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STUDIES ON WATER RELATIONS IN MUSTARD (*BRASSICA JUNCEA* L.)

M. PHIL. THESIS

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RAJSHAHI, BANGLADESH

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STUDIES ON WATER RELATIONS IN MUSTARD(*BRASSICA JUNCEA* L.)

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BY

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DEDICATED

TO

K.M.ROY

DECLARATION

I, Ranajit Kumar Mandal, hereby declare that the whole of the work now submitted as a thesis for the degree of Master of Philosophy to the University of Rajshahi is the result of my own investigation.

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CERTIFICATE

I, Ranajit Kumar Mondal, hereby certify that the work embodied in this thesis has not been submitted in substance of any degree, and is not being concurrently submitted in candidature for any other degree.

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ABSTRACT

Effect of soil moisture on growth, yield and water use of two mustard (*Brassica juncea* L.) cultivars (Sambal and Daulat) was studied. The two moisture levels were irrigation at every 10 days intervals and rainfed control.

Total dry matter (TDM), leaf area index (LAI) and leaf area duration (LAD) were significantly higher in the irrigated plants than that of the rainfed plants. The increase of TDM production was slow at the early vegetative phases but increased rapidly with the advancement of the growth period. Starting from a lower value, LAI and LAD reached a peak and then declined gradually.

Among the growth attributes, relative growth rate (RGR), leaf area ratio (LAR), relative leaf growth rate (RLGR) and leaf weight ratio declined throughout with the increasing time and plant weight. Specific leaf area (SLA) showed no clear pattern but crop growth rate (CGR) increased slightly with fluctuations. Net assimilation rate (NAR) increased at the later stages of growth. Significantly higher CGR, LAR, SLA and LWR were found in the irrigated plants of both the cultivars than that of the rainfed plants.

Simple correlation coefficients indicated that in the irrigated plants, seed yield was positively correlated with the pre-flowering LAI and CGR and the post-flowering NAR. In the rainfed plants,seed yield was positively correlated with LAI and CGR at the post-flowering stage and negatively correlated with the post-flowering NAR and the pre-flowering LAR.

Percentage of dry matter (DM) accumulation for stem and petiole was lower at the early stages, at the middle stages it increased to a peak and then gradually decreased with time. Percentage of DM accumulation in the leaves was found highest at the initial stage and gradully decreased with time and ultimately it became zero.Dry matter partitioning for pods gradually increased with plant age. No clear effect of soil moisture on partitioning of dry matter was found.

At the flowering stage, the irrigated plants had significantly higher relative leaf water content (RLWC)than the rainfed plants at 8 A.M. in both the cultivars. At the mid-pod filling stage, the irrigated plants had significantly higher RLWC at 8 A.M. and 4 P.M. than the rainfed plants of Sambal. The highest RLWC was observed at 8 A.M., but at the midday it decreased and later part of the day it increased gradually.

Soil moisture had no significant effect on chlorophyll a,b and total chlorophyll. Proline and sugar contents of leaves were significantly higher in the rainfed plants than that of the irrigated plants at both the flowering and mid-pod filling stages. Accumulation of proline and sugar was higher at the mid-pod filling stage than the flowering stage.

Time taken to stomatal closure and total transpiration rate at the flowering stage were significantly higher in the irrigated plants. The number of epidermal cells was significantly lower and stomatal index was significantly higher in the irrigated plants on the adaxial surface of leaves. Leaf thickness was significantly higher in the irrigated plants than that of the rainfed plants. Mean cross-sectional areas of palisade and spongy parenchyma cells were unaffected by soil moisture.

Plant height at first flowering and duration of flowering were significantly higher in the irrigated plants. Irrigated plants had always higher number of flowers than the rainfed plants. No significant effect of soil moisture was found on pod abortion. Soil moisture had little effect on seed growth of both the cultivars.

Significantly higher plant height, length of main axis,number of pods/plant, number of seeds/pod, pod weight/plant, 1000-seed weight and seed yield were found in the irrigated plants than that of the rainfed plants. In the irrigated condition, Daulat yielded more seeds than Sambal but in the rainfed condition it yielded less, though the differences were not significant. The irrigated plants had significantly higher consumptive water use and lower water use efficiency than the rainfed plants.

Simple correlation coefficients indicated that seed yield in the irrigated plants was positively correlated with the number of pods/plant, pod weight/plant, number of seeds/pod and harvest index, whereas in the rainfed plants it was related positively with plant height, number of pods on main axis, number of pods/ plant, pod weight/plant and harvest index. Oil content of the rainfed seeds was positively correlated with the number of seeds/pod and negatively with plant height and number of pods on main axis.

Effect of soil moisture stress at differnt stages of growth of two mustard cultivars (Sambal and Daulat) was studied. The five treatments were rainfed control (T_0), pre-flowering stress (T_1), flowering to mid-pod filling stress (T_2), post mid-pod filling stress (T_3) and uniformly irrigation throughout the growing season (T_4). The treatments T_1, T_2, T_3 and T_4 of Sambal received 50,70,50 and 80 mm of irrigation water, respectively. The corresponding values of Daulat were 40, 40, 50 and 70 mm.

The highest reduction of total dry matter (TDM) was found in continuously stressed (T_0) plants. TDM production was greatly reduced when soil moisture stress was imposed during pre-flowering (T_1) and flowering to pod filling (T_2) stages. It was not affected significantly in post mid-pod filling stress (T_3). No significant effect of soil moisture stress on partitioning of dry matter was found.

The severest effect was found in continuous soil moisture stress (T_0) for seed yield and most of the yield components. Seed yield and almost all the yield components were highly reduced when moisture stress was imposed during the pre-flowering (T_1) and the flowering to pod filling (T_2) stages. Soil moisture stress at the post mid-pod filling stage had no significant effect on yield and its components.

GENERAL INTRODUCTION

GENERAL INTRODUCTION

Mustard (*Brassica juncea* L.) is a crop of increasing importance in Bangladesh as its utilization for both the edible oil content and the protein content of the meal. *Brassica* oil is also used as lighting and hair oil in rural areas. A small fraction of oil cake is used for manuring. Oil-seed *Brassica* is cultivated in about 3, 18, 000 hectares in Bangladesh (Anon., 1990), which is about 64% of the land planted for oil seeds (Kaul and Das, 1986). Mustard is cultivated in about 25% of the total area in which *Brassica* is grown (Rahman, 1978) and the average yield is about 698 kg/ha (Anon., 1990).

Like any other crops, growth and yield of mustard is under the control of environmental factors. In a strict sense mustard is an irrigated crop (Andrews, 1972) since seed yield is greatly increased by the presence of adequate soil moisture (Banerjee *et al.*, 1967; Bhan, 1979; Jain and Jain, 1979; Reddy and Sinha, 1979; Joarder *et al.*, 1979; Bajpai *et al.*, 1981). Oil content and oil yield in mustard are increased with soil moisture treatment (Banerjee *et al.*, 1967; Bhati and Rathor, 1982; Chaniara and Damor, 1982). However, it is widely cultivated in the winter under rainfed conditions in Bangladesh. Average potential evapotranspiration during the growing period (November to February) of mustard was estimated to be 106.33 mm, whereas mean rainfall during that period was 12.28 mm (Manalo,1975), therefore a moisture stress of 94.05 mm occurred. Thus, erratic and limited rainfall seriously limits production of mustard in Bangladesh.

There are many physiological processes that are modified by water stress and that may contribute to loss of productivity (Thurling, 1974; Richards and

Thurling, 1978 a, b, c; Clarke and Simpson, 1978 a, b, c; Reddy and Sinha, 1987). As mustard is grown under areas relaying on moisture stored in the soil to support the crop, an improved understanding of crop responses to water stress would be helpful to manipulate higher yield.

Since rainfall during the winter season is inadequate and uncertain, mustard requires supplemental water for its proper growth and development, otherwise, water stress is likely to develop and reduce crop yields. The yield reduction does not only depend on the magnitude and duration of water stress but also on the stages of growth and development of plants. All stages of growth are not equally sensitive to moisture stress. Hence, it is essential to determine the specific stages of growth to soil moisture stress for proper irrigation scheduling in order to optimize crop production under limited water resources condition. The following two experiments were conducted in the present investigation :

Experiment 1. Effect of soil moisture on morphophysiological characters and yield of mustard (*Brassica juncea* L.).

Experiment 2. Effect of soil moisture stress at specific stages of growth on dry matter production and yield of mustard (*Brassica juncea* L.).

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Maini, Sandhu and Johal (1964) reported that one post-sowing irrigation gave high response both in seed yield and dry matter production of Toria. While two irrigations did not add much further to crop production. One post-sowing irrigation, as in the case of seed yield, registered marked increases in the growth of the plant while two irrigations appeared to be superfluous except that plant height continued to increase still further, highlighting the influence of water on extension growth. Under such conditions the number of primary and secondary branches suffered a setback possibly on account of development of the individual branch.

Banerjee, Das and Bhattacharjee (1967) studied the irrigation effect on yield and oil content of Toria and its economics. On the basis of seed yield, the differences in number of irrigation were significant. On an average, two irrigations yielded the highest (741 kg/ha) with 49% increased yield over the control (no irrigation). One irrigation stood second (651 kg/ha) with 31% increased yield over the control. There was a fall off in the response with three irrigations and the increased yield was only 19% over the control. The yield of control plot was very poor and yielded on an average 497 kg/ha. There was a slight increase in oil content up to one irrigation. The oil content declined a little with increasing number of irrigations.

Interrelationships between various yield components and yield of yellow sarson under conditions of soil drought were studied by Nathawat, Jain, Bagrecha and Bhargava (1969). A negative correlation between primary and secondary branches was found. The number of pods/plant was positively correlated with primary branches. Primary branches were negatively correlated with yield. The number of pods/plant increased the yield significantly.

Denna (1970) carried out an investigation on transpiration and the waxy bloom in *Brassica oleracea*. The stomatal and cuticular transpiration rates and quantity of wax per unit area of leaf surface were determined for seven glaucous and non-glaucous sibling lines. There were no statistically significant differences in the stomatal transpiration rates of glaucous and non-glaucous lines, but there were highly statistically significant differences between the two classes of lines in terms of cuticular transpiration. Rubbing the surfaces of leaves to remove lightly adhering wax deposits, such as the waxy bloom, significantly increased the cuticular but not the stomatal transpiration rates of both glaucous and non-glaucous plants. There was no appreciable correlation between the quantity of wax per unit leaf area and the loss of water through cuticular transpiration among either the glaucous or non-glaucous lines. It was concluded that the function of cuticular waxes in limiting cuticular transpiration is a product of the architecture of the quantity of wax per unit area of leaf surface.

The effect of irrigation, plant population and fertilizer was studied with 3 levels of each factor on yield and quality of Indian rape by Wankhede, Ahlawat and Sahni (1970). They observed that under 3 irrigations the growth and fruiting capacity of the plants increased further with 4 irrigations, whereas under 4 irrigations the branches/plant were reduced and the number of capsules/plant was also fewer. Three irrigations were optimum and gave about 6% higher seed yield than 2 and 4 irrigations. Irrigation had no significant effect on oil content. However, with 4 irrigations slightly higher percentage of oil was obtained.

Response of mustard to varying irrigation levels, spacing and fertilizer application was studied by Singh and Tomar (1971). They found that there was definite increase in yield due to application of irrigations over control. During 1969-70, a significant response to irrigation levels was recorded. Highest seed yield was recorded where irrigation was applied at every 40 days which was significantly superior over all others. Second best production was recorded with irrigation given at every 55 days followed by that given every 25 days. Lowest yield was recorded for control plots where no irrigation was given.

Irrigation requirement of raya and effect of irrigation applied at different growth stages in combination with three levels of nitrogen was studied by Mathur and Tomar (1972). Irrigation increased raya yield significantly. Irrigation at the pre-flowering stage was found to be the most beneficial. Two irrigations, first at the pre-flowering (40 to 45 days) and the second at the post-flowering (80 to 85 days) stages were recommended. The irrigation requirement of raya crop was to be around 32 cm which may be applied through heavy pre-sowing and two post-sowing irrigations at the aforesaid stages.

Free proline accumulation was measured by Waldren and Teare (1974) in leaves of intact sorghum and soybean grown in growth chambers and subjected to normal drought stress. Stomatal diffusive resistance and leaf water potential were used to determine the degree of stress at the time of proline analysis. Free proline did not accumulate markedly in either species until each was severely stressed, indicating that proline is not a sensitive indicator of drought stress. Free proline accumulated under less stress in soybean than in sorghum. Since soybean is less drought resistant than sorghum, proline accumulation may be indicator of drought resistance or susceptibility.

A field experiment was conducted by Krogman and Hobbs (1975) on yield and morphological responses of rape to irrigation and fertilizer treatments. Rape was grown for 3 years under four levels of irrigation. Irrigation produced more than double yield by promoting greater plant growth, more pods, more seeds/pod and larger seeds than where irrigation was not applied. Maximum yield (about 3000 kg/ha) was obtained where irrigation maintained soil moisture in the upper half of the available range until pod ripening. Oil content was increased by irrigation ; irrigation increased oil yield from 368 to 986 kg/ha.

Blum and Ebercon (1976) explored a possible association between free proline accumulation in water-stressed leaves and the drought resistance of various grain sorghum cultivars. Eight sorghum cultivars were grown in a growth chamber under a drying cycle and a subsequent recovery phase. Free proline, free ammonia, dark respiration rates and recovery rating were recorded, as well as desiccation tolerance of each cultivar when grown in the field. Proline accumulation was initiated in leaves of all cultivars as leaf water potential was reduced to -14 to -16 bars. Upon watering, free proline content was reduced abruptly. Cultivars differed significantly in maximum free proline accumulation. Free proline accumulation during water stress was correlated significantly with post-stress recovery rating. It was suggested that accumulated free proline in water-stressed sorghum leaves was related to the ability of cultivar to recover upon the relief of stress, possibly by way of proline's role as a source of respiratory energy in the recovering plant.

Clarke and Simpson (1978a) carried out an experiment to study the growth analysis of *Brassica napus* cv. Tower. The experiment was conducted in the field for two years under conditions with four planting densities and three water regimes. They noted that non-irrigated conditions caused a greater proportion of dry matter production to occur before flowering than after flowering, while the reverse occurred under irrigated conditions. Irrigation increased leaf area index (LAI). Maximum LAI occurred near the start of flowering and then declined rapidly. Maximum LAI was correlated with seed yield. Mean net assimilation rate (NAR) and mean crop growth rate (CGR) were influenced by irrigation. There was an increase in NAR during the ripening phase, suggesting increased photosynthetic efficiency. No evidence of a distinct optimum leaf area index was found.

Clarke and Simpson (1978b) studied the effect of irrigation and seeding rates on yield components of *Brassica napus* cv. Tower. The experiment was carried out in the field for two years under conditions of four planting densities and three water regimes. The number of branches/plant was scarcely affected by irrigation. The number of pods/plant was incresed by increased irrigation. The number of seeds/pod and 1000-seed weight also increased by irrigation. Yield was positively correlated with 1000-seed weight in both years. Yield component compensation was evident in the relationship of 1000-seed weight to pod number and number of seeds/pod.

Clarke and Simpson (1978c) reported that leaf osmotic potential was an indicator of crop water deficit and irrigation need in rapeseed. Leaf osmotic potential (L ψ_0) of field-grown rapeseed was measured under rainfed conditions and at two levels of irrigation. Seed yield of irrigated *B. napus* was substantially higher than that of the rainfed crop in both years. In 1975, the increase in yield of the low and high irrigation treatments were 89 and 213%, respectively. The corresponding increases for 1976 were 59 and 128%. Within year, seed yields of the three water regimes were significatly different.

Henry and MacDonald (1978) conducted an experiment to study the effect of soil and fertilizer nitrogen and moisture stress on yield, oil and protein contents of rape. They observed that yield and oil content increased with irrigation treatment..

Richards (1978) studied the genetic variatin in physiological and physicochemical parameters associated with drought resistance between cultivars in *Brassica napus* and *B. campestris*. Significant variation in proline accumulation, chlorophyll stability, germination rate and percentage, relative turgidity, growth rates and water use efficiency were found in plants grown under droughted conditions.

Richards and Thurling (1978a) investigated the variation between and within species of rape seed (*Brassica campestris* and *B. napus*) in response to drought stress. They observed a highly significant variation between cultivars in *B. campestris* for every parameters except straw weight. In *B. napus*, the yield components, pods/plant, pods/main axis, branches/plant and seeds/pod were all significantly reduced by drought. Thousand-seed weight was significantly affected by drought only in the late-flowering cultivars. With the exception of 1000-seed weight, yield component means in the treatment imposed from the commencement of pod-filling were significantly higher than those in the stem elongation or flowering treatments. Differences between means of the two latter treatments were not significant, which suggested that the plants were more sensitive to drought at flowering than at stem elongation.

Bhan (1979) studied the effect of soil moisture and nitrogen on mustard under Gangetic alluvium of Uttar Pradesh. Two varieties viz., Varuna and Appressed mutant, 4 soil moisture regimes and 4 levels of nitrogen showed profound variation in different growth and yield attributes. Varuna was found significantly superior to Appressed mutant in yield and yield contributing characters like siliquae/plant, length of siliqua and 1000-seed weight. Seed yield obtained with irrigation 75% available soil moisture depletion (ASMD) was found at par with irrigation after 60% ASMD and significantly superior to irrigation after 90% ASMD and unirrigated (control) plots. Plant height, secondary branches, siliquae/plant and 1000-seed weight were also improved significantly due to irrigation. The interactions of variety and irrigation showed a significant effect on seed yield indicating great responsiveness of Varuna to irrigation.

The response of Indian mustard to levels of irrigation and fertility in light-textured soil of Rajsthan was studied by Jain and Jain (1979). They observed an increase in yield with an increase in the irrigation over minimum level, but the differences were not significant. The overall average yield of 1893 kg/ha was with 3 irrigations. A further increase in irrigation gave an additional yield of only 100 kg/ha.

Joarder, Paul and Ghose (1979) conducted an investigation on the effect of irrigation and fertilizer on mustard. Three cultivars of mustard were grown on field plots with five levels of fertilizers and with or without irrigation. Irrigation gave 59% more seed yield than no irrigation. Higher seed yield in the irrigated plots were accompanied by increased pods/plant, seeds/pod and number of primary and secondary branches. The most significant increase (83%) was noted in the number of seeds/pod produced by late flowers under irrigation, whereas the increase for early-formed pods was only 6%. Increase in more than 20% for primary and secondary branches and pods/plant were also obtained with irrigation, but there were no significant differences in 1000-seed weight of early and late-flowered pods, though the seeds of irrigated plots were significantly heavier than the non-irrigated ones. Under irrigated conditions plants produced more primary and secondary branches, more late flowers produced seed-bearing pods and seeds grew slightly larger than without irrigation.

Bhan, Balaraju and Vidya Ram (1980) carried out an experiment on water use, yield and quality of rape as influenced by spacing, irrigation and time of harvest. They found that irrigation had a pronounced effect on the seed yield and the characters contributing to it, like siliquae/plant, seeds/siliqua and 1000-seed weight. The maximum yield was obtained with two irrigations administered at flower initiation and pod development. With one irrigation, better result was obtained when it was given at flower initiation than pod development. The yield was stepped up to 9.8 q/ha with irrigation at flower initiation from a mere 5.13 q/ha unirrigated control. The oil content in the seed was also highest (40.4%) with this treatment, which gave a difference of 2% over the unirrigated plot.

Bajpai, Singh and Chhipa (1981) studied the influence of sowing date and irrigation levels on growth and yield of mustard. The field study was conducted on 3 varieties, four sowing dates and three irrigation levels. The effect of moisture regimes on the yield was not found significant. But the plant height and number of pods/plant was influenced significantly due to moisture regimes and the maximum height and number of pods were recorded at irrigation water/cumulative pan evaporation (IW/CPE) ratio of 0.5.

Bhati and Rathor (1982) studied the response of Indian mustard to irrigation and nitrogen fertilizer. The treatment consisted of 3 levels of irrigation viz., no irrigation (I_0), one irrigation at flowering stage (I_1) and two irrigations, one at flowering and the other at seed setting stage (I_2). The experiment showed that irrigation treatment did not affect the seed yield, oil content and oil yield significantly yet a consistent increasing trend was observed. Except the number of siliquae/plant and stover yield, all other yield attributting characters also showed non-significant change due to irrigation. Studies on moisture depletion pattern from different soil depths and consumptive use indicate that the amount of water depleted from 0-15, 15-30 and 30-45 cm soil depth was 7.52, 5.43, 5.12; 10.01, 7.24, 6.60 and 11.64, 8.15, 7.09 cm in I_0, I_1 and I_2 treatments, respectively. The total consumptive water use thus obtained with different levels of irrigation was of the order of 18.07, 23.85 and 26.88 cm under I_0, I_1 and I_2 treatmetns, respectively.

Chaniara and Damor (1982) carried out a field experiment to study the effect of irrigation intervals and various levels of nitrogen and phosphorus on the yield of mustard variety Varuna. The treatment consisted of 3 levels of irrigation, 3 levels of nitrogen and two levels of phosphorus. The experiment indicated that the differences due to irrigation interval were significant in respect of number of siliquae/plant, weight of seeds/plant, seed yield and oil yield/ha. The average seed yield realised by 3, 5 and 7 irrigations during the crop growth period at 35, 25 and 15 days interval was 1686, 1893 and 1974 kg/ha, respectively. Maximum seed yield was recorded by giving 5 irrigations at 25 days interval. This may be attributed to higher number and weight of seeds/plant.

Singh (1983) investigated the response of mustard and chickpea to soil moisture in soil profile and plant population on aridisols. He obseved that the mean seed yield was 19.53 q/ha with high soil moisture and 13.66 q/ha with low soil moisture, the increase being 43% with soil moisture. An additional supply of 1 cm/1 m water in the soil profile gave 110.7 kg/ha greater mean seed yield of mustard. Seed yield of chickpea increased 23.3% with high soil moisture over low moisture. Harvest index in general increased with the supply of moisture. In chickpea, high moisture gave 21.9%

more straw yield. The harvest index in chickpea increased with an increase in soil profile moisture.

Khan and Agarwal (1985) worked on the effect of sowing methods, moisture stress and nitrogen levels on growth, yield components and seed yield of mustard. When compared with moisture stress on IW/CPE ratio of 0.4 enhanced all the growth and yield characters like plant height, branches/plant, dry matter, siliquae/plant, seeds/siliqua, 1000-seed weight and seed yield and a ratio of 0.6 further increased plant height and dry matter.

Mandal, Ray and Dasgupta (1986) made an investigation on the effect of water used by wheat, chickpea and mustard grown as sole crop and intercrop. They reported that with increase in the number of irrigations, there was an increase in the accumulation of dry matter and leaf area index (LAI). The grain yield of wheat showed an increasing trend with the increase in the level of irrigation. In chickpea, the differences between 2, 3 and 4 irrigations were not very high. Likewise, the difference between 3 and 4 irrigations was less in mustard.

Haque, Ahmed and Rahman (1987) worked on irrigation scheduling for optimum yield of M-248 (*Brassica juncea*) and M-12 (*Brassica campestris).* Crops were grown in the field and in the lysimeter (M-248 only) to investigate the effect of irrigation at particular stages of growth on the yield and water use efficiency. Significant increase in yield was found for most of the irrigation treatments compared with no irrigation. The yield increase was highly significant for two irrigations, one at the early vegetative stage and the other at the initial pod formation stage. The field and lysimetric results were almost identical in nature. The seed yield of 1103 and 1204 kg/ha was obtained for two irrigations in M-12 and M-248, respectively and the correspoding values for no irrigation were 269 and 416 kg/ha.

Reddy and Sinha (1987) studied the effect of irrigation and NP fertilization on the yield of Indian mustard. They observed that irrigation at 0.6 IW/CPE and 0.3 IW/CPE produced 17.9 and 16.4 q/ha while the unirrigated treatment gave 15 q/ha seed. Irrigation at o.6 IW/CPE produced significantly higher yield over no irrigation, but the difference in seed yield between 0.3 IW/CPE and 0.6 IW/CPE was not significant. Similarly, the difference in yield between 0.3 IW/CPE over no irrigation treatment was also not signficant. It was the combined effect of increased number of siliquae/plant and number of seeds/siliqua which resulted in higher seed yield under irrigation. One irrigation at 0.3 IW/CPE, which coincided with siliqua formation stage, was found critical for moisture. Irrigation at this stage mainly increased the siliqua size and seed size boosting total seed yield.

A field experiment was conducted by Singh, Gupta and Moinbasha (1987) to study the effect of moisture needs of Indian mustard-chickpea intercropping. They observed that with 1 and 2 irrigations, the grain yield of mustard increased by 4.19 and 4.93

q/ha over no irrigation in the first year and 3.41 and 4.46 q/ha in the second year. Further, the mustard yield with 2 irrigations was not significantly better than 1 irrigation. The plants utilized the maximum amount of water (213 and 230 mm) when they were irrigated twice instead of once (200.9 and 211.3 mm). Two irrigations caused 15.4 and 52.4 mm (mean) more moisture use than 1 irrigation and no irrigation, respectively. Moisture use efficiency increased with 1 irrigation by 0.18 kg/mm/ha over 2 irrigations and 0.57 kg/mm/ha over no irrigation. Thus, 1 irrigation produced 8.61 kg grain/mm/ha as compared with 8.43 and 8.04 kg grain/mm/ha with 2 irrigations and no irrigation, respectively.

Reddy, Sinha and Hedge (1988) conducted field experiments during rabi seasons of 1983-84 and 1984-85 to study the effect of irrigation, nitrogen and phosphorus fertilization on consumptive water use, yield, water use efficiency and moisture extraction by mustard. Irrigation at 0.6 IW/CPE produced significantly higher seed yield (21.6 q/ha) over no irrigation (18.3 q/ha), but the differences between the treatments 0.3 IW/CPE and 0.6 IW/CPE or 0.3 IW/CPE and no irrigation were not significant. Irrigation increased the number and size of the siliqua and seed yield per plant.

Sarkar, Ahsan, Sarker and Hossain (1989) studied the effect of nitrogen and irrigation at different stages of growth of mustard variety Sambal. There were four levels of irrigation : at (a) vegetative (25 DAS), (b) flowering (45 DAS), (c) siliqua-filling stage (65 DAS) and (d) rainfed control. They observed that the plant height was increased due to irrigation but the same at different stages of crop growth did not influence the height significantly. The plants irrigated at flowering stage produced the highest yield of seed. The stover yield was not significantly influenced by the irrigation at different stages of growth. The number of filled-siliquae/plant, the number of seeds/siliqua and 1000-seed weight increased due to irrigation at various stages of growth.

Sharma and Kumar (1989) conducted a field experiment to study the effect of irrigation on growth analysis, yield and water use in Indian mustard. They found that LAI, CGR, RGR, NAR and RLGR were significantly higher under 0.6 irrigation depth/cumulative pan evaporation ratio than under rainfed codition. An increase in the frequency of irrigation gave more branches/plant, siliquae/plant, seeds/siliqua, 1000-seed weight and seed yield in both the years. The moisture use from the soil decreased by 53.3 and 75.8% under 0.4 and 0.6 irrigation depth/cumulative pan evaporation ratio compared with rainfed condition.

A field experiment was conducted by Raja and Bishnoi (1990) to study root characters, evapotranspiration, water use efficiency, moisture extraction pattern and plant water relations of rape genotypes under varying irrigation schedules. They observed that increased irrigation frequency increased evapotranspiration but decreased water use efficinecy. The relative water content and osmotic potential of the leaves increased with more frequent irrigation, but plant water retention capacity decreased.

A field experiment was carried out by Sarker, Ahmed, Talukdar and Khan (1990) to study the influence of irrigation on the yield and water use of mustard mutant BINA-3. Irrigation treatments showed positive effect on the increase of yield of the mutant. The highest yield of 1.15 t/ha (17% higher over control) was obtained with one irrigation at the pre-flowering stage. Crop water use efficiency decreased with the increase of irrigation frequency. The results thus revealed that one irrigation at the pre-flowering stage (35-40 DAS) was sufficient for obtaining the optimum yield of the mustard mutant.

EXPERIMENT 1

EFFECT OF SOIL MOISTURE ON MORPHO-PHYSIOLOGICAL CHARACTERS AND YIELD OF MUSTARD(*BRASSICA JUNCEA* L.)

INTRODUCTION

Seed yield of mustard is increased by the presence of adequate soil moisture (Mathur and Tomar, 1972; Bajpai *et al.*, 1981; Bhati and Rathor, 1982; Mandal *et al.*, 1986; Reddy and Sinha, 1987). Water stress leads direct changes in the physical environment of the crops, and these changes may subsequently affect crop physiology. As the soil dries, the water potential decreases and so does the soil hydraulic conductivity. Thus it is more difficult for plants to extract water and, as a consequence the plant water potential tends to decrease (Gardner, 1960).

Water deficit in plants generally leads to reduced leaf water potential and stomatal closure, as manifested from an increased leaf resistance to transpiration. The effect of depletion and replenishment of soil water on transpiration are of specific importance to water use and its efficiency in crop production. The relative rates of absorption and transpiration determine plant's internal water balance, which directly affects the physiological and biochemical processes of plant growth (Teare and Kanemasu, 1972). Shortage of water in soil may cause a decrease in nutrient supply. Mobility of ions in the soil decreases as the soil dries and the ability of roots to take up some ions may also decrease (Dunhum and Nye, 1976). The consequent decrease in nutrient uptake may affect a wide range of physiological processes.

Variation in dry matter accumulation and yield influenced by soil moisture may be related to factors, such as leaf area index (LAI), crop growth rate (CGR), net assimilation rate (NAR) and leaf area ratio (LAR).

Crop plants accumulate free proline in their leaves when exposed to moderate to severe water stress (Palfi *et al.*, 1973).The physiological significance of this metabolic response to water is, however, contentious. Free sugars are also accumulated in the stressed plants (Stewart, 1971; Narasimha Rao and Shiv Raj, 1985). It is suggested that proline and sugar accumulating potential could serve as an index of drought resistance.

Stomata are recognized as the main site of transfer of water vapour and Co_2 between a plant and its environment (Milthorpe, 1969). There are few reports which indicate that stomatal frequency of leaves is affected by soil moisture (Ciha and Brun, 1975; Nerkar *et al.*, 1981).

The main objective of the present experiment was to study the effect of soil moisture on crop growth, development, dry matter production and partitioning, crop water use and yield of mustard.

MATERAIALS AND METHODS

Two mustard (*Brassica jencea* L.) cultivars viz., Sambal and Daulat were used as the plant material for the experiment.

The experiment was carried out in the Botanical Research Field of Rajshahi University. The soil of the experimental field was silty loam having a pH 7.5, low in organic carbon (0.44%), total N (0.43%) available P (15 ppm) and K (82 ppm). The field capacity of the soil was 35%. The field was prepared after repeated ploughing. Before sowing, a basal dose of nitrogen (60 kg/ha), phosphate (30kg/ha) and potash (30 kg/ha) were added. The experiment was arranged in a split plot design with three replications. After preparation of the field it was divided into two main plots. The main plots were treated as treatment plots. Each main plot was again subdivided into three replications. Each replication comprised 8 rows of 4 m long and 30 cm apart. Six rows for each cultivar were taken as experimental rows and two bordering rows were considered as non-experimental. The distance between plants within a row was approximatly 10 cm. Seeds were sown on I November, 1990. Two levels of irrigation treatment were adopted, viz., (i) irrigation at 10 days interval throughout the growing period (irrigated) and (ii) no irrigation (rainfed). On each occasion 10 mm of water was applied to the irrigated field with sprinklers. The irrigated Sambal received 80 mm and Daulat received 70 mm of irrigation water.

Twelve days after sowing (DAS), the seedlings were thinned to uniform and desirable number of plants. Necessary cultural practices, such as weeding and spraying of insecticides were done for normal growth and development of the plants.

Growth Analysis

Eleven harvests were taken at equal intervals of 7 days for growth analysis. Four plants were selected for each cultivar from each treatment for each harvest. The first harvest was taken at 20 DAS.At each harvest, the plants were cut just below the cotyledonary node and tops were separated into leaves, stem + petiole, flowers + buds and pods (when present). Before weighing, the plant parts were dried separately in an oven at about 85 ^{0}C for 24 hours till they reached constant weight.

Leaf area was measured by the disc method. Twenty discs were used in calculating the area. The area of the cork borer used for taking the discs was 0.5675 cm^2. Discs were weighed after oven-drying and leaf area was calculated by using following formula:

$$\text{Area of leaves} = \frac{\text{Area of dics} \times \text{Weight of leaves}}{\text{Weight of discs}}$$

Both the harvest interval method (classical technique) and the curve-fitting method (functional technique) were followed to determine different growth attributes. From the dry weight of different plant parts and leaf area data, the following growth attributes were calculated between two successive harvests by following the technique of growth analysis (Radford, 1967) :

1. Crop growth rate (CGR) = $\dfrac{W_2 - W_1}{t_2 - t_1}$

2. Relative growth rate (RGR) = $\dfrac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$

3. Net assimilation rate (NAR) = $\dfrac{(W_2 - W_1)\ (\log_e LA_2 - \log_e LA_1)}{(LA_2 - LA_1)\ (t_2 - t_1)}$

4. Leaf area ratio (LAR) = $\dfrac{(\log_e W_2 - \log_e W_1)\ (LA_2 - LA_1)}{(W_2 - W_1)\ (\log_e LA_2 - \log_e LA_1)}$

5. Relative leaf growth rate (RLGR) = $\dfrac{\log_e LA_2 - \log_e LA_1}{t_2 - t_1}$

6. Leaf area duration (LAD) = $\dfrac{(LA_1 + LA_2)}{2}\ (t_2 - t_1)$

The following attributes were calculated separately for each harvest :

7. Leaf area index (LAI) = $\dfrac{\text{Leaf area}}{\text{Ground area}}$

8. Specific leaf area (SLA)= $\dfrac{\text{Leaf area}}{\text{Leaf dry weight}}$

9. Leaf weight ratio (LWR) = $\dfrac{\text{Leaf dry weight}}{\text{Total plant dry weight}}$

Where, W_2 and W_1 are the tatal dry weights, LA_2 and LA_1 are the leaf area per plant at t_2 and t_1, the latter and the former harvest, respectively.

In the curve-fitting method, polynomial functions were fitted to natural logarithmic values of total dry weight and total leaf area, using a scientific calculator. The $\log_e$ transformation was made in order to render the variance homogeneous with time (Hughes and Freeman, 1967). The selection of appropriate polynomial regression model was made by 'lack of fit' method of Nicholls and Calder (1973). The second degree polynomial curves have been used in all respects. The second degree formulae for growth attributes in the functional technique used were as follows :

1. $RGR = b + 2\,ct$
2. $LAR = \text{Antilog}_e\ (\log_e LA - \log_e W)$
3. $NAR = RGR/LAR$
4. $RLGR = b' + 2\,c't$

Where, b and c are constants of dry weight and b' and c' are constants of leaf area per plant obtained from polynomial equations and t is the instanteneous time of harvest. From similar curves fitted to $\log_e$ total dry weights, $\log_e$ leaf weights and $\log_e$ leaf area, it was possible to derive values for specific leaf area (SLA) and leaf weight ratio (LWR).

Relative Leaf Water Content (RLWC)

Relative leaf water content (RLWC) was determined from the fully matured 3rd or 4th leaf. The leaves were collected at 8 A.M., 12 Noon and 4 P.M. and 20 discs were taken from leaves of each replication of each cultivar of each treatment. Their fresh weights were taken immediately and were sinked into water kept in petri dish for 3 hours. After 3 hours when the cells of the discs became fully turgid they were taken off from water and after drying with blotting paper their turgid weights were determined. Then the discs were dried in an oven and weighed. The relative leaf weter content was calculated from the following formula (Weatherly, 1950):

$$\text{Relative leaf water content(RLWC)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

RLWC was determined at both the flowering and the mid-pod filling stages.

Chlorophyll Content

Chlorophyll contents were estimated at both the flowering and the mid-pod filling stages. Three discs, each of 0.5675 cm^2 area were taken from three different positions of the 4th leaf. Chlorophyll was extracted with 80% aquous acetone using a morter and pestle to grind the tissues. The suspension was decanted into centrifuge tubes and centrifuged it for 3 minutes. The clear green solution was then decanted from the colourless residue and made up to 10 ml with 80% acetone. The optical density (O.D.) of this solution was determined against 80% acetone as blank using a Spectrophotometer at 645 and 663 nm. The chlorophyll a and b were determined according to the formulae given by Mackinney (1941) and later used by Arnon (1949) as follows :

Chlorophyll a = 12.717 A_2 - 2.584 A_1 = mg Chl. a per litre.

Chlorophyll b = 22.869 A_1 - 4.670 A_2 = mg Chl. b per litre.

