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GROWTH ANALYSIS OF WHEAT AND BARLEY ON DIFFERENT SOIL TYPES

M. M. KARIMI [1]

College of Agriculture, Isfahan University of Technology, Isfahan, Iran.
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ABSTRACT

An analysis of dynamics of dry matter (DM), green area index (GAI) relative growth rate (RGR) and crop growth rate (CGR) is presented for rainfed spring wheat *(Triticum aestivum L.)* cv. Gutha and barley *(Hordeum vulgare L.)* cv. O' Connor on different soil types of Merredin Research station in the eastern wheatbelt of Western Australia. RGR of both barley and wheat during the vegetative phase were greater on the Merredin sandy clay loam (MSCL) than Collgar loamy sand (CLS) or Norpa on acid loamy sand (NALS). This was associated with higher GAI and CGR at anthesis and greater dry matter and grain yield at the final harvest. The better growth in MSCL could be attributed to a greater water supply and nutrient status. The greater GAI and CGR at anthesis lead to higher biomass and grain yield for barley than for barley on both MSCL and CLS soil types. However, on NALS, barley had lower GAI and CGR at anthesis and produced less dry matter and grain yield at final harvest than wheat. This was most likely due to very acid subsoil of NALS. The higher growth rate and greater grain yield of barley and wheat in 1988 were attributed to more suitable distribution of rainfall. In general, GAI and CGR at anthesis were positively correlated with final yield.

1- Assistant Professor.

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آنالیز رشد گندم و جو در خاکهای مختلف

محمد مهدی کریمی
استادیار هواشناسی کشاورزی، دانشکدهٔ کشاورزی، دانشگاه صنعتی اصفهان، اصفهان، ایران.

چکیده

شاخصهای رشد شامل مادهٔ خشک (DM)، شاخص سطح سبز (GAI)، سرعت نسبی رشد (RGR) و سرعت رشد محصول (CGR) گندم(.Triticum aestivum L) رقم گوتا و جو (.Hordeum vulgare L) رقم اوکانور براساس شاخص گرمایی درجه - روز در خاکهای مختلف ایستگاه تحقیقاتی مریدین (Merredin) در شرق کمربند گندم استرالیای غربی مورد مطالعه قرار گرفت. بطور کلی، سرعت نسبی رشد گندم و جو در مرحله رویشی در خاک لومی - رسی شنی مریدین (MSCL) بیشتر از خاکهای شنی - لومی کالگار (CLS) و شنی -لومی اسیدی نورپا (NALS) بود. این برتری سرعت نسبی رشد در گندم و جو همراه با شاخص سطح سبز و سرعت رشد بیشتر گیاه در زمان گرده‌افشانی با تولید مادهٔ خشک و عملکرد دانهٔ بیشتری در موقع برداشت نهایی توأم بود. برتری سرعت نسبی رشد در مرحلهٔ رویشی در خاک لومی -رسی شنی مریدین احتمالاً به‌خاطر وضعیت بهتر رطوبت و مواد غذایی در خاک بود. شاخص سطح سبز زیادتر و سرعت رشد بیشتر در خاکهای لومی -رسی شنی مریدین و سنی -لومی کالگار باعث گردید تا جو مادهٔ خشک و عملکرد دانه بیشتری نسبت به گندم تولید نماید. در هر صورت جو در خاک شنی -لومی اسیدی نورپا با شاخص سطح سبز کوچکتر و سرعت رشد کمتر در زمان گرده‌افشانی، مادهٔ خشک و عملکرد دانه کمتری نسبت به گندم تولید نمود. رشد و عملکرد نامطلوب جو در خاک شنی -لومی اسیدی به حساسیت بیشتر جو به خاک اسیدی نسبت داده‌شد. توزیع مطلوب بارندگی در سال ۱۹۸۸ باعث رشد و عملکرد بیشتر گندم و جو نسبت به سالهای ۱۹۸۴ و ۱۹۸۷ گردید. این مطالعه نشان داد که بین شاخص سطح سبز و رشد گیاه در زمان گرده‌افشانی و عملکرد نهایی گندم و جو رابطهٔ مستقیم و معنی‌داری وجود دارد.

INTRODUCTION

In the Mediterranean type environment of Western Australia, observations from cereal variety trials and research trials have indicated that barley will outyield wheat on fine – textured soils as opposed to coarse – textured sandy soils (12). French and Ewing (5) showed that weath and barley grain yields were low on the Norpa acid loamy sand, most likely due to its very acid subsoil.

