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Full Length Article

Growth and Development of Safflower (C*arthamus tinctorius*) under Rainfed Conditions

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Abstract

Crop growth and development is imperative to study the plant behaviour under a set of environmental conditions. Genotypes may respond differently under same conditions according to their genetic makeup, photosynthesis and assimilation potential. Growth and development of safflower genotypes was studied through field experiments executed at PMAS-Arid Agriculture University, Rawalpindi during 2006-2007 and 2007-2008. Eight safflower genotypes Thori-78, SAF-30, SAF-31, SAF-32, Leed-00, SAF-128, SAF-129 and SAF-130 were evaluated for growth analysis viz. leaf area index (LAI), crop growth rate (CGR) and net assimilation rate carried out at 21 days interval after germination till maturity during both years. Significant differences were observed for the growth attributes among genotypes at different sampling intervals. LAI, CGR and NAR followed sigmoid pattern consistently increasing at the start of observation, attaining peaks and decreased thereafter till maturity. The decline in growth after zenith may be due to increased aging of older leaves and shifting of crop to reproductive stage. Similarly, genotypes differed statistically for biomass and seed yield. Environmental variables like rainfall and temperature influenced ontogenetic and developmental pattern of genotypes. Positive relationship concludes heavy dependence of biomass and yields with growth parameters.

Keywords: Growth rhythms; LAI; NAR; CGR; Safflower

Introduction

Safflower (*Carthamus tinctorius* L.) is a multi-use crop mostly grown for edible oil production throughout the world. Its seed contain 35% oil and occupies unique position among oilseed crops due to high polyunsaturated fatty acid contents, which may reach up to 90% (Ba_almal *et al.,* 2008; Beyyavas *et al*., 2011). Safflower can be grown under harsh climatic conditions due to high cold (Johnson and Li, 2008), salinity (Faraj *et al.,* 3013) and drought tolerance (Amini *et al*., 2013).

In crop growth analysis, primary data regarding weights and areas of plant and soil is used to study crop behaviour and interpret the plant form by determining the plant factors, which control the production of dry matter (Hunt *et al.,* 2002; Nasso *et al.,* 2011). Thus, understanding crop growth analysis may also be helpful in selection of genotypes based on identified factors important for the crop production under specific set of environmental conditions.

In other crops, Zajac *et al.* (2005) estimated productivity of linseed using growth analysis and found that meteorological conditions in successive growing years predisposed growth and development. Similarly, Hassan *et al.* (1999) observed progressive increase in leaf area index (LAI), net assimilation rate (NAR), crop growth rate (CGR) with the age of crop, then persistent decline after reaching at zenith, giving lowest values near maturity. Leaf area increased with the age of crop as maximum light was intercepted up to a certain growth stage, beyond that mutual shading of leaves result in declined CGR. Reduction in active leaves and LAI at advanced growth phases resulted in reduced translocation of photosynthates from vegetative to reproductive parts depicting abridged crop growth rate (Hassan *et al.,* 1997). Nalayini and Kandasamy (2003) analysed hybrid cotton under different nitrogen levels and weed management techniques using classical growth analysis and found higher net assimilation rates at earlier growth stages declining progressively at later stages. Isoda *et al.* (2011) related LAI, NAR and CGR with air temperature and found differences in growth rhythms among soybean genotypes. Sigmoid curves were observed for LAI, NAR, CGR showing an increase during vegetative growth and decline with the progression towards reproductive growth stages of sunflower (Kaleem *et al.,* 2010). Understanding growth and development give information about dry matter accumulation along with unveiling the key processes through, which a cultivar becomes more or less productive (Özalkan *et al*., 2010). There is limited information available regarding safflower growth cycle under rainfed conditions and keeping in view the importance of growth analysis, a study was conducted to observe the growth rhythms in safflower under rainfed conditions.

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Materials and Methods

Site Information

Field experiments were conducted at Agronomy fields, PMAS Arid Agriculture University (33º 38" N, 73º 05" E), Rawalpindi during 2006-2007 and 2007-2008 under rainfed conditions. Particular fields were summer fallow. The texture of the soil was loam with 46% silt, 43% sand and 11% clay, pH 7.4 and EC 0.66 mS cm^{-1}.

