Phenotypic and genotypic plasticity for yield and yield components in *Brassica napus*.

Thesis submitted in accordance with the requirements of the University of Liverpool, for the degree of Doctor in Philosophy

by

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Table 1.1 Common names of oilseed rape in Europe and Canada.

Species	Chromosome number/ genome	Common names in U.K.	France	Germany	Canada
Brassica campestris subspecies oleifera	2n = 20				
Var. annua	AA	Summer turnip rape	Navette d'ete	Summer rubsen	Summer Polish rape
Var. biennis	AA	Winter turnip rape	Navette d'hiver	Winter rubsen	Winter Polish rape
Brassica napus subspecies oleifera	2n = 38				
Var. annua	AACC	Summer rape	Chou colza	Kolza	Summer Argentine rape
Var. biennis	AACC	Winter rape	Navette	Steckrube	Winter Argentine rape

After Yarnell (1956) and Downey (1965)

just before anthesis on 12.7.79. Thirty cm were left on both ends of a harvest, and two rows on either side of the harvest acted as guard rows. At each harvest plants were cut at ground level and plant height measured in cms. Plants were then divided into leaf (less than 50% senesced), stem and inflorescence fractions. Inflorescence included pods and shoots from terminal and axillary flowering branches. These fractions were dried at 38°C for 7 days and dry weight measurements taken. Dry weight per plant was obtained by adding these fractions.

At maturity measurements of seed yield and its components were also made. All pods containing more than two seeds were removed from the plants, their numbers counted and the pods dried, again at 38°C for 7 days. Mean pod number per plant was calculated from these data. A sub-sample of five randomly selected plants was used to determine means for dry weight per pod, seed weight per pod, and number of seeds per pod. From these five plants, 10 to 15 pods were selected at random, the number depending upon the total number of pods per plant. Individual pods were weighed after drying, and seed number per pod and seed dry weight measured, giving mean values for these characters. From seed number and seed weight data, 1000-seed weight was calculated.

Hull weight per pod was determined by subtracting seed dry weight per pod from pod dry weight. The remaining pods from the plants were threshed by hand and the seed weighed. Total seed weight was determined by adding the two seed weight values. Harvest index was calculated by dividing mean total seed dry weight per plant by mean top dry weight. The data for each character is average of 10 plants per treatment per block. Analyses of variance were carried out on these characters and simple correlations determined for associations between the characters at maturity.

5.3 Results

The distribution of top dry weight per plant into its component parts i.e. leaf weight, stem weight and inflorescence weight for the experimental variables, varieties, fertilizers, and row spacings, is shown in Figures 5.1 and 5.2. The general growth pattern and allocation of dry matter production of varieties was similar to the experiment described in Chapter 2.

Analyses of variance of the individual plant characters from the harvests at 6,8,10,12 and 14 (maturity) weeks after germination are given separately and described in their respective sections. The mean of the variables and their interactions for which analyses of variance showed significant differences are also given in the tables next to the appropriate analysis of variance table. As the variables and their interactions were mostly non-significant, mean data are given only where items were significantly different. Complete data are given in appendix 8.

Dry weight per plant

There were no significant differences between varieties for dry weight per plant throughout the experiment (Table 5.1). Fertilizer treatments at W10, W12 and W14 (maturity) had a significant effect ($p < 0.001$, $p < 0.01$ and $p < 0.001$ respectively) on top dry weight per plant. The high fertilizer treatment at W10 had a significantly greater ($p < 0.001$) top dry weight per plant than the remaining fertilizer treatments (Table 5.2) and at W12 and W14 top dry weight per plant for high fertilizer treatment was significantly ($p < 0.01$ and $p < 0.001$ respectively) higher than low fertilizer treatment whereas the intermediate fertilizer treatment did not differ significantly from either high or low fertilizer levels.

Variety x row spacing interaction at W6 and variety x fertilizer and fertilizer x row spacing interactions at W10 were significant (Table 5.1).