Many studies have reported greater biomass and grain yield for wheat cultivars (4, 11, 13). The differences between biomass and grain yield of barley and wheat particularly on different soil types and seasons may be attributed to differences between relative growth rate (RGR) and crop growth rate (CGR) during the growing season. Studies reporting differences between soil types in RGR and CGR have not been published up to date and very little information is available on this topic. The objective of this study was to determine RGR and CGR of wheat and barley on different soil types and seasons and to discuss the observed differences with respect to the final biomass and grain yield.

MATERIALS AND METHODS

The design, layout and methodology used in this paper have been presented elsewhere (6, 7, 11, 12). However, a summary of the experimental details relevant to this study is presented here.

Soils

The soil types used in the 1984, 1987, and 1988 experiments were typical of those in Western Australia, developed from degraded lateritic plateux and depositional valley floors (6).

The soils of 1984 experiment were Norpa acid loamy sand (NALS) and a fine textured solonized red duplex soil described by Bettenay (1) as Merredin sandy clay loam (MSCL) and known as "Heavy" land. The clay content and pH increase with depth with trace of lime below 40 cm (1). In the 1987 experiment, the soil was a coarse-textured sandy duplex soil described as Collgar loamy sand (CLS) by Bettenay (1) and known as "Light" land. The CLS profile consisted of 40–50 cm of grey sand overlying a sandy clay with discontinuous silcrete layer at the surface of the clay B horizon (11). The soil types of 1988 experiment were MSCL and CLS which were very similar to MSCL of 1984 and CLS of 1987 experiments. For further details of the soil properties see Table 1.

Table 1. Some soil properties for Merredin experimental sites.

		NALS	CLS	MSCL
Texture				
	Surface	Loamy sand	Coarse loamy sand	Sandy loam
	Subsoil	Loamy sand	sandyclay	Fine sandy clay
pH (1:5) in water				
	Surface	4.5	5.2	5.5
	Subsurface	4.2	5.0	8.7
Clay (%)				
	Surface	2.8	9.4	20.0
	Subsurface	3.6	33.0	39.0
Organic carbon (%)				
	0–10 cm	0.55	0.65	0.92
Water-holding capacity at –0.01 MPa (mm mm-1)		130	170(0–0.7 m) 200(0.7–2.0 m)	180(0–0.2 m) 260(0.2–1.5 m)

Field Procedures

Growth indices of rainfed wheat, cv. Guthya and barley, cv. O'Connor were compared on different soil types and seasons at the Merredin Research Station (latitude: 31 ° 27′ S, longitude: 118° 17′ E, elevation: 315 m) in the eastern wheat belt of Western Australia.

The cultivars were sown in a randomized block design with four replicates. The plots were sown during the last week of May each year at a seed rate of 50 $kg \times ha^{-1}$. Plot size in the 1984 experiment was 40 m long by 5 m wide in two drill widths, with rows at 18 cm spacing. In 1987 and 1988 experiments, plots were 2.16 m wide (16 rows, 18 cm apart) and 40 m long. Plant densities at final harvest were about 100, 94, and 80 plants m^{-2} for 1984, 1987, and 1988, respectively.

Sampling Procedures

Plots were sampled at 2-weekly intervals from about 4 week after emergence to final harvest. In 1988, samples were taken weekly around the anthesis. Dry matter determination of 1984 and 1987 experiments were based on 1 m^2 quadrats harvested at ground level and 0.5 m^2 in 1988. Samples were dried in a forced-draft oven at 60°C and weighed. Concurrently twelve adjacent plants were taken for laboratory measurements of green area using an electronic planimeter. Total green area was calculated by adding the projected area of leaves, stems and emerged ears. Senesced and yellow leaves were excluded. The green area of 1 m^2 samples. The total green area of 1 m^2 samples. The total green area of the bulk samples was expressed as green area index (GAI). At final harvest, an undisturbed area of 4 m^2 in 1984 and 1 m^2 in 1987 and 1988 were harvested. Samples were oven dried, weighed and threshed and yield expressed on an oven-dry basis. Harvest index (HI) was calculated as the ratio of grain yield to total above ground dry matter.