Experimental Material, Design and Crop Management

Eight safflower genotypes Thori-78, SAF-30, SAF-31, SAF-32, Leed-00, SAF-128, SAF-129 and SAF-130 were obtained from National Agricultural Research Centre, Islamabad. Seed bed was prepared by giving one soil inverting plough followed by two ploughings by a tractor mounted cultivator. The experimental area was fertilized with N (60 kg ha^{-1}) and P_2O_5 (60 kg ha^{-1}) through urea and DAP. The experiments were laid out in randomized complete block design with four replications keeping net plot size of 5 x 4.8 m^2 having 8 rows. Planting was done with hand driven seed drill on November 23rd and 27th during 2006 and 2007, respectively. Intra row and plant distances were maintained at 60 and 10 cm by thinning, respectively. Plants were grown under rainfed conditions without any supplemental irrigation. Crop was kept weed free by manual hoeing whenever needed. Weather data was collected from the weather observatory located adjacent to the experimental site and presented in Fig. 1.

Plant Sampling and Data Collection

Five plants were sampled representing each replicated treatment after every 21 days from emergence till crop maturity. Leaf area (LA) of the plants was measured by using leaf area meter (CI-202 Area Meter, CID, INC, USA) and then sampled plants were oven dried for 72 h at 80^0C to dry the plants as described by Kaleem *et al.* (2010). LAI, CGR and NAR were calculated by using the formulae described by Radford (1967):

LAI = Leaf area / Land area
NAR (g m^{-2} d^{-1}) = (DW/DT) x (1/A)
CGR (g $m^{-2}d^{-1}$) = (1/SA) x (DW/DT).

Where, SA is the area of soil under plants, A is area of leaves and DW/DT is per day dry matter gain.

Statistical Analysis

MSTATC software was used by employing ANOVA technique (Freed and Eisensmith, 1986) to analyse the data statistically. DMRT was used to separate the means of genotypes, whereas LSD was used to separate the means of years at 5% and 1% probability level (Montgomery, 2001).

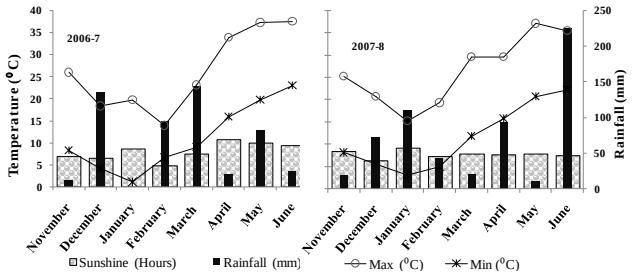

Fig. 1: Meteorological data of safflower growth seasons during 2006-2007 and 2007-2008

Results

Significant differences were observed for LAI among genotypes at 42 to 63 days after germination (DAG) and then at maturity (Table 1). Difference between years was also significant at 21 DAG (P<0.01), 84 DAG (P<0.05) and at maturity (P <0.01). Interactive effects of genotype and year was non significant except at 42 DAG. Non significant differences were observed for genotype, year and interaction at 105, 126 and 147 DAG. Significant difference among the genotypes (Table 2) appeared for the first time when genotype SAF-130 had maximum LAI at 42 DAG compared to other genotypes, and being slow in shattering the leaves it had maximum LAI at the maturity among all genotypes. Initially, genotype SAF-129 had similar LAI at 42 DAG with SAF-130 but at physiological maturity it exhibited minimum (1.08) LAI than SAF-130 and other cultivars with maximum LAI (1.16). There was increase in leaf area index of all the genotypes from germination till 126 DAG and then rapid decline thereafter till maturity. Maximum (2.35) LAI was observed at 126 DAG in genotype SAF-31, whereas lowest (2.10) was observed by exotic cultivars SAF-128 and SAF-129.