Where A_1 and A_2 are O.D. at wavelengths of 645 and 663 nm, respectively. Amount of chlorophyll per unit of area was calculated in the following way :

$$\frac{\text{mg Chl. a or b per litre} \times 10}{1000 \times \text{leaf area}}$$

Estimation of Proline

Proline estimation of the leaves was done according to Bates *et al.* (1973). For estimation of proline the reagents required were (1) 3% aquous sulphosalicylic acid, (2) Glacial acetic acid, (3) Toluene, (4) Proline (AR) and (5) Acid ninhydrin reagent [6M orthophosphoric acid (20 ml) + glacial acetic acid (30 ml) + ninhydrin (1.25 g)].

At first 0.5 g fresh leaf was homogenized in 10 ml of 3% aquous sulphosalicylic acid and centrifuged it for 6 minutes. The clear solution was separated and 2 ml of it was reacted with 2 ml of acid ninhydrin and 2 ml of glacial acetic acid in a test tube.

Then it was boiled in a boiling water bath for 1 hour and the reaction was terminated in an ice bath. The reaction mixture was then extracted with 4 ml of toluene, mixed vigorously with stirring for 15-20 seconds. The chromophore containing proline - toluene was separated with a separating funnel and warmed to room temperature. The optical density (O.D.) at 520 nm was read using toluene as blank. Proline content was determined from the standard curve (Figure 0.1). Proline (AR) was used for the preparation of standard curve.Proline content of leaves was determined at the flowering and mid-pod filling stages.

Stock solution of 1 millimole was prepared by dissolving 0.1151 g of proline (AR)in distilled water and made up to 1000 ml.By successive dilution 2 ml of solution containing 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 micromole concentrations were prepared and reacted with acid ninhydrin and glacial acetic acid as described earlier. The colour was read at 520 nm and the O.D. was plotted against concentration (Figure 0.1).

Estimation of Sugar

Estimation of total free sugar of the leaves was done according to the anthrone method. For estimation of sugar, the reagents required were (1) 0.2% anthrone reagent (200 mg of anthrone in 100ml of conc. H_2So_4), (2) Ethyl alcohol and (3) Standard glucose solution (10 mg of glucose in 100 ml of distilled water).

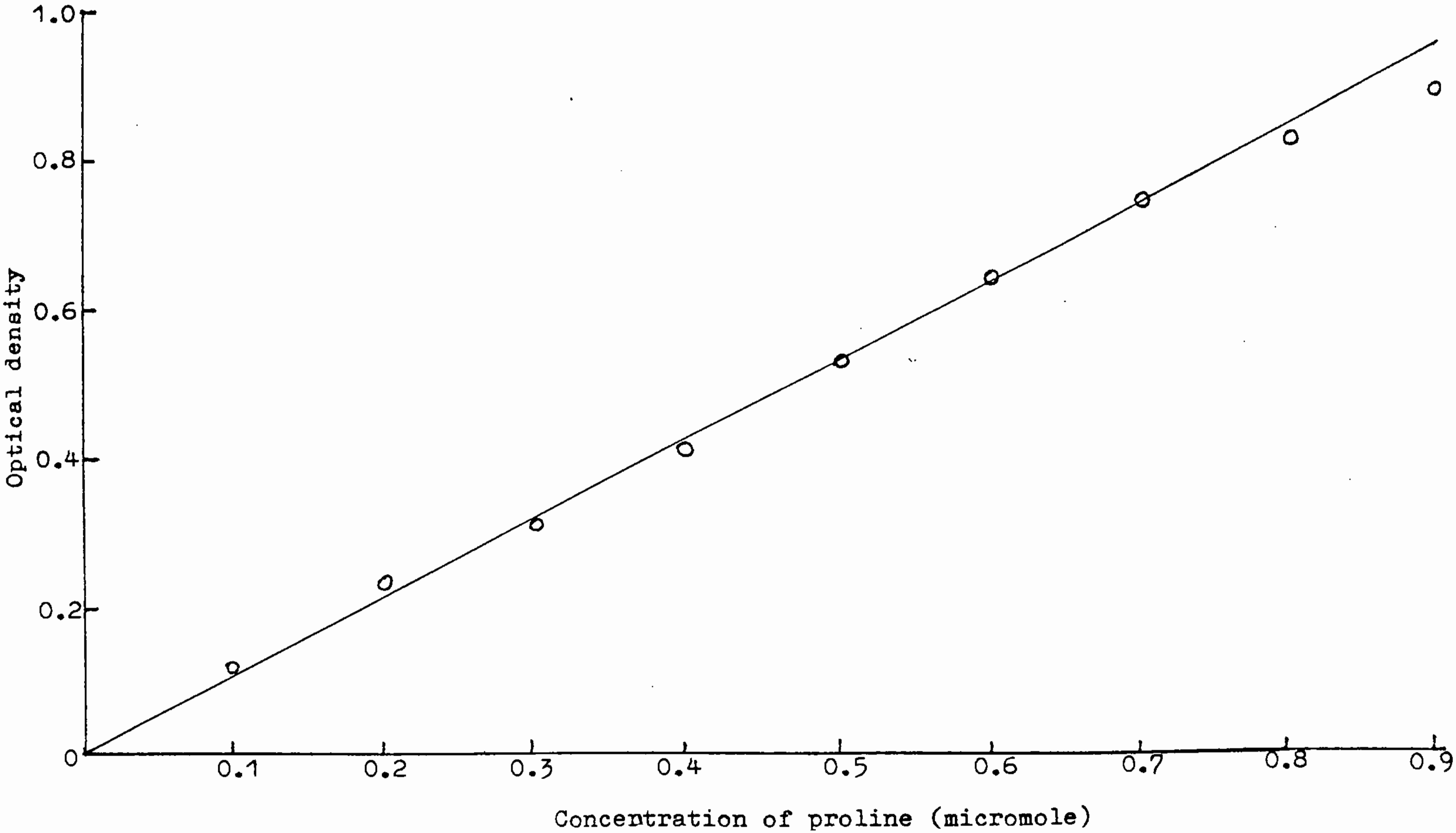

Figure 0.1. Standard curve for proline.

At first 1 g of dry leaf was homogenized with distilled water. The mixture was filtered with a double-layered muslin cloth. The filtrate was diluted with twice volume of ethyl alcohol and was kept in a cool place overnight. In the next morning, the mixure was centrifuged and the clear solution was separated. The volume of the extract was evaporated to about one-fourth of the volume over a water bath and cooled. This reduced the volume of the extract and was then transferred to a 100 ml volumetric flask and made up to the mark with distilled water.

One ml of the distilled extract from each sample was pipetted into test tubes. Four ml of the anthrone reagent was added to each of this solution and mixed well.Glass marbles were placed on top of each tube to prevent evaporation. The tubes were placed in boiling water bath for 10 minutes, then removed and cooled. A reagent blank was prepared by 1 ml of water and 4 ml of reagent in a test tube and treated similarly. The optical density (O.D.) of the blue green solution was measured at 620 nm using a Spectrophotometer. Sugar content was determined from the standard curve (Figure 0.2). Sugar content was determined at both the flowering and mid-pod filling stages.

The standard curve of glucose was prepared by taking 0.0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1 ml of standard glucose solution in different test tubes contaning 0.0, 10, 20, 40, 60, 80 and 100 μg of glucose, respectively and made the volume up to 1 ml with

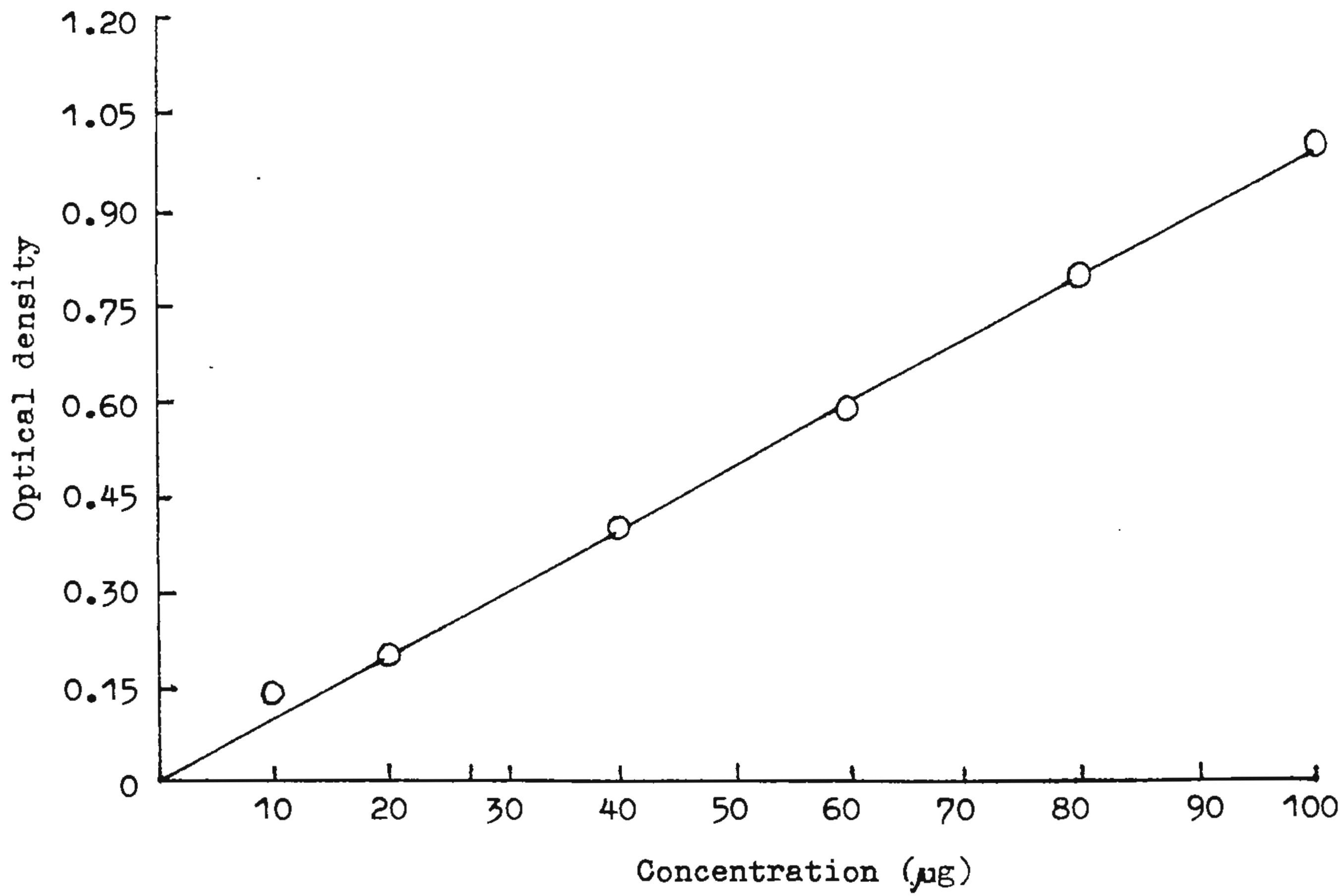

Figure 0.2. Standard curve for glucose.

distilled water. Four ml of anthrone reagent was added to each test tube and mixed well. All these solutions were treated similarly as described above. The colour was read at 620 nm and the O.D. was plotted against concentration (Figure 0.2).

The Relation Between Leaf Water Content and Transpiration Rate

Hygen's (1951) quick weighing method for the analysis of transpiration of detached leaves was used for the comparison of the relationship between leaf water status and stomatal behaviour. Leaf samples were collected on sunny morning in polythene bags. The cut end of the petiole of the leaves was kept into water in beakers under bell jars in a humid condition for about 3 hours. Leaves were then rapidly dried with filter paper and weighed. The water loss was followed for 3 hours by recording fresh weight(FW) at intervals of 10 minutes for the first 90 minutes and then at intervals of 30 minutes. Between weighings, the leaves were kept in semi-controlled environment (light intensity 2.37 klux, temperature 25 ^{0}C and R.H. 50%) with their adaxial surface uppermost. The leaves were drawn on chromatographic paper to determine leaf area and the dry weight (DW) of the leaves was taken at the end of the experiment. The initial weight was considered as the turgid weight (TW). Relative leaf water content (RLWC) at any point during a drying cycle was calculated from the following formula :

$$RLWC = \frac{FW - DW}{TW - DW} \times 100$$

The curve is divisible into 3 phases. The first and final linear phases when the stomata were opened (stomatal loss) and closed (cuticular loss), and a curvilinear phase during the time of stomatal closure. The point of intersection of the two linear portions of the curve has been taken as indicating the relative water content at stomatal closure (Jarvis and Jarvis, 1963). Stomatal and cuticular water loss have been calculated from the transpiration decline curves. These were determined at both the flowering and mid-pod filling stages.

Stomatal Characters and Leaf Anatomy

The number of stomata and the number of epidermal cells were counted and stomatal pore length was measured on the adaxial and abaxial surfaces by applying Quickfix (Wembley Enterprises, India) on the leaf segments. The number of stomata and epidermal cells of five random focuses was counted under a compound microscope with 15 x 40 magnification and subsequently converted to the number per mm^2 of leaf area. The stomatal pore lengths were measured and converted to µm. From the number of stomata and epidermal cells stomatal index was also calculated according to the following formula :

$$\text{Stomatal index} = \frac{\text{Number of stomata}}{\text{Number of stomata + Number of epidermal cells}} \times 100$$

For anatomical study, leaf segments were fixed in acetic-alcohol fixative (3 parts of 70% ethyl alcohol and 1 part glacial acetic acid)for about twelve days and then transferred to 70% ethyl alcohol. Transverse sections of the colourless segments were cut by a blade and were projected by a camera lucida and outline of the cells of the leaf tissues was drawn on paper. From the outline, leaf thickness was determined and was converted into µm. The outline of five random cells of palisade parenchyma and five spongy parenchyma were also drawn on chromatographic paper and the cross-sectional area was determined and then converted into μm^2.

Characters Related to Flowering

Days taken to first flowering were noted. Plant height and the number of leaves at first flowering were also recorded. Duration of flowering i.e., days taken from first flowering to last flowering was also noted.

Flowering Pattern and Pod Abortion

The cumulative number of flowers opened on the main axis and primary branches 1-3 was counted on alternate days. Pod abortion was also calculated on the main axis and primary branches 1-3 according to the following formula :

Pod abortion (%) =

$$\frac{\text{Number of flowers opened finally} - \text{Number of pods matured}}{\text{Number of flowers opened finally}} \times 100$$

Pod and Seed Growth

For determining pod and seed growth, 8 harvests were taken at equal intervals of 5 days. The first harvest was taken at 10 days after flowering (DAF).Twenty pods were taken from the lower part of the main branch per replication per cultivar per treatment. Then the pods were dried in an oven at about 85 ^{0}C for 24 hours and weighed.

For calculating seed growth, the seeds of a pod collected from mid-position of the main branch were also dried and weighed.

Yield and Yield Components

The final harvest was done for Sambal at 100 and Daulat at 95 Days after sowing. Six plants per replication per cultivar per treatment were harvested and measurments of yield and yield components were made. The following characters were recorded :

Plant height at maturity, length of main axis, number of branches/plant, number of pods on main axis, number of pods/plant, number of seeds/pod, pod weight/plant, straw weight, 1000-seed weight, seed-husk weight ratio, harvest index, seed yield/ha and oil content of seeds.

Harvest index was calculated as follows :

$$\text{Harvest index \%} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 = \frac{\text{Seed yield}}{\text{Total dry weight}} \times 100$$

Oil content of seeds was estimated by the Soxhlet method using petroleum ether (boiling point 40-60 ^{0}C) as solvent.

Soil Moisture Determination

Soil moisture was determined gravimetrically from five successive soil layers (0-20, 20-40, 40-60, 60-80, 80-100 cm) beginning from 15 DAS up to the final harvest at 10 days intarvals. The moisture content values were used to compute consumptive water use (Dastane, 1972) according to the following formula :

$$\text{Consumptive water use (CWU)} = IR + ER + \Sigma^{n}_{i=1} \frac{Mb_i - Me_i}{100} \times A_i \times D_i$$

Where IR =irrigation water, ER = rainfall, Mb_i = moisture % at the beginning of the season of the ith layer of the soil, Me_i = Moisture % at the end of the season of the ith layer of the soil, A_i = apparent specific gravity of the ith layer of soil, D_i = depth of the ith layer of the soil within root zone and n = no. of soil layers in the root zone D.

Water Use Efficiency (WUE)

WUE was computed by using the following formula :

WUE (kg/ha/mm) = Seed yield (kg/ha)/consumptive water use (mm).

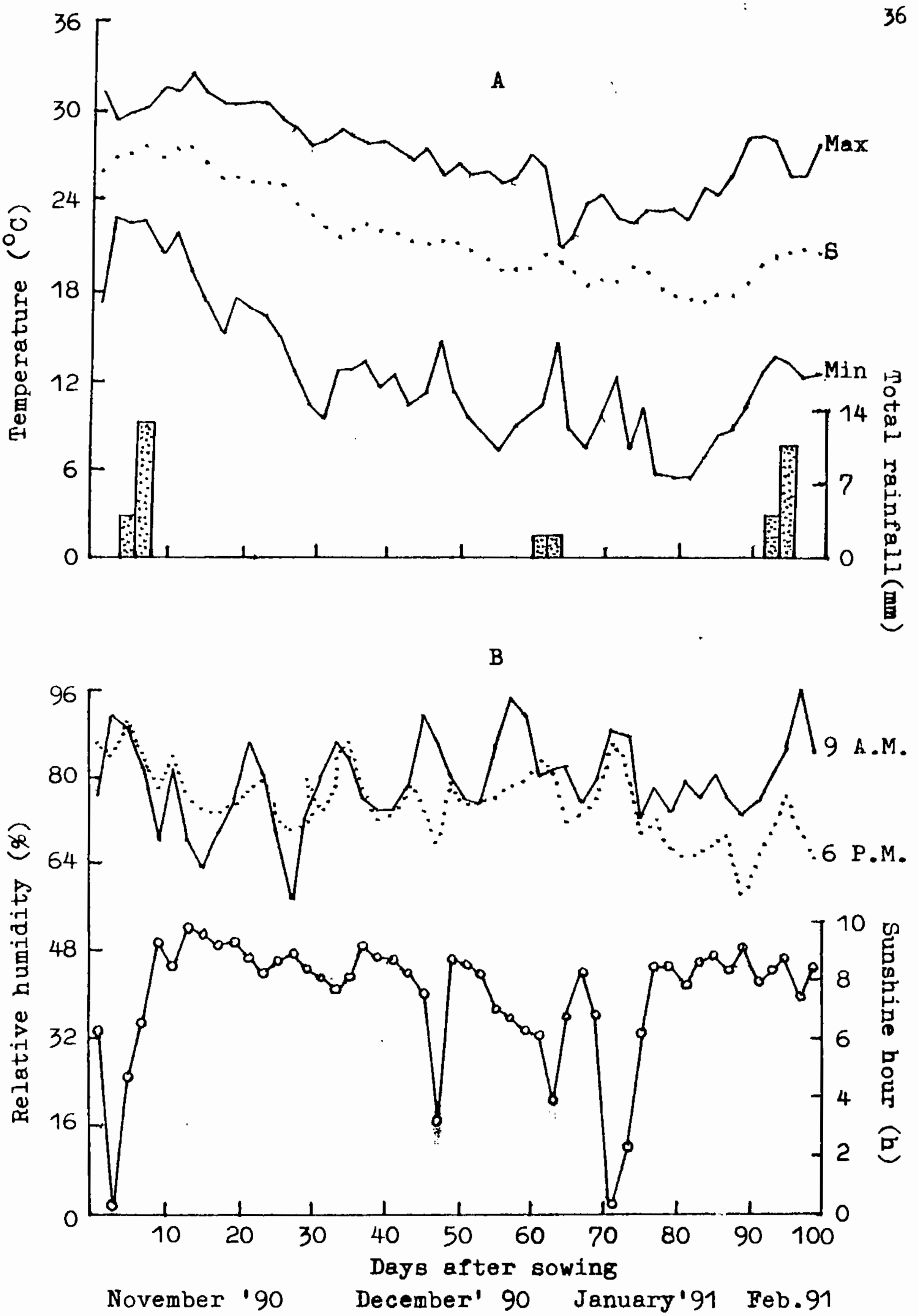

Figure. 0.3. Meteorological information during the crop period. A. Max=maximum, Min=minimum and S=soil temperature(°C) and total rainfall(histogram). B. Relative humidity at 9 A.M.(continuous line), 6 P.M.(dotted line) and sunshine hour (O-O).

Meteorological Data

Meteorological data were collected from the Regional Meteorological Station, Sampur, Rajshahi. The meteorological station is about 1 km from the experimental field. The information like maximum and minimum temperatures, humidity, rainfall, soil temperture and sunshine hours were collected (Figure 0.3).Total rainfall during the experimental period was 38 mm.

Statistical Analysis of Data

The experimental design was a split plot design and the analysis of variance was done accordingly. Least significance difference (LSD) values at 5% level were calculated, where the value of variance ratio (F) for treatment effect in case of figures and treatment, cultivar and interaction effects in case of tables were significant. Simple correlation coefficients were calculated between pair of characters.

The following notations have been used to specify statistical significance throughout the thesis :

* = Significant at p = 0.05

** = Significant at p = 0.01

*** = Significant at p = 0.001 and

NS = Non-significant

Vertical bars = LSD values at 5% level between treatments within a cultivar.

RESULTS

Choice of Growth Analysis Technique

Growth analysis has long been established as a standard technique for the study of plant growth and productivity.Out of the two approaches followed, the classical one relies strictly on the harvest data sets where parameters like mean growth rate (RGR) between a pair of harvests are taken into consideration, while the second one uses regression procedures. In the latter, a suitable mathematical function represented by a smooth curve is fitted to the recorded values of plant dry weight (W) or leaf area (LA) so that it approximates the real growth curve. However, the major difficulty encountered in the classical approach is of the sampling error of the primary data which seriously obliterates the derived functions. In the regression analysis, on the other hand, looser confidence limits are acceptable; however,the major problem lies in the choice of a suitable function that represents the best approximation of the observed growth. Amongst the various statistical models proposed, polynomial exponential model has been the most popular one because the simple mathematical and statistical properties of the model enable it to be fitted to data by an exact and relatively straightforward models of linear regression. After reviewing different methods it is concluded that use of polynomials is preferable in growth analysis. A polynomial exponential model has great potential in a purely empirical approach to the study of plant growth where the objective is to assess and compare either genetic or environmental influences.In the present experiment both the classical and the polynomial exponential techniques were followed.

The residual sum of squares were calculated for linear, quadratic and cubic equations fitted to $\log_e$ total dry matter per unit ground area, $\log_e$ LAI, $\log_e$ total dry matter per plant, $\log_e$ leaf area, and $\log_e$ leaf dry weight as a function of time (Table 1.1.).The changes in LAI, leaf area and leaf weight were adequatedly described by second degree polynomial in the two cultivars ($p = 0.01$), but in the case of total dry matter per unit ground area and total dry matter per plant a third degree polynomial was adequate. For comparison the second degree polynomial curves have been used in all the cases .

Coefficients obtained from quadratic fitted curves of $\log_e$ leaf area of two mustard cultivars as influenced by soil moisture are given in Table 1.2. For all the equations the a,b, a' and b' coefficients were positive and c and c' coefficients were negative. In all the cases the coefficients for the irrigated values were greater than the rainfed values, except for c and c', where, for Sambal these were equal and for Daulat the irrigated c and c' were smaller than that of the rainfed treatment .

Total Dry Matter (TDM)

Effect of soil moisture on total dry matter of two mustard cultivars at different stages of growth is shown in Figure 1.1.

Table 1.1. Reduction in mean squares due to successive terms of two mustard cultivars as influenced by soil moisture.

$\log_e$ Total dry Matter ($g\ m^{-2}$)

Sources of variation	df	Mean squares			
		Sambal		Daulat	
		Irrigated	Rainfed	Irrigated	Rainfed
Reduction due to linear	1	21.331**	19.287**	20.989**	17.680**
Deviation from linear	9	0.386	0.349	0.541	0.394
Reduction due to quadratic	1	3.217**	2.810**	4.231**	2.893**
Deviation from quadratic	8	0.033	0.041	0.080	0.081
Reduction due to cubic	1	0.210**	0.228**	0.611**	0.563**
Deviation from cubic	7	0.007	0.014	0.004	0.012

Contd ......

Table 1.1. (Continued).

$\log_e$ LAI

Sources of variation	df	Mean squares			
		Sambal		Daulat	
		Irrigated	Rainfed	Irrigated	Rainfed
Reduction due to linear	1	1.581	0.163	0.169	1.035
Deviation from linear	7	0.762	0.918	1.108	0.945
Reduction due to quadratic	1	5.003**	5.838**	7.394**	5.377**
Deviation from quadratic	6	0.056	0.098	0.060	0.207
Reduction due to cubic	1	0.010	0.156	0.089	1.078
Deviation from cubic	5	0.065	0.087	0.054	0.323

$\log_e$ Total Dry Matter (mg/plant)

Sources of variation	df	Mean squares			
		Sambal		Daulat	
		Irrigated	Rainfed	Irrigated	Rainfed
Reduction due to linear	1	20.360**	19.262**	22.470**	17.776**
Deviation from linear	9	0.018	0.349	0.498	0.397
Reduction due to quadratic	1	2.830**	2.811**	3.990**	2.918**
Deviation from quadratic	8	0.019	0.041	0.063	0.081
Reduction due to cubic	1	0.130**	0.231**	0.300*	0.564**
Deviation from cubic	7	0.003	0.014	0.027	0.013

Contd ......

Table 1.1. (Continued).

$\log_e$ Leaf Area (cm^2/plant)

Sources of variation	df	Mean squares			
		Sambal		Daulat	
		Irrigated	Rainfed	Irrigated	Rainfed
Reduction due to linear	1	1.542	0.125	0.178	1.004
Deviation from linear	7	0.743	0.858	1.059	0.909
Reduction due to quadratic	1	4.881**	5.066**	6.949**	5.437**
Deviation from quadratic	6	0.053	0.157	0.077	0.154
Reduction due to cubic	1	0.015	0.137	0.095	0.706
Deviation from cubic	5	0.061	0.160	0.074	0.044

$\log_e$ Leaf Weight (mg/plant)

Sources of variation	df	Mean squares			
		Sambal		Daulat	
		Irrigated	Rainfed	Irrigated	Rainfed
Reduction due to linear	1	1.115	0.063	0.124	1.051
Deviation from linear	7	0.725	1.046	1.011	1.049
Reduction due to quadratic	1	4.903**	6.370**	6.673**	5.793**
Deviation from quadratic	6	0.029	0.159	0.067	0.259
Reduction due to cubic	1	0.015	0.009	0.250	1.452
Deviation from cubic	5	0.031	0.189	0.031	0.020

Table 1.2. Constants obtained from quadratic fitted curves of $\log_e$ total dry matter and $\log_e$ leaf area of two mustard cultivars as influenced by soil moisture.

$\log_e$ Total Dry Matter (g/plant)

	a	b	c
		Sambal	
Irrigated	5.3429	0.1436	-0.0012
Rainfed	5.1368	0.1415	-0.0012
		Daulat	
Irrigated	5.1479	0.1620	-0.0014
Rainfed	5.0264	0.1407	-0.0012

$\log_e$ Leaf Area (cm^2/plant)

	a'	b'	c'
		Sambal	
Irrigated	3.4617	0.1669	-0.0026
Rainfed	3.4516	0.1529	-0.0026
		Daulat	
Irrigated	3.5914	0.1796	-0.0031
Rainfed	3.5401	0.1336	-0.0027

Increase of total dry matter was slow at the early vegetative phases (20, 27, 34 and 41 DAS), but increased rapidly with the advancement of the growth period in both the cultivars and treatments. The irrigated plants had always greater total dry matter than the rainfed plants. Significant increase of total dry matter production with irrigation was observed at almost all the stages of growth except at 20, 76 and 90 DAS in Sambal and 20 DAS in Daulat. Daulat had relatively higher dry matter accumulation than Sambal in the irrigated condition but it had lower dry matter in the rainfed condition .

Mean squares from the analysis of variance of curve-fitted values of TDM, LAI, LAD and some other growth attributes of two mustard cultivars as influnced by soil moisture are presented in Table 1.3. In case of TDM (g m^{-2}) significant effect was found for treatment,harvest date,cultivar x treatment and treatment x harvest date. The curves of TDM (Figure 1.1) indicated that they were not adequately fitted. The curve-fitting method yielded unusual curves for TDM, where there was a decline at the later stages of growth.

Leaf Area Index (LAI)

Effect of soil moisture on LAI showed that the pattern of its development was essentially similar in both the treatments and cultivars(Figure 1.2).In every cultivar and treatment starting from a lower value,LAI reached a certain peak and then declined to zero. In Sambal,both the irrigated and the rainfed LAI reached their peak

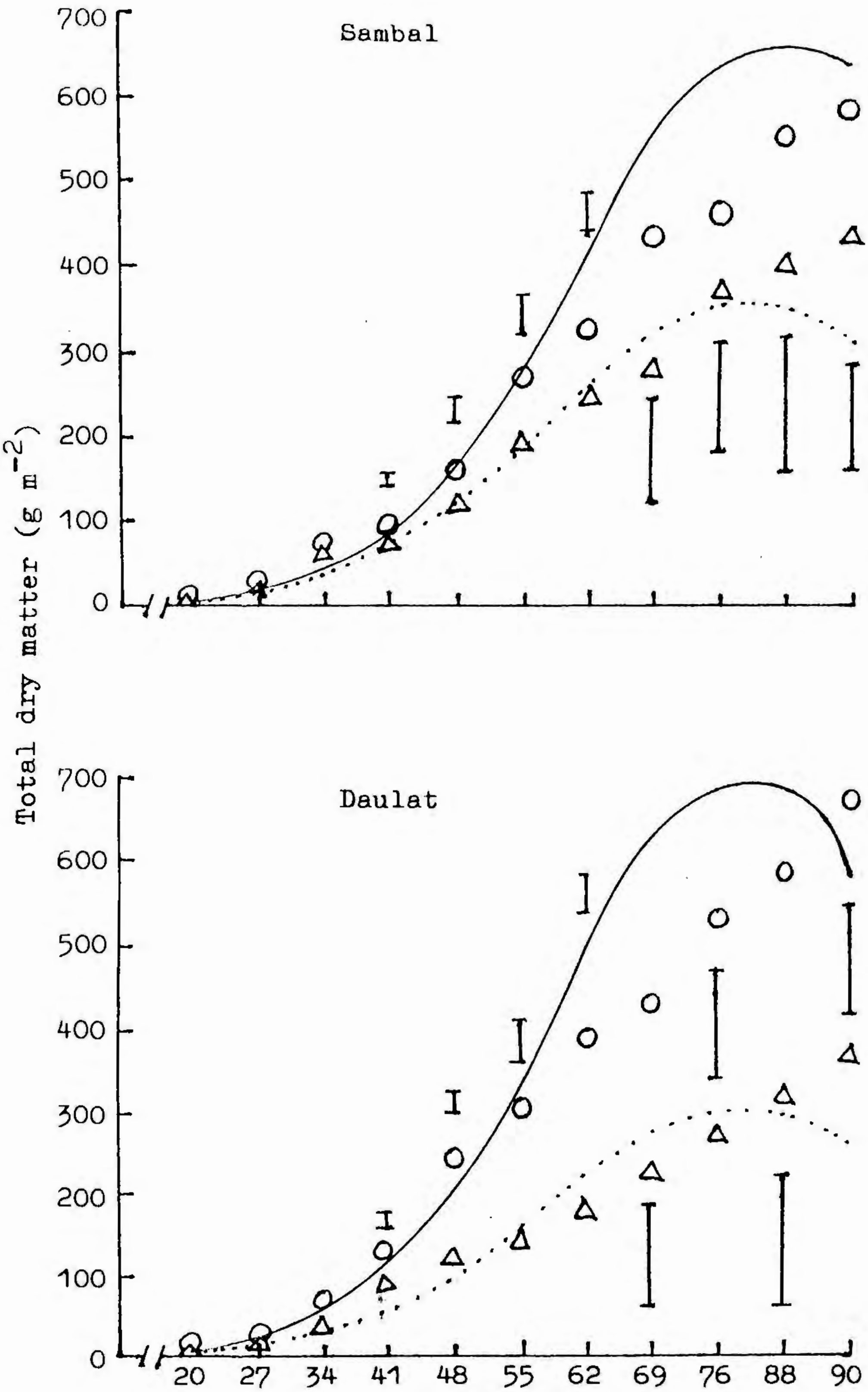

Figure 1.1. Effect of soil moisture on total dry matter (TDM) of two mustard cultivars at different stages of growth. O=irrigated and Δ=rainfed from original values ; smooth line for irrigated and dotted line for rainfed from quadratic curve-fitted values.

at 55 DAS but in Daulat the irrigated LAI at 55 and rainfed LAI at 48 DAS. The irrigated plants had higher LAI at all the stages of growth. Significantly higher LAI was found in the irrigated plants for Sambal at 24, 48, 55, 62 and 76 DAS and for Daulat at all the stages of growth except at 20 and 76 DAS. The highest LAI was found in the irrigated Daulat and the lowest in the rainfed Daulat .

Mean squares from the analysis of variance of curve-fitted values of LAI indicated that the soil moisture,cultivar and harvest date effects were significant (Table 1.3). The interactions like cultivar x treatment, treatment x harvest date were also significant. LAI calculated by the harvest interval method showed a close a correspondence with the instantaneous values of LAI obtained from curve-fitting method (Figure 1.2). Maximum LAI was under-estimated in the fitted data in all cases, except in the irrigated Sambal, where it was over-estimated .

Leaf Area Duration (LAD)

The pattern of LAD was similar as in LAI (Figure 1.3). In Sambal, LAD reached its peak at (55-62) DAS in both the irrigated and the rainfed plants, whereas in Daulat, it reached its peak at (48-55)DAS in the irrigated plants and at (41-48)DAS in the rainfed plants.The LAD values of the irrigated plants were higher than that of the rainfed plants in both the cultivars. The irrigated plants had significantly greater LAD at (20-27), (27-34), (48-55) and (62-69) DAS in Sambal and in Daulat at all the stages of growth except

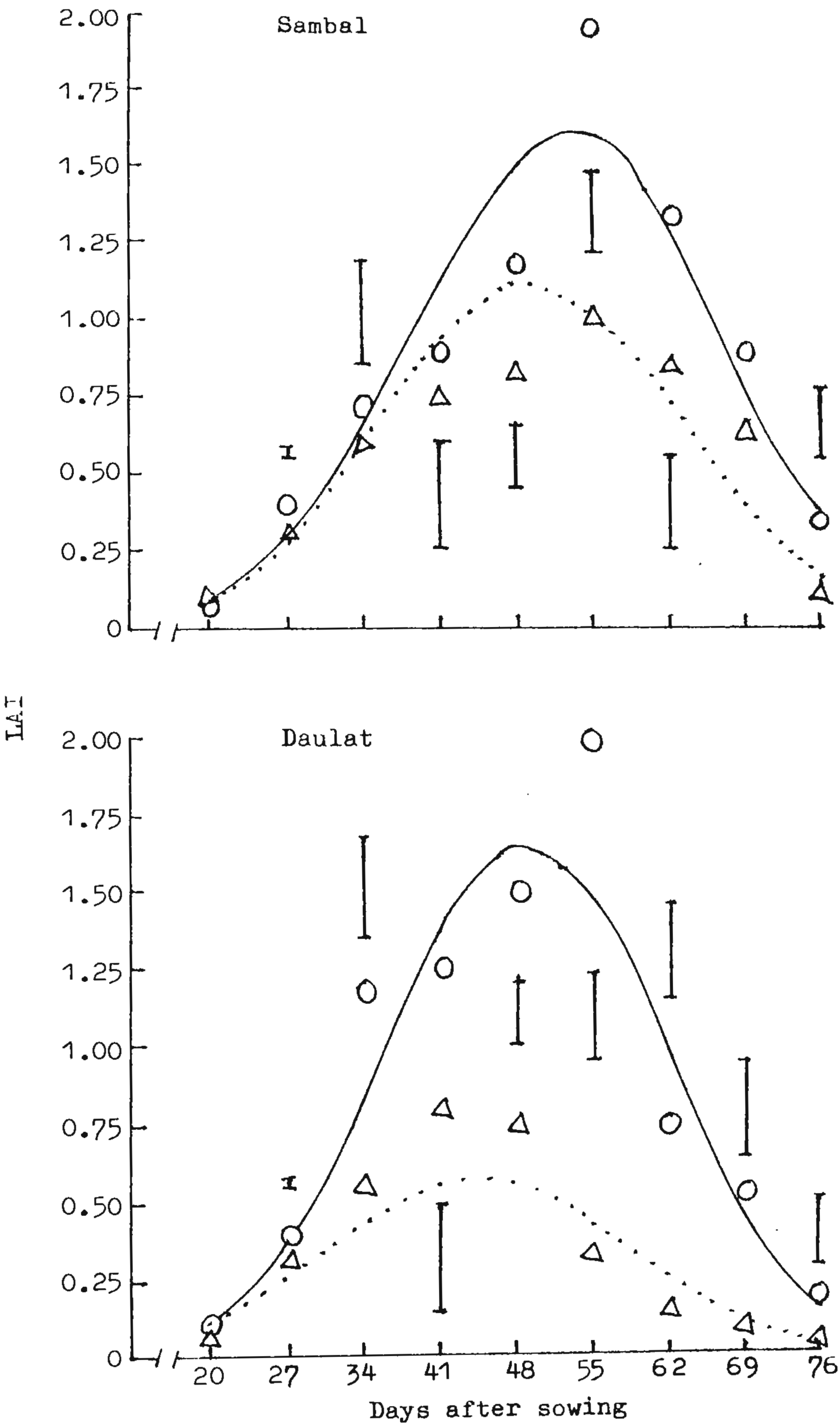

Figure 1.2. Influence of soil moisture on leaf area index (LAI) of two mustard cultivars at different stages of growth. O=irrigated and Δ=rainfed from original values ; smooth line for irrigated and dotted line for rainfed from quadratic curve-fitted values.