Estimation of Growth Indices

Relative growth rate (RGR) and crop growth rate (CGR) were calculated using the following equations (7):

$$RGR = (1/DM)(d\ DM/dH) \qquad [1]$$

$$CGR = (d\ DM/dH) \qquad [2]$$

where DM is dry matter (gm^{-2}) and H, temperature index ($H = \sum H_i$) measured in growing degree day units (GDD) and calculated by summing the GDD for each day from the date of sowing to the date of each sampling (7).

$$H_i = [(T_{max} + T_{min})/2] - T_b \qquad [3]$$

where H_i is the growing degree day for i^{th} day, T_{max} is the maximum daily air temperature with an upper limit of 30° C, T_{min} is the minimum daily air temperature with a lower limit of 0° C and T_b is set to 0° C, i.e. the base temperature below which no growth occurs (16). Then, using Nonlinear Statistical Graphics System (15), the following equations were fitted for DM and GAI (7).

$$DM = e^{a + bH^{1/2} + CH + dH^2} \qquad [4]$$

$$GAI = e^{a' + b'H^{1/2} + C'H + d'H^2 + e'H^3} \qquad [5]$$

where H is temperature index in growing days, (GDD) and a, b, c, d and a′, b′, c′, d′, e′ are equation parameters to be determined. Using equations [1] to [5] the RGR and CGR were calculated as :

$$RGR = (1/2\ bH^{-1/2} + C + 2dH) \qquad [6]$$

$$CGR = (1/2\ b'H^{-1/2} + C + 2d'H)\ e^{a + bH^{1/2} + cH + dH^2} \qquad [7]$$

RESULTS AND DISCUSSION

Weather Conditions

Rainfall during April and May was highest for 1984 and lowest for 1987 (Table 2). The July and August rainfall for 1988 was greater than for 1984 and 1987. However, the rainfall during the winter was lower in the 1984 than in 1987 and 1988. In general, rainfall distribution for 1984 and 1988 growing seasons was more suitable than 1987, while more rainfall occurred before June in 1984 and after June in 1988 (Table 2). September and October were notable for their higher temperature and lower rainfall. The 1984 growing season was cooler compared to 1987 and 1988 (Table 2).

Table 2. Monthly metereological data of Merredin (31°29′S., 118°12′E., altitude 315 m) for 1984, 1987 and 1988 growing seasons.

	Month rainfall(mm)			Max. Temp.(°C)			Min. Temp.(°C)			GDD		
	84	87	88	84	87	88	84	87	88	84	87	88
Apr.	53.1	23.4	30.8	25.1	27.6	26.7	13.8	12.8	14.9	583.5	606.0	624.0
May.	91.7	43.8	58.4	18.6	19.8	19.8	9.9	6.4	11.1	440.2	406.1	477.4
June	18.6	36.8	33.6	17.0	19.1	17.9	5.5	7.8	9.5	339.0	403.5	417.0
July	35.8	40.5	44.2	14.7	17.6	16.1	5.6	5.5	6.2	313.1	358.0	347.2
Aug	29.2	41.0	54.6	16.1	18.4	17.4	4.1	5.2	6.3	313.1	365.5	365.8
Sep.	21.4	12.0	18.2	18.7	22.7	21.0	6.2	6.7	6.4	375.0	441.0	405.0
Oct.	1.8	10.4	2.8	25.3	25.8	25.6	8.3	9.7	8.6	520.8	550.2	530.1
Apr. to Oct.	251.6	207.9	242.6	19.4	21.6	20.6	7.7	7.7	9.0	2885	3130	3166

Phenology

Barley cv. O'Connor and wheat cv. Gutha emerged together about 11 days after sowing and 128, 156 and 147 growing degree days (GDD) after sowing on 1984, 1987, and 1988, respectively. Both barley and wheat reached anthesis at about 1250 GDD after sowing and they matured at 1850–2050 GDD.

Growth Indices and Yield

Dry matter accumulation was estimated by using equation [4]. The coefficients of determination (R^2) for fitted curves were greater than 0.96 ($P < 0.01$) for wheat and barley on different soil types and seasons. The dry matter accumulation from the beginning of the season to anthesis was consistently higher on MSCL than on CLS or NALS (Fig. 1). Green Area Index (GAI) of both barley and wheat was greater on MSCL than on NALS (Fig. 2a) or CLS (Fig. 2b). The rate of GAI decline was faster on MSCL as compared to NALS or CLS (Fig. 2). Barley on both CLS and MSCL produced higher GAI than wheat and on NALS the GAI of barley was lower than wheat (Fig. 2). In general, GAI of 1988 crops was greater than 1984 and 1987 (Fig .2 and Table 3)

Fig. 3 represents the change in relative growth rate (RGR) during the growing season. RGR declined through the season. This was in agreement with the results of Karimi and Siddique (7). During the vegetative phase both barley and wheat had greater RGR on MSCL than on CLS or NALS. The relative growth rate differences between wheat and barley were small on MSCL and NALS (Fig. 3b). However, during the vegetative phase, barley on CLS had higher RGR than wheat (Fig. 3b).