Differences in crop growth rate (CGR) among safflower genotypes were significant (P < 0.01) throughout the crop cycle (Table 1). There were no interaction of genotype with years at all stages of crop growth and development for CGR. Non-significant differences were observed between years except at 84 and 126 DAG. Mean CGR at all stages showed significant differences among safflower genotypes (Table 2). Genotype SAF-128 had highest (1.32 g m^{-2} d^{-1}) CGR among all genotypes at 21 DAG and lowest at 42 DAG, 147 DAG and maturity. Whereas genotype SAF-31 having minimum (0.93 g m^{-2} d^{-1}) CGR at 21 DAG had maximum (1.64 g m^{-2} d^{-1}) CGR at physiological maturity. Inclined trend in CGR was observed till 105 DAG when all the genotypes took their peaks despite of exhibiting significant differences among them with maximum 10.95 g m^{-2} d^{-1} by genotype SAF-130 (Table 3).

Pronounced differences (P<0.01) were observed among safflower genotypes for net assimilation rate (NAR) from 21 DAG till maturity (Table 1). Highly significant difference appeared between the years at 42, 84 and 126

Table 1: Analysis of Variance for LAI, CGR and NAR

Sampling Interval	SOV	df	LAI	CGR	NAR
21 DAG	Replication	3	3.490E-05	0.00057	0.00521
	Variety	7	3.192E-05 (NS)	0.16808 (**)	1.68277 (**)
	Year	1	6.891E-04 (**)	0.00788 (NS)	0.00000 (NS)
	Variety × Year	7	6.920E-06 (NS)	0.00002 (NS)	0.00000 (NS)
	Error	45	2.156E-05	0.00631	0.06797
42 DAG	Replication	3	0.00042	0.01622	0.21945
	Variety	7	0.00043 (**)	0.08344 (**)	1.79067 (**)
	Year	1	0.02103 (NS)	0.01440 (NS)	4.92285 (**)
	Variety × Year	7	0.00004 (**)	3.571E-06 (NS)	0.00439 (NS)
	Error	45	0.00014	0.00775	0.40447
63 DAG	Replication	3	0.02615	0.01451	0.02229
	Variety	7	0.07209 (**)	0.21540 (**)	0.25702 (**)
	Year	1	0.01563 (NS)	0.02402 (NS)	0.00508 (NS)
	Variety × Year	7	0.00003 (NS)	0.00003 (NS)	0.00001 (NS)
	Error	45	0.01183	0.02145	0.03590
84 DAG	Replication	3	0.00168	0.02663	0.21945
	Variety	7	0.00174 (NS)	4.69960 (**)	1.79067 (**)
	Year	1	0.25629 (*)	2.61226 (**)	4.92285 (**)
	Variety × Year	7	0.00012 (NS)	0.00315 (NS)	0.00439 (NS)
	Error	45	0.03895	0.12097	0.40447
105 DAG	Replication	3	0.03274	1.0331	1.03967
	Variety	7	0.00330 (NS)	21.996 (**)	5.40099 (**)
	Year	1	0.02066 (NS)	1.1236 (NS)	0.82810 (NS)
	Variety × Year	7	0.00009 (NS)	0.0041 (NS)	0.00290 (NS)
	Error	45	0.02614	0.3609	0.31246
126 DAG	Replication	3	0.07379	0.03437	0.06344
	Variety	7	0.05456 (NS)	7.97177 (**)	1.95092 (**)
	Year	1	0.02641 (NS)	2.20522 (**)	0.76562 (**)
	Variety × Year	7	0.00011 (NS)	0.01124 (NS)	0.00455 (NS)
	Error	45	0.06813	0.14067	0.09389
147 DAG	Replication	3	0.00292	0.30339	0.07641
	Variety	7	0.00282 (NS)	4.75281 (**)	1.59174 (**)
	Year	1	0.01891 (NS)	0.05348 (NS)	0.07223 (*)
	Variety × Year	7	0.00001 (NS)	0.00074 (NS)	0.00079 (NS)
	Error	45	0.03067	0.08234	0.05737
At Maturity	Replication	3	7.292E-05	0.08178	0.07040
	Variety	7	0.00498 (**)	1.29067 (**)	1.00403 (**)
	Year	1	0.00640 (*)	0.00473 (NS)	0.01501 (NS)
	Variety × Year	7	8.483E-32 (NS)	0.00015 (NS)	0.00038 (NS)
	Error	45	9.229E-04	0.02175	0.01587

df = degree of freedom, (**) Highly significant at 1% probability level, * Significant at 5% probability level, (NS) = Non-significant, LAI = leaf area index, CGR = crop growth rate, NAR = net assimilation rate