Table 1.3. Mean squares from the analysis of variance of TDM, LAI, LAD and some other growth attributes of two mustard cultivars as influenced by soil moisture (calculated from quadratic curve-fitted values).

Sources of variation	TDM ($g\ m^{-2}$)		LAI		LAD (days)		CGR ($g\ m^{-2}\ day^{-1}$)		RGR ($g\ g^{-1}\ day^{-1}$)	
	df	Mean squares	df	Mean squares	df	Mean squares	df	Mean squares	df	Mean squares
Treatment (T)	1	280112***	1	1.3728***	1	67.29***	1	201.960***	1	950.59**
Cultivar (C)	1	37	1	0.5560**	1	9.88*	1	216.640***	1	199.33
Harvest (H)	10	165803***	8	0.1981**	8	31.46**	9	5.520	10	24205.93***
T x C	1	9524	1	0.1381*	1	6.80*	1	0.002	1	522.20*
C x H	10	520	8	0.0272	8	1.12	9	4.360	10	542.95**
T x H	10	20771***	8	0.0695*	8	3.45*	9	2.350**	10	308.18**
T x C x H	10	753	8	0.0146	8	0.94	9	7.010	10	78.60

Sources of variation	df	Mean squares				
		NAR x 10^{-4} ($g\ cm^{-2}day^{-1}$)	LAR ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ day^{-1}$)	SLA ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)
Treatment (T)	1	0.00033**	323.94**	0.00360***	0.21	0.0062
Cultivars (C)	1	0.00001	365.90*	0.00280***	5649.99***	0.0062
Harvest (H)	8	0.01296***	464.93**	0.04224***	387.42	0.4125***
T x C	1	0.00013*	61.80	0.00032*	1750.07*	0.0182*
C x H	8	0.00002	76.01	0.00012	102.47	0.0093*
T x H	8	0.00003	63.47	0.00006	516.69	0.0007
T x C x H	8	0.00002	27.02	0.00005	189.58	0.0018

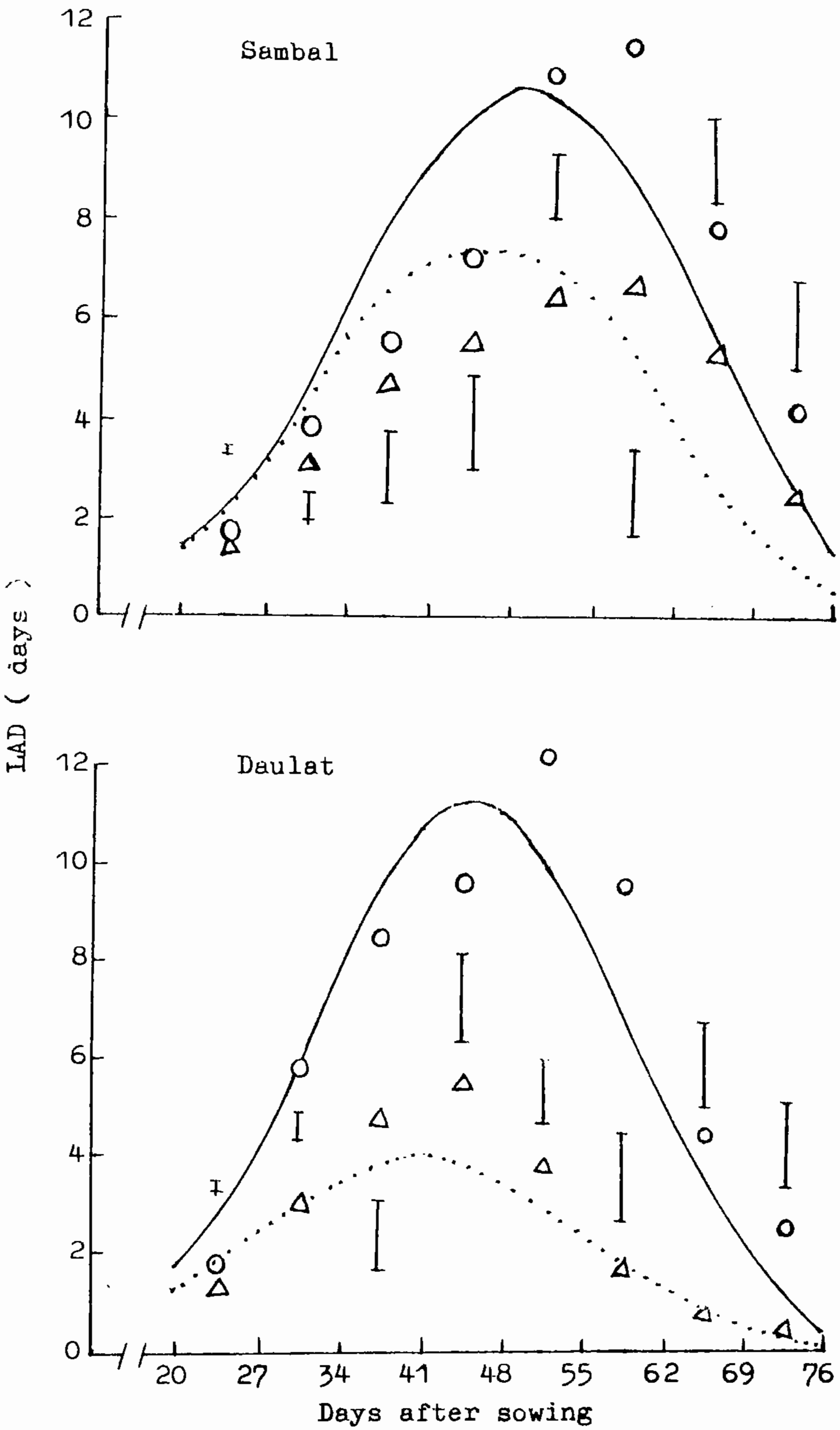

Figure.1.3. Effect of soil moisture on leaf area duration (LAD) of two mustard cultivars at different stages of growth, O=irrigated and Δ=rainf[illegible] rom original data ; smooth line for irrigated and d[illegible] d line for rainfed from quadratic curve-fitted da

at (55-62) DAS. Irrigated Daulat showed the highest and rainfed Daulat showed the lowest LAD.LAD calculated by the classical method showed a close agreement with the LAD obtained from the curve-fitted method (Figure 1.3). In the fitted data, all the maximum LAD values were under-estimated, except in the irrigated Sambal, where LAD was over-estimated .

Crop Growth Rate (CGR)

CGR fluctuated in both the cultivars and treatments (Figure 1.4a).Though it increased slightly at the early stages and declined at the later stages,yet no clear pattern was found. Highest CGR was found at (48-55) DAS in Sambal and at (41-48) and (34-41) DAS in the irrigated and the rainfed Daulat, respectively. The irrigated plants had higher CGR at all the stages of growth than the rainfed plants except at (69-76) DAS in Sambal.Significantly higher CGR was found at (62-69) and (76-83) DAS in Sambal and at all the stages of growth in Daulat except (34-41), (55-62) and (69-76) DAS in the irrigated plants than that of the rainfed plants. The highest CGR was observed in the irrigated Daulat and the lowest in the rainfed Daulat.

Mean squares from the analysis of variance of the curve-fitted values of CGR shown in Table 1.3 indicate that soil moisture treatment differences were significant. Cultivar and treatment and treatment x harvest date interaction were also significant. CGR calculated from the quadratic-fitted data gave uncharacteristically negative values late in the season (Figure 1.4b). In Daulat,CGR in

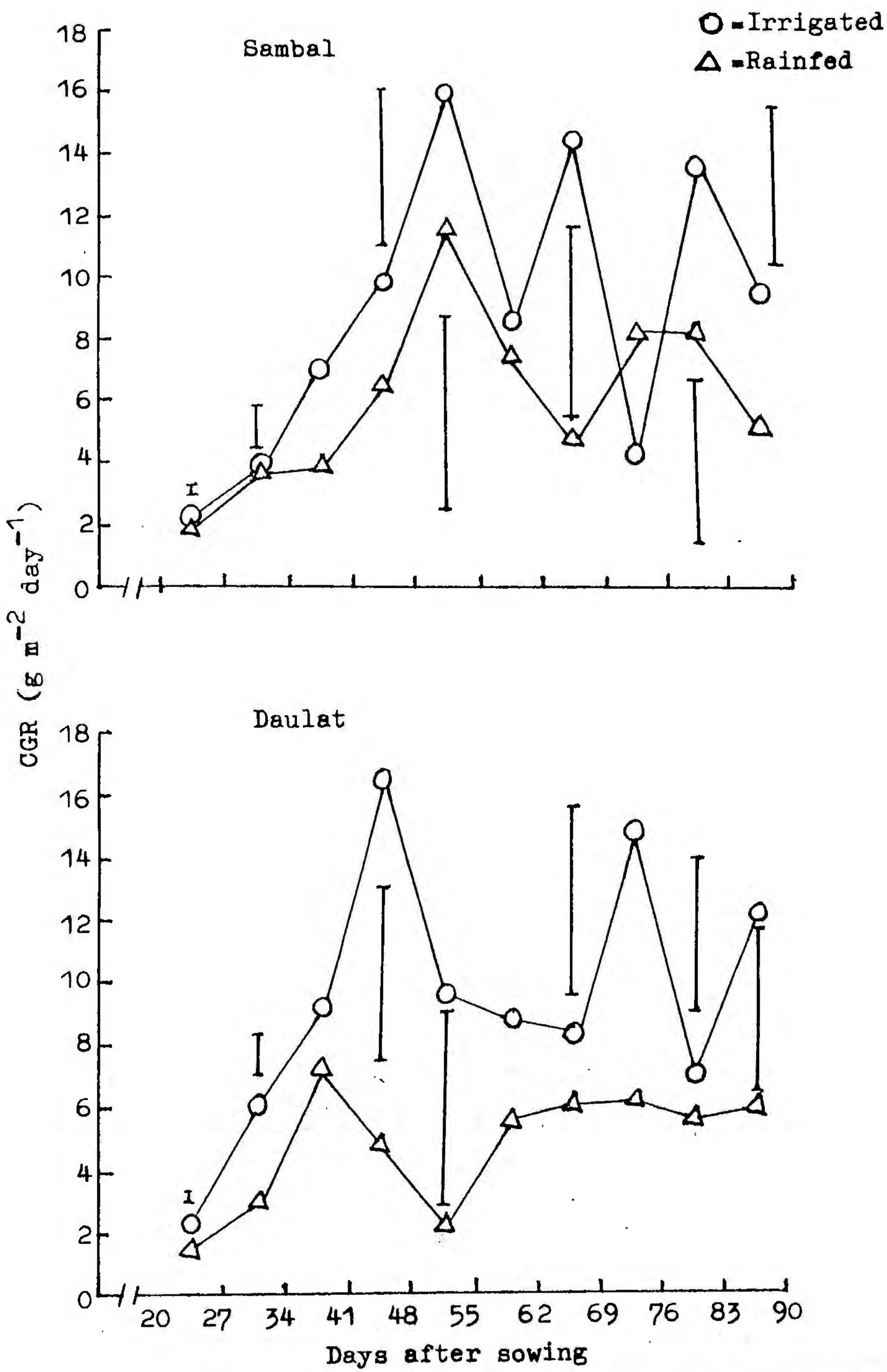

Figure 1.4a. Influence of soil moisture on crop growth rate (CGR) of two mustard cultivars at different stages of growth (by classical technique).

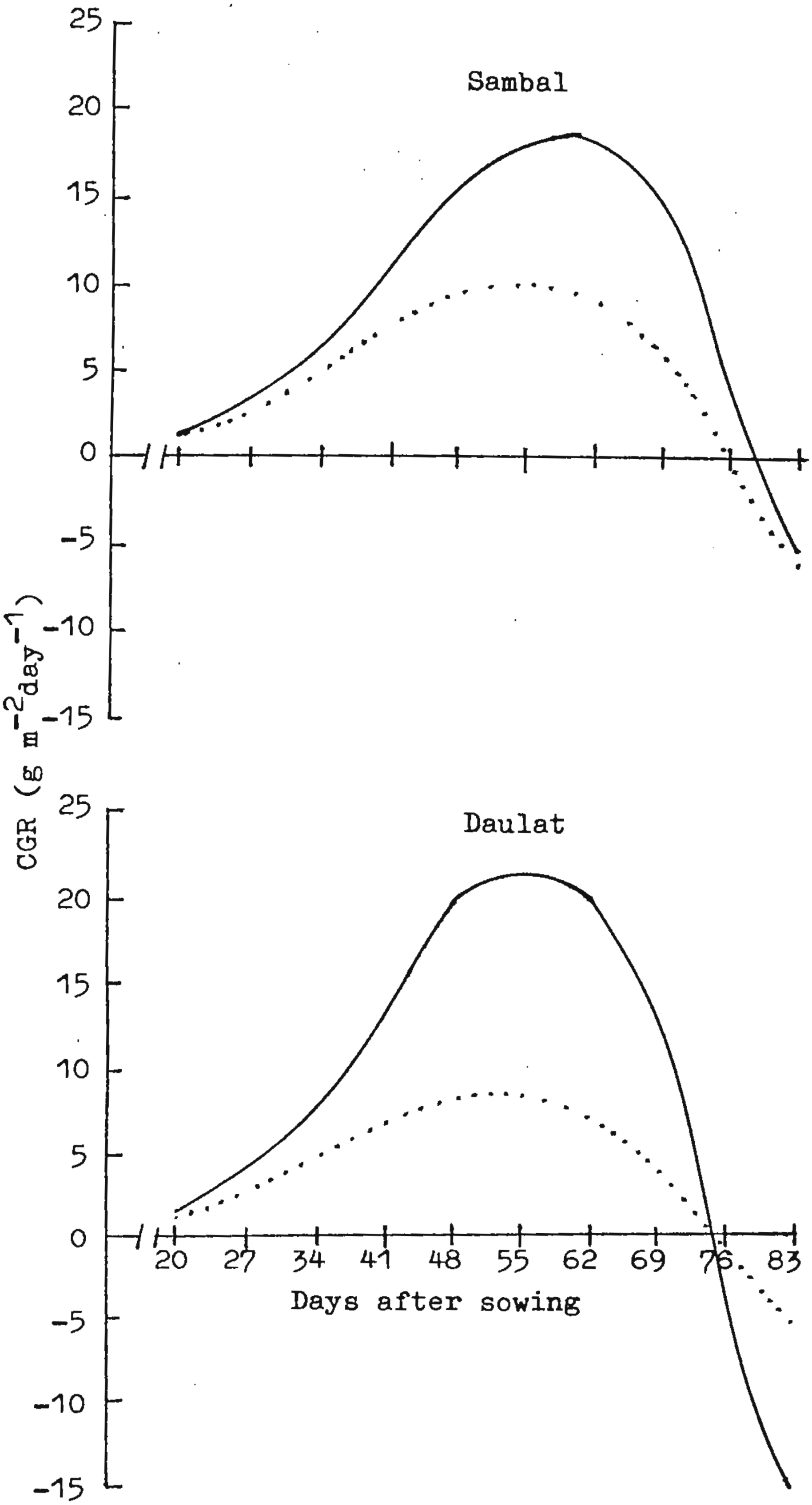

Figure.1.4b. Influence of soil moisture on crop growth rate (CGR) of two mustard cultivars at different stages of growth (smooth line for irrigated and dotted line for rainfed from quadratic fitted values).

negative values late in the season (Figure 1.4b). In Daulat,CGR in the irrigated plants became more negative than the rainfed plants.

Relative Growth Rate (RGR)

Effect of soil moisture on RGR of two mustard cultivars at different stages of growth is shown in Figure 1.5a. In both the cultivars, RGR of both treatments declined with slight fluctuation. At the early stages, it declined sharply but at the later stages it declined slowly. In irrigated condition, Sambal had higer RGR at (34-41), (48-55) and (69-76) DAS and Daulat at (20-27), (27-34), (41-48) and (48-55) DAS. Irrigated Daulat had significatly higher RGR at (41-48) DAS than the rainfed plants. The highest RGR was observed in Daulat .

Analysis of variance of the curve-fitted values of RGR (Table 1.3) indicates that the effect of soil moisture was significant. The effect of harvest date and interaction items like cultivar x treatment, cultivar x harvest date and treatment x harvest date were also significant.RGR declined sharply throuhout from a maximum value (Figure 1.5b). RGR calculated from the quadratic-fitted data gave also uncharacteristically negative values at the later stages of growth .

Net Assimilation Rate (NAR)

The pattern of soil moisture effect exhibited that NAR

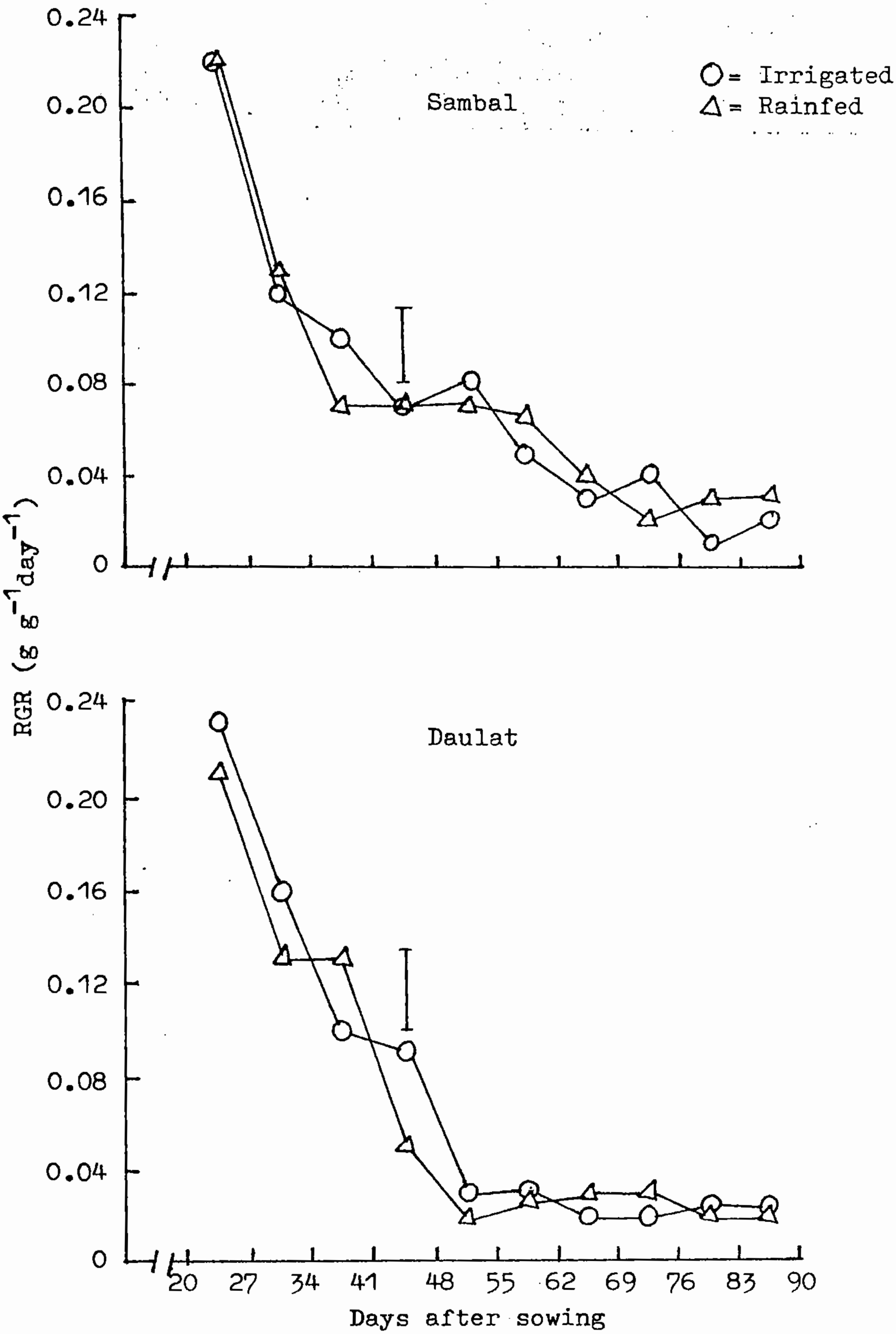

Figure 1.5a. Effect of soil moisture on relative growth rate (RGR) of two mustard cultivars at different stages of growth (by classical technique).

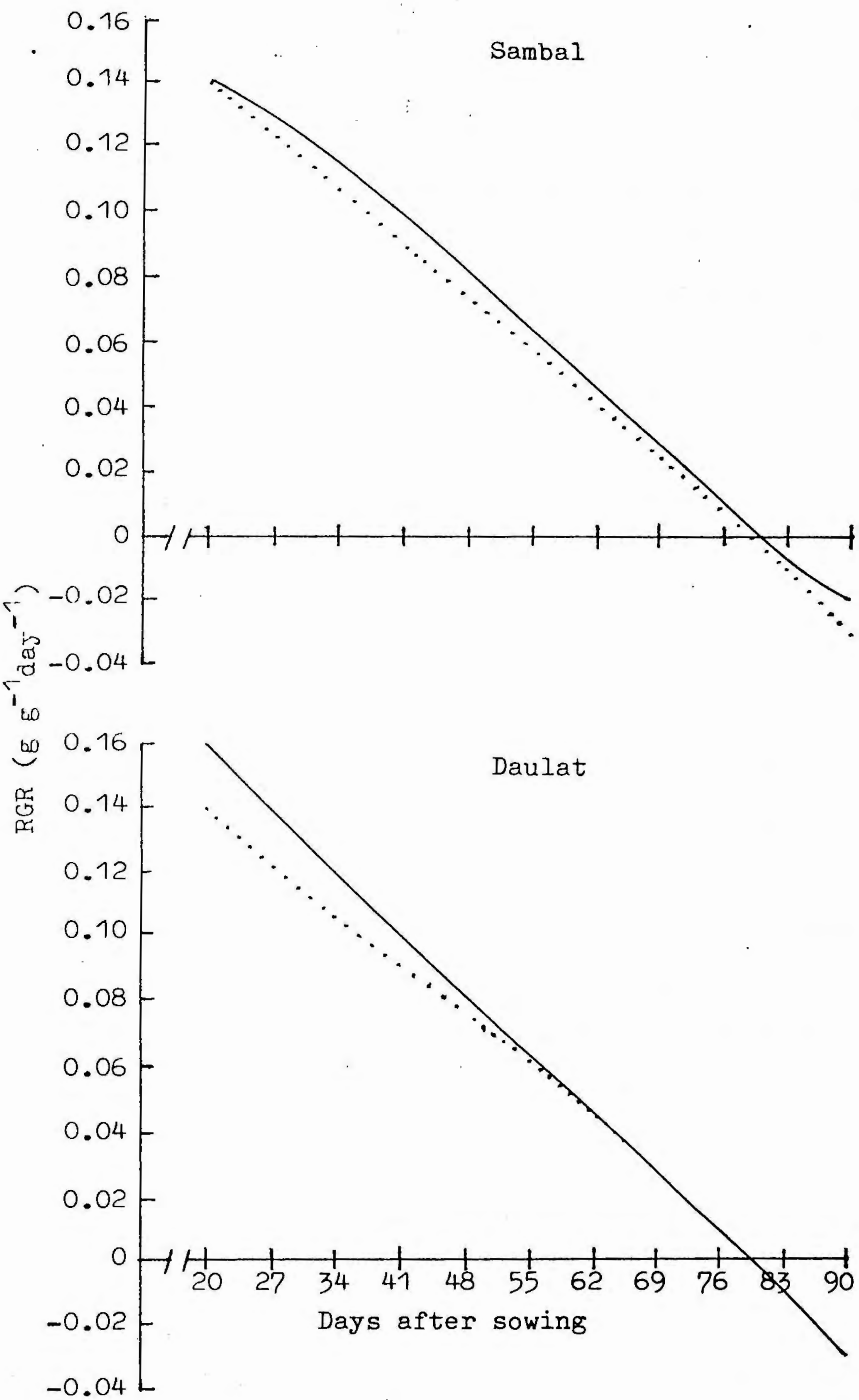

Figure 1.5b. Influence of soil moisture on relative growth rate (RGR) of two mustard cultivars at different stages of growth (Smooth line for irrigated and dotted line for rainfed from quadratic fitted values).

fluctuated in both the treatments of Sambal and Daulat (Figure 1.6a). Very little increase or depletion was found in Sambal up to (62-69) DAS and in Daulat upto (48-55) DAS and then increased very rapidly, except in the irrigated Sambal, where no such increase was observed. NAR values of the rainfed plants was higher at (27-34), (41-48), (48-55), (55-62) and (69-76) DAS in Sambal and at (34-41), (48-55), (55-62), (69-76) DAS in Daulat. The rainfed plants had significantly higher NAR at (69-76) DAS in Sambal and at (55-62), (62-69) and (69-76) DAS in Daulat. Maximum NAR value was found in rainfed Daulat .

Mean squares from the analysis of variance of the curve-fitted data of NAR (Table 1.3) indicates that soil moisture treatment was highly significant. Harvest date differences were also highly significant. Cultivar and treatment interaction was significant. NAR calculated by the harvest interval method showed a close correspondence with the instantaneous values obtained from the curve-fitting method (Figures 1.6a and 1.6b).The rainfed values remained lower at the early stages but became higher at the later stages of growth .

Leaf Area Ratio (LAR)

LAR values of both the treatments of the two cultivars were found maximum at (20-27) DAS and then declined steadily with increasing plant age (Figure 1.7a). The irrigated plants had higher LAR at all the growth stages in Sambal except at (20-27) and (41-48)

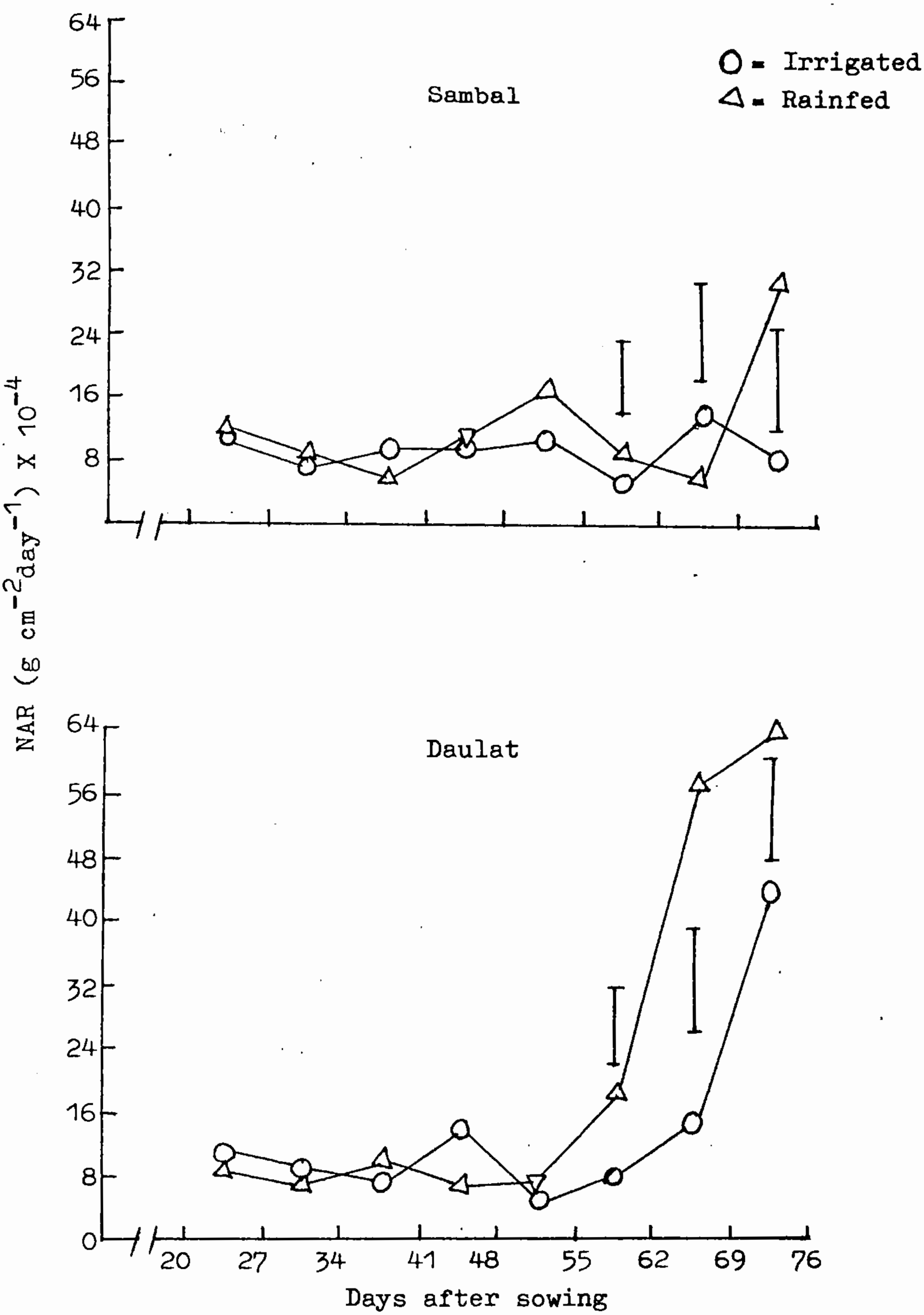

Figure 1.6a. Influence of soil moisture on net assimilation rate (NAR) of two mustard cultivars at different stages of growth (by classical technique).

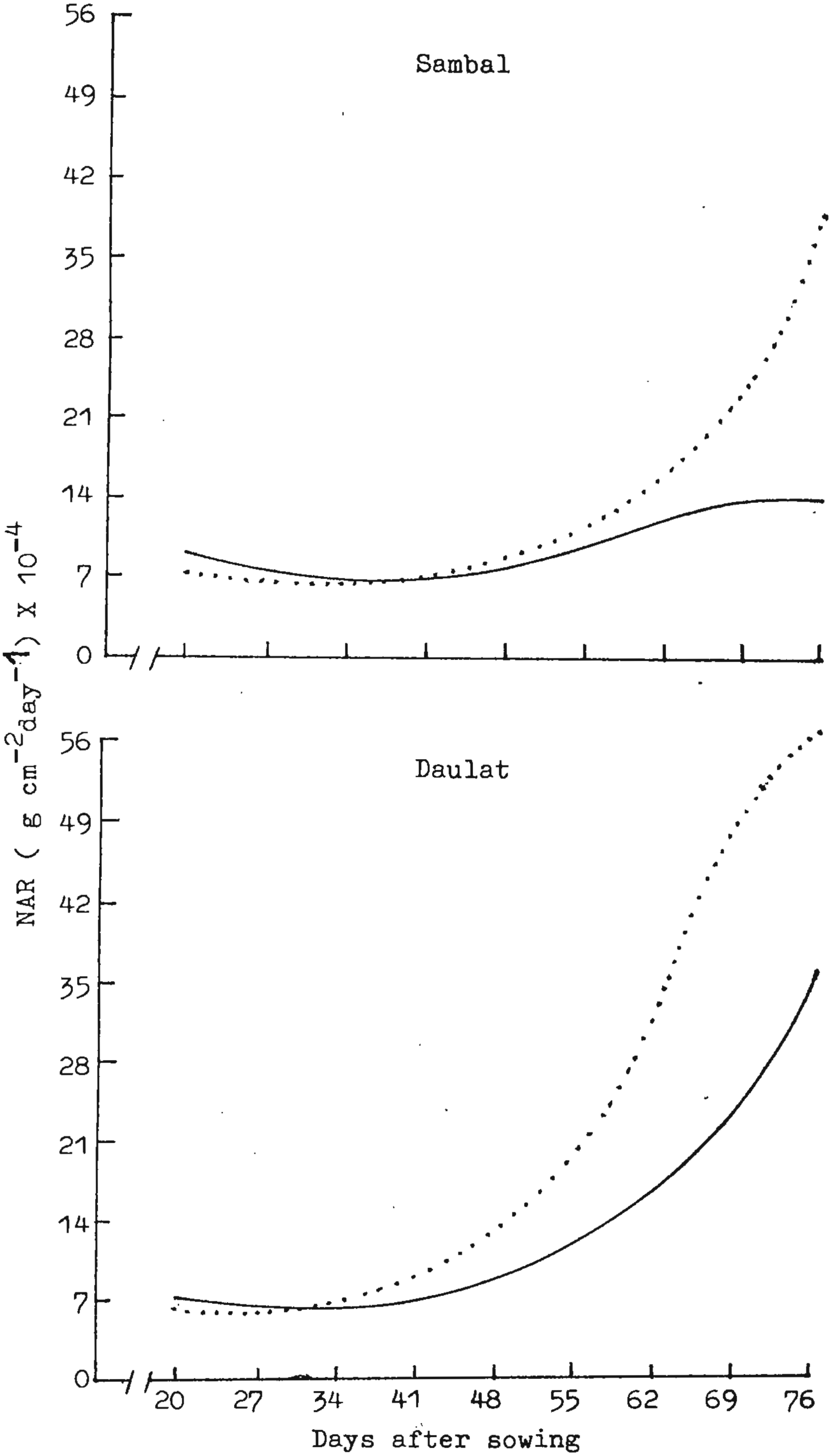

Figure 1.6b. Effect of soil moisture at different stages of growth on net assimilation rate (NAR) of two mustard cultivars (Smooth line for irrigated and dotted line for rainfed values from quadratic fitted values).

DAS. In the irrigated plants significantly higher LAR was found at (27-34), (48-55) and (55-62) DAS in Sambal and at (48-55), (55-62) and (62-69) DAS in Daulat than the rainfed plants. Significantly lower LAR was observed at (20-27) in the irrigated Daulat.The highest LAR was found in the rainfed Daulat.

Highly significant effect of soil moisture on LAR was present (Table 1.3). Cultivar and harvest date differences were also significant. The pattern of LAR calculated from the curve-fitted data was closer to that calculated from the original data (Figures 1.7a and 1.7b).

Relative Leaf Growth Rate (RLGR)

The maximum RLGR was found at (20-27) DAS in both the treatments and cultivars and then declined gradually with fluctuations (Figure 1.8a). In the irrigated Sambal plants, RLGR became negative at (55-62)DAS and in the rainfed Sambal it became negative first at (41-48) DAS,then increased into positive value and further became negative at (55-62) DAS. In the irrigated Daulat plants,RLGR became negative at (48-55) DAS and in the rainfed plants it became negative at (41-48) DAS.The highest RLGR was found in the irrigated plants of both the cultivars. Irrigated plants had higher RLGR at (20-27), (41-48), (48-55) and (69-76) DAS in Sambal and (20-27), (41-48), (48-55) and (62-69) DAS in Daulat than the rainfed plants. Significantly higher RLGR in the irrigated plants was found at (27-34) and (48-55) DAS in Daulat and (69-76) DAS in Sambal. Significantly lower RLGR in the irrigated plants was observed at (55-62) DAS in Sambal and at (69-76) DAS in Daulat than the rainfed plants.