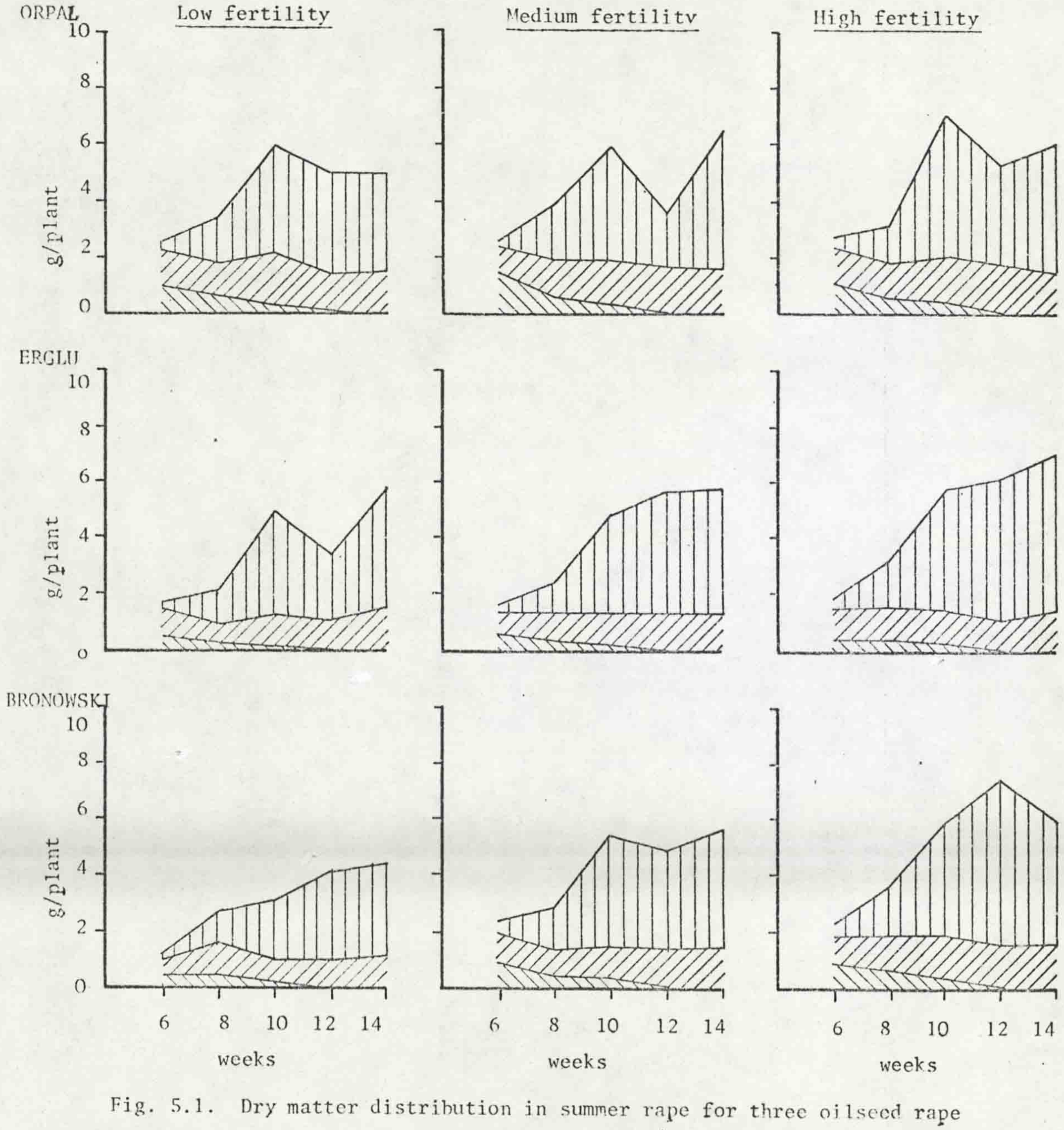

Fig. 5.1. Dry matter distribution in summer rape for three oilseed rape varieties and three fertility levels at 7.5cm row spacing.

▨, leaves; ▨, stem; ▥, inflorescence.