The crop growth rate was low at the beginning of the season and progressively increased to a peak value and then declined sharply (Fig.4). The CGR through the season in this study was very similar to that reported by Karimi and Siddique (7) who showed that CGR of modern cultivars generally increased rapidly to a peak around the 1250 GDD after sowing and then declined to zero prior to physiological maturity. The crop growth rate of both barley and wheat were generally greater on MSCL than on CLS or NALS soil types. However, barley on NALS had lower CGR than wheat. In general, CGR in 1988 season was greater than in 1984 and 1987 (Fig. 4 and Table 3).

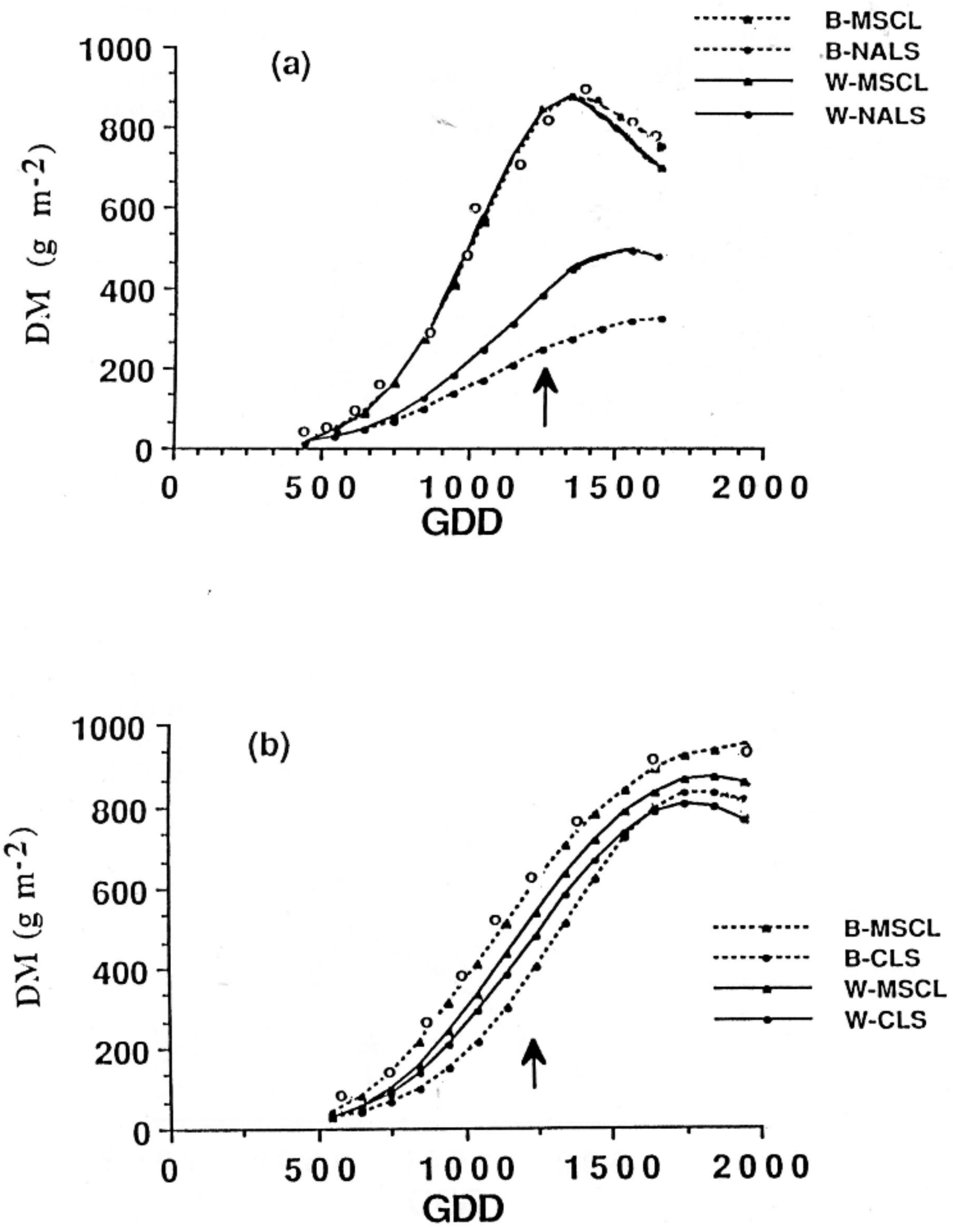


Fig. 1. Dry matter (DM) vs. growing degree days (GDD) accumulated from sowing for barley (B) and wheat (W) on different soil types in (a) 1984 and (b) 1988. Arrow indicates time of anthesis and open circle refers to the measured DM for B-MSCL.