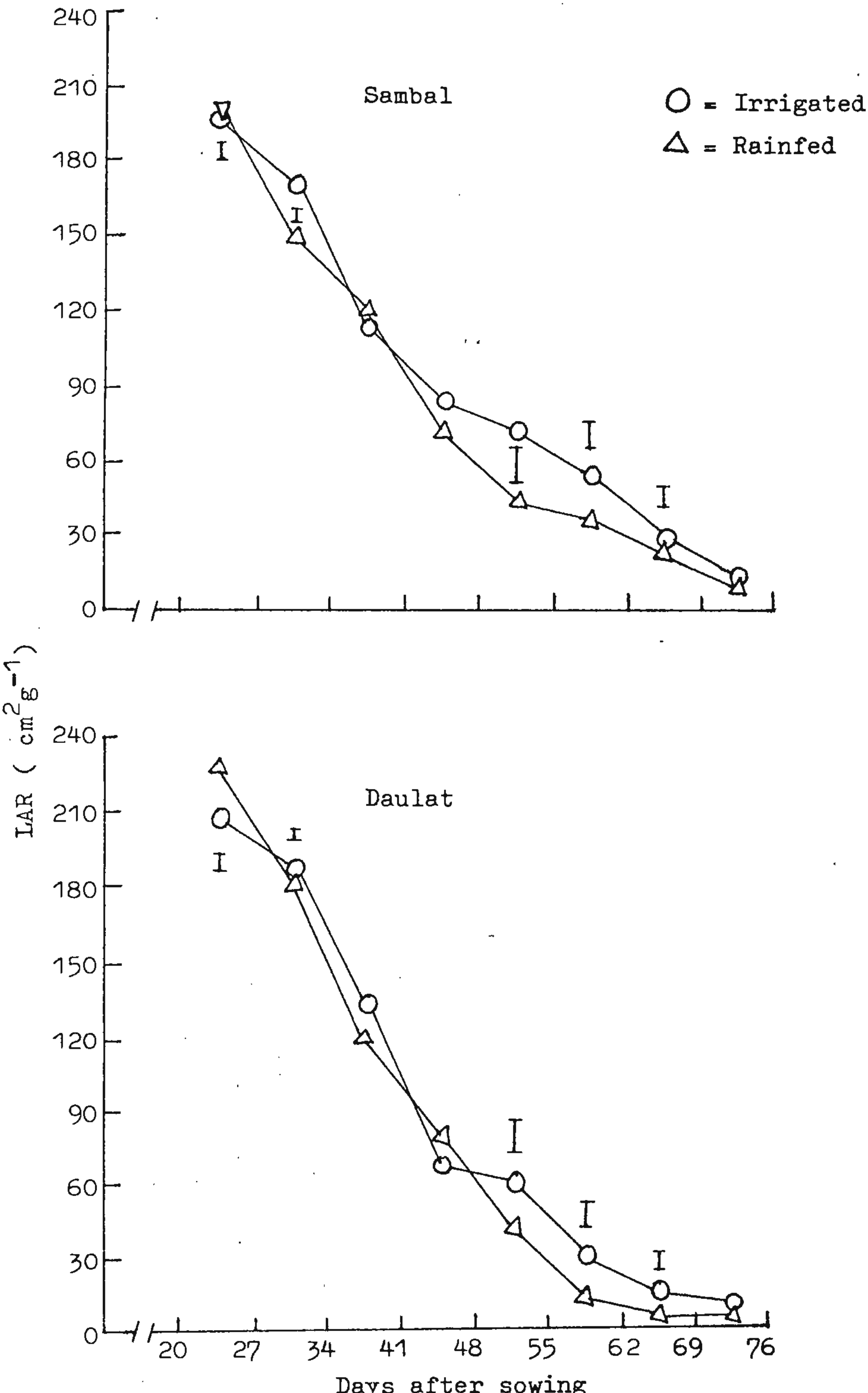

Figure.1.7a. Influence of soil moisture on leaf area ratio (LAR) of two mustard cultivars at successive stages of growth (by classical technique).

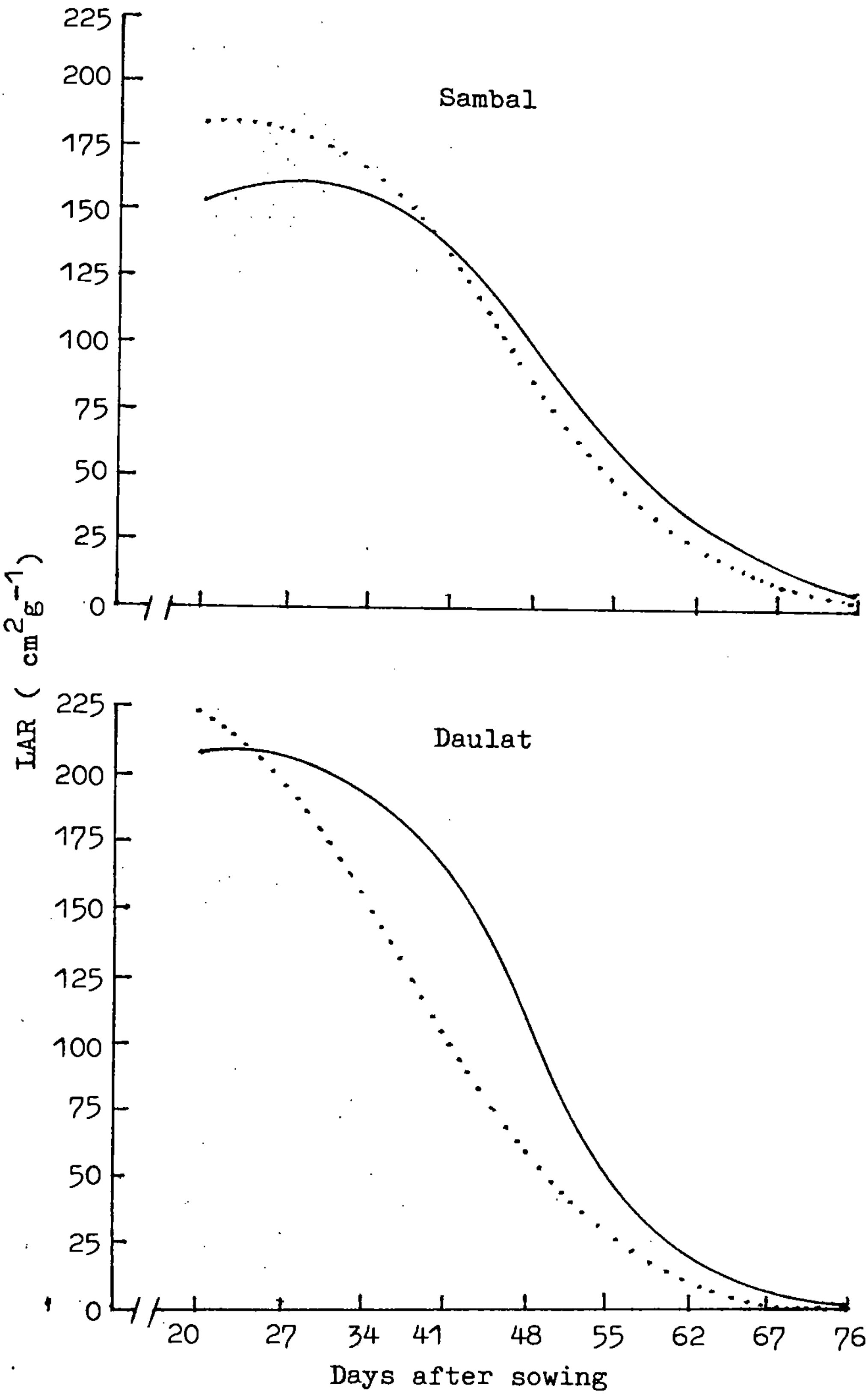

Figure 1.7b. Influence of soil moisture on leaf area ratio (LAR) of two mustard cultivars at different stages of growth (Smooth line for irrigated and dotted line for rainfed from quadratic fitted values).

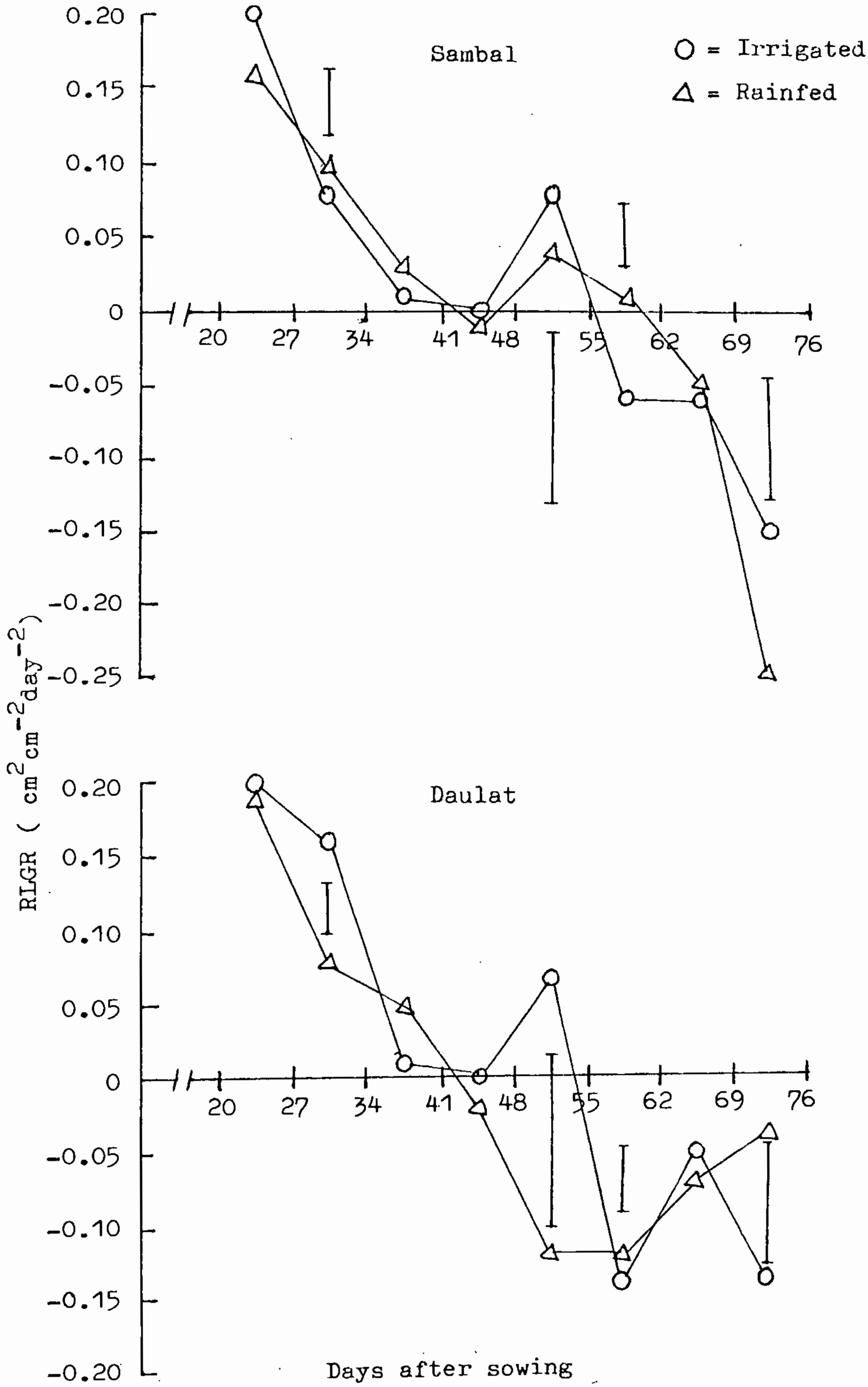

Figure 1.8a. Soil moisture effect on relative leaf growth rate (RLGR) of two mustard cultivars at different stages of growth (by classical technique).

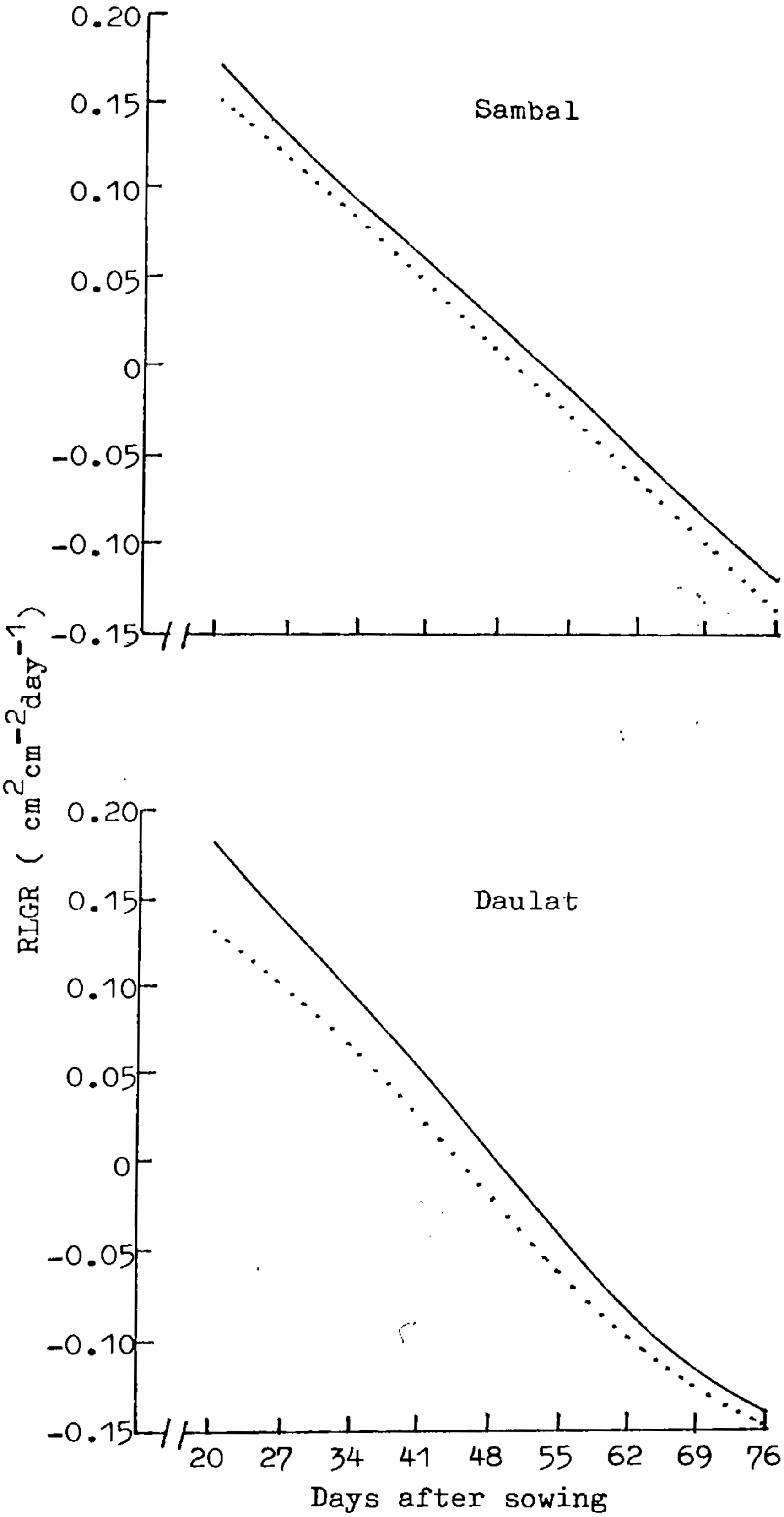

Figure.1.8b. Soil moisture effect on relative leaf growth rate (RLGR) of two mustard cultivars at various stages of growth (Smooth line for irrigated and dotted line for rainfed from quadratic fitted values).

Soil moisture treatment,cultivar and harvest date differences for RLGR, calculated from curve-fitted data were highly significant (Table 1.3). Cultivar x treatment effect was significant. Soil moisture effect on RLGR calculated from curve-fitted values showed a linear drift with increasing age (Figure 1.8b) .

Specific Leaf Area (SLA)

There were no clear patterns of soil moisture effect on SLA (Figure 1.9a). The irrigated plants had significantly higher SLA than the rainfed plants at 34, 48, 55 and 62 DAS in Sambal and 34 and 55 DAS in Daulat. The irrigated Daulat had significantly lower SLA at 48 DAS than the rainfed plants .

Mean squares from the analysis of variance of the curve-fitted data of SLA (Table 1.3) showed that the cultivar differences were highly significant. Cultivar x treatment was also significant. The curve-fitted values of SLA (Figure 1.9b) indicate that there was slight increase or depletion of SLA with increasing age. The irrigated plants had higher SLA at the middle stages of growth but it was lower at both the initial and terminal stages .

Leaf Weight Ratio (LWR)

Starting from a maximum value, LWR of both the treatments and cultivars declined sharply with increasing age (Figure 1.10a). The exception was found only at 27 DAS in the rainfed Daulat. Significantly higher LWR in the irrigated plants than the rainfed

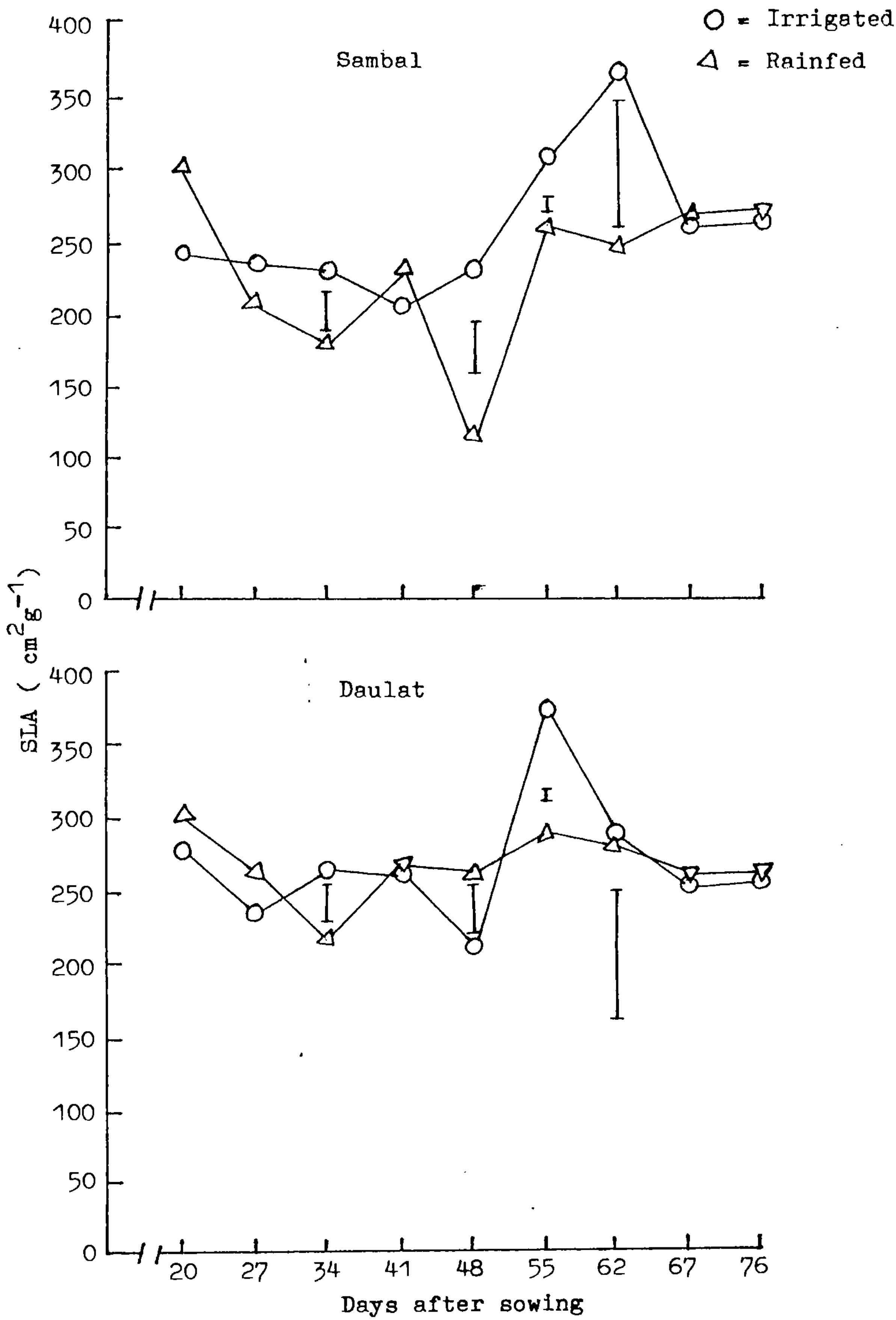

Figure 1.9a. Effect of soil moisture on specific leaf area (SLA) of two mustard cultivars at various stages of growth (by classical technique).

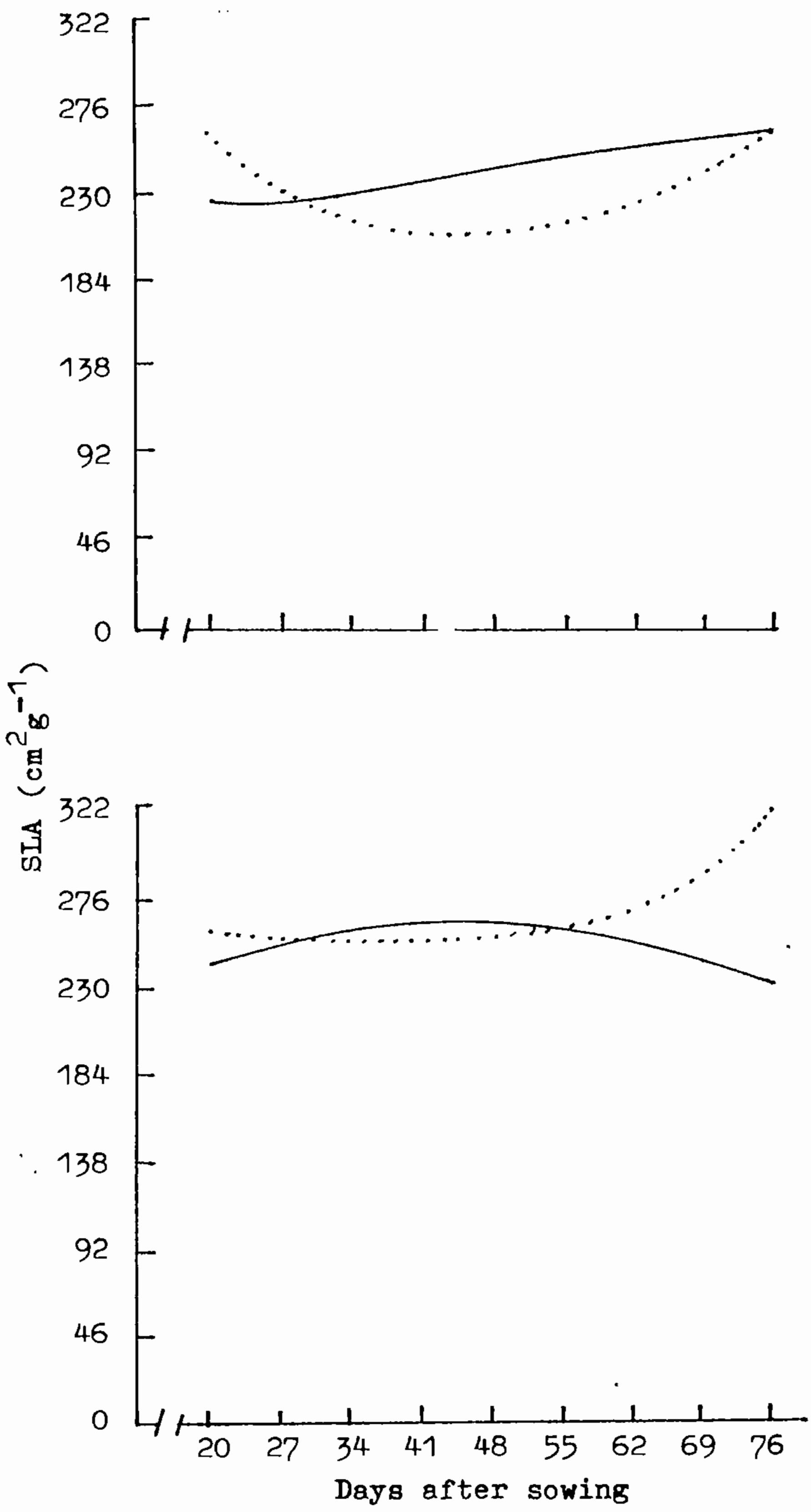

Figure 1.9b. Influence of soil moisture at different stages of growth of two mustard cultivars on specific leaf area (SLA) (Smooth line for irrigated and dotted line for rainfed from quadratic fitted values).

plants was found at 48 and 76 DAS in Sambal and at 55, 62 and 69 DAS in Daulat. The irrigated Sambal had significantly lower LWR at 69 DAS .

Highly significant effect of harvest date was found on LWR (Table 1.3). The interactions between cultivar and treatment and cultivar and harvest date were also found significant. The pattern of LWR obtained from the curve-fitted values was closure to LWR obtained from the original values (Figures 1.10a and 1.10b). LWR also showed downward drifts with age (Figure 1.10b).

The values of RGR and NAR (Figure 1.11), LAR and RLGR (Figure 1.12) and SLA and LWR (Figure 1.13) plotted against $\log_e$ plant dry weight, based on the fitted quadratic relationship between $\log_e W$ (dry weight) and $\log_e LA$ (leaf area) with time,are shown. The curves of RGR, LAR, RLGR and LWR with respect to $\log_e$ plant dry weight in both the treatments and cultivars showed similar declining trends. Very little increase or decrease of NAR was found at the initial stages but it increased very sharply with increasing dry weight.The pattern of SLA with increasing dry weight was similar as was with increasing time.

Correlation Coefficients Between Growth Attributes and Yield

Simple correlation coefficients between growth attributes and yield at two soil moisture levels are given in Table 1.4.

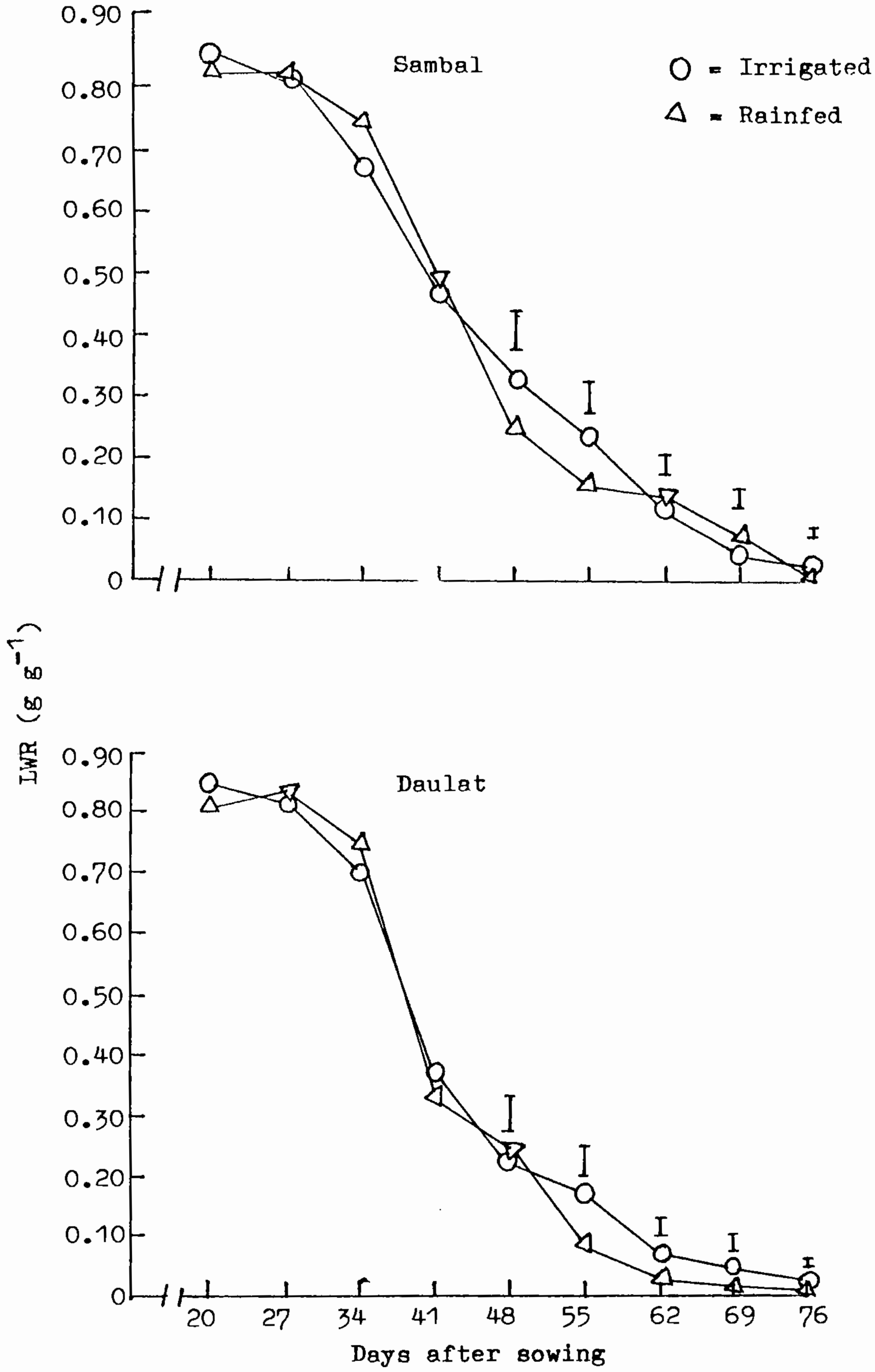

Figure 1.10a. Effect of soil moisture on leaf weight ratio (LWR) of two mustard cultivars at different stages of growth (by classical technique).

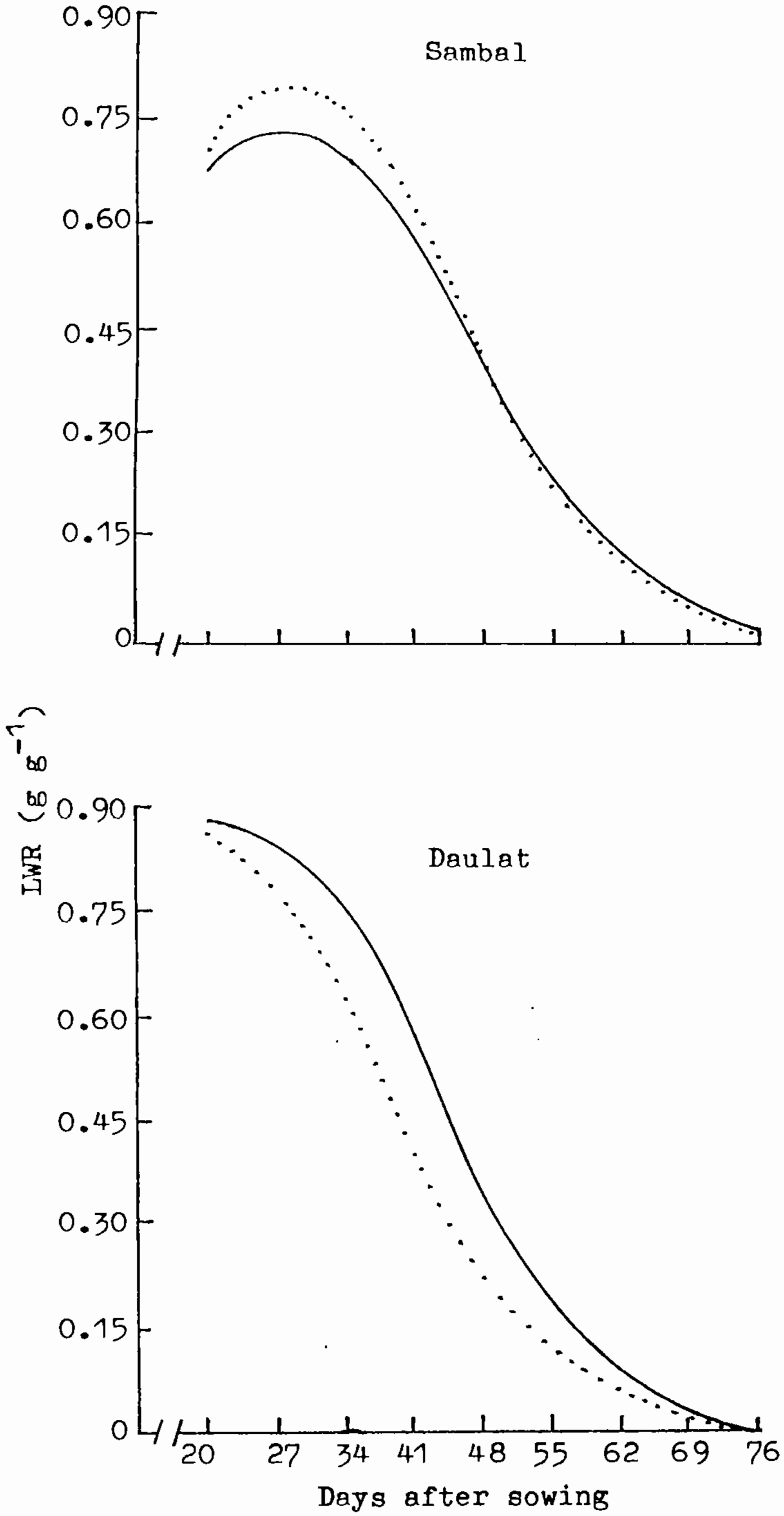

Figure 1.10b. Soil moisture effect on leaf weight ratio (LWR) of two mustard cultivars at different growth stages (Smooth line for irrigated and dotted line for rainfed from quadratic fitted values).

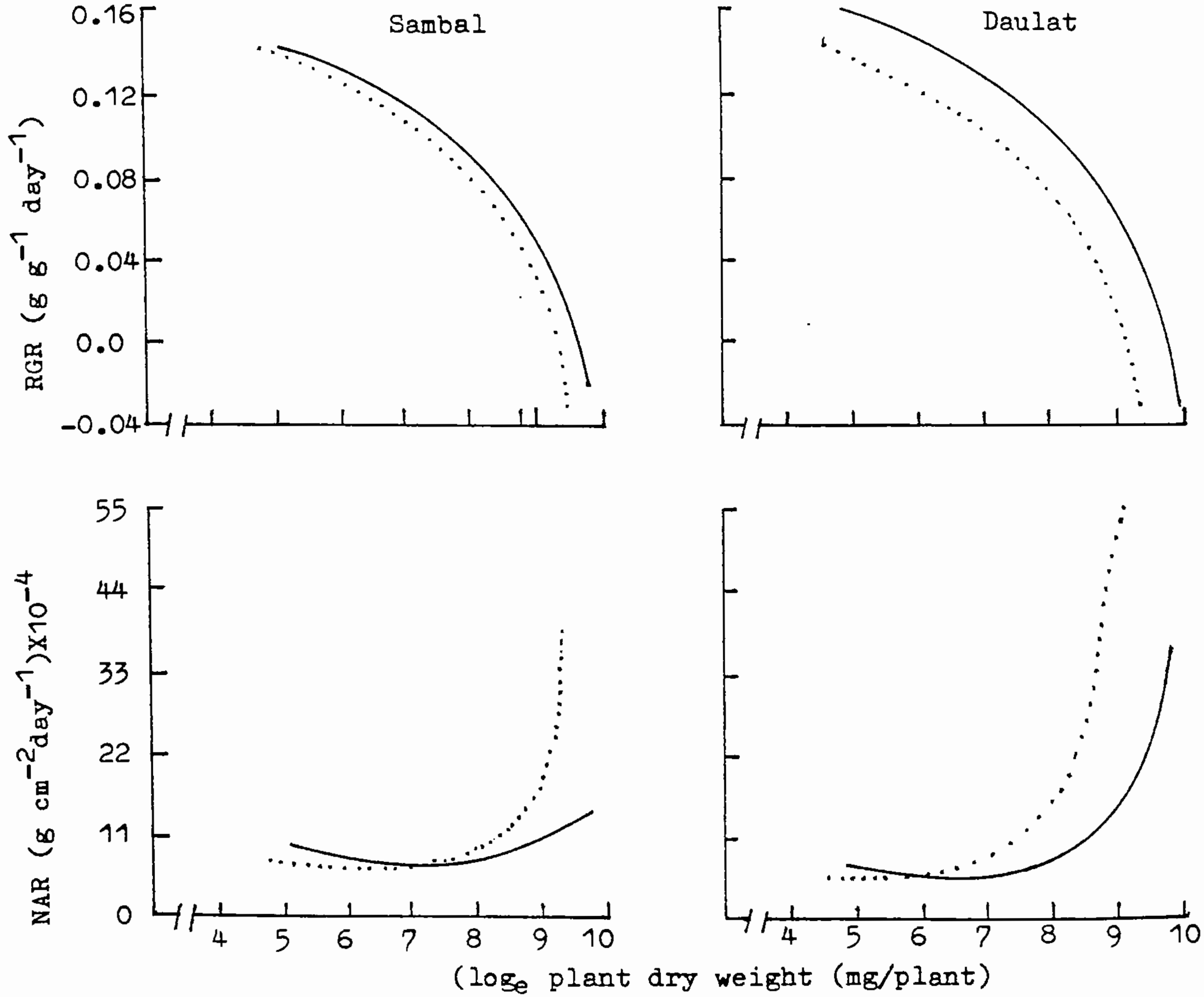

Figure 1.11 . RGR and NAR plotted against log$_e$ plant dry weight, based on fitted quadratic relations between log$_e$ W(dry weight) and log$_e$ LA(leaf area) with time (Smooth line for irrigated and dotted line for rainfed values).

