Effect of Timings of Water Supply on Dry Matter Partitioning and Yield of Mustard (*Brassica juncea* L.).

A. Majid and G.M. Simpson; Department of Crop Science and Plant Ecology, University of Saskatchewan, Saskatoon, S7N OWO.

ABSTRACT

Rapeseed and mustard, two of the major oilseed crops, are widely grown in the world. With improvements in seed oil and meal quality, mustard can compete with rapeseed in the local as well as international markets, and it would be desirable to improve its yield. The effects of timing of water supply: at flowering, pod formation and ripening phases, in addition to one dry treatment on growth, total dry-matter production and partitioning of dry matter, and yield, were studied in mustard in the field during 1991 and 1992. Above-ground plant material was harvested at seven-day intervals, and dry-matter production was determined. Water supply had a substantial effect on both the total amount of plant-dry-matter produced and the pattern of its accumulation. The rate of accumulation of dry matter remained high under full water supply until the late-ripening phase. The maximum, of both the leaf and pod area achieved, was under full watering. The minimum supply of water increased the leaf area index (LAI) just after the start of flowering up to the maximum. Watering had significant effects ($P<0.05$) on yield. The full supply of water significantly increased seed yields by 57% and 44% in subsequent years, over the dry conditions (4002/2551 Kg, 1991 - 3080/2140 Kg, 1992). Application of water had an insignificant effect ($P>0.05$) on the harvest index (HI). Water-use efficiency (WUE) was increased by 32% and 33% by the full supply of water in the consecutive years, over the minimum supply of water. It is concluded that three applications of an amount of water: at flowering, pod formation and ripening phases increase the seed yield by improving the photosynthetic (leaf and pod) area.

INTRODUCTION

The potential of mustard as an edible crop on western Canadian prairies has recently been demonstrated (Woods *et al.*, 1991). The problems associated with mustard oil include the presence of a high level of erucic acid which complicates the process of refining the oil and also has adverse effects on human health. The mustard meal also has high level of glucosinolates which contributes pungency to the meal. Few strains of *B. juncea* that are free of erucic acid (Kirk and Oram, 1981), and low (< 15 umoles g^{-1}) in glucosinolate (Love, 1988) have been identified. With improvements in seed-oil and meal quality, mustard can compete with rapeseed in both the local and international markets. Thus it would be desirable to improve yield of mustard through breeding and development of improved agronomic practices.

As it is generally accepted that water shortage is a major yield-determining factor (Day and Legg, 1983), the effect of water availability has been the subject of several studies. Attention has been paid to the identification of growth stages especially sensitive to lack of water.

Irrigation has been shown to increase seed yield (Stoker and Carter, 1984; Wright *et al.*, 1988). Response varies with the season, but there appears to be no benefit from applying more than two irrigations (Stoker and Cater, 1984). Rapeseed responds largely to water supply at the start of flowering (Davidson, 1976). According to Gangasaran and Gajendra Giri (1986), one irrigation at 45 to 90 days or two irrigations at 30 and 90 days (at preflowering and 50% of pod formation stages) significantly increase yield and yield components of mustard. Rathore and Patel (1989) reported that two irrigations applied respectively at branching and 50% flowering gave significantly more seed yield as compared to one irrigation at each of late-branching, 50% flowering and seed-filling. Water requirements of the crop vary with type of soil and climate of the region.

Therefore, this study was conducted to determine the effect of water supply: at flowering, pod formation and ripening phases; on growth, total dry-matter production and partitioning of dry matter, and yield of mustard.

MATERIALS AND METHODS

Field experiments were conducted on a loam soil in the investigation fields of the department of Crop Science, University of Saskatchewan, Saskatoon, during the 1991 and 1992 growing seasons. The Oriental mustard cultivar Cutlass of *B. juncea* was sown on 22 May 1991 and 18 May 1992. The experimental design was a randomized-complete-block design with 6 replications. Plot size was 4.3 x 9.2 m. Seeding rate of 6 kilograms per hectare was used. The mono ammonium phosphate fertilizer at the rate of 40 kilograms per hectare was applied according to the current recommendations which are based on soil testing.