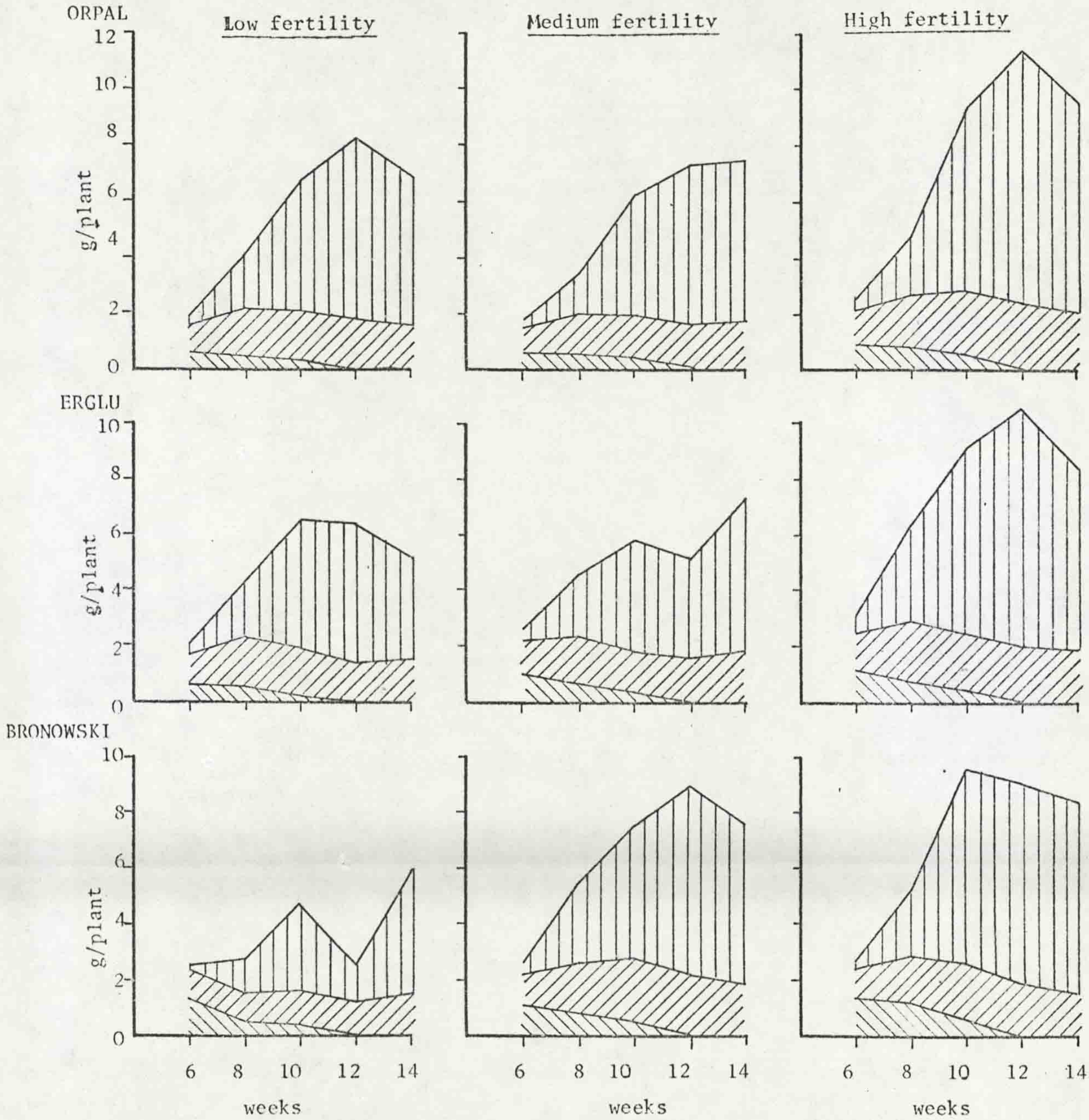

Fig. 5.2. Dry matter distribution in summer rape for three oilseed rape varieties and three soil fertility levels at 15cm row spacing.

▨, leaves; ▨, stem; ▥, inflorescence.

Table 5.1 Variance ratios and significance of differences from analyses of variance for top dry weight per plant for three spring oilseed rape varieties at three fertilizer levels with two row spacings harvested at 6,8,10,12 and 14 weeks after germination.

Item	df	Weeks after germination				
		6	8	10	12	14
Blocks	1	17.81***	0.71	2.16	0.25	3.39
Density (D)	1	1.79	16.05***	39.35***	14.35**	24.64***
Fertilizer (F)	2	2.30	3.29	23.84***	8.62**	13.60***
D x F	2	0.20	0.70	4.35*	1.25	1.90
Variety (V)	2	0.16	0.002	3.18	0.38	1.16
D x V	2	4.02*	2.14	1.67	1.57	1.60
F x V	4	0.27	0.87	3.77*	1.44	0.10
D x F x V	4	0.56	0.89	0.15	1.38	0.84
Error	17					

Table 5.2 * Values having the same letter in a row in a factor are not significantly different from each other. This is followed in Chapter 5 and 6.

Table 5.2. Means for top dry weight per plant (g) for three oilseed rape varieties at three fertilizer levels and two row spacings, where significant differences for the three factors and their interactions were found in analysis of variance of the data (Table 5.1).

Factors*

Weeks after germination	Fertilizer			row spacing	
	low	intermediate	high	15cm	7.5cm
8		NS		4.47a	2.99b
10	5.31b	5.95b	7.80a	7.31a	5.39b
12	4.87b	5.89ab	8.37a	7.71a	5.03b
14	5.47b	6.70ab	7.56a	7.40a	5.76b

Interactions

6 density x variety

		Varieties			
		Bronowski	Erglu	Orpal	LSD p = 0.05
row spacings	(15 cm	2.58	2.57	1.98	0.85
	(7.5cm	1.94	1.69	2.58	

10 fertilizer x variety

		Varieties			
		Bronowski	Erglu	Orpal	LSD p = 0.05
fertilizers	(low	3.87	5.70	6.36	
	(inter-mediate	6.49	5.26	6.11	1.39
	(high	7.80	7.37	8.22	

10 Fertilizer x density

		row spacings		
		15 cm	7.5 cm	LSD p = 0.05
fertilizers	(low	6.01	4.60	
	(inter-mediate	6.53	5.37	1.13
	(high	9.39	6.21	

At W6 Bronowski and Erglu had greater dry weight at 15cm row spacing than at 7.5 cm row spacing whereas Orpal produced more dry weight per plant at 7.5 cm than at 15 cm row spacing (Table 5.2). At W10 Bronowski produced dry weight per plant in the order high > intermediate > low fertility levels whereas Erglu and Orpal had dry weights in order of high > low > intermediate fertility levels. At W10 there was an increase in dry matter per plant from low to high fertilizer treatments in both 15 cm and 7.5 cm row spacing but with 15 cm row spacing the increase in dry weight from intermediate to high fertilizer treatment was much greater than at 7.5 cm row spacing.

Leaf dry weight per plant

Varieties did not differ significantly for leaf dry weight per plant throughout the experiment except at W8 (Table 5.3) when Bronowski produced more ($p < 0.05$) leaf weight than Erglu and Orpal (Table 5.4). At W8 and W10 plants at the high fertilizer treatment produced significantly more ($p < 0.001$) leaf dry weight than at low fertilizer level whereas leaf weight per plant at the intermediate fertilizer level did not differ from either low or high fertilizer treatments. At W8, 15 cm row spacing produced significantly more ($p < 0.001$) leaf weight than 7.5 cm row spacing (Table 5.4).

Cultivar x row spacing interaction at W6 was significant ($p < 0.001$), Table 5.3) when Bronowski and Erglu had more leaf weight at 15 cm than at 7.5 cm row spacing whereas Orpal had more leaf dry weight per plant at 7.5cm than at 15 cm row spacing (Table 5.4).

Leaf weights were highest at anthesis i.e. at the start of harvests at W6 and declined afterwards so that all the leaves had senesced by W12 (Fig. 5.1, 5.2).

Stem dry weight per plant

Varieties differed significantly from one another at W10 ($p < 0.01$, Table 5.5) and at W12 ($p < 0.05$). At W10 Orpal produced

Table 5.3. Variance ratios and significance of differences from analyses of variance for leaf weight for three spring oilseed rape varieties at three fertilizer levels with two row spacings harvested 6,8,10,12 and 14 weeks after germination.