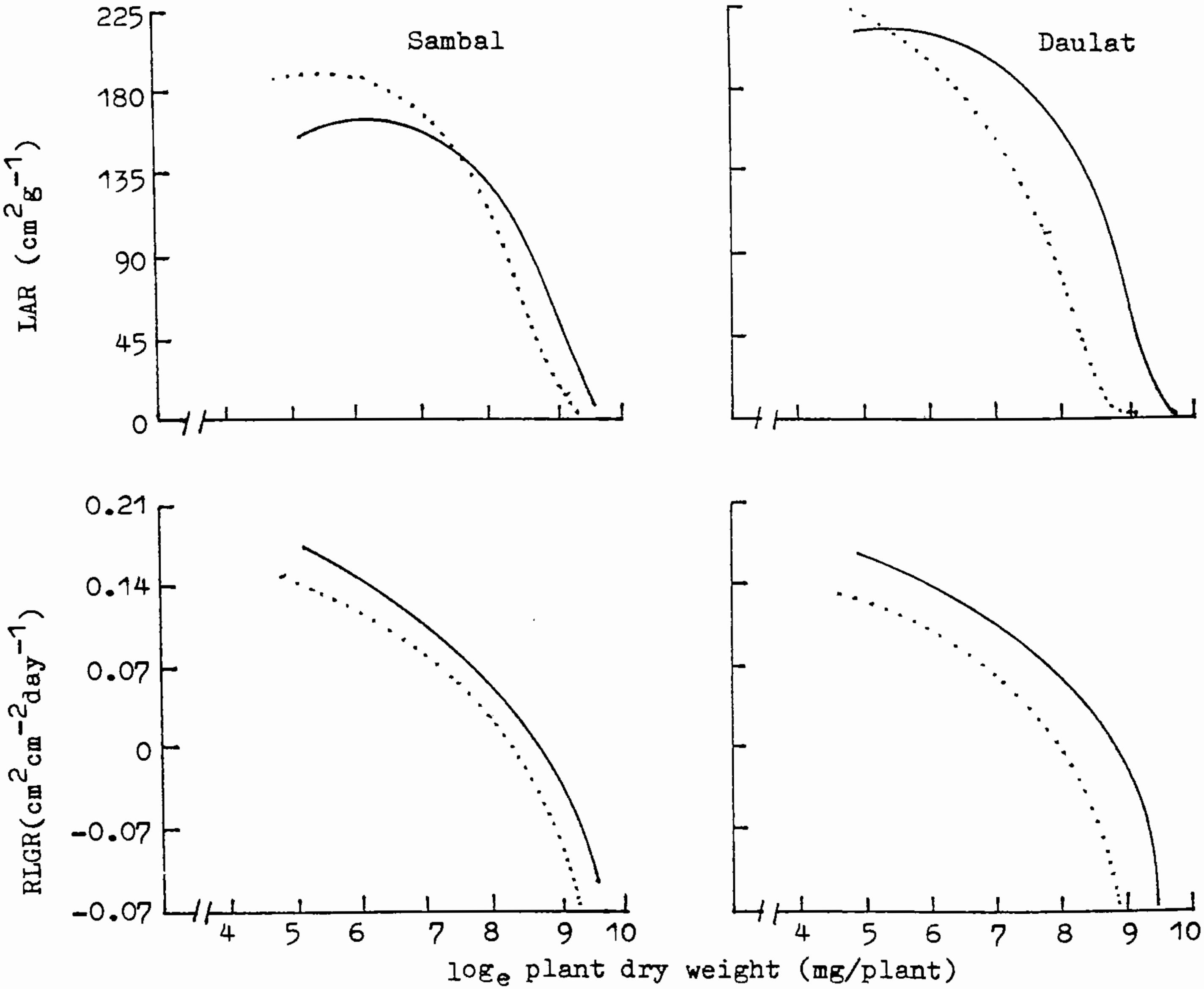

Figure 1.12 . LAR and RLGR plotted against $\log_e$ plant dry weight, based on fitted quadratic relations between $\log_e W$(dry weight) and $\log_e A$(leaf area) with time (Smooth line for irrigated and dotted line for rainfed values).

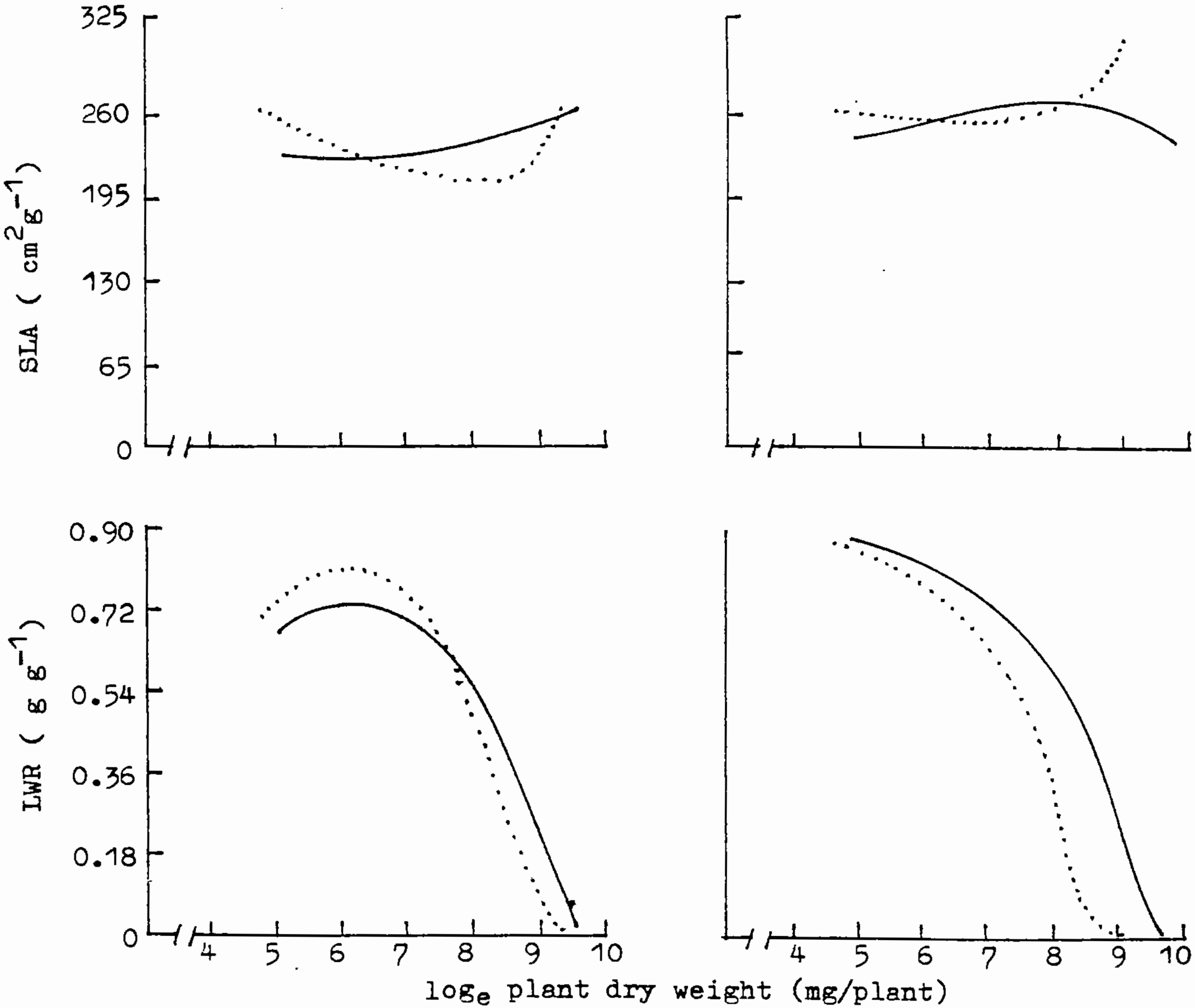

Figure 1.13 . SLA and LWR plotted against $\log_e$ plant dry weight, based on fitted quadratic relationship between $\log_e$ W (dry weight) and $\log_e$ LA(leaf area) with time (Smooth line for irrigated and dotted line for rainfed values).

Association between growth attributes and yield of irrigated plants

CGR at the pre-flowering stage was positively correlated with pre-flowering LAI and negatively correlated with the post-flowering RGR. RGR at the post-flowering stage was negatively correlated with LAI at the pre-flowering stage. NAR at the post-flowering stage was positively correlated with the pre-flowering LAR and negatively correlated with the post-flowering LAR. LAR at the pre-flowering stage was positively correlated with the post-flowering LAR. Seed yield was positively correlated with the pre-flowering LAI and CGR and the post-flowering NAR .

Association between growth attributes and seed yield of rainfed plants

CGR at the pre-flowering stage was positively correlated with RGR and NAR at the pre-flowering stage. CGR at the post-flowering stage was positively correlated with LAI (post-flowering) and negatively correlated with NAR (post-flowering) and LAR (pre-flowering).RGR at the pre-flowering stage was positively associated with NAR at the pre-flowering stage. The pre-flowering NAR was positively correlated with pre-flowering LAI. The post-flowering NAR was positively related with LAR (pre-flowering) and negatively with LAI (pre-flowering) and LAR (post-flowering).The pre-flowering LAR was negatively and the post-flowering LAR was positively associated with the post-flowering LAI. Seed yield was positively

Table 1.4. Simple correlation coefficients between growth attributes and yield (upper diagonal irrigated and lower diagonal rainfed values).

	LAI		CGR		RGR		NAR		LAR		Seed yeild
	Pre-flowering (1)	Post-flowering (2)	Pre-flowering (3)	Post-flowering (4)	Pre-flowering (5)	Post-flowering (6)	Pre-flowering (7)	Post-flowering (8)	Pre-flowering (9)	Post-flowering (10)	(11)
1		-0.52	0.89*	-0.06	0.60	-0.81*	0.11	0.73	0.89*	-0.89*	0.82*
2	0.01		-0.74	0.46	-0.70	0.65	-0.53	-0.57	-0.55	0.70	0.01
3	0.78	-0.52		-0.38	0.73	-0.97**	0.48	0.51	0.76	-0.77	0.18
4	0.03	0.81*	-0.48		-0.51	0.37	-0.76	0.25	0.26	0.07	0.84*
5	0.71	-0.53	0.86*	-0.65		-0.56	0.76	0.48	0.39	-0.72	-0.29
6	0.51	0.64	0.06	0.72	-0.21		-0.44	-0.34	-0.71	0.61	-0.19
7	0.79*	-0.35	0.89*	-0.55	0.93**	0.06		-0.17	-0.11	-0.14	-0.77
8	-0.05	-0.97**	0.50	-0.80*	0.44	-0.54	0.34		0.82*	-0.92**	0.81*
9	0.04	-0.97**	0.57	-0.79*	0.60	-0.70	0.38	0.89*		-0.84*	0.67
10	0.50	0.84*	-0.02	0.77	-0.14	0.81*	0.05	-0.85*	-0.77		-0.45
11	-0.25	0.84*	-0.76	0.86*	-0.69	0.36	-0.70	-0.89*	-0.79*	0.60	

correlated with LAI and CGR at the post-flowering stage and negatively correlated with the post-flowering NAR and the pre-flowering LAR.

Distribution of Dry Matter

Effect of soil moisture on distribution of dry matter (DM) of two mustard cultivars at successive stages of growth is shown in Figures 1.14 and 1.15 . At the early stages of growth only stem + petiole and leaves were present, whereas, at the later stages only stem and pods were present. Percentage of DM accumulation for stem + petiole was lower at the early stages, at the middle stages it reached a certain peak and then gradually declined with time. In Sambal the irrigated plants had peak stem + petiole DM (78%) at 62 DAS and the rainfed plants (78%) at 55 DAS. Daulat had its peak DM of stem + petiole (70.4%) at 55 DAS in the irrigated plants and (74%) also at 55 DAS in the rainfed plants.

Percentage of DM accumulation in the leaves revealed that it was highest at the initial stage and gradually declined with increasing age and at 83 DAS it became zero. The irrigated plants accumulated higher leaf DM than the rainfed plants at 20, 48, 55, and 76 DAS in Sambal and at 20,41, 55, 62, 69 and 76 DAS in Daulat.

Dry matter accumulation for buds + flowers started at 41 DAS and gradually increased up to several harvests and then declined with increasing time. The irrigated plants had higher percentage of

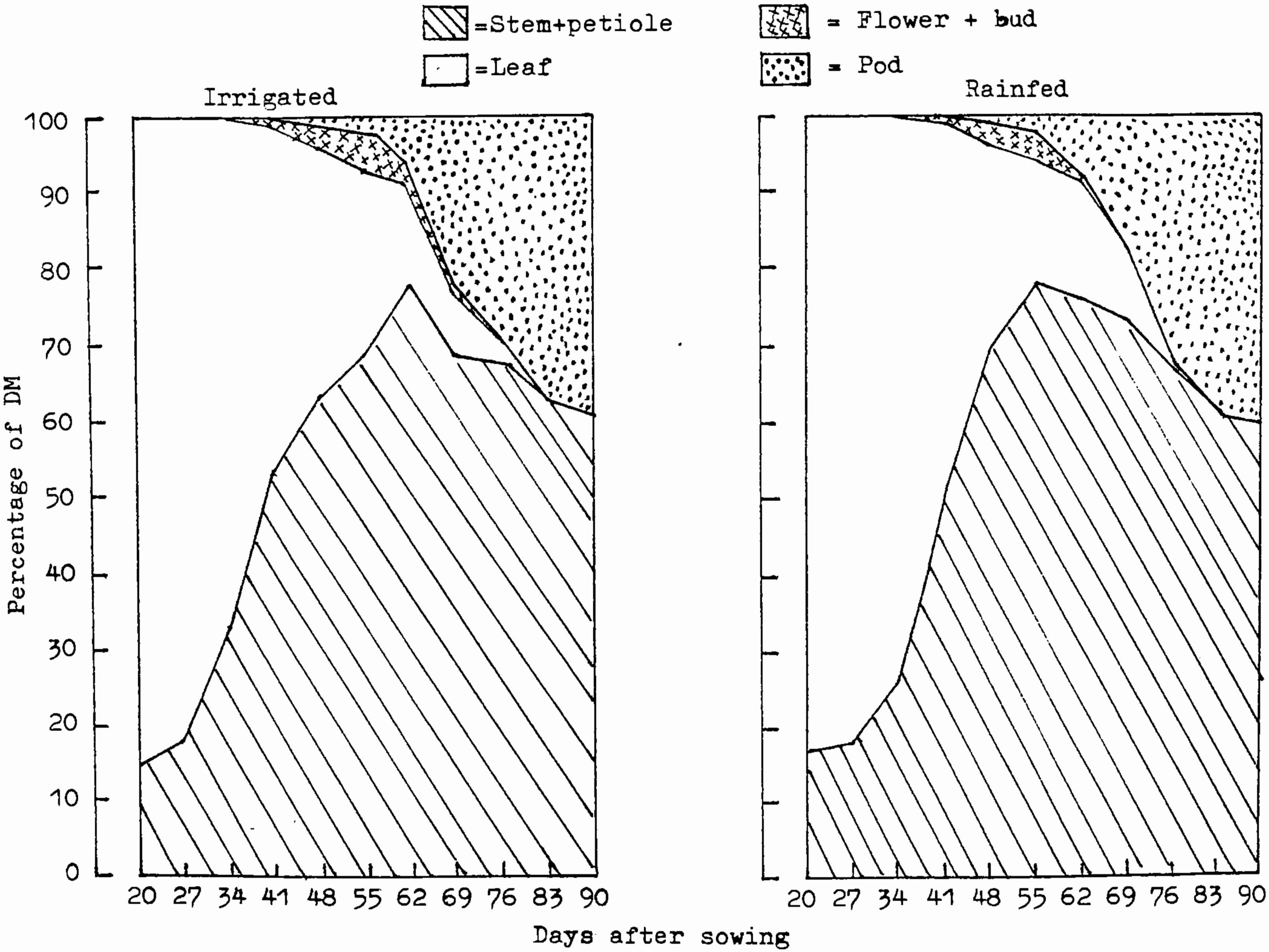

Figure 1.14. Influence of soil moisture on distribution of dry matter (DM) of Sambal at successive stages of growth.

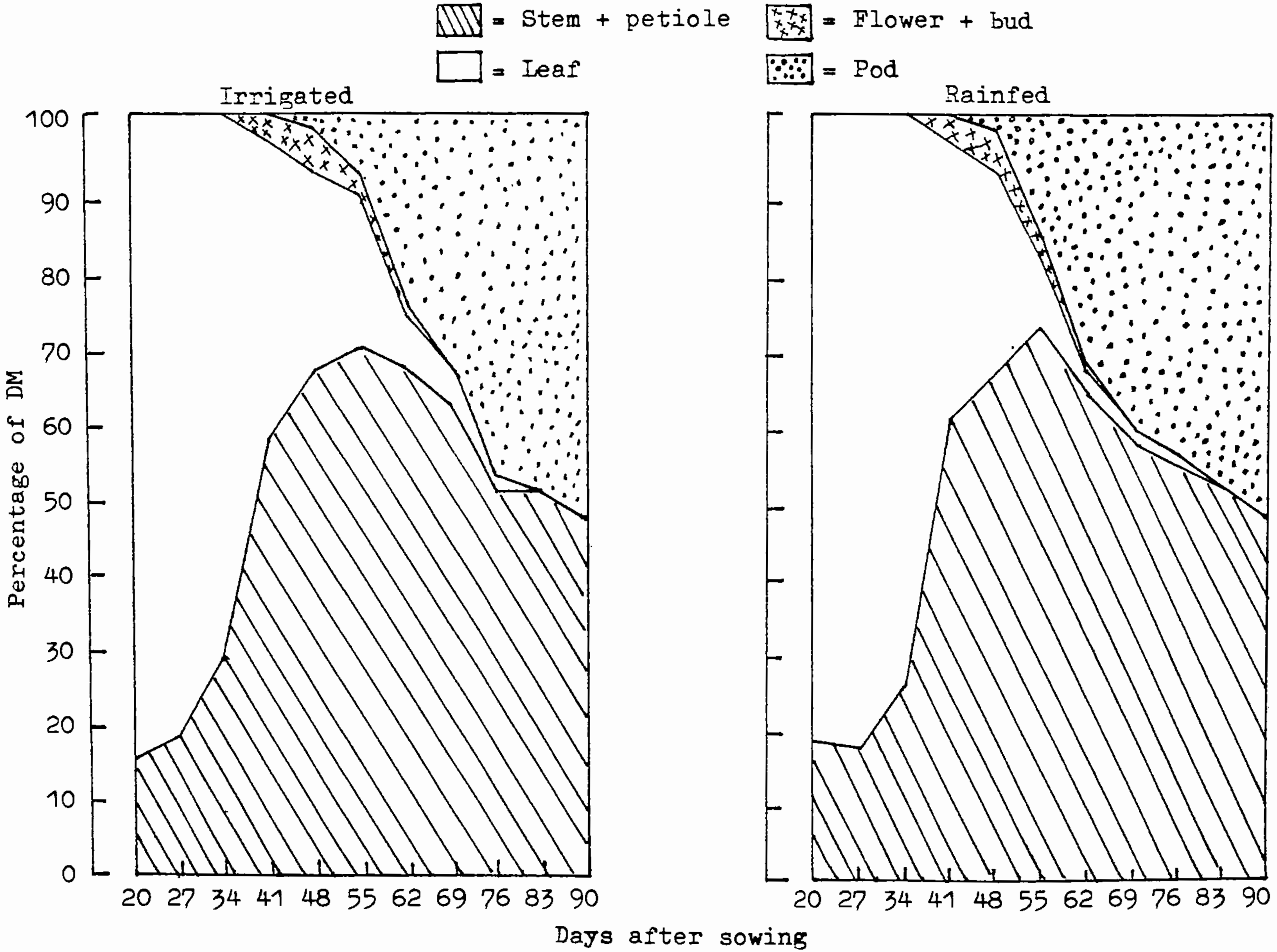

Figure 1.15. Influence of soil moisture on distribution of dry matter (DM) of Daulat at successive stages of growth.

DM accumulation for buds + flowers than the rainfed plants at 55 and 62 DAS in Sambal.

Percentage of DM accumulation for pods was found lowest at 48 DAS and gradually increased with plant age. Higher percentage of DM accumulation was found in the rainfed plants at 62, 83 and 90 DAS in Sambal and at 55, 62 and 69 DAS in Daulat .

Relative Leaf Water Content (RLWC)

The effects of soil moisture on RLWC of two cultivars at different times of a day at the flowering and the mid-pod filling stages are given in Figures 1.16a and 1.16b. The irrigated plants had higher RLWC than that of the rainfed plants in all cases.At the flowering stage, the irrigated plants had significantly higher RLWC than the rainfed plants at 8 A.M. in both the cultivars. At mid-pod filling stage, the irrigated plants had significantly higher RLWC at 8 A.M. and 4 P.M.than the rainfed plants of Sambal. The highest RLWC was observed at 8 A.M. but at the midday it decreased and at the later part of the day it increased gradually .

Chlorophyll, Proline and Sugar Contents

Mean values of chlorophyll, proline and sugar contents of two cultivars as influenced by soil moisture are given in Table 1.5.

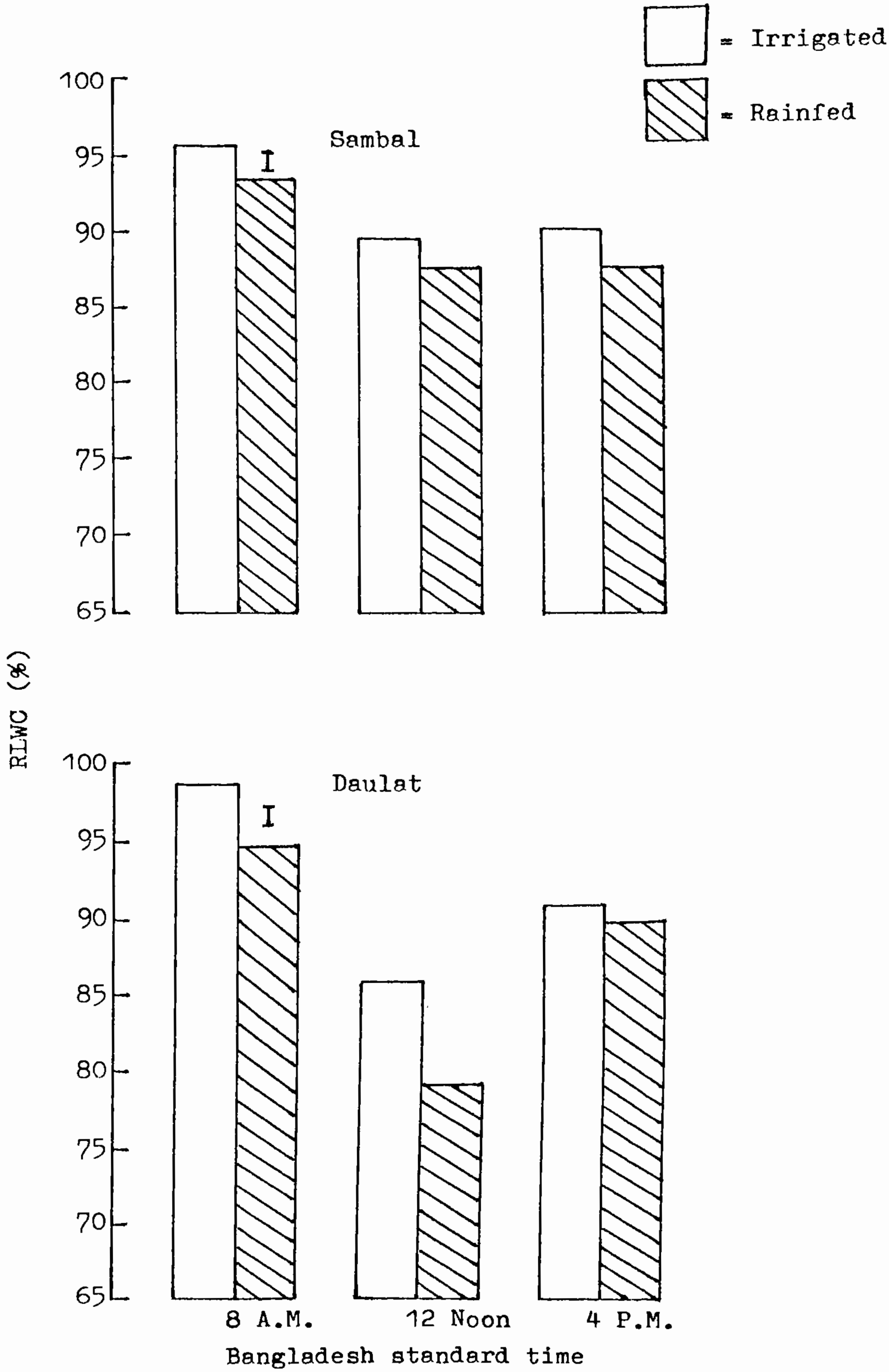

Figure 1.16a. Relative leaf water content (RLWC) of two mustard cultivars as influenced by soil moisture at flowering stage.

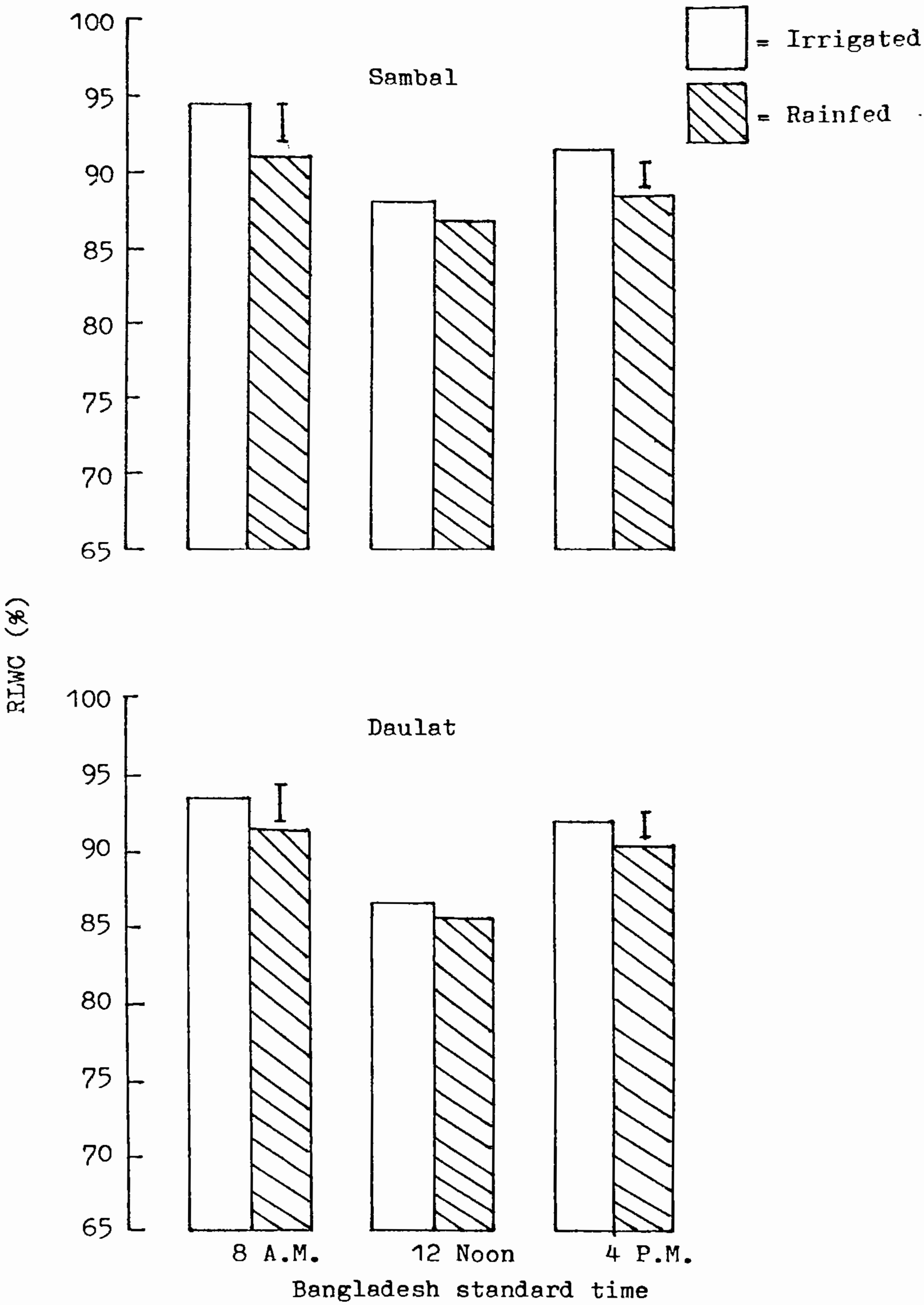

Figure 1.16b. Relative leaf water content (RLWC) of two mustard cultivars as influenced by soil moisture at mid-pod filling stage.

Soil moisture effect was not significant for chlorophyll a, chlorophyll b and total chlorophyll at both the flowering and mid-pod filling stages.Chlorophyll b of Daulat was significantly higher than that of Sambal plants at the flowering stage. At the mid-pod filling stage chlorophyll a ,b and total chlorophyll were slightly higher in the irrigated plants than the rainfed plants .

The rainfed plants had significantly higher proline than that of the irrigated plants at both the flowering and mid-pod filling stages. At the flowering stage, Sambal had significantly higher proline than Daulat. At the mid-pod filling stage such difference was not significant. Proline content was higher at the mid-pod filling stage than that of the flowering stage .

The leaves of the rainfed plants accumulated significantly higher quantity of sugars at both the flowering and mid-pod filling stages. Rainfed Sambal accumulated significantly higher sugars at both the stages. At the mid-pod filling stage, rainfed Sambal had significantly higher sugars than the rainfed Daulat. Accumulation of sugar was higher at the mid-pod filling stage than the flowering stage.

Relative Leaf Water Content (RLWC) and Time At Which Stomata Closed

The curves from which relative leaf water content and the time taken to stomatal closure were calculated by extrapolation are

Table 1.5. Mean values of chlorophyll, proline and sugar contents at the flowering and the mid-pod filling stages of two mustard cultivars as influenced by soil moisture.

	Chlorophyll a (mg dm^{-2})			Chlorophyll b (mg dm^{-2})			Total chlorophyll(mg dm^{-2})		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
				Flowering stage					
Irrigated	2.42	2.72	2.57	0.97	1.09	1.03	3.40	3.80	3.61
Rainfed	2.49	2.58	2.53	1.00	1.14	1.07	3.49	3.72	3.60
Mean	2.46	2.65		0.99	1.12		3.45	3.76	
LSD at 5%	(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)0.10,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS		
				Mid-pod filling stage					
Irrigated	2.73	2.62	2.68	1.07	1.14	1.11	3.81	3.93	3.87
Rainfed	2.20	2.26	2.23	1.01	0.95	0.98	3.21	3.21	3.21
Mean	2.47	2.44		1.04	1.05		3.51	3.57	
LSD at 5%	(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS		

	Proline ($\mu g\ g^{-1}$ fresh weight of leaf)			Sugars content (mg g^{-1} dry weight)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean
			Flowering stage			
Irrigated	68	60	64	8.1	10.1	9.1
Rainfed	100	78	89	13.1	13.7	13.4
Mean	84	69		10.6	11.9	
LSD at 5%	(a)20,(b)14,(c)14,(d)13			(a)3.6,(b)NS,(c)NS,(d)2.3		
			Mid-pod filling stage			
Irrigated	145	121	133	12.4	14.9	13.7
Rainfed	187	163	175	22.9	17.5	20.2
Mean	166	142		17.6	16.2	
LSD at 5%	(a)31,(b)NS,(c)NS,(d)40			(a)1.1,(b)NS,(c)3.6,(d)3.2		

(a) = Difference between treatments
(b) = Difference between cultivars
(c) = Difference within treatment between cultivars
(d) = Difference within cultivar between treatments

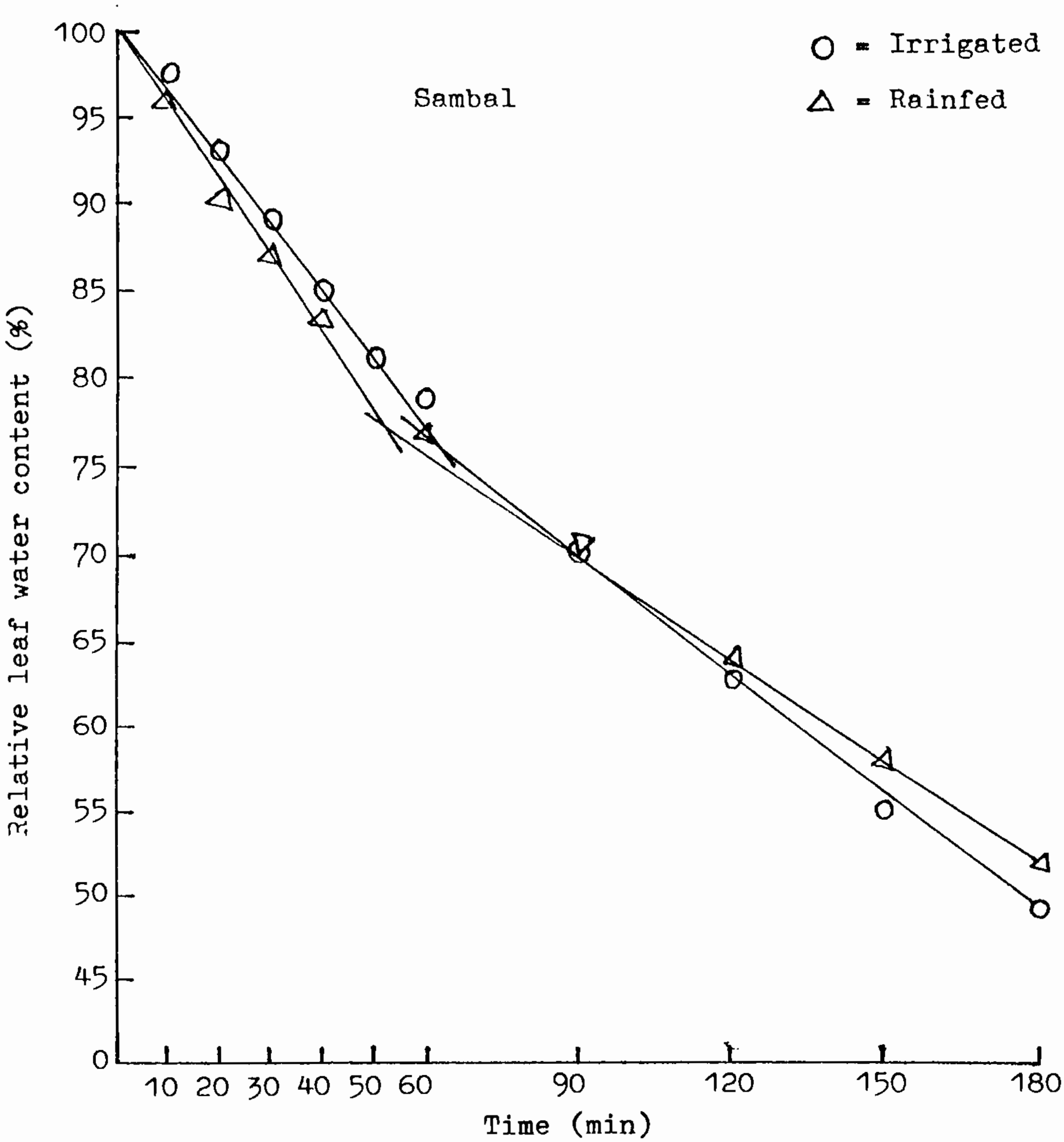

Figure 1.17a. Effect of soil moisture on relative leaf water content and stomatal closure showing extrapolation of the straight line parts intersecting at closure at flowering stage.