Three levels of watering (full, medium and minimum) in addition to one dry treatment (check) were maintained. For full-watering treatment, water was applied at 10% of flowering, of pod formation and of ripening phases, at the rate of 2-hectare centimetres per application. In medium-watering treatment, water was applied at 10% of flowering at the rate of 2-hectare centimetres and at 10% of pod formation at the rate of 4-hectare centimetres. The minimum watering included only a single application of water at the rate of 6-hectare centimetres at 10% of flowering. An equal amount of water (1524 cu. meters per hectare) was supplied during the growing season to all the plants in all irrigated treatments. In dry treatments, no water was applied, and a gutter drainage system was development one month after seeding, by placing tar-paper sheets in between the plant rows to drain out the rainfall water.

The plant material for the growth measurements was obtained from each treatment. After the plant had emerged, each 4.3 x 9.2 m plot was divided into areas for growth-measurement sampling and for seed yield determination. Sampling was started 4 weeks after seeding and continued within two weeks of harvest. Samples were taken at seven-day intervals through the growing season. At each sampling time, a randomly designated area of 0.25 m^2, was used for plant growth measurements.

Dry matter of plant components was determined by drying the material for 24 hours at 70 ^{0}C in forced-air oven. The area of leaf and pod was measured with an electric planimeter with a continuous belt feeding. Leaves which were greater than 50% necrotic or yellowed were not included in the measurement. Total leaf area per 0.25 m^2 was calculated on the basis of plant number. The pod area per 0.25 m^2 was calculated on the basis of the mean pod area of the plant and the number of plants per 0.25 m^2. The net-yield area of 32.9 m^2 of each plot was harvested by combine when seed moisture content was 12-15%, and seed yield was measured. Harvesting index was calculated on the number of plants per 0.25 m^2 quadrat, sampled randomly at the time of harvesting.

RESULTS

Water supply had a substantial effect on both the total amount of dry matter of plants produced and the pattern of its accumulation (Fig. 1). Under water supply, the rate of accumulation of dry matter of the plant remained high until the late-ripening phase. The total-plant-dry-matter accumulation of the full watered plants during the pod formation and ripening phases, was comparatively higher than that of medium-watered plants, while it was significantly ($P < 0.05$) higher than that of the minimum-watered and dry conditioned plants. At ripening stage, plant-dry-matter accumulation by full watering in 1991 and 1992, was 67% and 89% higher than by dry conditions, respectively. In general, there was rapid production of dry matter during the flowering, pod formation and early-ripening phases. A plateau was reached during the late-ripening phase.

Water supply also affected the pattern of dry-weight accumulation of plant parts. The pattern of dry-weight accumulation of the stem and leaf fractions was nearly the same under full-water supply and dry conditions (Table 1). In 1991, leaf-dry weight during the ripening phase remained high under full-water supply followed by medium-water supply, while in 1992, the medium supply of water produced higher leaf-dry matter than full supply of water. Dry weight accumulation of the pod (pod + seed) was also substantially affected by watering. An increase in dry weight of the pod was continued for longer period under prolonged watering than under dry conditions. Dry weight of the pod fraction increased during the middle of ripening and then reached a plateau during late ripening phase. The general pattern of plant-parts-dry-weight accumulation was; maximum leaf-dry weight at flowering, maximum stem-dry weight near the end of flowering, and maximum pod-dry weight at near maturity.

Water supply increased the leaf area significantly ($P < 0.05$) during the flowering, pod formation and ripening phases over dry conditions. Leaf area index (LAI) was maintained for longer periods and a higher level by watering after flowering (Fig. 2). Under minimum-water supply, plants produced maximum LAI during flowering, but this was drastically decreased during the pod formation and ripening phases. The full and medium supply of water maintained the maximum LAI during the pod formation and ripening phases. The maximum pod area achieved was highest under water conditions (Fig. 3). The pod area with watering during the ripening phase, both in 1991 and 1992, was almost double that in dry conditions. Pod area increased rapidly during flowering and reached its maximum at about the time flowering ceased. After flowering, increasing pod area more than off-set the decline in leaf area, thus increasing the total plant-photosynthetic (leaf + pod) area. The total photosynthetic area reached its maximum at the end of flowering, and then declined.

Water supply had significant effects ($P < 0.05$) on seed yield (Table 2). The seed yield in 1991 and 1992, was decreased to 2551 and 2140 kilograms per hectare by dry conditions compared to the seed yield of 4002 and 3080 kilograms per hectare by supplying full water (the increase of 57% and 44% over dry conditions, respectively). There were insignificant differences ($P > 0.05$) in seed yield between the full- and medium-supply of water. Among three levels of the supply of water, the minimum supply produced the lowest seed yield , and full supply produced the highest. The average seed yield in 1991 was higher than in 1992. There were no significant differences ($P > 0.05$) in harvest index, between the watered and dry conditions and among the timings of water supply (Table 2). In 1992, harvest index was higher than in 1991. The highest water-use efficiency (WUE) of the mustard plants was recorded with three splits of water: at flowering, pod formation and ripening stages (Table 2). The full-supply of water significantly increased the WUE by 32% and 33% in the subsequent years, over the minimum supply of water.