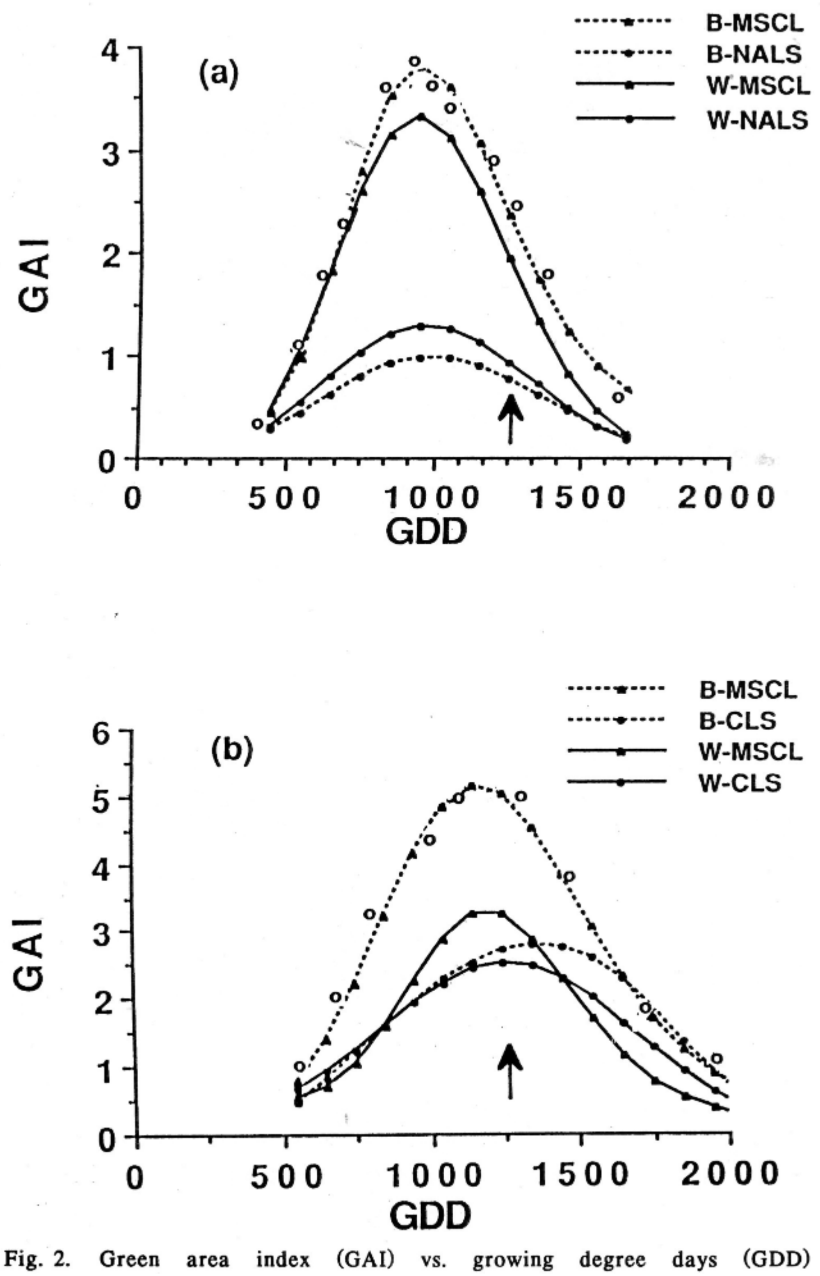
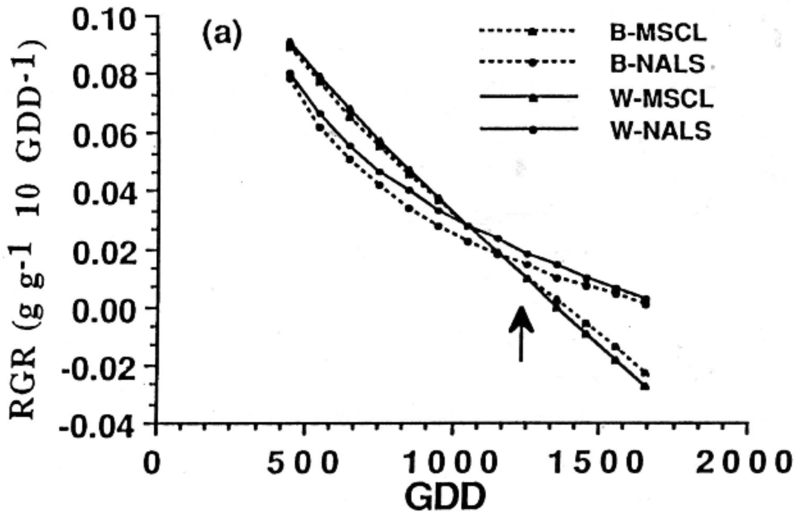


Fig. 2. Green area index (GAI) vs. growing degree days (GDD) accumulated from sowing for barley (B) and wheat (W) on different soil types in (a) 1984 and (b) 1988. Arrow indicates time of anthesis and open circle refers to the measured GAI for B-MSCL.