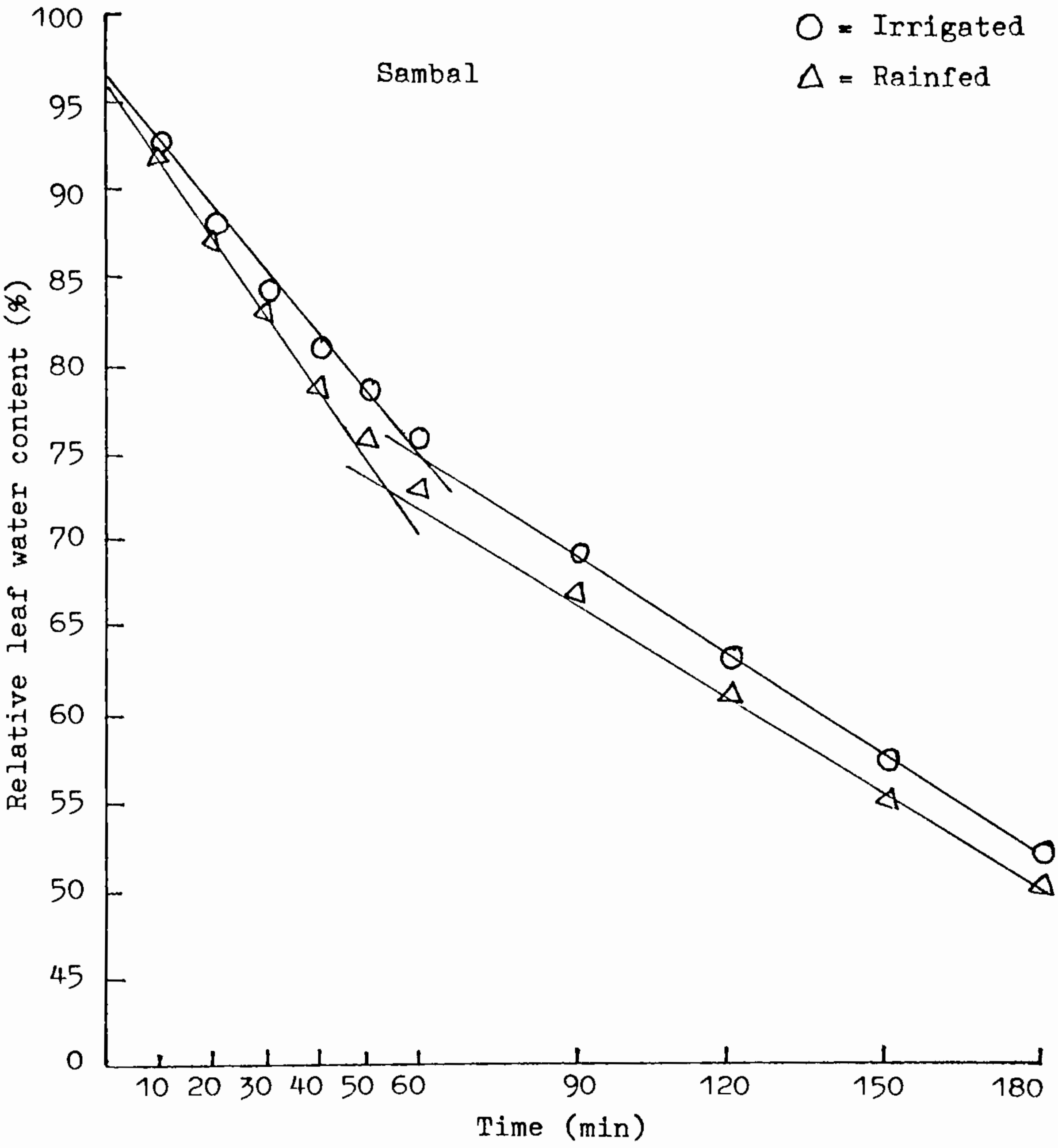

Figure 1.17c. Effect of soil moisture on relative leaf water content and stomatal closure showing extrapolations of the straight line parts intersecting at closure at mid-pod filling stage.

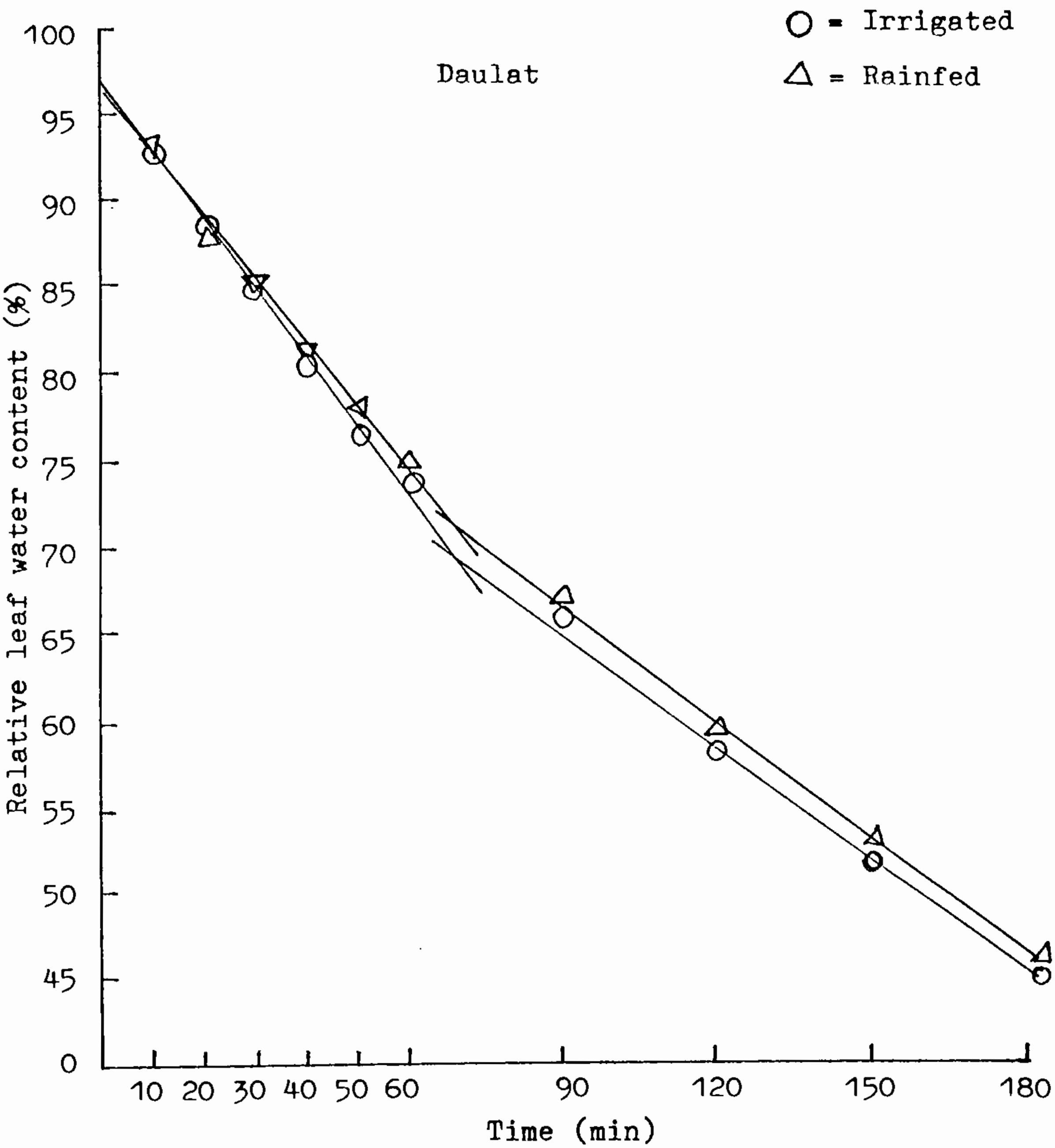

Figure 1.17d. Effect of soil moisture on relative leaf water content and stomatal closure showing extrapolation of the straight line parts intersecting at closure at mid-pod filling stage.

Table 1.6. Mean values of relative leaf water content (RLWC) and time at which stomata closed of two mustard cultivars as influenced by soil moisture at the flowering and the mid-pod filling stages.

	RLWC at which stomata closed (%)			Time taken to stomatal closure (min)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean
			Flowering stage			
Irrigated	76.00	73.70	74.85	66.00	75.00	70.50
Rainfed	77.50	74.20	75.85	51.70	52.70	51.90
Mean	76.80	74.00		58.90	63.90	
LSD at 5%	(a)NS,(b)NS,(c)NS,(d)NS			(a)14.50,(b)NS,(c)NS,(d)18.70		
			Mid-pod filling stage			
Irrigated	74.50	68.50	72.60	61.70	69.00	58.50
Rainfed	72.80	71.50	73.30	54.00	67.00	60.50
Mean	73.65	70.00		51.15	68.00	
LSD at 5%	(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS		

(a) = Difference between treatments
(b) = Difference between cultivars
(c) = Difference within treatment between cultivars
(d) = Difference within cultivar between treatments

shown in Figures 1.17a-d. The relative turgidity at the point of intersection was taken as a critical level for stomatal closure. Relative water content of leaves at points of stomatal closure and time at which stomata closed at the flowering and the mid-pod filling stages are given in Table 1.6. Treatment and cultivar effects were non-significant at both the flowering and mid-pod filling stages for both the characters, but at the flowering stage, time taken to stomatal closure was significantly higher in the irrigated plants.

Transpiration Rates

Mean values of transpiration rates of two cultivars as influenced by soil moisture at the flowering and mid-pod filling stages are presented in Table 1.7. At the flowering stage, soil moisture effect was found significant on total transpiration rate. Total transpiration rate was significantly higher in the irrigated plants at the flowering stage. Sambal had higher rate of total and cuticular transpiration at the flowering stage. At the mid-pod filling stage, soil moisture effect on total,stomatal and cuticular transpiration rates were found non-significant.The irrigated Sambal had singificantly higher cuticular rate than that of the rainfed plants. The stomatal transpiration rate was found higher than the cuticular transpiration rate in all the cases .

Stomatal Characters

Mean values of stomatal frequency,stomatal pore length,number

Table 1.7. Mean values of transpiration rates (mg cm^{-2} h^{-1}) of two mustard cultivars as influenced by soil moisture at the flowering and the mid-pod filling stages.

	Total transpiration rate			Stomatal transpiration rate			Cuticular transpiration rate		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
				Flowering stage					
Irrigated	9.67	7.65	8.66	6.99	6.39	6.69	2.68	1.26	1.97
Rainfed	8.24	7.28	7.76	6.52	5.66	6.09	1.72	1.62	1.67
Mean	8.96	7.47		6.76	6.03		2.20	1.44	
LSD at 5%	(a)0.85,(b)1.25,(c)NS,(d)1.42			(a)NS,(b)NS,(c)1.09,(d)NS			(a)NS,(b)0.71,(c)1.40,(d)0.87		
				Mid-pod filling stage :					
Irrigated	6.26	6.55	6.41	5.44	5.86	5.66	2.81	0.69	0.75
Rainfed	6.40	6.59	6.50	5.89	6.12	6.01	0.51	0.47	0.49
Mean	6.33	6.57		5.67	6.01		0.66	0.58	
LSD at 5%	(a)NS,(b)NS,(d)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)0.21,(d)0.19		

(a) = Difference between treatments
(b) = Difference between cultivars
(c) = Difference within treatment between cultivars
(d) = Difference within cultivar between treatments

of epidermal cells and stomatal index of both the adaxial and abaxial surfaces are given in Table 1.8. Although soil moisture effect was not significant, stomatal frequency of the abaxial surface was higher than that of the adaxial surface. The irrigated plants had lower stomatal frequency than the rainfed plants. Stomatal pore lenth was also unaffected by soil moisture .

Significant effect of soil moisture on epidermal cells of the adaxial surface was found. The irrigated plants had significantly lower number of epidermal cells on both surfaces of Sambal and on the abaxial surface of Daulat.The irrigated plants had significantly higher stomatal index on the abaxial surface. The irrigated Sambal plants had significantly higher stomatal index than that of the rainfed plants on both the adaxial and abaxial surfaces, while the irrigated Daulat had on the adaxial surface only. The stomatal index was higher in the abaxial surface than that of the adaxial surface.

Anatomical Characters of Leaves

Mean values of leaf thickness and cross-sectional areas of palisade and spongy paranchyma cells are presented in Table 1.9. Leaf thickness was significantly higher in the irrigated plants. The irrigated plants showed increased thickness of leaves and mean cross-sectional areas of palisade and spongy parenchyma cells. The mean cross-sectional area of spongy cells of Daulat was higher than that of Sambal. Within the irrigated plants, Daulat had higher leaf thickness and mean cross-sectional areas of palisade and spongy

Table 1.8. Mean values of stomatal characters of two mustard cultivars as influenced by soil moisture .

	Stomatal frequency (No. of stomata mm^{-2})			Stomatal pore length(μm)			Number of epidermal cells mm^{-2}			Stomatal index (%)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
						Adaxial surface						
Irrigated	162	179	170	20.91	17.81	19.36	524	701	612	23	20	22
Rainfed	192	196	193	19.41	20.27	19.84	724	737	731	21	21	21
Mean	177	188		20.16	19.04		624	719		22	21	
LSD at 5%	(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)184			(a)NS,(b)NS,(c)2.0,(d)1.7		
						Abaxial suface						
Irrigated	343	318	330	20.27	18.56	19.41	666	739	702	34	30	32
Rainfed	356	319	338	20.69	21.33	21.01	816	916	866	30	26	28
Mean	350	319		20.48	19.95		714	828		32	28	
LSD at 5%	(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS			(a)135,(b)NS,(c)NS,(d)115			(a)1.8,(b)NS,(c)NS,(d)3.9		

(a) = Difference between treatments
(b) = Difference between cultivars
(c) = Difference within treatment between cultivars
(d) = Difference within cultivar between treatments

parenchyma cells. In the irrigated plants,all these characters were higher than that of the rainfed plants in both the cultivars .

Table 1.9. Mean values of some anatomical characters of leaves of two mustard cultivars as influenced by soil moisture.

	Leaf thickness(μ m)			Cross-sectional area of palisade parenchyma(μm^2)			Cross-sectional area of spongy parenchyma(μm^2)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	330	365	378	1000	862	931	511	394	453
Rainfed	296	319	308	827	738	783	409	341	375
Mean	313	342		914	800		460	368	
LSD at 5%	(a)31,(b)NS,(c)28,(d)19			(a)NS,(b)NS,(c)NS,(d)NS			(a)NS,(b)NS,(c)NS,(d)NS		

(a) = Difference between treatments, (b) = Difference between cultivars
(c) = Difference within treatment between cultivars, (d) = Difference within cultivar between treatments

Characters Related to Flowering

Mean effects of soil moisture on plant height, number of leaves at first flowering, days taken to first flowering and duration of flowering are given in Table 1.10. Plant height at first flowering and duration of flowering were significantly higher in the irrigated plants than that of the rainfed plants. All these characters were significantly higher in Sambal, except duration of flowering. Within the irrigated plants,plant height and the number of leaves at first flowering were significantly higher in Sambal. Within the rainfed plants, all the above characters were significantly higher in Sambal, except duration of flowering. The irrigated plants were significantly taller in both the cultivars. The number of leaves was significantly higher in the irrigated plants than that of the rainfed plants of Sambal.

Table 1.10. Mean values of some characters at flowering stage of two mustard cultivars as influenced by soil moisture.

	Plant height at first flowering (cm)			Number of leaves at first flowering			Days taken to first flowering			Duration of flowering (days)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	72.22	69.67	71.94	13.67	11.11	12.39	38.67	38.00	38.34	22.89	20.11	21.50
Rainfed	64.67	59.89	62.28	12.22	10.78	11.50	39.22	38.00	38.61	20.22	17.11	18.67
Mean	68.45	64.78		12.95	10.95		38.95	38.00		21.56	18.61	
LSD at 5%	(a)7.32,(b)2.82, (c)3.99,(d)2.91			(a)NS,(b)0.83, (c)1.78,(d)0.80			(a)NS,(b)0.55, (c)0.79,(d)NS			(a)2.19,(b)NS (c)NS,(d)NS		

Table 1.11. Mean values of pod abortion (%) on main axis and other branches of two mustard cultivars as influenced by soil moisture.

	Main axis			Primary branch 1			Primary branch 2			Primary branch 3		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	28.95	35.95	32.45	47.44	51.11	49.28	51.00	58.33	54.67	54.67	59.89	57.28
Rainfed	30.81	32.32	31.57	51.00	51.67	51.34	55.28	60.67	57.98	60.11	66.66	63.39
Mean	29.88	34.14		49.22	51.39		53.14	59.50		57.39	63.28	
LSD at 5%	(a)NS,(b)2.29, (c)3.24,(d)2.65			(a)NS,(b)NS, (c)NS,(d)NS			(a)NS,(b)6.18, (c)NS,(d)NS			(a)NS,(b)NS (c)NS,(d)NS		

(a) = Difference between treatments
(b) = Difference between cultivars
(c) = Difference within treatment between cultivars
(d) = Difference within cultivar between treatments

Flowering Pattern

Effect of soil moisture on cumulative number of flowers on the main axis and the primary branches 1-3 of two cultivars is shown in Figures 1.18a-d. The irrigated plants had always higher number of flowers than the rainfed plants. There was little variation regarding the initiation of flowering on different branches between treatments, except in primary branch 3, where flowers of the irrigated Sambal initiated at 44 DAS and the rainfed plants initiated at 48 DAS. The initiation of flowers on the main axis, primary branches 1, 2 and 3 were at 38, 42, 42 and 44 DAS, respectively. Flowering of the irrigated and the rainfed plants in all cases took place at the same time but in branch 3 it was accomplished later in the irrigated than the rainfed plants in both the cultivars. Thus, the duration of flowering of branch 3 of the irrigated plants was higher than the rainfed plants.

Pod Abortion

Mean values of pod abortion on the main axis and the primary branches 1-3 as influenced by soil moisture are given in Table 1.11. Pod abortion was less in the irrigated plants than the rainfed plants, though they were not significantly different. Significantly higher number of pods was aborted on the main axis and primary branch 2 of Daulat. The irrigated Daulat had lesser pod abortion than the rainfed plants on the main axis. The highest percentage of pod abortion was observed on the primary branch 3 and the lowest

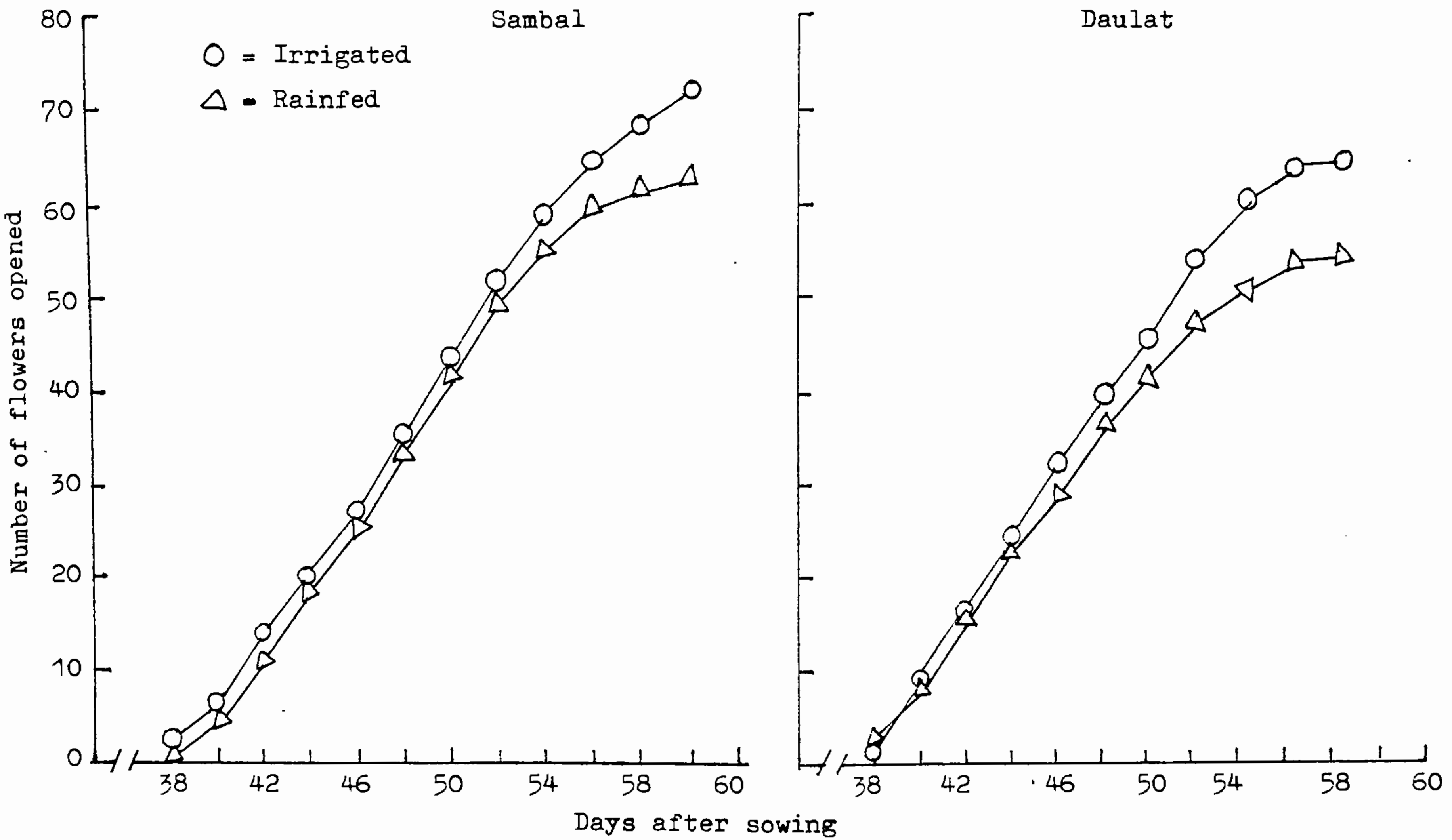

Figure 1.18a. Influence of soil moisture on cumulative number of flowers opened on main axis.

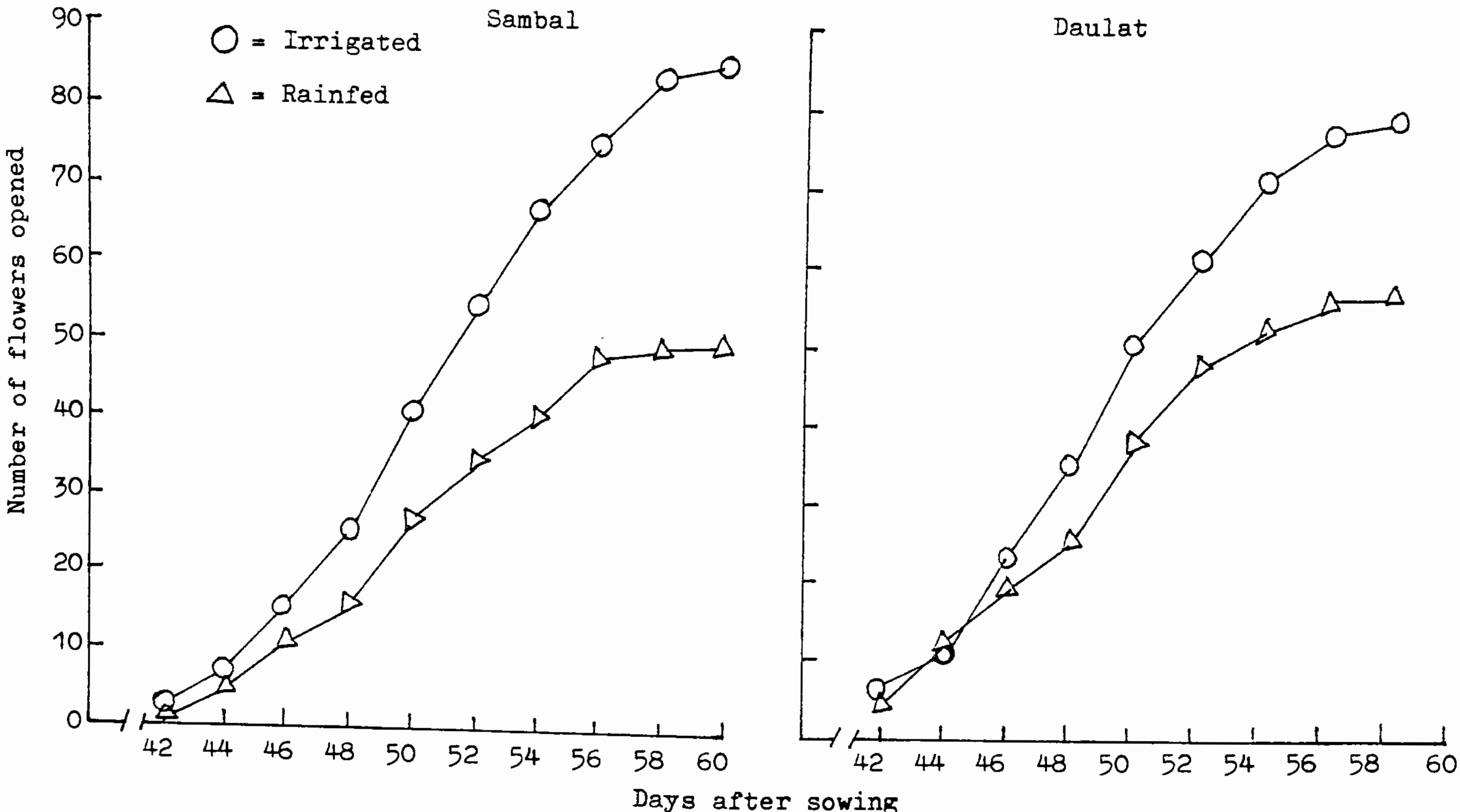

Figure 1.18b. Influence of soil moisture on cumulative number of flowers opened on primary branch 1.

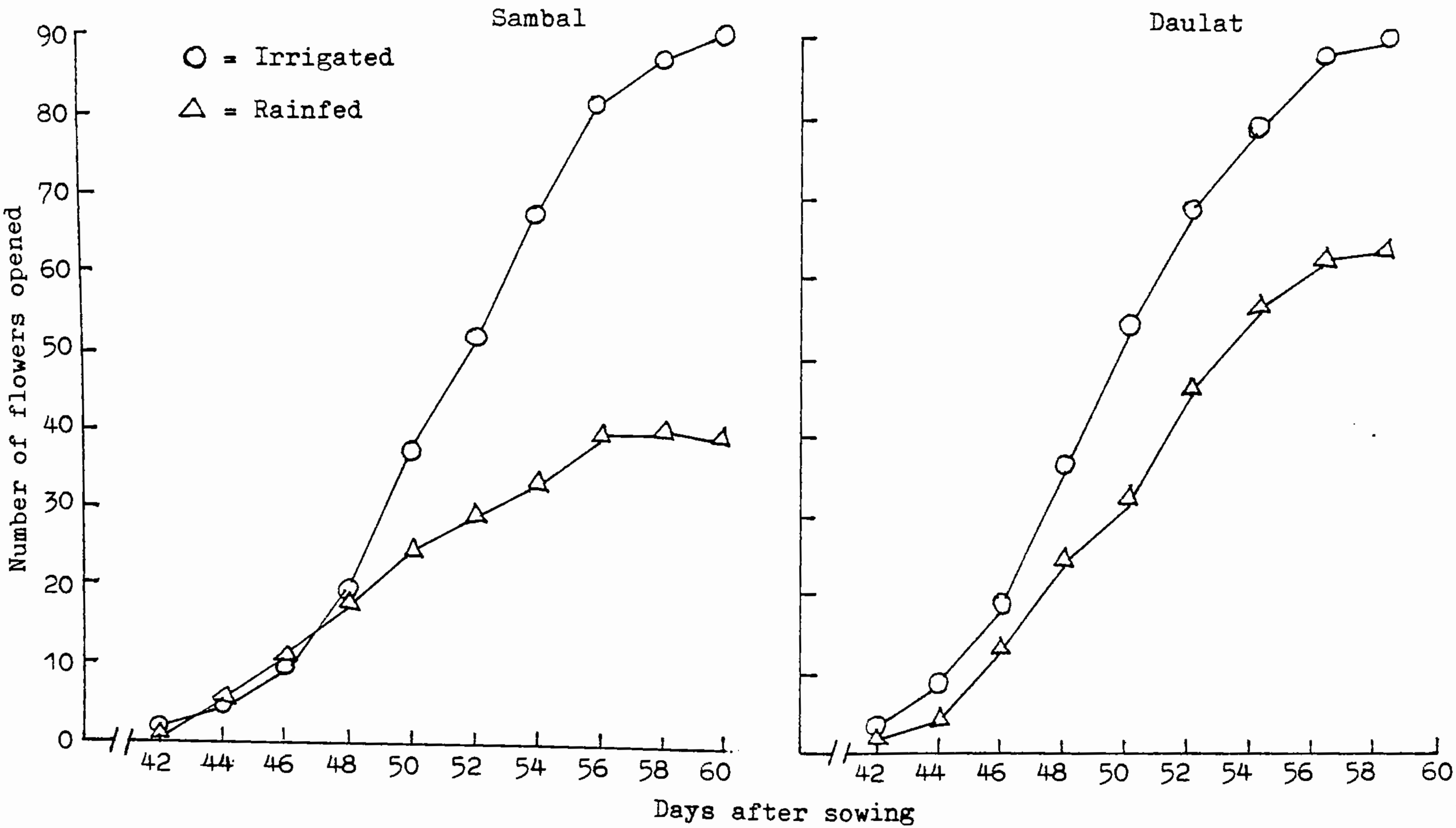

Figure 1.18c. Influence of soil moisture on cumulative number of flowers opened on primary branch 2.

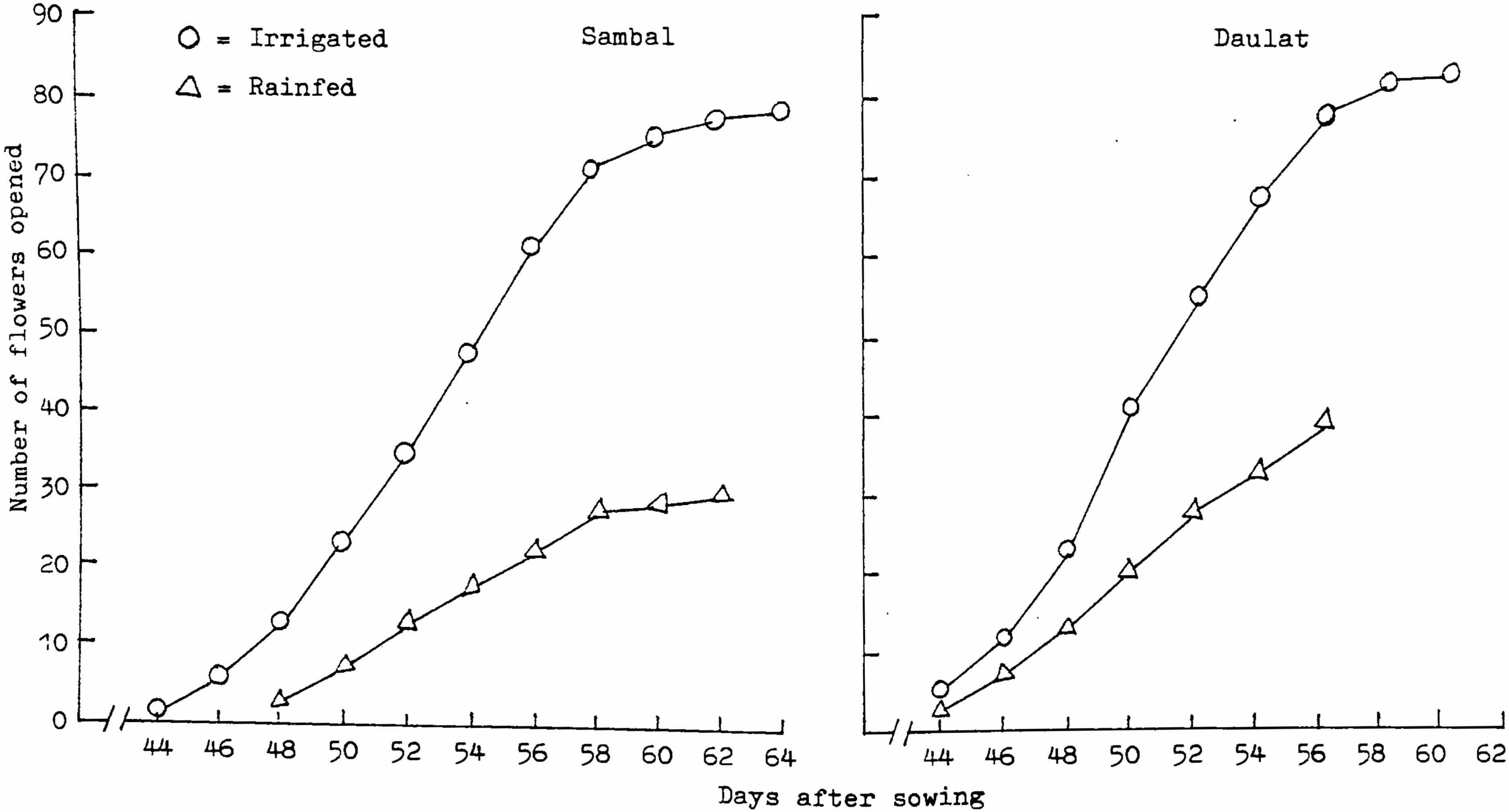

Figure 1.18d. Influence of soil moisture on cumulative number of flowers opened on primary branch 3.

on the main axis in both the treatments and cultivars.

Pod Growth

Effect of soil moisture on pod growth is shown in Figure 1.19. Starting from a lower value, pod weight increased with increasing age. The irrigated plants had increased growth of pods than the rainfed plants at all the stages of growth, except at 10 and 30 days after flowering (DAF) in Sambal and at 10 DAF in Daulat. The irrigated Daulat had significantly higher pod growth at 20, 30, 35, 40 and 45 DAF, whereas the irrigated Sambal had higher pod growth only at 40 and 45 DAF. Daulat had higher pod growth than Sambal.

Seed Growth

Seed weight increased with increasing age at all the stages of growth, except at 45 DAF in rainfed Daulat (Figure 1.20). Soil moisture had no significant effect on seed growth of both the cultivars. The irrigated plants had higher seed weight at 20, 30, 40 and 45 DAF in Sambal and only at 45 DAF in Daulat. Sambal had higher seed weight than Daulat .

Yield and Yield Components, Consumptive Water Use and Water Use Efficiency

Mean values of plant height, length of main axis, number of branches/plant, number of pods on main axis, number of pods/plant, number of seeds/pod, pod weight/plant, straw weight, 1000-seed

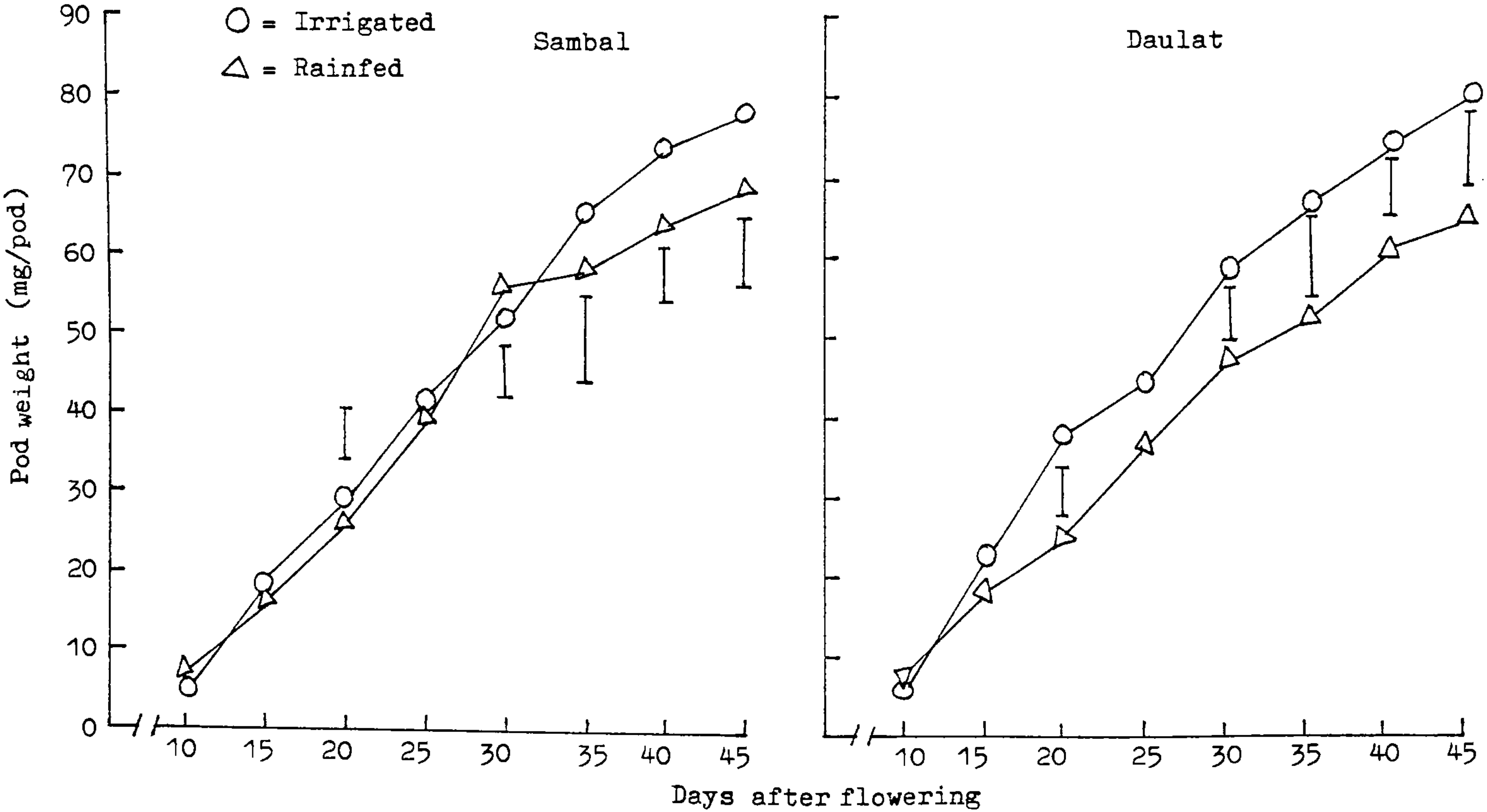

Figure 1.19 . Effect of soil moisture on pod growth of two mustard cultivars at successive stages of growth.