DISCUSSION

Total production of dry matter of *B. juncea* was significantly increased by water supply. A similar response to irrigation was reported by Natharson *et al.* (1984), Khan and Agarwal (1988) and Garside *et al.* (1992). The results of the study showed that the major proportion of dry matter was produced just near the ripening phase (72-79 days after seeding). Khan and Agarwal (1988) measured the maximum dry matter production between 40 and 100 days after sowing (DAS). Application of water increased the proportion of dry matter production after flowering. High dry matter accumulation was probably increased by incident light intercepted by the increased photosynthetic tissues (leaf + pod) of the watered plants of mustard. Wright *et al.*(1988) observed that dry matter production strongly related to the amount of incident light intercepted, as a direct function of the crop's LAI. Delgado *et al.*(1992) reported that a decrease in dry matter production by water stress was due to a decrease in total leaf area per plant and a decrease in number of cell per unit leaf area. The changes in total-dry-matter accumulation during the ripening phases under both the water regimes and dry conditions were essentially due to changes in the pod (pod + seed) weight. This study shows that water supply both during pod formation and early-ripening phases, is important for development of maximum pod fraction.

Leaf area was maintained for a long time and at a high level by water supplied after flowering. The maximum leaf area indexes (LAI) measured in this study ware 6.6 and 4.2 in 1991 and 1992, respectively, occurring in the water supplied material. The increase in LAI would be due to the availability of high soil moisture for a long period of time during the crop growth. A significant positive correlation between the

LAI of the water material and its water-use efficiency (WUE), was observed (Table 3). Sharma and Kumar (1989) also reported a significant increase in leaf area index in mustard at 60 and 90 days after sowing. Water regime also caused a significant increase in pod area. The maximum increases in pod area by full-supply of water at just before maturity were 145% and 330% over dry conditions in 1991 and 1992, respectively. After flowering, increased pod area more than off-set the decline in leaf area thereby increasing overall plant-photosynthetic area. Irrigation similarly increased pod-surface area and LAI in *B. napus* (Clarke and Simpson 1979).

Seed yield responded positively to increasing watering frequency in both years although yield levels differed between two years. The increase in seed yield could be accounted for by increase in photosynthetic area (leaf + pod), with subsequent accumulation of total plant-dry matter. The maximum LAI occurred near the start of flowering; this would have an effect on the size and nutritional status of plant, and these two factors together then influenced pod development. The supply of water exhibited a positive association of LAI with seed yield. Thakral *et al.* (1983) also reported a significant positive correlation between LAI and seed yield. The maximum pod area development would tend to support a high number and size of seeds by increasing photosynthetic apparatus during the period of ripening. The latter would produce a high economic yield derived from the high HI. The HI is an indicative of the efficiency with which photosynthetates are translocated from the organs of assimilation (leaves + pods) to the organ of economic value (seeds) (Thakral *et al.* 1983). Thus the results of the study emphasize the critical importance of availability of water, as influenced by the timings of it supply, in maximizing mustard yields. This provides conformation of earlier studies (Bhan 1981; Gangasaran and Gajendra Giri 1986; Siag and Verma 1990 and Prakash et al. 1991).

It would be important to interpret the responses in this study in terms of the "self-destruction" theory of Sinclair and de Wilt (1976), who suggest that, when seed filling commences in soybeans, the demand for assimilates, particularly nitrogen, is so great that senescence is hastened by the withdrawal of nitrogen from the leaves to satisfy seed demands. The removal of nitrogen results in the loss of biosynthetic capacity within the leaves which in turn reduces overall assimilated supply. In the present study, progress towards senescence appears to have been delayed by the water supplied during pod formation and ripening phases of the growth of mustard. This was because more frequent water supply improved water status, which was probably the reason for maintenance of leaf area and presumably photosynthesis late in the growing period. Seed yield increases with increasing irrigation frequency through the promotion of and prolongation of crop growth (Garside et al. 1992), and the growth rates of most components of the plant are enhanced by frequent irrigation. A decrease in seed yield from 57% to 44% in dry materials over the full-watered materials in subsequent years, was probably due to water stress which could not meet the water requirements of the plant because of atmospheric evaporative demands (Yang and Dejang 1972). Bram (1981) reported that a reduction in seed yield occurred if available soil moisture fell below 50% during the period from flowering to green maturity. A positive significant association (+ 1.00) of increase in seed yield of irrigated material of mustard with its WUE was observed in this study, which was confirmed by the earlier studies of Simmis et al. (1988).