Item	df	weeks after germination				
		6	8	10	12	14(maturity)
Blocks	1	12.97**	13.84**	7.22*		
Density (D)	1	0.87	18.51***	2.93		
Fertilizer (F)	2	1.22	11.69***	6.64**		
D x F	2	1.10	1.80	0.70		
Variety (V)	2	1.82	5.57*	2.51		
D x V	2	6.99**	3.05	1.54		
F x V	4	0.09	0.96	0.59		
D x F x V	4	0.62	0.47	0.13		
Error	17					

Table 5.4. Means for leaf weight per plant (g) for three oilseed rape varieties at three fertilizer levels and two row spacings, where significant differences for 3 factors and their interactions were found in analysis of variance of the data (Table 5.3)

Factors

Weeks after germination	Varieties			fertilizers			row spacings	
	Bronowski	Erglu	Orpal	low	medium	high	15cm	7.5cm
8	0.66a	0.46b	0.51b	0.41b	0.51ab	0.70a	0.65a	0.44b
10		NS		0.17b	0.32ab	0.36a	NS	

Interactions

6 row spacing x variety

	Varieties			LSD
	Bronowski	Erglu	Orpal	p = 0.01
row spacings (15 cm	1.20	0.91	0.65	0.61
(7.5cm	0.75	0.50	1.17	

as an early maturing type in response to particular ecological requirements. According to Prakash (1980) Yellow Sarson (Brassica campestris) arose in the Indus-Ganges plains as a mutant of superior quality which was selected for its light seed coat. Mizushima and Tsunoda (1967) suggested that B. campestris originated in the highlands near the Mediterranean sea. It is believed to have spread from there northwards and westwards into Scandinavia, Germany and eastern Europe into those areas under cultivation, and to have differentiated into numerous different plant types in both Asia and Europe.

Whether or not B. napus exists in a truely wild form is not known (McNaughton 1976b). He describes Linnaeus as having recorded it in sandy areas of Sweden, but the plants he saw may have been escapes from cultivation. By the nineteenth century British rape and continental rape were recognised as being distinguishable on leaf characters. It is certain that rape was the biennial form of B. napus, and was used as an autumn forage for sheep. Sometimes it was grazed lightly and left to yield an oil crop in the following summer (Fussell 1955). It is established (McNaughton 1976b) that B. napus is an amphiploid derived from the hybridization of B. campestris (AA genome, 2n = 20) and B. oleracea (CC genome, 2n = 18). So its chromosome number, 2n = 38 and genome designate is AACC (Fig. 1.1).

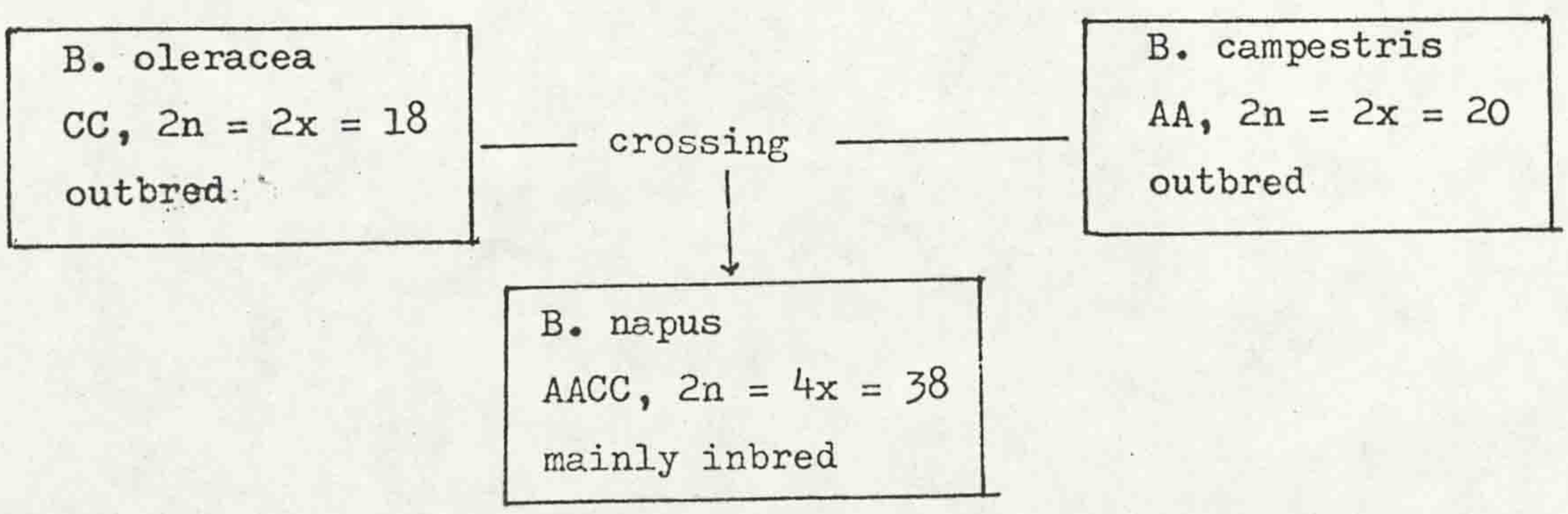

Figure 1.1. Evolution of B. napus (after McNaughton, 1976b).

Table 5.5. Variance ratios and significance of differences from analyses of variance for stem weight for three spring oilseed rape varieties at three fertilizer levels with two row spacings harvested at 6,8,10,12 and 14 weeks after germination.