Table 2: Mean leaf area index (LAI) of safflower genotypes at different days after germination (DAG)

Genotypes/days after germination (DAG)	21	42	63	84	105	126	147	Maturity
Thori-78	0.31	0.60 ab	1.07 b	1.69	1.94	2.13	1.75	1.13 abc
SAF-30	0.31	0.59 b	1.05 b	1.69	1.92	2.11	1.77	1.15 ab
SAF-31	0.31	0.60 ab	1.08 b	1.65	1.91	2.35	1.74	1.12 bc
SAF-32	0.31	0.59 b	1.05 b	1.66	1.92	2.11	1.74	1.12 bc
Leed-00	0.31	0.59 ab	1.33 a	1.68	1.92	2.12	1.76	1.14 abc
SAF-128	0.31	0.59 b	1.04 b	1.67	1.90	2.10	1.73	1.11 cd
SAF-129	0.31	0.61 a	1.09 b	1.66	1.90	2.10	1.76	1.08 d
SAF-130	0.31	0.61 a	1.08 b	1.66	1.96	2.16	1.79	1.16 a
LSD 0.05	n.s	0.11	0.109	n.s	n.s	n.s	n.s	0.03

n.s = Non-significant, Means in a column with different letters differ significantly at 5% probability level

DAG while there was non-significant interactive effects of genotypes and years at all observations. Moreover, mean NAR depicted significant differences among the genotypes at all stages (Table 4). Genotype SAF-130 assimilated at maximum rate (5.62 g m^{-2} d^{-1}) at 105 DAG. NAR was maximum at 105 DAG in all the genotypes except SAF-128 and SAF-129 with maximum zenith at 84 DAG. Difference among genotypes was more pronounced at maturity when NAR as low as 0.41 g m^{-2} d^{-1} in genotype SAF-128 and as high as 1.46 g m^{-2} d^{-1}.

There were also significant differences observed for seed and biological yields among safflower genotypes (Table 5). Maximum seed yield (933 kg ha^{-1}) was produced by SAF-129 and minimum seed yield (502.2 kg ha^{-1}) by SAF-130. Like wise biological yield ranged from 4225 kg ha^{-1} for SAF-129 to 5949 kg ha^{-1} for SAF-130.

Table 3: Mean crop growth rate (g m^{-2} day^{-1}) of safflower genotypes at different days after germination (DAG)

Genotypes/days after germination (DAG)	21	42	63	84	105	126	147	Maturity
Thori-78	0.97 d	1.37 cd	2.03 abc	7.13 b	10.44 ab	5.04 d	4.07 a	1.33 b
SAF-30	1.00 cd	1.43 bc	2.15 a	7.28 b	10.19 b	6.32 a	4.05 a	0.80 cd
SAF-31	0.93 d	1.58 a	1.88 cd	6.20 c	8.86 c	4.00 e	3.49 b	1.64 a
SAF-32	1.07 c	1.33 d	1.68 e	6.39 c	8.19 d	5.32 cd	2.99 c	0.91 c
Leed-00	1.20 b	1.50 ab	1.98 bc	6.30 c	10.28 b	5.76 b	2.61 d	0.66 de
SAF-128	1.32 a	1.31 d	1.74 de	7.31 b	7.34 e	3.91 ef	2.03 e	0.46 f
SAF-129	1.27 ab	1.32 d	1.94 c	6.17 c	6.36 f	3.57 f	2.34 d	0.56 ef
SAF-130	1.08 c	1.51 ab	2.11 ab	8.35 a	10.95 a	5.58 bc	2.61 d	0.97 c
LSD 0.05	0.08	0.09	0.15	0.35	0.61	0.38	0.29	0.15

Means in a column with different letters differ significantly at 5% probability level