ACKNOWLEDGEMENT

Financial support provided by the Canadian International Development Agency (CIDA), is gratefully acknowledged. The senior author also wishes to express his thanks to Professor, B. Baker, Department of Crop Science and Plant Ecology, University of Saskatchewan, for aid with the statistical analysis.

REFERENCES

Bram, A. 1981. Plant water relations of rapeseed. In: production and utilization of protein in oilseed crops. E.S. Bunting (ed). Martus Nijhoff, The Hague, Netherlands, : 190-202.

Bhan, S. 1981. Water use and water-use efficiency of mustard in relation to variety, soil moisture regimes and nitrogen under Uttar Pradesh. Indian J. Agron., 26: 62-65.

Clarke, J.M. and G.M. Simpson. 1978. Growth analysis of *Brassica napus* Cv. Tower. Can. J. Pl. Sci., 58: 731-737.

Davidson, D.M. 1976. Oilseed rape agronomic experiences, problems and potential. Proceedings Agron. Soc. of New Zealand, 6: 57-60.

Day, W. and J. Legg. 1983. Water relations and irrigation response. In: P.D. Hebblethwaite (Ed), The faba bean, pp 217-231. Butterworths, London.

Delgado, E.; M.A.J. Parry and H. Medrano. 1992. Effect of water stress on photosynthesis, leaf characteristic and productivity of field grown *Nicotiana tabacum* L. genotype, selected from survival at low Co_2. J. Exp. Bot., 43: 10001-10008.

Gangasaran and G.Gajendra. 1986. Growth and yield of mustard (*Brassica juncea*) as influenced by irrigation and plant population. Ann. Agric. Res., 7: 68-74.

Garside, A.L.; R.J. Lawn and D.E. Byth. 1992. Irrigation management of soybean in Semi-Arid Tropical Environment. 1. Effect of irrigation frequency on growth, development and seed yield. Aust. J. Agric Res., 43: 1003-1017.

Khan, G.M. and S.K. Agarwal. 1988. Physiological basis of growth analysis of mustard in relation to sowing methods, water stress and nitrogen levels. Haryana J. Agron., 4: 91-96.

Kirk, J.T.O. and R.N. Oram. 1981. Isolation of erucic acid and free lines of *Brassica juncea*: Indian mustard now a potential oilseed crop in Australia. J. Aust. Agric. Sci., 47: 51-52.

Love, H.K. 1988. Inheritance of seed aliphatic glucosinolates in oilseed Brassica species. Ph.D. Thesis. Univ. of Sask., Saskatoon.

Nathanson, K.; R.J. Lawn; Dejabrum and D.E. Byth. 1984. Growth nodulation and nitrogen accumulation by soybeans in saturated soil culture. Field Crops Res., 8: 73-92.

Prakash, V.; K. Arvind and R.P Singh.1991. Consumptive use, water-use efficiency and yield of mustard as influenced by irrigation and Jalshakti levels. Ann. Agric. Res., 12: 100-103.

Rathore, A.L. and S.C. Patel. 1989. Effect of irrigation and nitrogen on mustard. Haryana J. Agron., 5: 148-151.

Sharma, D.K. and A. Kumar. 1989. Effect of irrigation and nitrogen on growth, yield, consumptive use and water-use efficiency of Indian mustard. Indian J. Agric. Sci., 59: 127-129.

Siag, R.K. and B.L. Verma. 1990. Effect of irrigation schedules on growth and yield of mustard. Indian J. Agron., 35: 395-399.

Simmis, T.W.; B.A. Kratky and I.P.Wu. 1988. Effect of limited irrigation on lettuce and Chines cabbage yield. Irrig. Sci., 9: 187-198.

Sinclair, T.R. and C.T. De Wilt. 1976. Analysis of carbon and nitrogen limitations to soyabean yield. Agron. J., 68: 319-324.

Stoker, R. and K.E. Cater. 1984. Effect of irrigation and nitrogen on yield and quality of oilseed rape. New Zealand J. Exp. Agric., 12: 219-224.

