T_M, °C), minimum temperature (T_m, °C), mean temperature (T_{mn}, °C), rain (Rn, mm), daily insolation (I, %) and total daily radiation (Rad, 10 kJ/m^2) during 1979, 1980 and 1981.

T_{mn}, Rn and Rad were the only climatic data used in the partial and multiple correlations because they gave the greatest simple correlation coefficients. The remaining factors were not taken into account in the partial and multiple correlations owing to the very small simple correlation coefficients obtained. However, using mean temperatures, it was thought advisable to introduce the daily range between T_M and T_m (ΔT, °C) in the partial and multiple correlations. Table 1 shows the simple, partial and multiple correlation coefficients of values of CDW, LAI and 1/LAR compared with the climatic factors used. It has been shown that CDW and 1/LAR are significantly and positively correlated with T_{mn} and Rad; the same is true for CDW and LAI when compared with T_{mn} and Rn, although they were negatively correlated with ΔT.

In the case of simple, partial and multiple correlations between CGR, $\overline{\text{LAI}}$ and NAR and environmental factors, it was seen (Table 2) that the correlation coefficients obtained were lower than those obtained with CDW, LAI and 1/LAR. In addition, it was only the multiple coefficients that showed any statistical significance.

Relationships between growth indexes

To investigate the relative importance of LAI and 1/LAR on CDW and $\overline{\text{LAI}}$ and NAR on CGR, simple power regressions were fitted between them, year by year and for all 3 years together (Table 3). The values of LAI and $\overline{\text{LAI}}$ were highly correlated with CDW and CGR respectively in each year individually and combined, while 1/LAR and NAR showed a smaller influence respectively on CDW and CGR.

Table 3. *Power correlation coefficients (annual and combined) between CDW, LAI and 1/LAR and CGR, $\overline{LAI}$ and NAR*

	1979	1980	1981	Combined
CDW–LAI	0·87	0·91	0·99	0·91
CDW–1/LAR	0·46	0·77	0·98	0·70
No. of data	5	6	5	16
CGR–$\overline{\text{LAI}}$	0·95	0·99	0·97	0·89
CGR–NAR	0·94	0·90	0·51	0·80
No. of data	4	5	4	13

In addition, it is worth noting that the correlation coefficients between LAI–CDW and $\overline{\text{LAI}}$–CGR were higher than between 1/LAR–CDW and NAR–CGR, in all 3 years.

Grain yield and vegetative growth

As noted above, under the environmental conditions prevailing in southern Spain, the pre-anthesis period exercises a decisive influence on grain yield. For this reason, it would appear reasonable to assume that the magnitude of crop growth during this period is related to final grain production. Therefore, to confirm this hypothesis, a power curve between grain yield (Y, g/m^2) and CDW at a critical point, i.e. when LAI reached its maximum value, was fitted. Figure 2 shows both the regression equation and the correlation coefficient obtained for all 3 years combined.

DISCUSSION

The pattern of vegetative growth in southern Spain was very similar to that described for temperate cereals in northern Europe (Watson, Thorne & French, 1963; Stoy, 1963). CDW increased progressively during early stages of development and reached a maximum at anthesis, as a result of the trends in its components (LAI and 1/LAR). In 1979 and 1980 the maximum values of LAI were obtained at 10 and 15 days, respectively, before anthesis; however, in 1981 the maximum LAI values were obtained during anthesis, probably because of greater water availability in the soil that year than in 1979 and 1980, which extended the growth and development of leaf area. In fact, during the 30 days previous to anthesis, precipitation in 1981 (95·2 mm) was higher than in 1979 (52·6 mm) and 1980 (37·9 mm) by 1·8 and 2·5 times, respectively. On the other hand, during 1979 and 1980 CGR showed inflexion points