Table 4: Mean net assimilation rate (g m^{-2} day^{-1}) of safflower genotypes at different days after germination (DAG)

Genotypes/days after germination (DAG)	21	42	63	84	105	126	147	Maturity
Thori-78	1.89 abc	2.27 cde	3.13 e	4.25 b	5.41 a	2.40 b	2.35 a	1.18 b
SAF-30	2.06 a	2.41 bcd	3.29 de	4.35 ab	5.35 ab	3.02 a	2.32 ab	0.70 cd
SAF-31	1.75 bcde	2.64 a	3.03 e	3.80 b	4.66 bc	2.12 c	2.02 bc	1.46 a
SAF-32	1.63 de	2.23 de	3.49 d	3.96 b	4.30 c	2.55 ab	1.73 cd	0.81 c
Leed-00	1.51 e	2.50 ab	3.81 bc	3.88 b	5.37 ab	2.75 ab	1.49 de	0.57 de
SAF-128	1.68 cde	2.21 de	4.29 a	4.47 ab	3.94 cd	1.89 c	1.18 e	0.41 e
SAF-129	1.79 bcd	2.16 e	3.12 e	3.78 b	3.37 d	1.72c	1.33 de	0.52 e
SAF-130	1.96 ab	2.47 abc	3.52 cd	5.16 a	5.62 a	2.60 ab	1.48 e	0.84 c
LSD 0.05	0.19	0.17	0.26	0.64	0.56	0.31	0.24	0.13

Means in a column with different letters differ significantly at 5% probability level

Discussion

Physiological behaviour of crop changes with age by passing through different phenological and developmental stages. In present study, growth and development parameters followed sigmoid pattern like most of the crop plants with slow at start followed by rapid increase and after reaching peak in the middle declined. Leaf area index reflects the differences in production efficacy of the genotypes by describing the size of assimilatory area and photosynthetic potential (Addo-Quaye *et al.,* 2011). Genotypes with higher potential to produce leaf number with more leaf area are likely to produce more LAI. The leaf area index of the crop indicates its photosynthetic potential or the level of its dry matter accumulation (Dar *et al.,* 2009). Among all the safflower genotypes in both years followed sigmoid trends (Fig. 2a). Differences among safflower genotypes at earlier stages might be their capricious genetic response to prevailing environmental conditions. Leaf area index inclined at earlier stages due to continuous increase in leaf number and expansion of leaf area till attaining its peak at 126 DAG. At reproductive stage, LAI started declining possibly due to the progressive senescence of lower leaves due to shading of older leaves. Progressive development of LAI in safflower was similar to other crops like linseed (Hassan *et al*., 1999), wheat (Wajid *et al.,* 2004) and sunflower (Kaleem *et al*., 2010).

The difference in crop growth rate (CGR) of genotypes at different stages may be attributed to the genetic variation among the genotypes. Growth and development is primarily function of temperature, provided water availability stands up to the optimum level of satisfaction

Table 5: Mean seed yield (kg ha^{-1}) and biological yield (kg ha^{-1}) of safflower genotypes

Genotypes	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})
Thori-78	667.10 b	5410 ab
SAF-30	761.40 b	5210 bc
SAF-31	656.60 b	4679 cd
SAF-32	676.30 b	4645 cd
Leed-00	664.60 b	5190 bc
SAF-128	651.10 b	4340 d
SAF-129	502.20 c	4225 d
SAF-130	933.00 a	5949 a
LSD 0.05	88.02	644.10

Means in a column with different letters differ significantly at 5% probability level

(Rasul *et al.,* 2011). In present study, difference between years for CGR at 84 DAG was possibly due to the difference in rainfall, temperatures and sunshine hours. Maximum and minimum daily temperatures remained low in February 2007 compared to February 2008. Sunshine hours were less during Feb 2007 due to cloudy weather thus resulted in decreased photosynthetic activity and slow crop growth rate, whereas during Feb 2008, ample sunshine increased temperature, which resulted in higher photosynthetic activity and increased biomass accumulation. After reaching peak, decline in CGR was noticed in all genotypes till maturity. Mean trend of all genotypes followed sigmoid curve for CGR (Fig. 2b). Differences among the genotypes were more pronounced at later vegetative and reproductive stages. Significant differences among the genotypes at different growth stages may be due to genetic potential in radiation use efficiency along with the differences in LAI. Differences in radiation use