Table 3. Biomass yield (BY), grain yield(GY) , and harvest index (HI) at final harvest and GAI and CGR at anthesis for barley and wheat on diferrent soil types and seasons.

Season	Soil	Crop	BY g m-2	GY g m-2	HI	GAI	CGR g m-2 10 GDD-1
1984	MSCL	Barley	760	249	0.33	2.4	8.6
	NALS	Barley	299	124	0.42	0.8	3.3
	MSCL	Wheat	696	190	0.28	2.0	8.0
	NSCL	Wheat	442	168	0.38	0.9	6.9
	L.S.D (P=0.05)		98.7	33.2	0.051	0.23	3.61
1987	CLS	Barley	616	211	0.34	1.8	6.4
	CLS	Wheat	527	189	0.36	1.5	5.3
	L.S.D (P=.05)		92.5	40.6	0.051	0.18	1.31
1988	MSCL	Barley	1073	322	0.30	5.1	31.0
	CLS	Barley	709	295	0.41	2.7	11.5
	MSCL	Wheat	871	248	0.28	3.3	17.5
	CLS	Wheat	606	219	0.36	2.6	12.0
	L.S.D (P=0.05)		138.9	42.7	0.052	0.27	3.78



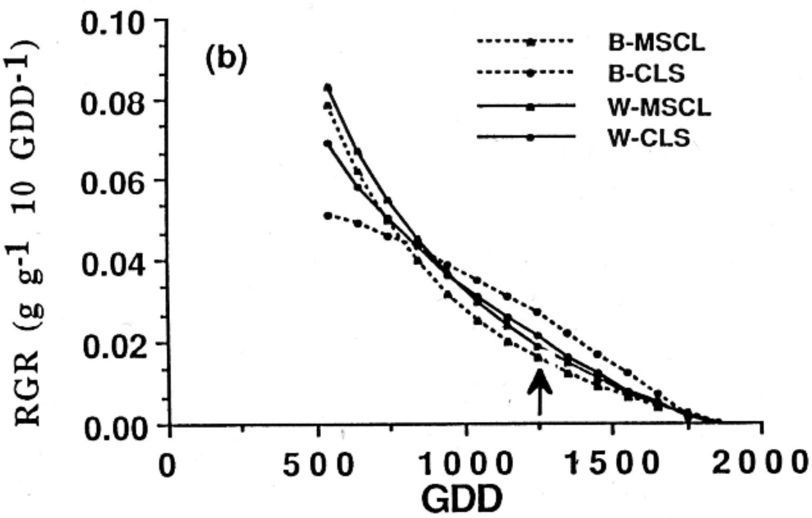


Fig. 3. Relative growth rate (RGR) vs. growing degree days (GDD) accumulated from sowing for barley (B) and wheat (W) on different soil types in (a) 1984 and (b) 1988. Arrow indicates time of anthesis.