Thakral, N.K.; P. Kumar; T.P. Yadava and S.K. Thakral. 1983. Association of some physiological determinants with seed yield in Toria (*Brassica compestris*). Proceeding of 6th Inter. Rapeseed Conf., Paris, France, 1: 138-140.

Woods, D.L.; J.J. Capcara and R.K. Downey.1991. The potential of mustard (*Brassica juncea* L.) as an edible oil crop on the Canadian prairies. Can. J. Pl. Sci., 71: 195-198.

Wright, G.C.; C.J. Smith and M.R. Woodroofe. 1988. The effect of irrigation and nitrogen on rapeseed production in South-Eastern Australia. 1. Growth and seed yield. Irrig. Sci., 9: 1-13.

Yang, S.J. and E. Dejong. 1972. Effect of aerial environment and soil-water potential on transpiration and energy status of water in wheat plants. Agron. J., 64: 574-578.

Table 1: Dry-matter-accumulation fraction of above-ground plant components at different growth stages of B. juncea (cv. Cutlass) grown in the field during the growing seasons of 1991 and 1992, under full-water supply (at flowering, pod formation and ripening), medium-water supply (at flowering and pod formation), minimum-water supply (at flowering), and dry conditions.

Growth stages	Plant Components	% of total plant dry matter			
		Levels of water supply			
		Full	Medium	Minimum	Dry
1991					
Flowering	Stem	60	63	61	62
	Leaf	40	37	39	38
	Pod	-	-	-	-
Pod formation	Stem	47	45	47	44
	Leaf	9	9	5	5
	Pod	44	46	48	51
Ripening	Stem	39	39	42	39
	Leaf	5	4	1	1
	Pod	56	57	57	60
1992					
Flowering	Stem	63	61	65	56
	Leaf	37	39	35	44
	Pod	-	-	-	-
Pod formation	Stem	55	52	50	42
	Leaf	10	12	11	11
	Pod	35	36	39	47
Ripening	Stem	43	42	42	36
	Leaf	6	6	5	4
	Pod	51	52	53	60

: Values calculated over six replications.

Table 2: Mean seed yield (SD), harvest index (HI) and water-use efficiency (WUE) of B. juncea (cv. Cutlass) grown in the field during the growing seasons of 1991 and 1992, under full-water supply (at flowering, pod formation and ripening), medium-water supply (at flowering and pod formation), minimum-water supply (at flowering), and dry conditions.

Water Regimes	SD (kg ha^{-1})		HI		WUE (Kg ha^{-1}Cu.m)	
	1991	1992	1991	1992	1991	1992
Full	4001.9 a	3080.0 a	38.32 a	41.76 a	2.63 a	2.02 a
Medium	3800.7 a	2807.5 a	37.40 a	41.24 a	2.49 a	1.84 a
Minimum	3026.9 b	2316.2 b	35.68 a	40.87 a	1.99 b	1.52 b
Dry	2551.4 c	2140.3 b	35.52 a	39.70 a		
Mean	3345.2	2586.1	36.73	40.89	2.20	1.70
Pr>	0.00	0.00	0.76	0.67	0.00	0.00
LSD(0.05)	297.37	419.60	6.53	6.62	0.19	0.27

- Means over six replications.
- Means in column followed by the same letter(s) are not significantly different at 5% level by LSD.

Table 3: Correlations between seed yield (SD), harvesting index (HI), water-use efficiency (WUE), plant-dry matter (PDM) and plant-photosynthetic area (PPSA) of *B. juncea* (cv. Cutlass) for three water regimes (full, medium and minimum) and dry conditions during the growing seasons of 1991 and 1992.

	Parameters					
Parameters/ Water regimes	WUE		HI		SD	
	1991	1992	1991	1992	1991	1992
PDM						
Dry			-0.050	0.503	0.349	0.301
Minimum	0.617	0.490	-0.792	0.260	0.617	0.490
Medium	-0.137	0.503	0.700	0.464	-0.137	0.503
Full	0.214	0.453	0.407	-0.589	0.214	0.453
PPSA						
Dry			0.287	0.191	0.030	-0.107
Minimum	0.814*	0.963**	-0.521	0.032	0.814*	0.963**
Medium	0.042	0.551	0.538	0.900*	0.042	0.551
Full	0.473	0.591	0.486	-0.618	0.473	0.591
LAI						
Dry			0.618	-0.071	-0.274	-0.358
Minimum	0.406	0.932**	-0.628	0.070	0.406	0.932**
Medium	0.053	0.623	0.608	0.791	0.053	0.623
Full	0.709	0.702	0.358	-0.630	0.709	0.702
WUE						
Dry						
Minimum			-0.772	-0.199	1.000**	1.000**
Medium			0.361	0.486	1.000**	1.000**
Full			0.211	-0.714	1.000**	1.000**
HI						
Dry					-0.378	0.945**
Minimum					-0.772	-0.199
Medium					0.361	0.486
Full					0.211	-0.714