Item	df	Weeks after germination				
		6	8	10	12	14
Blocks	1	13.08***	15.38**	25.21***	17.67***	3.87
Density (D)	1	2.16	27.76***	49.27***	10.89**	12.41**
Fertilizer (F)	2	1.65	2.80	11.85***	7.05**	3.52
D x F	2	0.14	0.43	1.49	0.67	0.74
Variety (V)	2	0.24	0.52	8.50**	3.97*	1.91
D x V	2	1.12	1.79	2.29	0.31	0.23
F x V	4	0.65	0.47	7.03**	0.97	0.58
D x F x V	4	0.35	1.05	2.92	1.16	2.49
Error	17					

Table 5.6. Means for stem weight per plant (g) for three oilseed rape varieties at three fertilizer levels and two row spacings, where significant differences for the factors and their interactions were found in analyses of variance of the data (Table 5.5).

Factors

Weeks after germination	Varieties			fertilizers			row spacings	
	Bronowski	Erglu	Orpal	low	medium	high	15cm	7.5cm
8	NS			NS			1.72a	1.13b
10	1.54b	1.48b	1.80a	1.46b	1.53ab	1.84a	1.84a	1.37b
12	1.51ab	1.38b	1.76a	1.26b	1.63ab	1.76a	1.73a	1.37b
14	NS			NS			1.67a	1.43b

Interactions

10 fertilizer x variety

		Varieties			LSD
		Bronowski	Erglu	Orpal	p=0.01
fertilizers	low	1.03	1.50	1.84	0.42
	medium	1.69	1.29	1.60	
	high	1.89	1.65	1.97	

heavier stems than both Bronowski and Erglu (Table 5.6), and at W12 Orpal again produced heavier stems than Erglu but Bronowski was intermediate and did not differ significantly ($p > 0.05$) from either Orpal or Erglu. Fertilizer treatments had a significant effect at W10 ($p < 0.001$) and at W12 ($p < 0.01$). Stem dry weight per plant was greatest at the high fertility level at W10 and at W12 and it was significantly greater ($p < 0.001$ and $p < 0.05$ respectively) than at the low fertility level but was not significantly different from the intermediate fertility level (Table 5.6). Plants produced significantly more stem dry weight at 15 cm row spacing ($p < 0.01$) than at 7.5 cm row spacing from W8 to W14 (maturity).

At W10 varieties interacted with fertilizer treatments (Table 5.5). Bronowski responded in the order of high fertility > intermediate fertility > low fertility treatments whereas for Erglu and Orpal the order was high fertility > low fertility > intermediate fertility treatments.

Inforescence dry weight per plant

There were no significant differences between varieties in total inflorescence dry weight per plant at any of the harvests (Table 5.7). Fertilizer treatments had a significant effect on inflorescence production at W10 ($p < 0.001$), W12 ($p < 0.01$) and W14 ($p < 0.001$). At W10 and W12, plants in the high fertility treatment produced significantly more ($p < 0.001$ and $p < 0.01$ respectively) inflorescence dry weight per plant than in the other two fertilizer treatments (Table 5.8). At W14 (maturity) plants in the high fertility treatment had significantly ($p < 0.001$) heavier inflorescences than plants in the low fertility treatment whereas the data for the intermediate fertilizer level did not differ significantly from either high or low treatments. Plants in rows 15 cm apart produced heavier inflorescence than those in rows 7.5 cm apart at W8 ($p < 0.05$), W10 ($p < 0.001$), W12 ($p < 0.01$)

Table 5.7. Variance ratios and significance of differences from analyses of variance for inflorescence weight for three spring oilseed rape varieties at three fertilizer levels with two row spacings harvested at 6,8,10,12 and 14 weeks after germination.

Item	df	weeks after germination				
		6	8	10	12	14(maturity)
Blocks	1	4.71*	1.64	0.01	0.03	6.11*
Density (D)	1	0.17	7.83*	31.81***	13.64**	22.24***
Fertilizer (F)	2	3.21	1.72	23.14***	8.66**	13.56***
D x F	2	0.01	0.52	4.86*	1.20	2.14
Variety (V)	2	1.80	0.14	2.11	0.16	0.79
D x V	2	0.72	1.67	0.97	2.24	2.26
F x V	4	1.70	1.41	3.15*	1.48	0.08
D x F x V	4	0.52	0.80	0.32	1.47	0.64
Error	17					

Table 5.8. Means for inflorescence weight per plant (g) for three oilseed rape varieties at three fertilizer and two row spacings, where significant differences for the factors and their interactions were found in analysis of variance of the data (Table 5.7).

Factors

Weeks after germination	fertilizers low	medium	high	row spacings 15 cm	7.5 cm
8		NS		2.10a	1.42b
10	3.69b	4.10b	5.60a	5.14a	3.78b
12	3.60b	4.26b	6.60a	5.98a	3.67b
14	4.04b	5.11ab	5.93a	5.73a	4.32b

Interactions

10 fertilizer x variety

		Varieties Bronowski	Erglu	Orpal	LSD p = 0.05
fertilizers	low	2.58	4.13	4.36	
	medium	4.40	3.73	4.18	1.10
	high	5.57	5.40	5.82	

10 fertilizer x row spacing

		row spacings 15 cm	7.5 cm	LSD p = 0.05
fertilizers	low	4.19	3.18	
	medium	4.43	3.77	0.89
	high	6.80	4.40	

and W14 (maturity $p<0.001$).