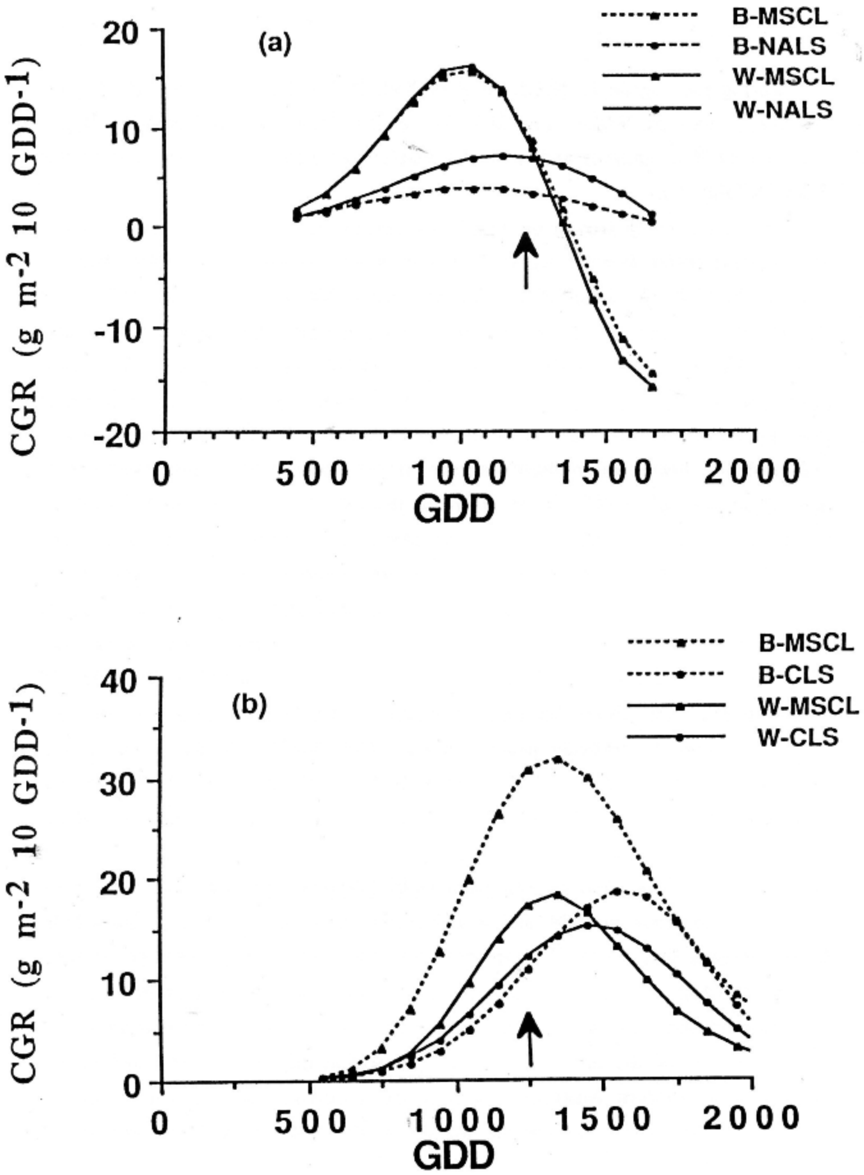


Fig. 4. Crop growth rate (CGR) vs. growing degree days (GDD) accumulated from sowing on different soil types for barley (B) and wheat (W) in (a) 1984 and (b) 1988. Arrow indicates time of anthesis.

During the vegetative phase, RGR of both barley and wheat were greater on the MSCL than on NALS (Fig. 3a). The higher RGR were followed by larger GAI and CGR at anthesis and more dry matter and grain yield at the end of the season (Table 3).

The better early growth on MSCL can be attributed to greater water supply and perhaps better nutrient status. Ricket *et al.* (10) reported that water holding capacity in CLS was lower than MSL and this is likely to encourage more root growth at the expense of top growth. They concluded that fewer shoots and smaller leaves slowed down canopy development and water use. They also suggested that CLS is a leached profile with less nutrients in the upper horizons and applied nitrogen is likely to be leached downward. In 1984, the lower rainfall and probably lower soil moisture storage around anthesis (6) caused both barley and wheat to decline GAI faster, decrease their CGR more rapidly and produce lower dry matter at final harvest on MSCL as compared to CLS. Rickert *et al.* (10) showed that the surface of heavy soil remains wet for a longer period than the surface of light land fllowing rainfall and with fewers roots near the surface of the latter, presumably due to loss of water through soil evaporation. They also showed that maximum wetting front for CLS and MSL were 130 and 90 cm, respectively. From the above evidence, it can be concluded that moisture supply at depth is probably greater in CLS than MSCL. Probably, the greater rainfall around anthesis in 1988 caused barley and wheat plants to be less dependent on moisture storage (compared to 1984). This is why the plants produced more dry matter on MSCL than CLS.

The GAI, CGR biomass and grain yield differences between soil types were greater in 1984 than in 1988, and it was related to a very poor crop growth on NALS. French and Ewing (5) reported that wheat and barley grain yields were lower on NALS than on other soils. A major cause of depressed growth on acid soils is aluminum toxicity (8). Also Dolling and Porter (3) suggested that aluminum toxicity is one of the major consequence of soil acidity in northern and eastern wheatbelt of Western Australia. However the difference between soil types was greater for the barley than for the wheat due to greater growth potential barley on MSCL (13).