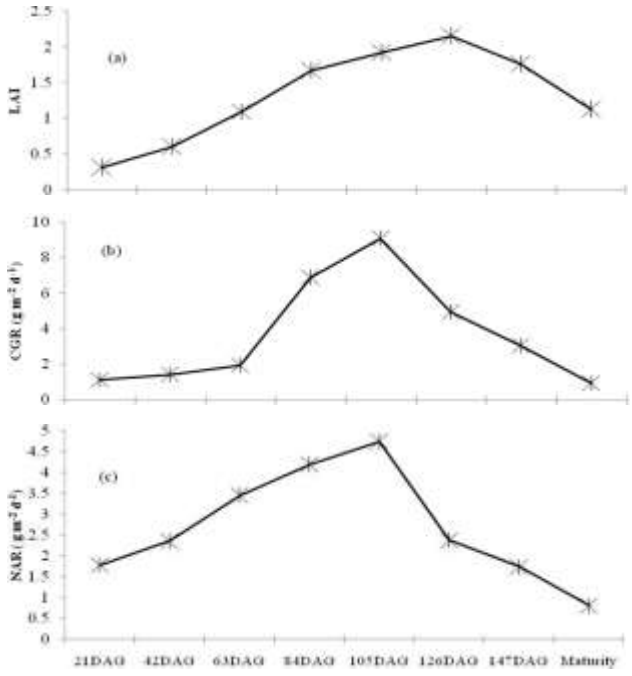

Fig. 2: LAI, CGR and NAR of Safflower at different days after germination till maturity

efficiency among alfalfa genotypes at different growth stages have also been reported by Akmal *et al.* (2011). Accelerated CGR at early vegetative growth period may be attributed to the increasing LAI that helped in intercepting more sun light and as a result, more photosynthates were produced. Shading of lower leaves might have reduced CGR at 126 DAG even when LAI was at maximum. Reduction in CGR at late stages, after attaining a peak might be due to the decreasing LAI with aging of leaves and translocation of photosynthates to flowers. Gour *et al.* (2010) found similar kind of growth pattern in fenugreek.

Although all tested genotypes followed sigmoid pattern for net assimilation rate (NAR) but attaining peaks by genotypes SAF-129 and SAF-130 much earlier than the rest of genotypes may be attributed to their differential genetic make up for photosynthesis as NAR equates net photosynthesis (Surendar *et al.,* 2013). Increase in NAR (Fig. 2c) may be the result of increasing CGR when plants were increasing their exposed area. Intercepting more radiation and production of more photosynthates may result in increased assimilation rate. NAR started declining after reaching peak as a consequence of decline in LAI, photosynthetically active area and increased air temperature. Significant differences between years for NAR after reaching peaks till 126 DAG were due to the differences in rainfall and sunshine duration, lesser sunshine hours yielded less assimilation. Although temperature favoured increase of NAR but very high temperature resulted decline in productive efficiency and net assimilation (Timlin *et al.,* 2006). Kaleem *et al.* (2010) also reported increasing trend