*, ** :Significant at 0.05 and 0.1 levels, respectively.
:Values calculated over six replications.

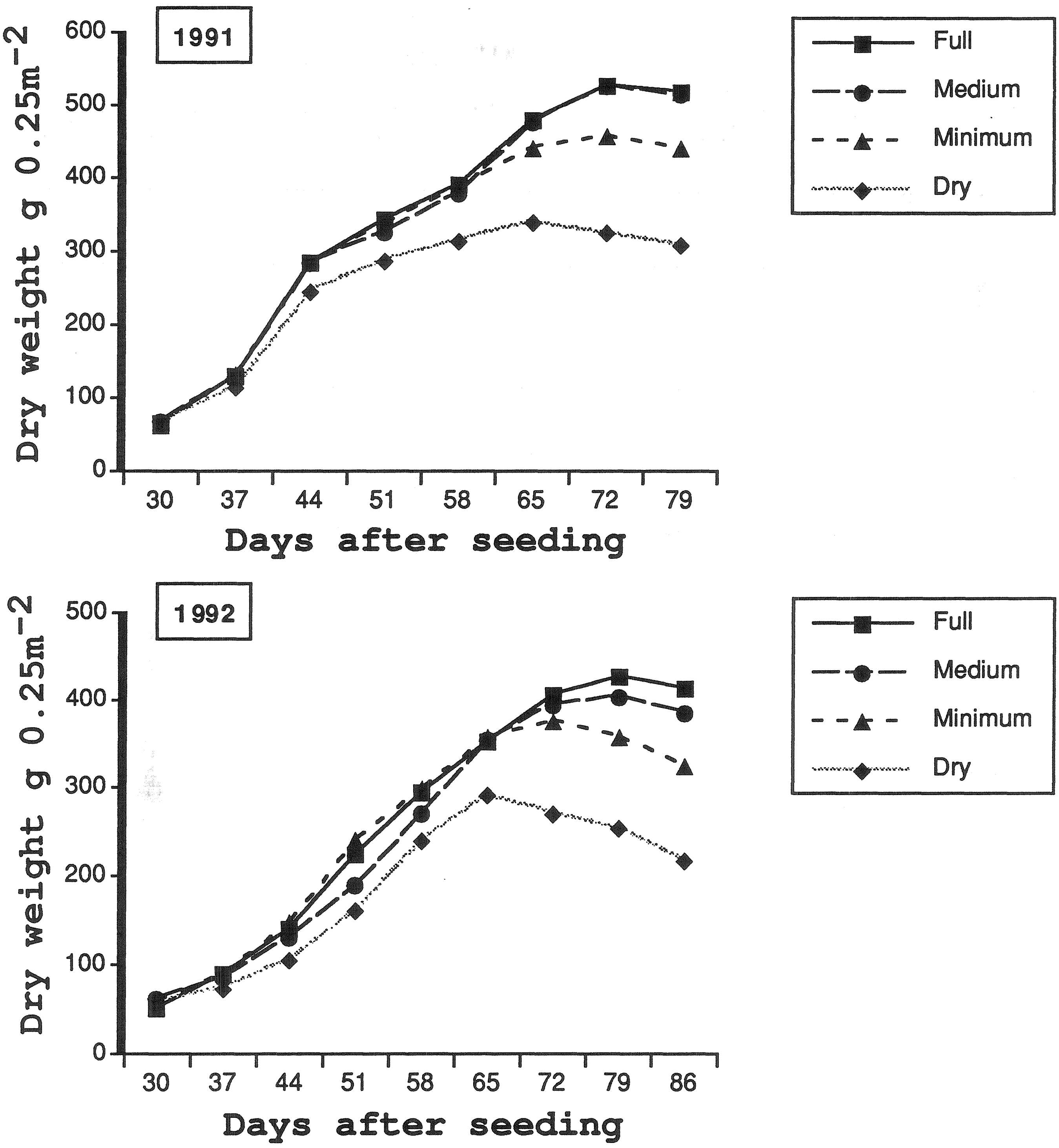

Fig 1: Mean dry matter accumulation of *B. juncea* (cv. Cutlass) grown in the field during the growing seasons of 1991 and 1992, under full-water supply (at flowering, pod formation and ripening), medium-water supply (at flowering and pod formation), minimum-water supply (at flowering), and dry conditions.