At W10 variety x fertilizer and fertilizer x row spacing interactions for inflorescence weight were significant ($p<0.05$). For variety x fertilizer interaction Bronowski produced inflorescence weight in the order of high fertility> intermediate fertility> low fertility treatments but for Erglu and Orpal the order became high fertility> low fertility> intermediate fertility treatment (Table 5.8). Fertilizer x row spacing interaction, with both 15 cm and 7.5 cm row spacings inflorescence dry weight increased with higher fertilizer treatments from the low to the high fertility levels but at 15 cm row spacing increment in inflorescence dry weight per plant was at a much higher rate from medium to high fertility level, than at 7.5 cm row spacing.

Plant height

Analyses of variance for plant height of the three varieties at three fertility levels and two row spacings during the growth period (6,8,10,12,14 weeks after germination) are given in Table 5.9, and the means for significant items and interactions in Table 5.10. Varieties did not differ significantly in plant height throughout the experiment. Fertilizer effects were however significant at W10 and W12 ($p<0.05$ and $p<0.01$ respectively). Both at W10 and W12 plants of high fertility treatment were taller than those of low fertility treatments but at W10 plant height at intermediate fertility level was not significantly different either from high or low fertility level. Plants in rows 15 cm apart were significantly taller ($p<0.05$) than those in rows 7.5 cm apart for all the harvests except harvest 1 (W6).

Table 5.9. Variance ratios from analyses of variance for plant height for three spring oilseed rape varieties at three fertilizer levels with two row spacings harvested 6,8,10,12 & 14 weeks after germination.

Item	df	Weeks after germination				
		6	8	10	12	14 (maturity)
Blocks	1	0.01	13.05**	9.48**	17.77***	10.89**
Density (D)	1.	2.22	13.54**	7.50*	12.23**	14.04**
Fertilizer (F)	2	0.84	2.95	3.73*	8.37**	2.13
D x F	2	0.73	0.16	0.11	0.90	0.90
Variety (V)	2	1.34	1.53	1.79	0.80	1.89
D x V	2	0.31	0.24	0.80	0.48	0.47
Fx V	4	0.57	0.50	4.00*	2.68	1.84
D x F x V	4	0.60	1.19	0.76	0.76	0.12
Error	17					

Table 5.10. Means for plant height (cm) for three spring oilseed rape varieties at three fertilizer levels and two row spacings, where significant differences for the factors were found in analyses of variance of the data (Table 5.9).

Factors

Weeks after germination	fertilizers low	medium	high	row spacings 15 cm	7.5 cm
8		NS		86.95a	77.17b
10	79.92b	82.26ab	87.85a	86.68a	80.00b
12	77.25b	86.33a	85.83a	86.70a	79.58b
14		NS		89.88a	82.14b

Interaction

10 fertilizer x variety

		Varieties			LSD
		Bronowski	Erglu	Orpal	p = 0.05
fertilizers	high	73.09	84.79	81.87	
	medium	90.66	79.63	76.50	11.07
	low	94.94	85.22	83.40	

At W10 fertilizer x variety interaction was significant ($p < 0.05$). Bronowski had plant height in the order of low> medium> high fertility levels whereas Erglu and Orpal had plant height in the order low > high> medium fertility level (Table 5.10).

The analyses of variance for the data of seed yield and yield components from the final harvest (W14) are given in Table 5.11 and their means are given in Table 5.12.

Seed weight per plant

Significant effects were found due to varieties ($p < 0.05$), fertilizers ($p < 0.001$) and row spacing ($p < 0.001$) treatments. Orpal produced significantly more ($p < 0.05$) yield per plant than both Erglu and Bronowski. The high fertility level gave significantly higher ($p < 0.01$) seed weight per plant than the intermediate level which in turn gave significantly more seed weight per plant than low fertility (Table 5.12). A row width of 15 cm produced significantly higher ($p < 0.001$) seed yield per plant than 7.5 cm wide rows.

Pod number per plant

Varieties did not differ significantly for pod number per plant (Table 5.11). The high fertility treatment gave a significantly greater pod number per plant ($p < 0.05$) than intermediate fertility treatment which in turn produced a significantly greater pod number than low fertility treatments (Table 5.12). Plants in rows 15 cm apart had a greater pod number than those in rows 7.5 cm apart.

Seed number per pod

Bronowski produced significantly more ($p < 0.001$) seeds per pod than Erglu which in turn produced significantly more ($p < 0.001$) seeds per pod than Orpal (Table 5.12). There were no effects on seed number per pod due to fertilizer treatments or row spacings.

Table 5.11. Variance ratios and levels of significant differences from analyses of variance for seed yield and yield components at maturity for three spring oilseed rape varieties grown at three fertilizer levels with two row spacings.

Item	df	Seed weight per plant	Pod number per plant	Seed number per plant	1000-seed weight	Seed weight per pod	Dry weight per pod	Hull weight per pod	Harvest index
Blocks	1	16.48***	1.06	7.62*	6.07*	13.97**	12.04**	5.82*	9.24**
Density (D)	1	31.93***	40.13***	1.74	0.52	1.74	2.52	2.94	0.05
Fertilizer(F)	2	21.73***	19.54***	0.88	0.30	0.14	0.03	0.05	1.16
D x F	2	2.85	2.89	3.00	0.54	0.23	0.42	0.66	0.12
Variety (V)	2	4.27*	3.35	95.05***	45.48***	9.96**	11.47***	14.61***	2.53
D x V	2	0.89	2.10	8.12**	0.83	1.54	0.81	0.06	0.68
F x V	4	0.32	0.32	3.79*	0.33	0.46	0.61	1.72	1.01
D x F x V	4	0.54	0.50	2.28	0.70	0.20	0.09	0.15	1.38
Error	17								

The parental species are extremely difficult to cross artificially, although crossing followed by chromosome doubling has apparently taken place on a number of occasions in nature, and it is believed that all the existing polyploid species arose in this manner. Occasional artificial forms of B. napus have been successfully raised from crosses of diploid parents and colchicine treatment of the progeny. Crossing autotetraploid forms of parents has also been successful (McNaughton 1976b).