The greater GAI and CGR of barley at the anthesis caused larger biomass and grain yield than for wheat on MSCL. However, the GAI, CGR, biomass and grain yield differences between barley and wheat on CLS were small (Table 3). Simpson *et al.*(13) reported that as a consequence of rapid leaf appearance and tillering, barley generally produced a greater GAI than wheat which would facilitate greater radiation interception, photosynthesis and subsequently greater DM production. In the trials of Siddique *et al.*(11) a high GAI and CGR at the anthesis of barley was associated with high radiation interception and finally greater biomass and grain yield at the end of season. On the NALS soil type, the lower GAI and CGR at anthesis of barley resulted in lower biomass and grain yields at finall harvest, most likely due to its very acid subsoil. Porter and Wilson (9) reported that on acid soils, barley yield was very poor, i.e., about 30 percent less than wheat.

The wheat roots penetrated deeper on NALS than barley roots (Fig. 5). The lower penetration of barley roots on NALS can be attributed to very acid subsoil. Porter and Wilson (9) suggested that the main reason for poor root growth in the acid subsoil of the eastern wheat belt is due to aluminium toxicity. They also reported that the stunted roots can not explore the subsoil thoroughly to extract enough water and nutrients.

The GAI and CGR at anthesis and biomass and grain yields at the end of season for both barley and wheat were greater in 1988 than 1984 and 1987 (Table 3). These differences can be mainly related to better rainfall distribution of 1988 season (Table 2). In 1984, the GAI and CGR reached a peak before anthesis on MSCL (Fig. 2a and 4a), perhaps due to lower air temperature (Table 2) and soil moisture stress (6) around anthesis. In 1987 and 1988, the GAI on MSCL reached a peak close to anthesis, but on CLS, anthesis happened before CGR peak. It seems that around anthesis both barley and wheat on CLS soil can use more moisture from subsoil and keep their GAI for a longer period (Fig. 2b) as compared to MSCL and this can increase CGR after anthesis (Fig. 4b).

The harvest index (HI) was lower on MSCL than CLS and NALS (Table 3). The GAI and CGR at anthesis were positively correlated to both biomass and grain yield (Table 4). Karimi and Siddique (7) reported a positive correlation between wheat CGR at the anthesis and both boimass and grain yield at the end of season. They suggested that cultivars with greater CGR at anthesis may translocate more carbohydrates to grains.

Table 4. Correlation coefficients (r) of growth indices (GAI & CGR) at anthesis and biomass and grain yield at final harvest.

Growth indices	Biomass	Grain yield
CGR	0.87**	0.80**
GAI	0.95**	0.90**

** P<0.01

CONCLUSION

This study showed that RGR values of wheat and barley during the vegetative phase were higher on the MSCL than CLS or NALS. The greater early growth on MSCL was associated with higher GAI and CGR at anthesis and larger dry matter and grain yield at final harvest. Barley with a greater GAI and CGR at anthesis and biomass and larger dry matter and grain yield at final harvest. Barley with a greater GAI and CGR at anthesis yielded more on MSCL and CLS as compared to wheat. The GAI and CGR at anthesis and biomass and grain yield at final harvest were lower on NALS for barley than for wheat, demonstrating the higher sensitivity of barley to low pH. The suitable rainfall distribution in 1988 resulted in a better growth and greater yield.

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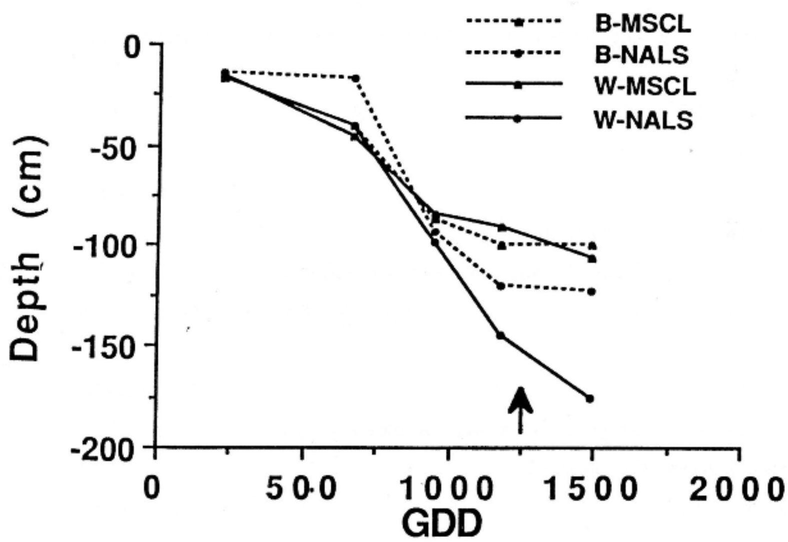

Fig. 5. Maximum root depth (cm) vs. growing degree days (GDD) accumulated from sowing on different soil types for barley (B) and wheat (W) in 1984. Arrow indicates time of anthesis.

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