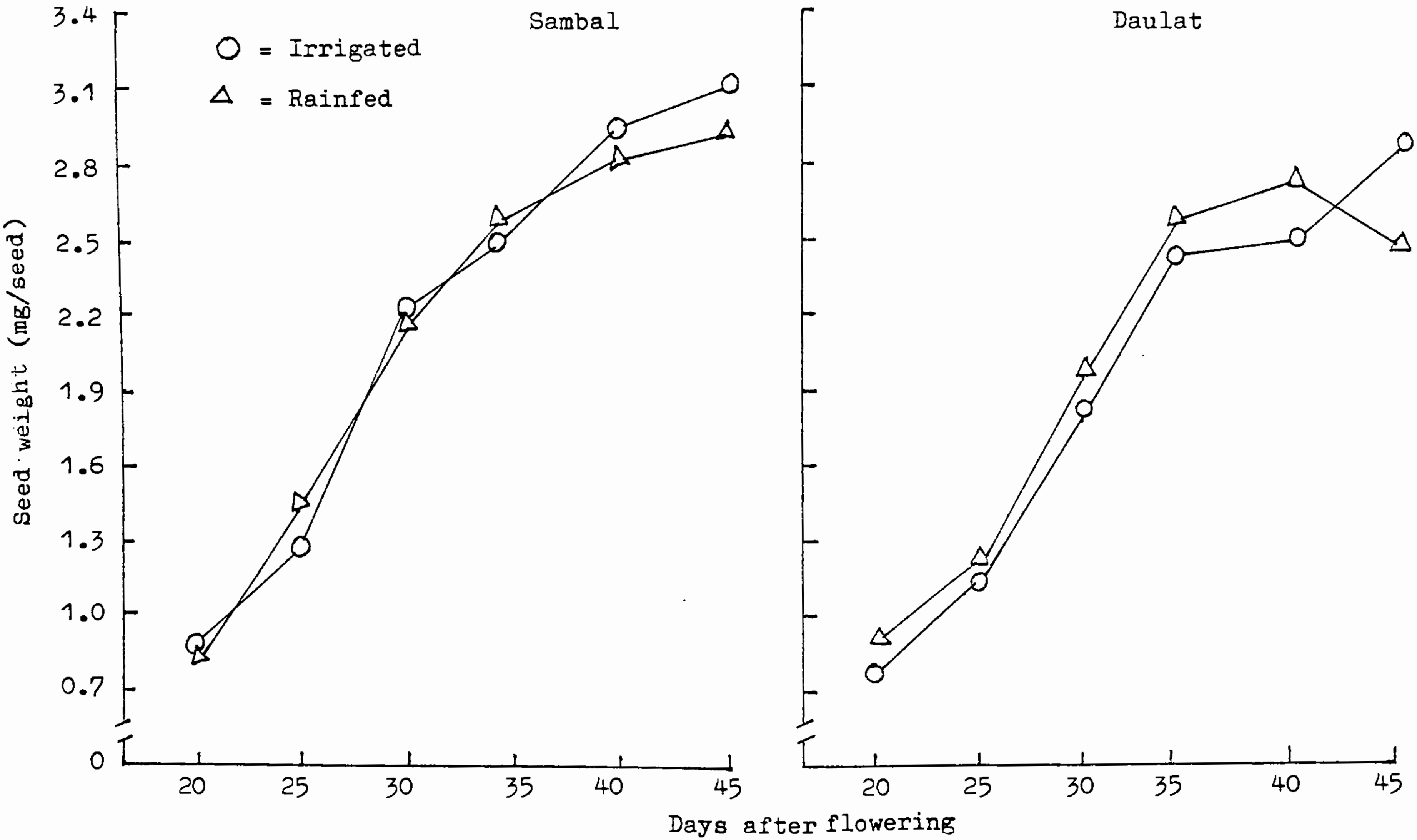

Figure 1.20. Effect of soil moisture on seed growth of two mustard cultivars at different stages of growth.

weight, seed-husk weight ratio, harvest index, seed yield, oil content, consumptive water use and water use efficiency of two cultivars as influenced by soil moisture are given in Table 1.12. Soil moisture effect was significant for all the above characters, except the number of branches/plant, the number of pods on main axis seed-husk weight ratio, harvest index and oil content of seeds. Sambal had significantly higher plant height, length of main axis, number of pods on main axis straw weight, 1000-seed weight and water use efficiency than those of Daulat. But the number of seeds/pod and harvest index were significantly higher in Daulat than Sambal .

Plant height at maturity : The irrigated plants were taller than rainfed plants. Sambal was taller than Daulat.

Length of main axis : The main axis of the irrigated plants was longer than that of the rainfed plants. Sambal showed longer main axis than Daulat. Within the irrigated plants, longer main axis was also shown in Sambal. The longest main axis was present in the irrigated Sambal.

Number of branches/plant : The irrigated plants had higher number of branches/plant than the rainfed plants but the difference was not significant. Daulat showed higher number of branches/plant though it was not significantly different from Sambal.

Number of pods on main axis : The number of pods on main axis was higher in the irrigated than that of the rainfed plants but it was not significantly different. Sambal had significantly higher number of pods on main axis. The irrigated Daulat had significantly higher number of pods on main axis than that of the rainfed plants.

Number of pods/plant : The irrigated plants had higher number of pods/plant than the rainfed plants. Significantly higher number of pods/plant was found in the irrigated Daulat. In the rainfed conditions, Sambal had higher number of pods, though the differece was not significant .

Number of seeds/pod : The number of seeds/pod was significantly higher in the irrigated plants than that of the rainfed plants. Daulat had significantly higher number of seeds/pod.

Pod weight/plant : The irrigated plants had significantly higher pod weight than the rainfed plants. The irrigated Daulat had higher pod weight, while the rainfed Daulat had lower pod weight, though the differences were not significant .

Harvest index : Harvest index was higher in the irrigated plants, but it was not significantly different from the rainfed plants. Daulat had significantly higher harvest index than Sambal.

Seed yield : Seed yield was significantly higher in the irrigated plants (2240 kg/ha) than that of the rainfed plants (1042 kg/ha). Average yield of Sambal was slightly higher than Daulat but the difference was not significant. In the irrigated condition Daulat yielded more seeds than Sambal but in the rainfed condition it yielded less though these differences were not significant.

Oil content of seeds : Oil content of seeds was not significantly influenced by soil moisture. In the seeds of the irrigated plants, oil content was lower than that of the seeds of the rainfed plants. Daulat yielded higher quantity of oil than Sambal .

Consumptive water use : Consumptive water use of the irrigated plants was significantly higher than the rainfed plants. Daulat had higher consumptive water use in the irrigated condition but lower in the rainfed condition than Sambal, though the differences were not significant .

Water use efficiency : The irrigated plants had significantly lower water use efficiecy (12.04 kg ha^{-1} mm^{-1}) than the rainfed plants (15.30 kg ha^{-1} mm^{-1}).Significantly higher water use efficiency was found in Daulat than Sambal.The highest water use efficiency was observed in the rainfed Daulat .

Table 1.12. Mean values of yield and yield components, consumptive water use and water use efficiency of two mustard cultivars as influenced by soil moisture.

	Plant height at maturity (cm)			Length of main axis (cm)			Number of branches/plant		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	180	139	160	81	61	71	5.08	5.50	5.29
Rainfed	170	116	143	68	48	58	4.75	4.92	4.83
Mean	175	128		75	55		4.92	5.21	
LSD at 5%	(a)15.21,(b)22.76, (c)32.19,(d)22.30			(a)7.14,(b)7.18, (c)10.16,(d)6.94			(a)NS,(b)NS, (c)NS,(d)NS		

	Number of pods on main axis			Number of pods/plants			Number of seeds/pod		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	59	51	55	255	277	266	13.1	14.3	13.7
Rainfed	52	40	46	146	124	135	11.9	12.6	12.3
Mean	51	46		186	201		12.5	13.5	
LSD at 5%	(a)NS,(b)3.78 (c)5.35,(d)10.15			(a)9.94,(b)NS (c)NS,(d)38.18			(a)1.31,(b)0.83 (c)1.18,(d)0.80		

Contd ......

Table 1.12. (Continued).

	Pod weight/plant (g)			Straw weight/plant (g)			1000-seed weight(g)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	12.82	13.66	13.24	15.14	11.23	13.24	2.80	2.30	2.55
Rainfed	6.89	5.74	6.31	8.07	5.03	5.92	2.50	2.16	2.33
Mean	9.86	9.70		11.61	8.13		2.65	2.23	
LSD at 5%	(a)0.25,(b)NS, (c)NS,(d)0.92			(a)1.88,(b)1.65, (c)2.33,(d)1.59			(a)0.19,(b)0.29 (c)0.40,(d)0.28		

	Seed-husk weight ratio			Harvest index (%)			Seed yield (kg/ha)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	1.05	1.06	1.06	23.44	28.10	25.77	2163	2317	2240
Rainfed	1.03	0.97	1.00	23.38	26.24	24.81	1151	933	1042
Mean	1.04	1.02		23.41	27.17		1657	1625	
LSD at 5%	(a)NS,(b)NS, (c)NS,(d)0.04			(a)NS,(b)1.90, (c)2.68,(d)NS			(a)190,(b)NS (c)NS,(d)219		

Contd ......

Table 1.12. (Continued).

	Oil content (%)			Consumptive water use (mm)			Water use efficiency (kg $ha^{-1}mm^{-1}$)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
Irrigated	33.33	33.67	33.50	183	189	186	11.82	12.26	12.04
Rainfed	34.00	36.00	35.00	82	60	71	14.04	16.55	15.30
Mean	33.67	34.84		133	125		12.93	14.41	
LSD at 5%	(a)NS,(b)NS, (c)NS,(d)NS			(a)55,(b)NS, (c)NS,(d)69			(a)2.65,(b)2.12, (c)NS,(d)3.04		

(a) = Difference between treatments
(b) = Difference between cultivars
(c) = Difference within treatment between cultivars
(d) = Difference within cultivar between treatments

Correlation Coefficients Between Yield and Yield Components

Simple correlation coefficients between yield and yield components influenced by soil moisture are shown in Table 1.13 .

Association between yield and yield components of the irrigated plants

The number of pods on main axis was positively correlated with the number of branches/plant. Pod weight/plant was positively associated with the number of pods/plant and the number of seeds/pod. Thousand-seed weight was positively related to plant height and the number of pods on main axis but negatively related with the number of pods/plant and the number of seeds/pod. Harvest index was positively correlated with the number of pods/plant, number of seeds/pod and pod weight/plant but negatively correlated with plant height and 1000-seed weight. Seed yield was positively correlated with the number of pods/plant, number seeds/pod, pod weight/plant and harvest index. Oil content had no significant relation with any of the yield component.

Association between yield and yield components of the rainfed plants.

The number of pods on main axis was positively correlated with plant height,the number of branches/plant,number of pods/plant and pod weight/plant. Pod weight/plant was positively associated with plant height and the number of pods/plant.Thousand-seed weight was positively correlated with plant height. Harvest index had negative association with plant height and positive association with the number of seeds/pod.Seed yield showed positive correlation with plant height, number of pods on main axis, the number of pods/plant, pod weight/plant and harvest index.Oil content of seeds had positive relation with the number of seeds/pod and negative relation with plant height and the number of pods on main axis.

Table 1.13. Simple correlation coefficients between yield and yield components (upper diagonal irrigated and lower diagonal rainfed values).

	Plant height at maturity (1)	Number of branches/ plant (2)	Number of pods on main axis (3)	Number of pods/plant (4)	Number of seeds/pod (5)	Pod weight/ plant (6)	1000-seed weight (7)	Harvest index (8)	Seed yield (9)	Oil content (10)
1		-0.01	0.51*	-0.02	-0.21	0.12	0.58**	-0.60**	0.13	-0.35
2	-0.06		-0.46*	0.29	0.05	0.37	-0.06	0.10	0.33	-0.24
3	0.64***	-0.45*		0.11	-0.01	0.14	0.44*	-0.19	0.18	0.10
4	0.34	0.08	0.54*		0.36	0.91***	-0.41*	0.48*	0.90***	-0.04
5	-0.35	0.16	-0.30	-0.03		0.46*	-0.43*	0.50*	0.48*	-0.02
6	0.42*	-0.03	0.47*	0.82***	0.24		-0.24	0.49*	0.99***	-0.11
7	0.50*	-0.22	0.10	-0.15	-0.06	0.23		-0.63**	-0.27	-0.08
8	-0.48*	0.30	-0.36	0.26	0.63***	0.38	-0.09		0.55**	0.19
9	0.39*	0.06	0.39*	0.79***	0.30	0.98***	0.21	0.48*		-0.12
10	-0.61**	0.21	-0.61**	-0.28	0.40*	-0.17	-0.38	0.27	-0.17	

DISCUSSION

Like any other crop, growth and yield of mustard is under the control of many environmental factors;soil moisture is one of them.In a strict sense mustard is an irrigated crop (Andrews,1972). Proper maintenance of soil moisture in the crop encourages its growth and development and ultimately reflects to the yield.

Although the use of exponential polynomial equation in growth analysis is advocated (Hurd, 1977; Hunt, 1978; Sivakumar and Shaw, 1978) due to the difficulty of selecting the degree of polynomial to be fitted, Nicholls and Calder (1973) suggested a statistically objective method. However, a serious problem arises when unequal degrees of polynomials describe the relationship between $\log_e$ dry weight and $\log_e$ leaf area with time in different sets of data under comparison. The main reason is that this results in strongly dissimilar patterns of derived growth parameters such as CGR, NAR, etc.,for which no physiological explanation can be offered. Therefore, Hurd (1977) and Hunt (1978) suggested the use of simplest, quadratic relationship for all cultivars or treatments under comparison, and the same was followed in the present work. A close agreement between the harvest interval and curve-fitting method in the present work, also suggests that the selected polynomial adequately described the data except the dry weight.

The results of the present study showed that total dry matter production was significantly greater in the irrigated plants. Similar result was reported by Khan and Agarwal (1985), Mandal *et* *al.*(1986), Singh *et al.*(1987) and Haque *et al.* (1987) in mustard, Krogman and Hobbs (1975) and Clarke and Simpson (1978 a) in rape, Nageswara Rao *et al.*(1985) and Srinivasan *et al.*(1987) in groundnut and Farah (1981) in field beans. The increase of total dry matter was due to increased LAI in the early stages (Watson, 1947) in the irrigated plants. Total dry matter increased slowly at the early vegetative phases but increased rapidly with the advancement of the growth period (Figure 1.1). The rapid increase of total dry matter at the later stages was due to green stem and pod photosynthesis (Scott *et al.*, 1973). The quadratic polynomials predicted dry weights to drop just prior to maturity,while the actual dry weights continued to increase. It may be attributed that cubic polynomials was most appropriate expression for fitting dry weight data.

Significantly higher LAI was found in the irrigated plants (Figure 1.2).This result corroborates the findings of Mandal *et al.* (1986) in mustard and Clarke and Simpson (1978 a) in rape. Similar result was also reported in several plants other than *Brassica*,like barley (Kirby,1969), sorghum (Constable and Hearn, 1978; Sivakumar *et al.*,1979 and Rabindrnath and Shiv Raj, 1983), sunflower (Connor and Jones,1985) and peanut (Nageswara Rao *et al.*,1988).The increase of LAI occurred due to increase of the leaf expansion in the irrigated plants. Soil moisture increased turgor pressure in the cells and turgor forces played a part in the process of leaf expansion (Hsiao and Acevedo,1974). With the increase in the level of irrigation, uptake of nutrients was more hence more expansion of leaf took place (Mandal *et al.*,1986). Soil moisture increased the relative leaf water content(RLWC) (Figures 1.16a,b) which increased cell expansion and ultimately leaf area increased. Reduced LAI in the rainfed plants may be caused by the faster rate of leaf senescence and reduced number of leaves. Water stress is known to hasten leaf senescence (Asana, 1961) and reduces the number of leaves (Sivakumar and Shaw, 1978 and Turk *et al.*, 1980). Mare and Palmer (1976) found that the total number of leaves produced by the primary stem of sunflower was reduced due to water stress .This may be due to the inhibition of the initiation and differentiation of leaf primordia due to water stress.Starting from a lower value,LAI reached a certain peak and then declined throughout (Figure 1.2). Senescence and abscission of the older leaves caused the depletion of LAI at the later stages. The pattern of LAI obtained from curve-fitting method was similar with that of the original data. This is due to the best fit of the leaf area data in the quadratic polynomials.

The irrigated plants had significantly higher LAD in both the cultivars. Higher LAD of the irrigated plants was due to higher LAI for a longer period. Krogman and Hobbs (1975) found that irrigation of rape slowed the senescence of leaves and thereby increased the total green surface area of the plants. Constable and Hearn (1978) reported that soil water deficit during pod filling in soybeans caused early leaf death. The pattern of LAD calculated from curve-fitting method was closer to that calculated from the original data. The best fitness of leaf area data in the quadratic polynomials is the cause of this similar pattern.

Significantly higher CGR was found in the irrigated plants at almost all the stages of growth in the present investigation (Figure 1.4a). Higher CGR in the irrigated plants was also observed by Clarke and Simpson (1978a) in rape and Srinivasan *et al.*(1987) in groundnut. Rabindranath and Shiv Raj (1983) reported that the CGR values reduced considerably with water stress. Higher CGR in the irrigated plants was due to higher production of dry matter owing to higher LAI. CGR calculated from the quadratic-fitted data increased up to a certain peak and decreased thereafter giving uncharacteristically negative values late in the season (Figure 1.4b). CGR is the most meaningful growth function, since it represents the net result of photosynthesis, respiration and canopy area interactions. As noted by Williams *et al.* (1965), CGR is also representative of the most common agronomic measurment, i.e.,yield of dry matter per unit land area.

The irrigated plants had higher RGR at several stages of growth in both the cultivars but significantly higher only at (41-48) DAS in Daulat. This result corroborates the finding of El Nadi (1969) and Nerkar *et al.*(1981) in *Vicia faba*. Richards (1978) found that RGR was reduced in more severe drought treatment in rape. RGR in the irrigated plants increased because of the increase of LAR,as LAR is a component of RGR. In the present study, RGR declined with increasing age and plant dry weight.Similar result was reported for RGR in *Dactylis glomerata* (Eagles, 1969; 1971), in rape (Clarke and Simpson, 1979) and in *Pennisetum americanum* (Chanda *et al.*, 1987). It had been suggested that the decrese in RGR could be attributed to selfshading of lower leaves by upper leaves (Thorne, 1961). The decreasing trends in RGR with age was mainly due to the decline in LAR (Chanda *et al.*, 1987). The pattern of RGR was similar in both the curve-fitting and the classical methods.

At the early stages NAR values were slightly higher in the irrigated plants, but at the later stages it was significantly higher in the rainfed plants. Due to higher LAI, NAR was lower in the irrigated plants (Watson, 1952 ; Donald, 1961 ; Harper, 1963 and Rees, 1963). Watson (1958) has attributed the decline in NAR to increased mutual shading of leaves, resulting in reduced photosynthesis. Higher NAR due to higher soil moisture was found by El Nadi (1969) and Nerkar *et al.*(1981) in beans and Rabindranath and Shiv Raj (1983) in sorghum. Soil moisture effect in the present study (Figures 1.6a and 1.6b) showed that very little increase or depletion of NAR was found at the early stages but at the later stages it increased very sharply.A similar occurence was evident in *Brassica napus*(Allen and Morgan,1972,1975) and in soybean (Buttery, 1969; Koller *et al.*, 1970). The increase of NAR at the later stages may be due to decreased leaf area and increased stem and pod photosynthesis. The upswing in NAR occurred after the cessation of flowering, and after maximum pod area would have occurred (Tayo and Morgan,1975). Inanga and Kumara (1974) reported that maximum photosynthetic rate of rape occurred before the establishment of maximum pod area, after which the photosynthetic rate of all plant parts declined. As a result,the observed upswing in NAR can be attributed to a sudden increase in photosynthetic contribution by pods. Koller *et al.*(1970) suggested that the observed upswing in NAR of soybean was the response of the photosynthetic apparatus to increased demand for assimilates by the rapidly growing seeds. Results of Thorne and Koller (1974) have shown that assimilate demand has a marked influence on source-leaf photosynthesis, and formation and export of carbohydrates in soybean. In *Brassica napus*, there is a rapid increase in seed weight late in the ripening phase (Norton and Harris, 1975); this effect would have provided the high sink demand which in turn increased photosynthetic activity. The pattern of NAR calculated from curve-fitting method showed a close correspondence with that calculated from the original data (Figures 1.6a and 1.6b).

The irrigated plants had higher LAR values at most of the stages of growth, but in Daulat it was significantly lower at 20 DAS. In *Vicia faba*, Nerkar *et al.* (1981) found that LAR increased with the increased level of soil moisture. Higher LAR in the irrigated plants may be due to increased SLA and LWR, since SLA and LWR are the two components of LAR. LAR values declined sharply with plant age in both the treatments and cultivars. Wallace and Munger (1965) reported that in dry beans LAR was highest during the early vegetative stage and later decreased rapidly with advancement of age. The pattern of curve-fitted LAR was similar with that of the original data.

Significantly higher RLGR was found in the irrigated plants of Sambal at (69-76) DAS and of Daulat at (27-34) and (48-55) DAS. Significantly lower RLGR was found at (55-62) DAS in Sambal and at (69-76) DAS in Daulat. Richards (1978) reported that RLGR was not affected by drought stress in rape. The maximum RLGR was found at (20-27) DAS in both the cultivars and treatments and then declined with increasing age. Similar decline of RLGR was found in soybean (Buttery, 1969); in blackgram (Pandey *et al.*, 1978) and in pearl millet (Chanda *et al.*, 1987). Much of this decline can be attributed to self-shading at the early stages and abscission and senescence of leaves at the later stages. Saha (1983) observed a positive relation between RLGR and LAR in jute. So, due to decline of LAR, RLGR would have been declined. RLGR values obtained from the curve-fitting method drifted with increasing plant age and also with increasing plant weight (Figures 1.8b and 1.12).

The irrigated plants had significantly higher SLA at 34, 48, 55 and 62 DAS in Sambal and at 34 and 55 DAS in Daulat (Figure 1.9a). Higher SLA in the irrigated plants may be attributed due to less number of cells per unit leaf area and lower compactness between cells. SLA increased slightly at the later stages of growth in all the treatments and cultivars except that in the irrigated Daulat. The increase of SLA at the later stages may be due to translocation of assimilates from the leaves to the sink organs. Chanda *et al.* (1987) observed that SLA values decreased with increasing plant dry weight in pearl millet.

In the present experiment, the LWR values of the irrigated plants were significantly greater at 48 and 55 DAS in Sambal and 55, 62, 69 and 76 DAS in Daulat (Figure 1.10a). The increase of LWR in the irrigated plants may be attributed due to increased leaf weight. LWR values declined very sharply with increasing plant age and plant dry weight. Strong drift of LWR with increasing plant dry weight was reported by Chanda *et al.* (1987) in pearl millet. The decrease of LWR was caused by increased plant dry weight and decreased LAI at the later stages.

Correlation analysis indicated that the pre-flowering CGR was positively correlated with pre- flowering LAI and negatively correlated with RGR and NAR at the pre-flowering stage of the rainfed plants (Table 1.4). This indicated that soil moisture had a direct effect on the association between CGR and LAI of the pre-flowering stage. CGR at the post-flowering stage of the rainfed plants showed positive correlation with the post-flowering LAI and negatively correlated with NAR (post-flowering) and LAR (pre-flowering).Pandey *et al.*(1981) observed a positive relation between CGR and LAI in cowpea. Post-flowering RGR (irrigated) was negatively correlated with LAI at the pre-flowering stage. This indicates that RGR decreased with increasing LAI at the pre-flowering stage of the irrigated plants. NAR (pre-flowering) was positively correlated with LAI at pre-flowering stage in the irrigated plants. NAR (post-flowering) was positively correlated with LAR (pre-flowering) and negatively correlated with LAR at post-flowering in both the treatments. Post-flowering NAR of the rainfed plants was also correlated negatively with the post-flowering LAI.This relationship postulates that with decreasing LAI in the rainfed plants NAR increased at the post-flowering stage. Thurling (1974) and Tan *et al.*(1978) reported that NAR was negatively correlated with LAR and LAI. Seed yield was positively correlated with LAI at the pre-flowering stage and CGR and NAR at the post-flowering stage in the irrigated plants. But in the rainfed plants, seed yield was positively correlated with LAI and CGR at the post-flowering stage and negatively correlated with NAR at the post-flowering and LAR at the pre-flowering stages (Table 1.4). Seed yield was found significantly correlated with LAI in mustard (Reddy and Sinha, 1987 and Chaturvedi *et al.*, 1988) and with RGR, NAR and LWR in *B. campestris and* with LAI and LWR in *B. napus* (Thurling, 1974).In other crops also, the growth attributes like LAI and LAD had positive correlation with yield (Thorne, 1960; Saini and Das, 1979).

Developmental factors affecting the accumulation of dry matter and subsequent partitioning of assimilates are of great importance in determining the final yield in crops (Watson, 1971; Wareing and Patric, 1975). In the present investigation, the percentage of DM accumulation for stem + petiole was lower at the early stages, at the middle stages it increased and then gradually decreased with time (Figures 1.14 and 1.15). Percentage of DM accumulation for stem + petiols was lower in the irrigated plants. DM accumulation in the leaves was found highest at the initial stage and gradually declined with increasing time and at 83 DAS it became zero. The irrigated plants accumulated higher percentage of DM for leaves. The irrigated plants had higher percentage of DM for buds + flowers. Pods accumulated DM first at 48 DAS and gradually increased with age. The rainfed plants had higher accumulation of DM for pods. Similar result were reported in rape (Krogman and Hobbs, 1975); in soybean and sorghum (Constable and Hearn, 1978); in *Vigna radiata* (Nagarajah and Schulze, 1983) and in groundnut (Srinivasan *et al.*, 1978). Allen *et al.* (1971) suggested that pods of rape produce the assimilates for their own development and for the seeds they contain and that the effect of leaves in seed growth is minor and indirect. However, Hozyo *et al.*(1972) and Freyman *et al.*(1973), who traced assimilates from the leaves to the seeds, showed that leaves do contribute to seed formation. Soil drought reduced partitioning into leaves but increased partitioning into stems (Nagarajah and Schulze, 1983). In sorghum and soybeans, the significant loss in stem dry weight during grain filling suggests that there could have been reallocation of dry matter from the stem to the developing grain (Constable and Hearn, 1978).

In the present study, the irrigated plants had higher RLWC than that of the rainfed plants. Similar result was reported by Raja and Bishnoi (1990) in rape and Joshi *et al.*(1988)in groundnut. Mehrotra *et al.* (1969) found that with increased soil moisture relative turgidity increased. Sivakumar *et al.*(1979) observed less negative leaf water potential in the irrigated plants than that of the rainfed sorghum. Average relative turgidity attained the minimum value at higher soil moisture tension and the maximum value at lower soil moisture tension (Nayak *et al.*,1983).The higher RLWC was associated with higher dry matter production rates of the irrigated plants because cell turgidity is important in relation to the opening and closing of stomata, expansion of leaves and flowers and movement of water and nutrients to various parts of the plant (Kramer,1969). Wein *et al.*(1979) reported that the water potential decreased with increasing soil moisture stress in *Vigna*. They suggested a increase in the plant resistance to water flow as soil moisture stress increased, which would help in maintaining suitable plant water status. But Hall and Schulze (1980) exhibited that the plant resistance to water flow definitely increased in *Vigna* with soil moisture stress. In the morning and afternoon, RLWC remaind higher but at noon it decreased (Figures 16a and 16b). The decrease of RLWC at the midday may be due to higher evapotranspiration owing to increased temperature and light intensity.

Chloroghyll a and b are the most important pigments active in the photosynthetic processes. In the present experiment, chlorophyll a,b and total chlorophyll slightly increased in the irrigated plants at the mid-pod filling stage, but the difference was not significant (Table 1.5). Hussein (1973) reported that water regime had no significant effect on the concentration of total chlorophyll in the leaves of cotton. There was an increase in the percentage of chlorophyll in the leaves of cotton with decreasing water stress at different periods of plant growth (El-Fouly *et al.*,1971; El-Saidi and El-Mossallami,1972). There was an increasing concentration of total chlorophyll,chlorophyll a and b in the leaves of cotton with a decreasing in the amount of available moisture depletion before irrigation at the early stages of growth and at the later stages of growth chlorophylls were highest at the 70% available soil moisture before irrigation (Moursi *et al.*,1976).

The rainfed plants accumulated significantly higher amount of proline than the irrigated plants at both the flowering and mid-pod filling stages. Proline content increased at the mid-pod filling stage than the flowering stage (Table 1.5). Increased proline accumulation in the stressed plants was found in sorghum (Blum and Ebercon, 1976), in wheat (Quarrie, 1980) and in foxtail millet (Narasimha Rao and Shiv Raj,1985). But no relationship was observed by Richards (1978)in rape between the amount of proline accumulated and the water status of the leaves, nor between the proline content in turgid and wilted leaves of the same cultivar. In sorghum,leaves of water-stressed field-grown plants accumulated proline to a level of several times greater than that in non-stressed plants (Waldren *et al.*, 1974). Stewart *et al.* (1966) and Blum and Ebercon (1976) suggested that the accumulated proline could also serve as a readily available energy and nitrogen source for use upon the relief of stress. Accumulated proline may be oxidized and serve as a source of energy, especially when carbohydrate content is low (Wang, 1968; Oaks*et al.*,1970 and Stewart, 1972). However Hanson (1979) suggested that the free proline accumulated in response to water stress was inert and played no cellular role. Previous conjectures have projected proline: (a) as a detoxifying agent, rendering harmless NH_3 released by proteolysis (Kemble *et al.*, 1954), but experimental evidence has discounted this role (Blum and Ebercon, 1976); (b) as a temporary storage compound for N, providing a major and readily available source of energy and N for post-stress recovery (Stewart *et al.*, 1966 ; Blum and Ebercon, 1976);and (c) as a hydrophilous agent for maintaining the colloidal properties of cell protoplasm against the extremes of dehydration (Protsenko *et al.*,1968). More recent evidence suggests that proline may confer protection on some mitochondrial and solubilized enzymes against heat instability (Nash *et al.*,1980). Beneficial as they may be, these proven and unproven cellular role of proline are usually to satisfactorily account for the agronomic expression of drought resistance.

Significantly higher sugar accumulation was found in the rainfed plants at both the flowering and mid-pod filling stages (Table 1.5).Sugar content increased at the mid-pod filling stage than the flowering stage.Stewart (1971) and Narasimha Rao and Shiv Raj (1985) reported that sugar accumulation increased as a result of water stress. The soluble sugars were significantly higher in both the unirrigated sunflower and sorghum plots than in the irrigated plots (Turner *et al.*, 1978). Easten and Ergle (1948) suggested that starch would be converted into sugars under stress. Sugars are also known to stabilize protoplasmic membranes (Larson, 1975).

Relative leaf water content (RLWC) at which stomata closed was not significantly affected by soil moisture treatment (Table

1.6). Similar result was reported by Nazrul-Islam and Yasmin (1982) in tomato. Bannister (1964) has shown that *Calluna vulgaris* from dry sites had a lower relative turgidity at stomatal closure than those from wet site. The water potential for stomatal closure was significantly correlated with the osmotic potential of the leaves at stomatal closure,i.e., as the osmotic potential of the leaves decreased the leaf water potential for stomatal closure decreased (Turner *et al.*,1978). The irrigated plants took significantly more time to close their stomata at the flowering stage (Table 1.6). Stomata of the plants of moist sites took more time to close than that of the dry site (Nazrul-Islam and Yasmin, 1982). In sunflower and sorghum, Turner *et al.*(1978) observed that time for stomatal closure was greater in the irrigated plants than that of the unirrigated plants. In the present investigation, Sambal closed its stomata well before Daulat. As the quickness of stomatal closure is a means of drought tolerance, Sambal is more resistant to drought.

At the flowering stage, total transpiration rate was signficantly higher in the irrigated plants. Stomatal and cuticular transpiration rates were not affected significantly by soil moisture treatment.Significant effect of soil moisture was found on total and stomatal transpiration by Nazrul-Islam and Yasmin (1982) in tomato and Nazrul-Islam and Alam (1986) in jute. Joshi *et al.*(1988) observed higher transpiration rate with stress-free plants than that of the stressed-plants of groundnut. Transpiration rates were similar in the irrigated and the unirrigated groundnut (Black *et al.*,1985).

Stomatal characters are known to be associated with CO_2-exchange rates (Dornhoff and Shibles, 1976). Soil moisture had no significant effect on stomatal frequency and pore length on both the surfaces of leaves. The epidermal cells decreased and stomatal index increased significantly on the abaxial surface of the irrigated leaves. Although soil moisture had no significant effect, stomatal frequency of both the surfaces decreased in the irrigated plants.Similar result was noted by Ciha and Brun (1975)in soybeans. Penfound (1931) reported fewer stomata/unit area when plants were grown under optimum soil moisture conditions compared with plants grown under water stress conditions. The decrease in stomatal frequency with water supply suggests that increased leaf expansion due to enlargement of cells caused this decrease. A greater stomatal frequency was observed on the abaxial surface than the adaxial surface. Similar results were also observed in *Vicia faba* (Nerkar *et al.*,1981), in soybean (Miller,1938; Dornhoff,1971; Teare and Kanesasu, 1972; Ciha and Brun, 1975).

Thickness of leaf was increased significantly in the irrigated plants (Table 1.9). Mean cross-sectional areas of palisade and spongy parenchyma were higher in the irrigated plants than the rainfed plants but the variations were not significant.Begum (1991) found that leaf thickness,mean cross-sectional area of palisade and spongy parenchyma increased with irrigation in mustard.The increase of leaf thickness may be due to increased cell size of the plants. Due to increased RLWC in the irrigated plants, cross-sectional area of mesophyll cells increased.

Plant height at first flowering and duration of flowering were significantly increased and the number of leaves at first flowering and days taken to first flowering were unaffected by soil moisture (Table 1.10). Increased height of stem may be caused for increased elongation of the cells due to higher turgidity (Allen *et al.*,1976; Vivekanandan and Gunasena, 1976). Longer duration of flowering for the irrigated plants may be due to delayed termination of flowering. This delaying may be caused as higher number of flower buds were initiated in these plants which took longer time to open.

Irrigated plants had always higher cumulative number of flowers on the main axis and the primary branches 1-3 than the rainfed plants (Figures 1.8a-d). In the primary branch 3, duration of flowering was shorter for the rainfed plants. The initiation and differentiation of reproductive primordia and further development of the differentiated cells are sensitive to moisture stress (Slatyer, 1973). Moisture shortage at final differentiation may result in defective floral organs, sterility, reduced number of flowers and failure of flowers to open (Slatyer, 1973).

The percentage of pod abortion was higher in the primary branches of the rainfed plants, but the difference was not significant (Table 1.11). The cause of pod abortion may be due to shedding of flowers. Some flower-shedding may be due to competition between a large number of flowers and metabolic products and root activity in relation to salt and water absorption may be retarded during the flowering phase (Lochwing, 1940).El Nadi (1969) reported that a wet regime during the flowering phase significantly reduced the intensity of flower shedding,but a dry treatment during this stage, the incidence of flower shedding was aggravated to a considarable extent. It is likely that the efficiency of water transport and mineral uptake is reduced during flowering and this is aggravated under conditions of water stress.