Mizushima and Tsunoda (1969) argued that B. napus originated on the coast of northern Europe because B. oleracea occurred along the coast there, and B. campestris expanded its territory into northern Europe from the Irano-Turanean region (Hedge 1976) because it showed adaptability to cool climatic conditions. Sinskaia (1928), however, believed that B. napus is a Mediterranean species and Schieman (1932) supposed that B. napus may have originated in the Mediterranean region, or in western or northern Europe. Rudorf (1950) and Olsson (1954) have emphasized the possibility that various forms of B. napus have been formed at various places and from various original crosses including crosses between cultivated forms of B. campestris and B. oleracea.

To summarize, B. napus may or may not be a cultigen. Its domestication is recent, so that the swedes and rapes are probably a few hundred years old. A multiple origin from different parental combinations of B. campestris and B. oleracea is possible (McNaughton 1976b). B. napus is an original analogue.

1.3 Uses of Rapeseed

Although both storage organs and leaves of B. campestris and B. napus are utilized in the varying forms of these two species it is their seed which is of paramount importance. Oil which is extracted

Table 5.12. Table of mean seed yield and yield components at maturity for three spring oilseed rape varieties grown at three fertilizers and two row spacings.

	Seed weight per plant (g)	pod number per plant	Seed number per pod	1000-seed weight (g)	Seed weight per pod (mg)	Dry weight per pod (mg)	Hull weight per pod (mg)	Harvest index
Varieties								
Bronowski	3.10b	46.93	25.38a	2.65b	68.23b	134.36a	66.13a	0.50
Erglu	3.20b	53.36	22.34b	2.84b	62.43b	118.98b	56.56b	0.49
Orpal	3.58a	50.98	19.84c	3.71a	75.38a	139.28a	63.90ab	0.52
LSD	0.37*	NS	1.62***	0.57***	6.23*	9.46*	7.45***	NS
Fertilizers								
low	2.74c	42.07c	22.78	3.09	68.45	130.83	62.38	0.51
medium	3.27b	51.56b	22.53	3.11	68.03	130.39	62.36	0.49
high	3.87a	57.64a	22.25	3.19	69.55	131.40	61.85	0.51
LSD	0.50**	5.37*	NS	NS	NS	NS	NS	NS
Row spacings								
15 cm	3.68a	56.92a	22.30	3.09	67.11	128.01	60.90	0.50
7.5 cm	2.90b	43.93b	22.74	3.17	70.24	133.74	63.49	0.50
LSD	0.56***	8.25***	NS	NS	NS	NS	NS	NS

Variety x fertilizer and variety x row spacing interactions were however significant ($p<0.01$ and $p<0.05$ respectively). Bronowski (V x F, Table 5.13) produced the greater number of seeds per pod in all fertilizer treatments followed by Erglu and Orpal. Bronowski and Orpal had highest seed number per pod at low fertility level whereas Erglu had highest seed number per pod at intermediate fertility level. Variety x row spacing interaction, Bronowski had a greater seed number per pod in 7.5 cm than in 15 cm row spacing ($p<0.05$) whereas in Erglu and Orpal seed number per pod in both 7.5 cm and 15 cm row spacings was almost the same.

1000 -seed weight

Orpal had a significantly greater ($p<0.001$) 1000-seed weight than Erglu and Bronowski (Table 5.12). No significant effects were found due to fertilizer or row spacing treatments or interactions between items.

Seed weight per pod

Orpal had a significantly greater seed weight per pod ($p<0.05$) than Erglu and Bronowski. No other significant effects on seed weight per pod were found due to any item.

Dry weight per pod

Orpal and Bronowski did not differ significantly ($p<0.001$) for dry weight per pod, and had more dry weight per pod than Erglu. None of the other items was significant.

Hull weight per pod

Bronowski produced a significantly greater hull weight per pod ($p<0.001$) than Erglu, but Orpal did not differ significantly from either Bronowski or Erglu.

Table 5.13. Means for seed number per pod at maturity (W14) for three spring oilseed rape varieties at three fertilizer levels and two row spacings, where significant differences for their interactions were found in analysis of the data (Table 5.11).

fertilizer x variety

		Varieties			LSD
		Bronowski	Erglu	Orpal	p = 0.05
fertilizers	low	26.64	21.56	20.16	
	medium	24.60	23.30	19.67	1.49
	high	24.91	22.17	19.67	

row spacing x variety

		Varieties			LSD
		Bronowski	Erglu	Orpal	p = 0.05
row spacings	15 cm	24.29	22.86	19.75	1.22
	7.5 cm	26.47	21.82	19.92	

Harvest index

This did not vary in the experiment, there were thus no significant effects for harvest index due to any other factor or their interactions.