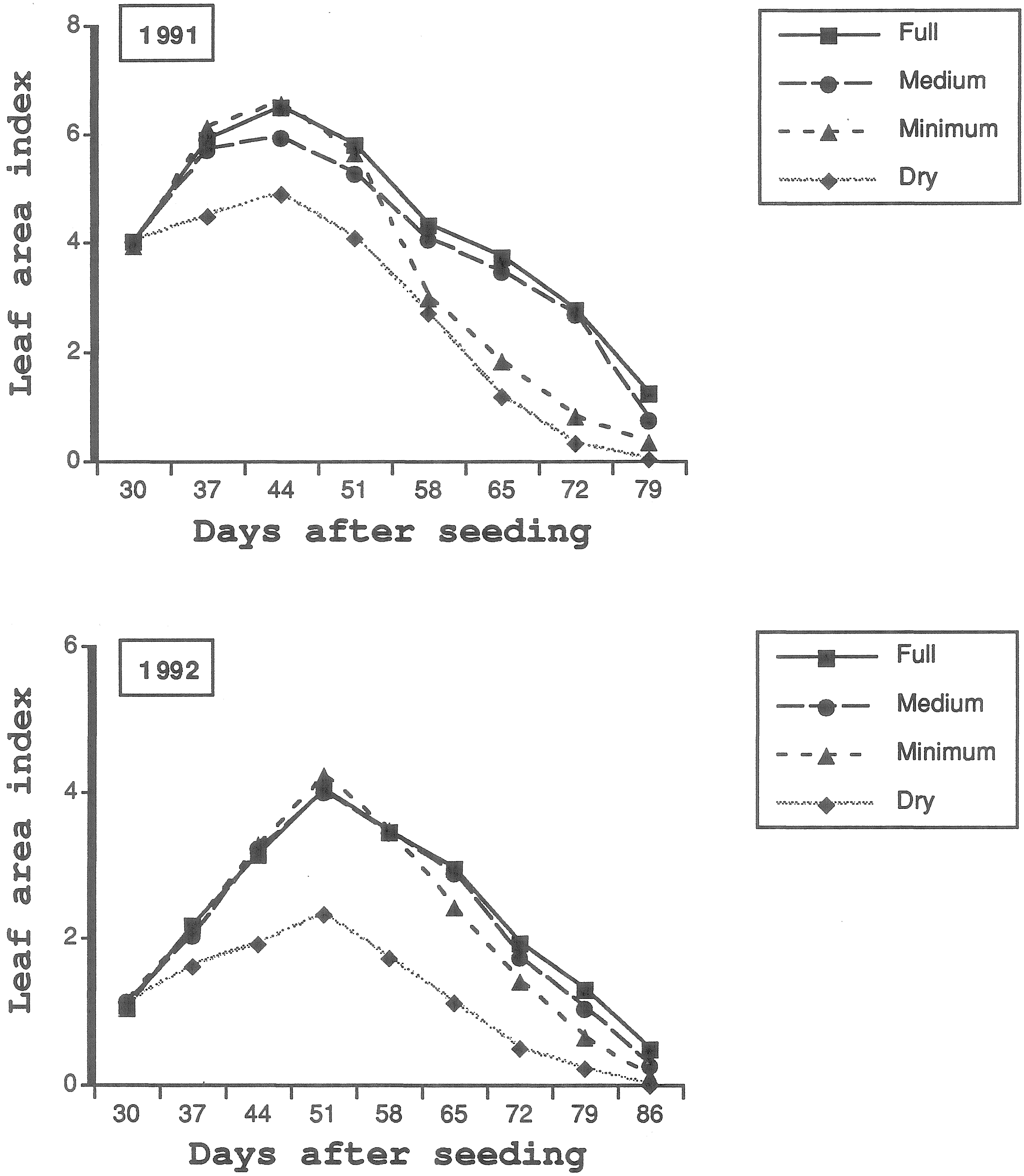

Fig 2: Mean leaf area index (LAI) of *B. juncea* (cv. Cutlass) grown in the field during the growing seasons of 1991 and 1992, under full-water supply (at flowering, pod formation and ripening), medium-water supply (at flowering and pod formation), minimum-water supply (at flowering), and dry conditions.