The irrigated plants showed higher pod growth rate. Kaufmann (1972) stated that reduction in fruit size was caused by water deficit during the period of fruit enlargement. Pod growth rate and the yield of seeds are not simple functions of leaf area index and that sources of materials other than the leaves are important in affecting the yield of pods and seeds (Milbourn and Hardwick, 1968).

In the present investigation, higher rate of seed growth was observed in the irrigated plants at 20, 30, 40 and 45 DAF in Sambal and at 45 DAF in Daulat, but the defference was non-significant (Figure 1.20).The increase in dry weight of grains was significantly affected under water stress in sorgham (Narasimha Rao and Shiv Raj,1988). Wardlaw (1967, 1968, 1971) concluded that reduction in grain yield under stress was not due to effects on photosynthetic rate but due to vein loading. However, Begg and Turner (1976) concluded that reduction in translocation caused by water stress was due to reduced photosynthesis or sink growth but not due to effect on conducting system.

Plant height at maturity, length of main axis, number of pods/plant, number of seeds/pod, pod weight/plant, straw weight, 1000-seed weight and seed yield were significantly higher in the irrigated plants (Table 1.12). Similar results were reported by some other workers in mustard and rape. Signifiantly higher plant height, number of branches/plant, number of pods/plant and number of seeds/pod were found in mustard (Joarder *et al.*,1979; Bajpai *et al.*,1981; Singh *et al.*,1987 and Reddy and Sinha, 1987) and in rape (Maini *et al.*,1964; Krogman and Hobbs,1975; Clarke and Simpson ,1978 b and Bhan *et al.*,1980). But Bhati and Rathor (1982) and Chaniara and Damor (1982) found no significant effect of soil moisture on plant height, number of branches/plant and 1000-seed weight in mustard.

Seed yield was significanly higher in the irrigated plants. Similar result was observed by Mathur and Tomar (1972), Joarder *et al.*(1979),Bhan (1979), Chaniara and Damor (1982), Mandal *et al.* (1986), Singh *et al.* (1987), Reddy and Sinha (1978) and Reddy *et al.* (1988) in mustard and by Maini *et al.* (1964),Banerjee *et al.* (1967), Clarke and Simpson(1978b) and Bhan *et al.*(1980) in rape. No significant effect of soil moisture on yield was found in mustard by Bajpai *et al.*(1981) and Bhati and Rathor (1982) and in rape by Wankhede *et al.*(1970). Soil moisture had no significant effect on oil content of seeds (Table 1.12). Similar result was found in mustard(Chaniara and Damor, 1982 and Bhati and Rathor, 1982) and in rape (Wankhede *et al.*,1970). Oil content of seeds was higher in the irrigated plants in rape (Bhan et al.,1980) and in groundnut

(Mehrotra *et al.*,1969). There was a slight increase in oil content up to one irrigation and then declined a little with increasing number of irrigations (Banerjee et al.,1967).

Consumptive water use increased and water use eficiency decreased with irrigation (Table 1.12). Similar relult was also reported by Singh and Singh (1978), Bhan (1981) and Reddy *et al.* (1988). The lower water use efficiency with higher soil moisture status was due to proportionately more increase in evapotranspiration than the increase in seed yield. The increased frequency of irrigation increased the amount of moisture use as well as water use efficiency in rape (Bhan *et al.*,1980).

The correlation coefficients showed that 1000-seed weight was positively correlated with the number of pods on main branch and negatively correlated with the number of pods/plant and the number of seeds/pod in the irrigated plants (Table 1.13). This indicates that 1000-seed weight is increased with increasing number of pods on main branch but the relation is reverse in case of the number of pods/plant and the number of seeds/pod. Clarke and Simpson (1978b) found a negative correlation of 1000-seed weight with the number of pods/plant and the number of seeds/pod. Irrigation affected 1000-seed weight, probably because of a combination of their effects on assimilate supply and distribution in the plants.

Seed yield in the present investigation was positively correlated with the number of pods/plant, pod weight/plant and harvest index in both the treatments and number of seeds/pod in the irrigated plants only (Table 1.13). Clarke and Simpson (1978b) reported that seed yield in the high irrigated plants of *Brassica napus* was positively associated with 1000-seed weight and negatively related with the branches/plant and the number of seeds/pod. Seed yield was positively correlated with the number of pods/plant, the number of seeds/pod,the number of primary branches/plant and pod weight/plant (Reddy and Sinha,1987). Oil content of the rainfed plants was positively associated with the number of seeds/pod and negatively with plant height and the number of pods on main axis but no relation was observed in the irrigated plants.

The overall results of the present experiment indicate that TDM, LAI, LAD and some growth attributes like CGR, LAR, RLGR, SLA and LWR were increased significantly by soil moisture. Seed yield was correlated with LAI, CGR and NAR in the irrigated plants. Proline and sugar contents were significantly higher in the rainfed plants and increased with increasing age. The irrigated plants had higher leaf thickness, plant height at first flowering, duration of flowering and number of flowers. Yield and yield components like plant height at maturity, length of main axis,number of pods/plant, number of seeds/pod,pod weight/plant,straw weight, 1000-seed weight and seed yield were found significantly higher in the irrigated plants.Seed yield in the irrigated plants was positively correlated with the number of pods/plant, pod weight/plant, number of seeds/pod and harvest index. Therefore, optimum soil moisture treatment may be recommended and selection should be based on t characters for better yield. Proline and sugar accumulation and seed yield of Sambal were higher in the rainfed condition, whereas these characters of Daulat were higher in the irrigated condition. Thus, Daulat is more susceptible to water stress than Sambal. Therefore, to get higher yield, Sambal may be recommended for cultivation in the rainfed condition and Daulat in the irrigated condition.

EXPERIMENT 2

EFFECT OF SOIL MOISTURE AT
SPECIFIC STAGES OF GROWTH ON
DRY MATTER PRODUCTION AND YIELD
OF MUSTARD (*BRASSICA JUNCEA* L.)

INTRODUCTION

Mustard is usually grown as a rainfed crop in Bangladesh. Soil moisture deficits frequently occur under rainfed condition; where the crop has to depend upon the stored soil moisture which is soon depleted through evapotranspiration causing depression in growth and yield of the crop. Plants fail to recover if permanent wilting occurs due to severe moisture stress. When rewatered after a prolonged and severe moisture stress plant will recover its growth. However, yield of crops may be depressed due to soil moisture stress of any degree. The rate of yield reduction will depend on the degree of stress.

Plants are not equally sensitive to soil moisture deficits at various stages of growth. There are some specific stages of plants during which they are more prone to soil moisture deficit. The vegetative stage of many plants are not sensitive to soil moisture stress. This may be due to the reason that plants resume their growth after releasing stress. Soil moisture stress at the flower initiation and flowering stage reduces the yield of legumes through the formation of defective floral organs, sterility, reduced number of flowers and failure of flowers to open (Slatyer, 1973). Moisture stress during the period of fruit development reduces the yield through the reduction of pod and seed size (Kaufmann,1972). This is caused due to insufficient transportation of nutrient reserves into the pod and seed. Soil moisture stress at the stage of maturity is less harmful to the yield of crops as it is the stage of dehydration.

Information is limited about the effects of water stress at different growth phases on crop growth and development of mustard. Due to an increase in the frequency of drought, declining water table, and increased costs of irrigation water, it is essential to evaluate water management of mustard. In spite of the reputed drought tolerance of mustard, information on the growth phases most sensitive to moisture stress is inadequate.

The aim of this study was to examine the effects of soil moisture stress imposed at specific growth phases on the growth, development and yield of two mustard cultivars.

MATERIALS AND METHODS

The plant material for the experiment was also Sambal and Daulat of mustard (*Brassica juncea* L.)

The experiment was arranged in a randomized complete block design with two replications. The size of each block was 2.1 m x 1 m. The distance between two blocks was 1 m. There were 8 rows in each block of 1 m long and 30 cm apart. The distance between plants within a row was approximately 10 cm. Seeds were sown on 2 Nvember, 1990. There were 5 irrigation treatments as follows :

T_0 = No irrigation .

T_1 = No irrigation until the start of flowering, uniformly irrigation thereafter.

T_2 = Irrigation until the start of flowering followed by no irrigation until mid-pod filling stage, uniformly irrigation thereafter.

T_3 = Irrigation until mid-pod filling stage followed by no irrigation until crop harvest.

T_4 = Uniformly irrigation throughout.

The measured amount of water (10 mm on each occasion) was uniformly added with sprinklers. The treatments T_1, T_2, T_3 and T_4 of Sambal received 50, 70, 50 and 80 mm of irrigation water, respectively, whereas the corresponding treatments of Daulat received 40, 40, 50 and 70 mm of irrigation water. The similar cultural practices were done as in the experiment 1.

Dry Matter Determination

For dry matter determination, 5 harvests were taken at equal intervals of 7 days. The first harvest was taken at 59 DAS. Four plants were harvested from each treatment of each replication of each cultivar. At each harvest, plants were cut off just below the cotyledonary node and tops were separated into leaves, stem and others (petiole + buds + flowers) and pods. Before weighing, all plant parts were dried separately in an oven at about 85 ^{0}C for 24 hours till they reached constant weight.

Yield and Yield Components

The final harvest was done at 100 DAS for Sambal and at 95 DAS for Daulat. Six plants per replication per treatment per cultivar were harvested and dried in the sun and the measurements of yield and yield contributing characters were taken. The following characters were recorded :

Plant height at maturity, length of main axis, number of branches/plant, number of pods on main axis, number of pods/plant, number of seeds/pod, pod weight/plant, straw weight, 1000-seed weight, seed-husk weight ratio, harvest index, seed yield/ha and oil content of seeds.

Statistical Analysis of Data

The experimenatal design was a randomized complete block design and the analysis of variance was done accordingly.

RESULTS

Total Dry Matter

Mean squares from the analysis of variance for total dry matter (TDM) as influenced by soil moisture stress at specific stages of growth are presented in Table 2.1. Soil moisture stress effect was significant at all the growth periods except 73 DAS. Cultivar x soil moisture interaction was non-significant.

The effect of soil moisture stress at specific stages of growth on dry matter is shown in Figure 2.1. In Sambal, decrease of TDM in the stressed plants over stress-free plants (T_4) was observed. The highest reduction of TDM production was found in continuous stressed (T_0) and the second and the third reduced position was found in the flowering to mid-pod filling stress (T_2) and pre-flowering stress (T_1), respectively. The lowest reduction of TDM was found in T_3, where water stress was imposed after mid-pod filling stage.

In Daulat, all the plants except T_3 yielded reduced TDM than the stress-free plants (T_4). Maximum reduction of TDM production was found in the plants grown under continuous stress (T_0). The socond position of reduced production was found in T_2 at 59, 66 and 87 DAS. Post mid-pod filling stressed plants (T_3) produced increased amount of TDM than that of the stress-free plants (T_4), though the difference was not significant.

Table 2.1. Mean squares from the analysis of variance of total dry matter (TDM) of two mustard cultivars as influenced by soil moisture stress at specific stages of growth.

Sources of variation	df	Mean squares				
		Days after sowing				
		59	66	73	80	87
Replication	1	6444	1730	2761	16075	31
Treatment (T)	4	15279*	20804**	20623	35783**	72485***
Cultivar (C)	1	7881	7	551	238	2398
T x C	4	2695	2537	7847	3580	8098
Error	9	2709	2504	6445	4692	5298

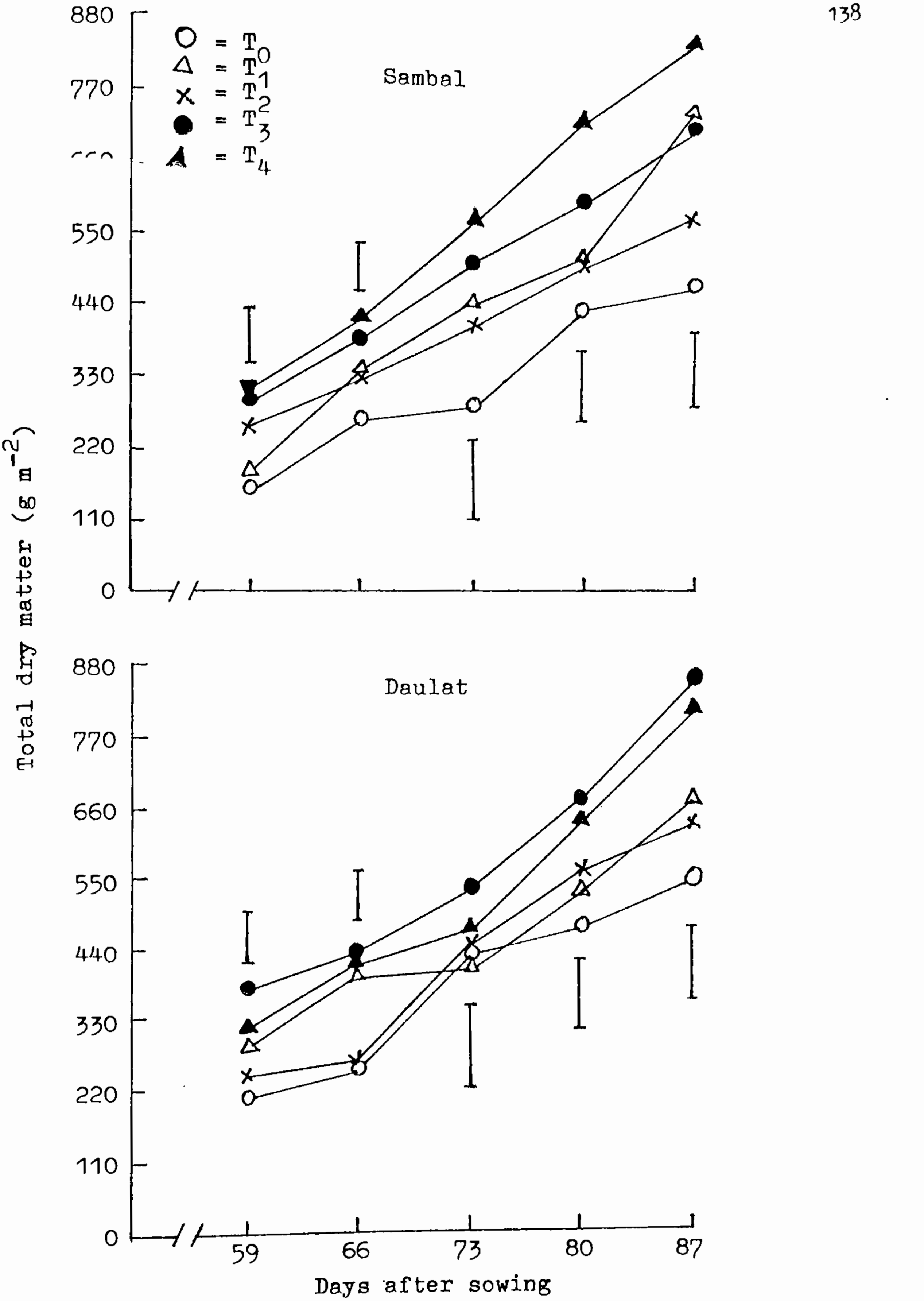

Figure 2.1. Effect of soil moisture stress at specific stages of growth of two mustard cultivars on total dry matter (TDM).

Distribution of Dry Matter

Influence of soil moisture stress at specific stages of growth of two cultivars on distribution of dry matter (DM) is shown in Figure 2.2. Percentage of DM of stem and others (petiole, buds and flowers), leaves and pods are shown in these figures. No significant effect of soil moisture stress on dry matter distribution was found. Percentage of DM accumulation in stem and others and leaves decreased with increasing age in both the cultivars. But in pods, DM accumulation increased with increasing age. Dry matter percentage of stem and others was highest in T_0 and lowest in T_4 at the initial stages but reverse was found at the later stages. The highest percentage of DM accumulation in leaves of Sambal was found in T_1. The lowest DM accumulation in leaves of Daulat was in T_0. The highest percentage of DM in pods was found in T_1 at 87, in T_2 at 59, in T_3 at 80 and T_4 at 73 and 87 DAS in Daulat.

Yield and Yield Components

Mean squares from the analysis of variance of plant height at maturity, length of main axis, number of branches/plant, number of pods on main axis, number of pods/plant, number of seeds/pod, pod weight/plant, straw weight, 1000-seed weight, seed-husk weight ratio, seed yield and oil content of seeds of Sambal and Daulat as influenced by soil moisture stress at specific stages of growth are given in Table 2.2. Soil moisture effect was significant for all the characters except 1000-seed weight, seed-husk weight ratio and

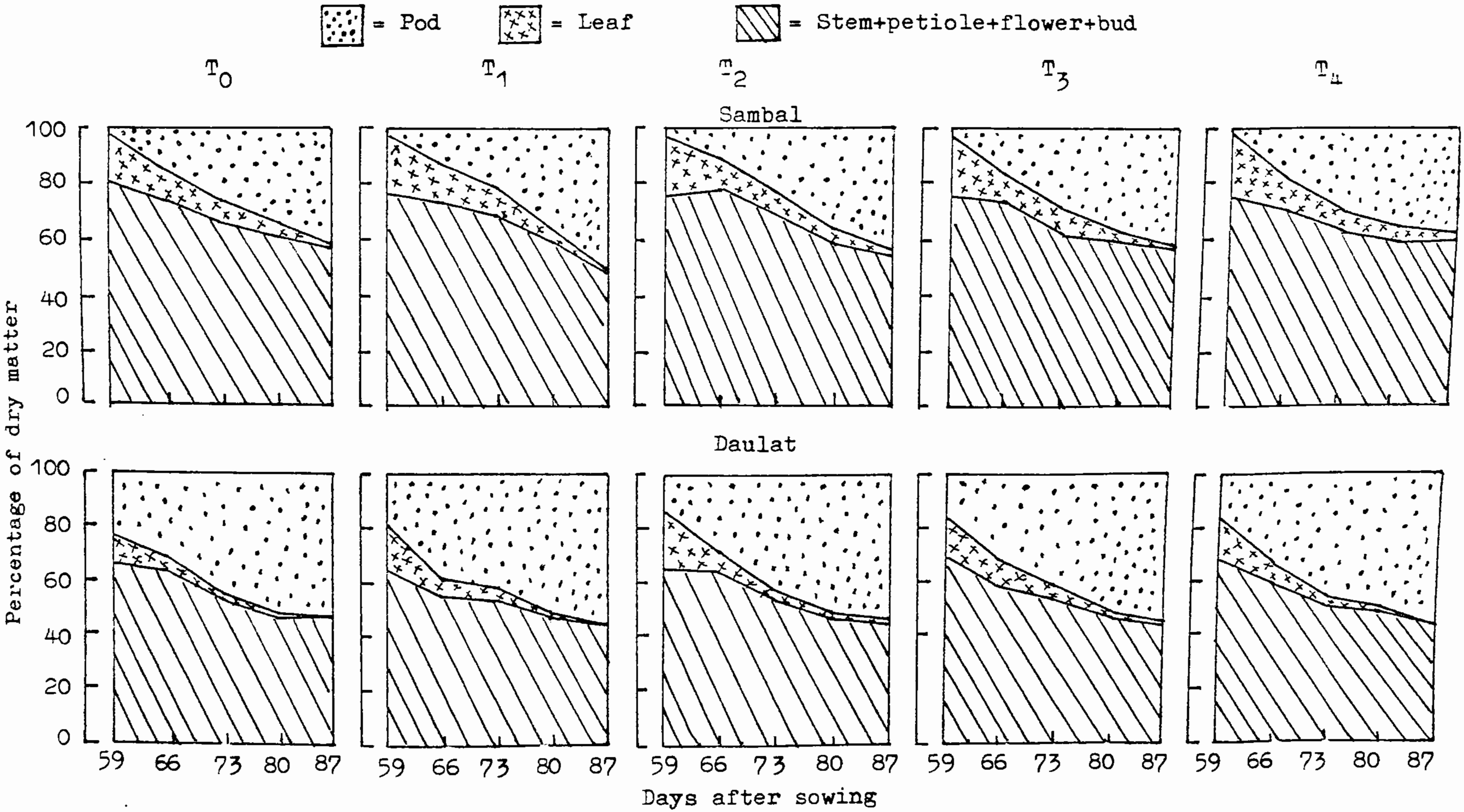

Figure 2.2. Influence of soil moisture stress at specific stages of growth of two mustard cultivars on distribution of dry matter (DM).

Table 2.2. Mean squares from the analysis of variance of yield and yield components of two mustard cultivars as influenced by soil moisture stress at specific stages of growth.

Sources of variation	df	Mean squares						
		Plant height at maturity (cm)	Length of main axis (cm)	Number of branches/ plant	Number of pods on main axis	Number of pods/plant	Number of seeds/pod	Pod weight/ plant(g)
Replication	1	9.80	24.20	0.01	3.20	5951	0.58	32.82**
Treatment (T)	4	208.83*	55.18*	1.71*	48.80**	25374***	3.15*	86.09***
Cultivar (C)	1	9331.20***	1036.80***	0.95**	352.80***	2808*	25.54***	2.95
T x C	4	58.33	34.18	0.22	8.05	1275	0.15	0.82
Error	9	55.58	12.76	0.24	7.42	1009	0.57	4.32

Sources of variation	df	Mean squares					
		Straw weight /plant (g)	1000-seed weight (g)	Seed-husk weight ratio	Harvest index(%)	Seed yield (kg/ha)	Oil content of seeds(%)
Repication	1	7.47**	0.07	0.0012	7.28	850000*	1.25
Treatment (T)	4	59.30***	0.08	0.0018	213.01	2502250*	15.68**
Cultivar (C)	1	82.34***	0.08	0.0912*	0.73	413000	22.05**
T x C	4	6.89**	0.22	0.0023	1.65	14500	9.68*
Error	9	0.56	0.11	0.0141	3.46	137749	2.25

harvest index. Cultivar differences were significant for all the characters except pod weight/plant, 1000-seed weight, harvest index and seed yield. Cultivar x treatment interaction effect was significant for straw weight and oil content of seeds only.

Mean values of seed yield and its components of two mustard cultivars as influenced by soil moisture stress at specific stages are given in Table 2.3.

Plant height at maturity : Plant height at maturity was reduced in the stressed plants than that of the stress-free (T_4) plants. The continously stressed (T_0) plants had significantly shorter height than the T_4 plants. Post mid-pod filling stressed plants (T_3) was taller than the stress-free plants but the difference was non-significant. Sambal was taller than Daulat. Plants grown under continuous (T_0) and pre-flowering stress (T_1) had significantly reduced plant height over the stress-free plants of Sambal.

Length of main axis : Length of main axis of the stressed plants was reduced over the stress-free plants, except in T_3 where it increased slighty. Significantly reduced main axis length was found in the continuous stressed (T_0) plants. Length of main axis was significantly higher in Sambal. Sambal had significantly reduced main axis length in T_0 and T_1 than that of the T_4 plants. Slight increase of main axis length was found in T_1, T_2 and T_3 over T_4 of Daulat but the differences were not significant.

Number of branches/plant : The stressed plants had reduced number of branches over the stress-free plants. Plants grown under T_0, T_1, T_2 and T_3 had 20, 13, 12 and 5% reduced number of branches, respectively over the stress-free plants. Significant reduction of the number of branches was found in T_0 and T_1. Daulat had higher number of branches than Sambal. In Sambal, T_0 and T_2 had significantly reduced number of branches/plant over the stress-free plants.

Number of pods/plant : The stressed plants yielded reduced number of pods/plant than that of the stress-free plants, except T_3 where the number of pods/plant was increased slightly. The number of pods/plant was significantly reduced in T_0 (47%), T_1 (30%) and T_2 (33%) over T_4. Daulat had higher number of pods/plant than Sambal, but the difference was not significant. Both Sambal and Daulat had signficantly reduced number of pods/plant in T_0, T_1 and T_2 over T_4.

Pod weight/plant : Pod weight of the stressed plants diminished in respect to stress-free plants. Plants grown under T_0 (57%), T_1 (42%) and T_2 (36%) had significantly decreased pod yield than that of the stress-free plants (T_4). Daulat had higher pod weight/plant than Sambal, but the difference was non-significant.

Straw weight : Reduction of straw weight in the stressed plants was found over the stress-free plants. Straw weight reduced significantly in T_0 (57%), T_1 (38%), T_2 (36%) and T_3 (9%) than that of the stress-free plants. Sambal had significnatly reduced straw weight in T_0, T_1, T_2 and T_3 and Daulat in T_0, T_1 and T_2.

1000-seed weight : No Significant effect of soil moisture stress on 1000-seed weight was found.

Seed-husk weight ratio : Seed-husk weight ratio was not significantly affected by soil moisture stress. The ratio was significnatly higher in Daulat than Sambal.

Harvest index : Significantly higher harvest index was found in Daulat than that of Sambal. Harvest index increased slightly in the stressed plants of Sambal, though it was not significantly different.

Seed yield : Seed yield of the stressed plants was reduced than that of the stress-free plants. Significantly reduced seed yield was found in plants grown under T_0 (59%), T_1 (59%) and T_2 (37%) over that of T_4 plants. Seed yield was non-significantly higher in T_3 (8%) than T_4. Seed yield in Daulat was higher than Sambal, but the difference was not significant. In Sambal, the reduction of seed yield in T_0, T_1, T_2 and T_3 over T_4 was 58, 37, 38 and 12%, respectively. The corresponding values of Daulat were 61, 37, 33 and 4%.

Oil content of seeds : Oil content of seeds of the stressed plants increased than the stress-free plants (T_4) except in continuous stress treatment (T_0). Significantly increased oil content was found in T_1 (9%) and T_2 (12%). Seeds of Daulat had significantly higher percentage of oil than that of Sambal. The increase of oil content of Sambal in T_0, T_1, T2 and T3 over T_4 was 3, 8, 5, and 6% respectively and of Daulat in T_1 and T_2 was 9 and 18%.

Correlation Coefficients Between Seed Yield and Its Components

Simple correlation coefficients between seed yield and its components as influenced by soil moisture stress are given in Table 2.4. Seed yield was positively correlated with the number of pods/plant, pod weight/plant and harvest index in T_0, with the number of branches/plant, number of pods on main axis, number of pods/plant, pod weight/plant and harvest index in T_1, with the number of pods/plant, pod weight/plant and harvest index in T_2 and T_3 and with the number of pods/plant, number of seeds/pod and harvest index in T_4. There was no significant correlation between oil content and seed yield in any of the treatment.

Table 2.3. Mean values of yield and yield components of two mustard cultivars as influenced by soil moisture stress at specific stages of growth.

	Plant height at maturity (cm)			Length of main axis (cm)			Number of branches/plant		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
T_0	157.50	118.50	138.00	70.50	56.50	63.50	4.75	5.42	5.06
T_1	164.00	129.50	146.75	71.50	64.00	67.75	5.33	5.67	5.50
T_2	172.00	128.50	150.25	74.50	62.50	68.50	4.92	6.25	5.59
T_3	178.50	134.50	156.50	81.00	66.00	73.50	6.00	6.08	6.04
T_4	181.50	126.50	154.00	82.05	59.00	70.75	6.08	6.59	6.34
Mean	170.70	127.50		76.00	61.60		5.42	6.00	
LSD at 5%	(a)11.92,(b)7.54,(c)16.86			(a)5.71,(b)3.61,(c)8.08			(a)0.78,(b)0.50,(c)1.11		

	Number of pods on main axis			Number of pods/plant			Number of seeds/pod		
	Sambal	daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
T_0	53.00	45.50	49.25	185	213	199	11.85	13.75	12.80
T_1	58.00	52.50	55.25	255	264	260	12.00	14.30	13.15
T_2	57.00	50.50	53.75	253	244	249	12.85	14.75	13.80
T_3	62.00	52.00	57.00	335	418	377	13.65	16.50	15.08
T_4	64.50	52.00	58.25	369	378	374	12.95	15.30	14.13
Mean	58.90	50.50		279	303		12.66	14.92	
LSD at 5%	(a)1.21,(b)0.76,(c)1.71			(a)50.81,(b)NS,(c)71.86			(a)1.21,(b)0.76,(c)NS		

Contd ......

Table 2.3. (Continued).

	Pod weight/plant (g)			Straw weight/plant (g)			1000-seed weight (g)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
T_0	8.07	8.95	8.51	7.97	6.23	7.01	2.47	2.37	2.42
T_1	12.28	12.56	12.42	11.57	8.55	10.06	2.21	2.37	2.29
T_2	12.45	13.21	12.83	11.79	9.07	10.38	2.78	2.01	2.40
T_3	17.06	19.24	18.15	17.30	12.94	14.90	2.42	2.87	2.65
T_4	20.09	19.84	19.97	20.64	12.19	16.42	2.74	2.38	2.56
Mean	13.99	14.78		13.82	9.80		2.52	1.40	
LSD at 5%	(a)3.32,(b)NS,(c)4.70			(a)1.20,(b)0.76,(c)1.69			(a)NS,(b)NS,(c)NS		

	Seed-husk weight ratio			Harvest index (%)			Seed yield (kg/ha)		
	Sambal	Daulat	Mean	Sambal	Daulat	Mean	Sambal	Daulat	Mean
T_0	0.94	1.09	1.02	24.14	30.48	27.31	1356	1353	1355
T_1	1.02	1.09	1.06	25.82	31.04	28.43	2025	2165	2095
T_2	0.95	1.14	1.05	24.93	31.36	28.15	2008	2314	2161
T_3	1.02	1.12	1.07	25.08	31.06	28.07	2842	3308	3075
T_4	0.95	1.12	1.04	23.90	32.56	28.23	3228	3454	3341
Mean	0.98	1.11		24.77	31.30		2269	2557	
LSD at 5%	(a)NS,(b)0.12,(c)NS			(a)NS,(b)1.88,(c)NS			(a)594,(b)NS,(c)840		

Contd ......

Table 2.3. (Continued).

Oil content of seeds (%)			
	Sambal	Daulat	Mean
T_0	32.00	30.50	31.25
T_1	33.50	36.00	34.75
T_2	32.50	39.00	35.75
T_3	33.00	33.00	33.00
T_4	31.00	33.00	32.00
Mean	32.40	34.30	
LSD at 5%	(a)2.40,(b)1.50,(c)3.40		

(a) = Difference between treatments
(b) = Difference between cultivars
(c) = Difference between interactions

Table 2.4. Correlation coefficients between seed yield and its components as influenced by soil moisture stress at specific stages of growth.

	Seed yield with								
	Plant height at maturity	Number of branches/ plant	Number of pods on main axis	Number of pods/plant	Number of seeds/pod	Pod weight/plant	1000-seed weight	Harvest index	Oil content
T_0	0.07	0.42*	0.10	0.74***	0.38	0.97***	0.28	0.64***	-0.15
T_1	0.30	0.55**	0.47*	0.83***	0.34	0.96***	0.25	0.52**	-0.01
T_2	-0.08	0.21	0.30	0.80***	0.35	0.96***	-0.20	0.69***	0.18
T_3	-0.25	0.25	0.19	0.78***	0.25	0.47*	-0.26	0.52**	-0.34
T_4	-0.11	0.14	0.07	0.85***	0.54**	0.30	-0.18	0.48*	-0.11

DISCUSSION

The growth and yield of crop plants are often reduced by soil moisture stress. The crops should be supplied with adequate water before the soil moisture has been depleted to such an extent as to cause the severe reduction in plant growth. When rewatered after a prolonged and severe moisture stress plant will recover its growth. However, yield of crops may be depressed due to soil moisture stress of any degree. The rate of yield reduction will depend on the degree of stress. Plants are not equally sensitive to soil moisture stress at various stages of growth.

In the present experiment, almost all the plants of Sambal and Daulat in the stressed condition yielded reduced TDM than the stress-free plants (T_4). Maximum reduction of TDM production was found in the plants grown under continuous stress (T_0). The second highest reduction was found in the flowering to mid-pod filling stress (T_2). Water shortage significantly affected total dry matter in beans (Farah, 1981). Increase in the water deficits resulted in progressive reductions in the total biomass accumulated (Nageswara Rao *et al.*, 1985). A progressive increase in water stress will first affect the elongation of cells followed by cessation of elongation and marked reduction in cell multiplication and finally the reduction in dry weight of shoot through continued respiration (Jain and Misra, 1972). In groundnut, when the plants were stressed beyond early pod development phase, a loss in biomass production occurred (Ramesh Babu *et al.*, 1984). Others have shown that continuous water deficit reduces dry matter production (Stansell *et al.*, 1976; Vivekanandan and Gunasena, 1976; Pallas *et al.*, 1979).

Yield and yield components were reduced by soil moisture stress. The height of the plants reduced due to water stress. The continuously stressed plants (T_0) had significantly shorter height than that of the stress-free plants (T_4). Plants grown under continuous stress (T_0) and pre-flowering stress (T_1) had significantly reduced plant height over the stress-free plants in Sambal. Similar result was found in *Corchorus olitorius* by Ayodele and Fawusi (1990). Plant height reduction is due to stunted growth of stem. Cell enlargement is so sensitive to water deficits that stem elongation can be inhibited in some species by small diurnal water deficits (Slatyer, 1973). Boote and Hammond (1981) reported that droughts during early pegging and pod formation period in groundnut reduced vegetative growth by reducing both the rate of node formation and by reducing elongation growth. Ramesh Babu *et al.* (1984) stated that moisture stress imposed at early flowering, at peak flowering and and at early pod development stages in groundnut caused a reduction in plant height. Stress at the late pod development stage did not reduce plant height because the plant elongation was completed by this time. However,continously stressed plants exhibited severe reduction in plant height during the entire life span.

Significantly higher number of branches/plant was found in continuous stress (T_0) over stress-free plants (T_4). Similar result was found by Ayodele and Fawusi (1990) in *Corchorus capsularis*. The number of branches/plant in groundnut was reported to be unaffected by moisture deficits (Lenka and Misra, 1973).

In the present investigation, the number of pods/plant was significantly reduced in T_0, T_1, and T_2 over T_4. The cause of this reduction may be due to reduced plant height, length of main axis and number of branches/plant (Table 2.3). It may also be caused due to shedding of flowers by soil drought. Imposing moisture stress at flowering and pod formation stages led to a reduction of 64.20% and 46.92% in pod number compared with control plants (Ayodele and Fawusi, 1990). Reduced number of pods/plant was found due to stress in rapeseed by Richards and Thurling (1978a) and Bhan *et al.*(1980).

The plants grown under T_0, T_1 and T_2 had significantly reduced pod weight/plant (57%, 42% and 36% respectively) than the plants grown under T_4 (Table 2.3). The main cause of this reduction was due to reduced number of pods/plant. Srinivasan *et al.*(1987) found higher pod yield in the plants grown under stress-free condition.

Straw weight was reduced significantly in T_0(57%), T_1 (38%), T_2 (36%) and T_3(9%) over the stress-free plants (T_4). Similar result was found by Richards and Thurling (1978a) in rapeseed. Reduced straw yield was observed in the plants grown at low soil moisture than that grown at high soil moisture in mustard and chickpea (Singh, 1983).

No significant effect of soil moisture stress on 1000-seed weight was found (Table 2.3). Similar result was found by Bhan *et al.* (1980) in rapeseed. But Richards and Thurling (1978a) found significantly reduced 1000-seed weignt in the stressed plants. Soil moisture stress had no clear cut effect on harvest index (Table (2.3). Richards and Thurling (1978a) and Singh (1983) observed similar effect in rapeseed.

Significantly reduced seed yield was found in plants grown under T_0 (59%),T_1(37%) and T_2 (35%) over plants grown under stress-free condition (T_4). Similar result was reported by Richards and Thurling (1978a)in repeseed. Seed yield was reduced in the stressed plants in rapeseed (Bhan *et al.*,1980) and in mustard and chickpea (Singh, 1983). The reason for reduced seed yield may be due to reduced number of pods/plant and weight of pods/plant. Haque *et al.* (1990) observed that in mustard seed yield increased significantly for two irrigations,one at the early vegetative stage and the other at the initial pod formation stage.

Oil content of seeds of the stressed plants grown under T_1 and T_2 was increased by 9 and 12%, respectively than that of the stress-free plants (Table 2.3). But Bhan *et al.*(1980) found reduced oil content in rapeseed due to soil moisture stress.

The overall results of the experiment indicate that TDM, seed yield and its components were highly reduced when moisture stress was imposed during the pre-flowering (T_1) and the flowering to pod filling (T_2) stages. Moisture stress at the post mid-pod filling stage had no significant effect on yield and its components. Thus, it may be concluded that the pre-flowering (T_1) and the flowering to pod filling (T_2) stages are more sensitive to soil moisture stress. Therefore, to obtain better yield it may be recommended that proper soil moisture should be maintained at those two stages for obtaining higher seed yield of mustard.

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