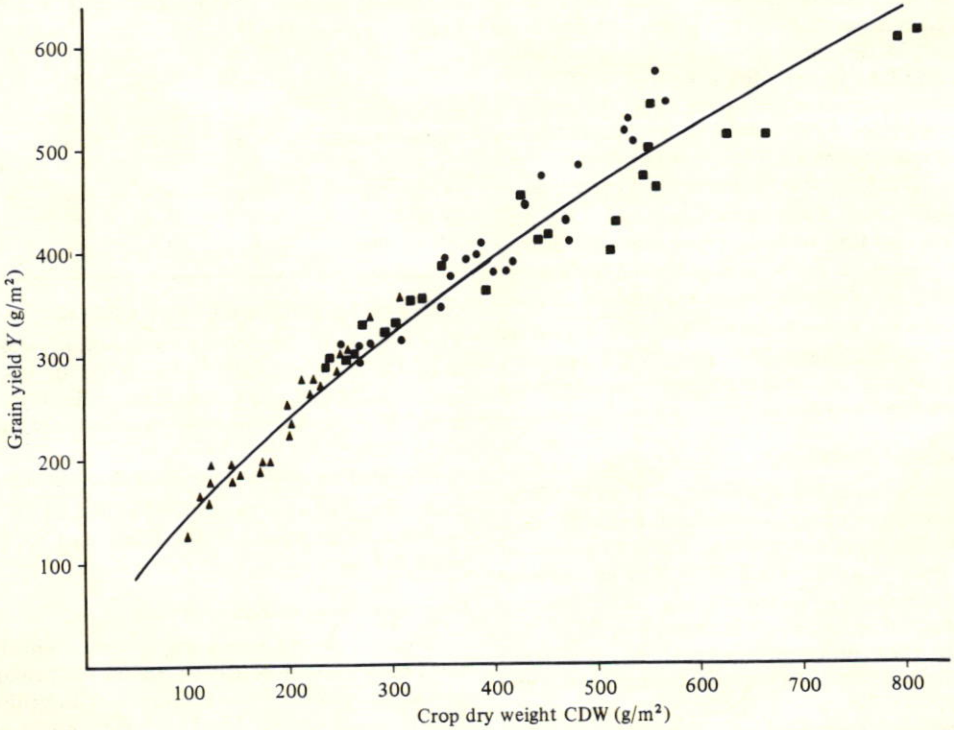

Fig. 2. Relationship and correlation between grain yield and CDW ($Y = 5{\cdot}6\ \mathrm{CDW}^{0{\cdot}7}$; $r = 0{\cdot}98$) during 1979 (▲), 1980 (●) and 1981 (■) combined.

which coincided in time with those of LAI. This well-known fact is due to the ontogenetic drift which brings about a decline in growth rate when the crop approaches maturity (Thorne, 1960, 1961). In 1981, CGR continued to increase until anthesis.

The influence of environmental conditions on growth indexes, as shown in this study, supports the conclusion of several authors. LAI increased with both mean temperature and precipitation, principally through an increase in number of tillers (García del Moral, Ramos & Recalde, 1984), because the number of leaves per tiller remained very constant. On the other hand, LAI was affected negatively by the daily range between maximum and minimum temperatures. 1/LAR was more closely dependent on incoming radiation than other environmental factors, being directly correlated with it. This is expected because 1/LAR constitutes an estimate of the efficiency of the photosynthetic machinery. To a lesser extent, mean temperature also influenced 1/LAR, since this factor regulates photosynthesis and respiration rates, both processes being the most important ones in the carbohydrate balance (Thorne, 1960; Blackman, 1968). CDW was affected by the climatic factors prevailing upon its components, LAI and 1/LAR. As commonly observed in other studies (Evans, 1972), the effect of environmental conditions on CGR, $\overline{\text{LAI}}$ and NAR was obscured by the ontogenetic drift.

Under our cultivation conditions, the vegetative growth of barley depends more closely on the size of the canopy than on its efficiency in dry-matter production; this agrees with the findings of Watson (1952, 1956). This fact appears reasonable, since in hot, dry areas (southern Spain) water, not radiation, is the main climatic factor that establishes the production level for most crops.

The close relationship between CDW (when LAI reaches its maximum) and grain yield confirms the great importance of pre-anthesis reserves for grain filling in dry, hot areas, as pointed out by several authors (Austin *et al.* 1980; Lawlor *et al.* 1981). Under these conditions, therefore, agricultural treatments should be designed to increase the capacity for carbohydrate production and storage in barley plants, especially by modifying LAI, the index which exercises the greatest influence on CDW.

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