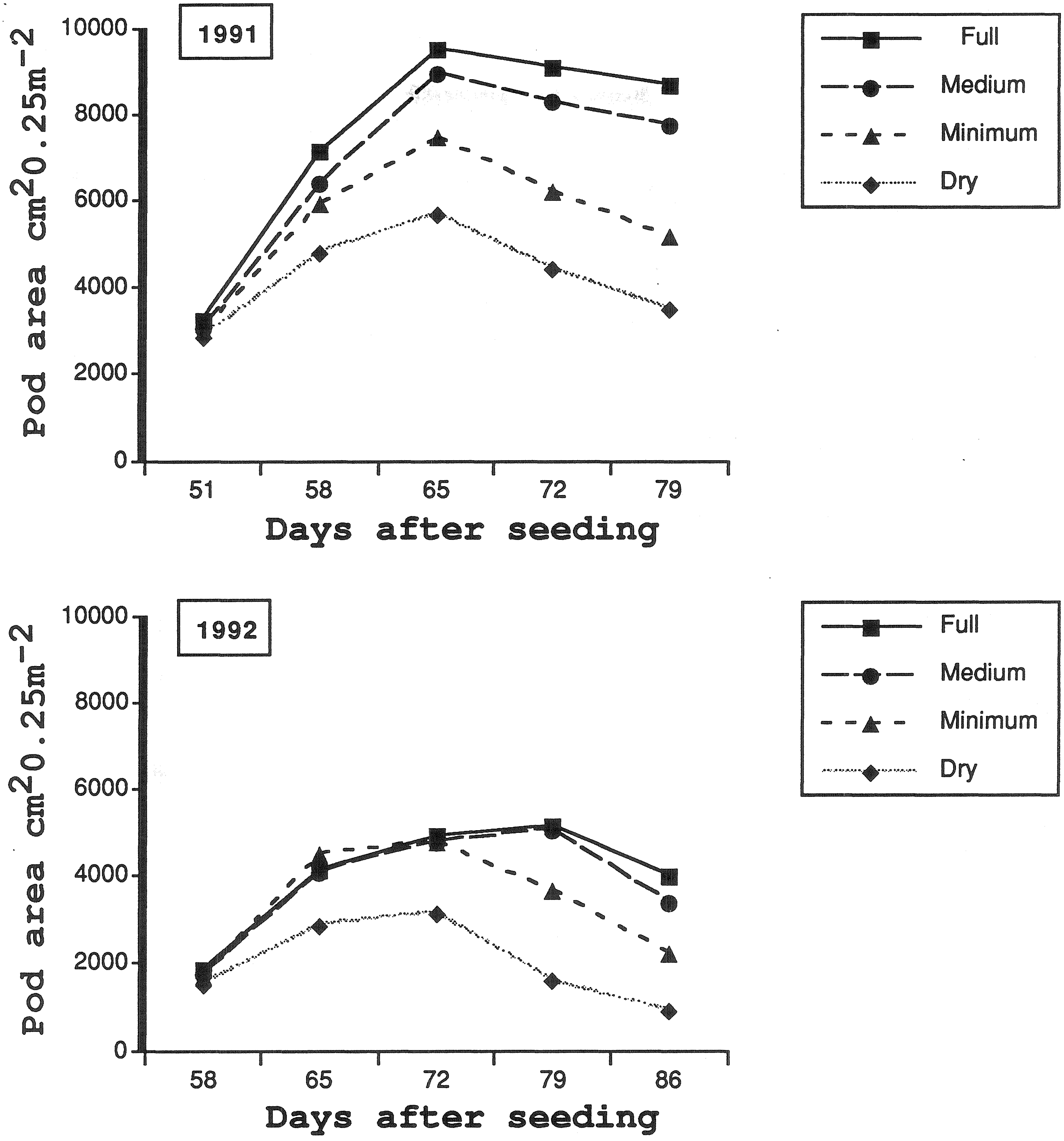

Fig 3: Mean pod area of *B. juncea* (cv. Cutlass) grown in the field during the growing seasons of 1991 and 1992, under full-water supply (at flowering, pod formation and ripening), medium-water supply (at flowering and pod formation), minimum-water supply (at flowering), and dry conditions