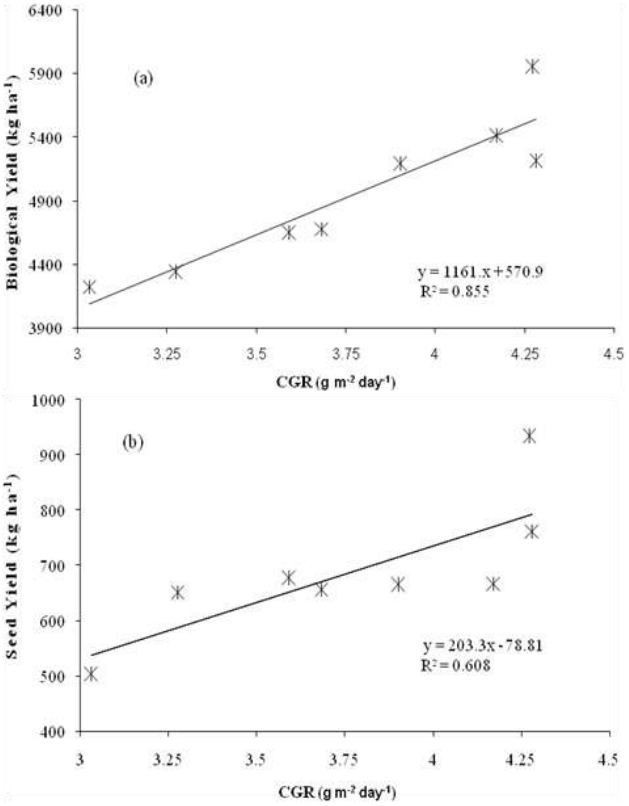

Fig. 3: Relationship of seed yield and biological yield with CGR

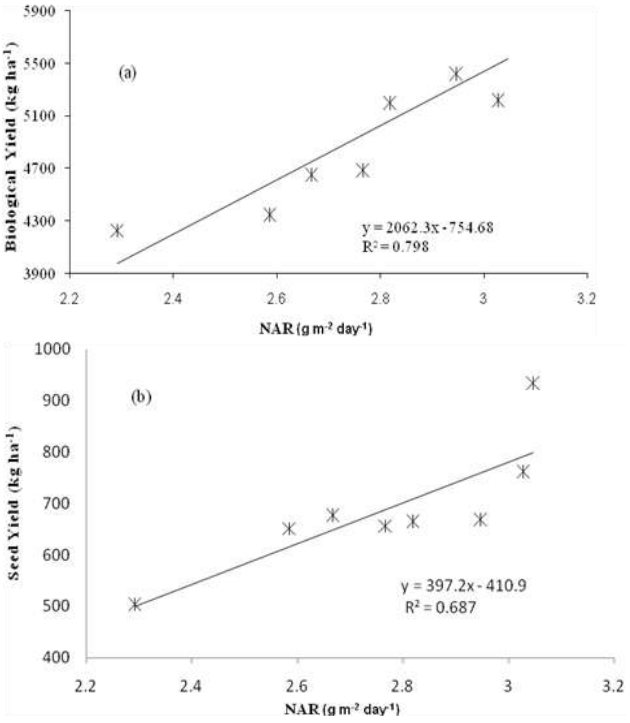

Fig. 4: Relationship of seed yield and biological yield with NAR

for NAR at earlier stages, reaching at peak and declined thereafter till maturity in sunflower.

There were significant differences among safflower genotypes for seed and biological yields due to their differences for CGR and NAR. Mean CGR and NAR affected seed and biological yields in linear fashion (Fig. 3 and 4). It is evident that genotypes with more CGR and NAR produced more seed and biological yields depicting the clear dependence of yields on ontogenetic development of safflower crop. Strong positive relation (R^2 = 0.855) between biological yield and CGR (Fig. 3a) signifies the heavy dependence of biomass production on mean crop growth. Likewise positive relation (R^2= 0.798) between biological yield and NAR (Fig. 4a) also magnifies the importance of assimilate accumulation to produce more plant biomass resulting in higher biological yield as genotypes with more NAR and CGR produced more yields. Positive relation (R^2 = 0.608) between seed yield and CGR suggested that higher growth rate during growth and development would result in higher seed production (Fig. 3b). Similarly positive relationship (R^2 = 0.687) between seed yield and NAR (Fig. 4b) suggests translation of assimilates into ultimate seed yield. Positive relationships among yields and growth kinetics manifest the importance of classical ontogenetic studies to understand crop growth, development and performance.

Conclusion

Ontogenetic and developmental pattern of genotypes followed sigmoid pattern influenced by environmental variables like temperature, rainfall and sunshine duration. Positive significant relationship of seed and biological yields with CGR and NAR concludes the dependence of earlier on later. SAF-130 produced more seed yield compared to rest of the genotypes thus it can be adopted by farmers for cultivation under rainfed conditions.

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