Correlations between yield components

Simple correlation coefficients between seed yield and other characters at maturity are given in Table 5.14. Plant height showed a significant positive correlation ($p<0.05$) with mean dry weight per plant and pod number per plant. Plant heightwas negatively but significantly correlated with seed weight per pod ($p<0.05$) and harvest index ($p<0.01$). Correlations of plant height with other characters were not significant. Top dry weight per plant and seed weight per plant and pod number per plant showed significant and positive correlation ($p<0.001$) amongst themselves. Seed weight per plant showed a positive significant correlation with pod number per plant ($p<0.001$) and 1000-seed weight ($p<0.05$). Correlation of seed weight per plant with seed number per pod was negative and with harvest index and seed weight per pod were positive but were not significant. Pod number per plant had a negative significant correlation ($p<0.05$) with hull weight. Seed number per pod showed a negative significant correlation ($p<0.001$) with 1000-seed weight. The correlation of 1000-seed weight with seed weight per pod and harvest index was positive and significant ($p<0.001$ and $p<0.01$ respectively). The characters, seed weight per pod, dry weight per pod and harvest index showed positive and significant correlation ($p<0.001$) amongst themselves.

Table 5.14. Correlation coefficients amongst height, yield and yield components at maturity for three spring oilseed rape varieties grown at three fertilizer levels and two row spacings.

	Dry weight per plant	Seed weight per plant	Pod number per plant	Seed number per pod	1000-seed weight	Seed weight per pod	Dry weight per pod	Hull weight per pod	Harvest index
Plant height	0.38*	0.20	0.38*	-0.04	-0.20	-0.33*	-0.27	-0.12	-0.45**
Dry weight per plant		0.93***	0.94***	-0.16	-0.18	0.06	-0.02	-0.15	-0.11
Seed weight per plant			0.87***	-0.17	0.34*	0.28	0.19	0.003	0.26
Pod number per plant				-0.18	0.03	-0.17	-0.25	-0.33*	-0.11
Seed number per pod			-0.68***	-0.07	0.07	0.26	-0.05		
1000-seed weight				0.74***	0.62***	0.30	0.48**		
Seed weight per pod					0.95***	0.68***	0.64***		
Dry weight per pod						0.88***	0.62***		
Hull weight per pod							0.46**		

5.4 Discussion

The development of new varieties in oilseed rape to some extent parallels developments in cereals where new varieties have been sought which have shorter and stiff stems (semi-dwarf and dwarf variety), and stand heavy fertilizer input and, higher nutrient levels may therefore be used to increase seed yields. The main objectives in breeding of oilseed rape varieties are high seed yield, better oil and protein quality, and resistance to diseases and insects. To give high seed yields the crop needs large amounts of fertilizer. An important objective in modern varieties is therefore high response to added fertilizer.

Old varieties tend to grow tall and when high doses of fertilizer are applied produce large amounts of vegetative growth. They therefore under high fertility conditions lodge and give poor seed yields. Modern varieties however are bred with the emphasis on shorter and stiffer haulms to reduce lodging. More photo-assimilate is then potentially available for increase in reproductive growth and hence seed. This difference between Orpal, a new variety, and Bronowski and Erglu, old varieties, can be seen from the data. Orpal had a similar and consistent plant height during growth period in all the fertility and density levels. Bronowski plants were shorter in low fertility but taller in the medium and high fertility levels, whereas Erglu varied with no consistent pattern in these environments during the growth period. Orpal reflects the characteristics of a new variety, which has more uniform growth pattern than Erglu and is shorter than Bronowski. Even though plant height in Orpal was also affected by fertilizer and density, the stiff stem enables it to avoid lodging. The heavier stem in Orpal reflects its strength.

Plant height in the three varieties was significantly affected by both fertilizer (till W12) and row spacings, these data being in agreement with the results of Allen, Morgan and Ridgman (1971) who reported that nitrogen application in oilseed rape varieties resulted in increased stem length, and the data of Degenhardt and Kondra (1981) who reported that oilseed rape sown at low density (low seeding rate) had an increased plant height.

No significant differences were found between varieties (analysis of variance, Table 5.1) in top dry weight per plant. This was mainly because inflorescence weight is the main contributor to total plant weight at maturity but this again did not differ significantly across the treatments.

Though no significant differences in dry weight per plant were shown by analysis of variance (Table 5.1), certain trends in dry matter production per plant were seen for all three varieties. Dry matter accumulation and partition into different plant parts was similar in the three fertilizer levels and in the two densities (Fig. 5.1, 5.2). The pattern of dry weights (leaves, stem and inflorescences) shown by these data reflect the growth and development of the oilseed rape plant. After germination plant develops at a fast rate to rosette stage when several petiolate leaves are formed. At that time total plant weight will mainly consist of leaves. This happened before the start of the harvests. After this, elongation of internodes begins, and stem weight increases, upper sessile leaves are formed and the terminal inflorescence initiates. So total dry weight consists of all these parts. At W6 i.e. at the start of harvests all plants consisted of the three components, leaves, stem and inflorescence, stem being the main contributor to total plant weight. Flower buds appear first on terminal inflorescence and flowering begins. This

is the time when leaf weights and leaf areas are still high. Flowering branches and buds, and upper leaves shade the lower leaves which senesce and die. After W6 leaf weights began to decline and inflorescence weight was increasing and exceeded stem weight. Inflorescence weight increased at a high rate from W8 to W10 after which the rate slowed down. After W8 stem weight increased little, and total dry weight largely consisted of inflorescence weight (mainly pods) because pods continue to increase in weight till near maturity. When the pods are developing, they and the branches shade the remaining leaves which senesce and die, so at the end of W12 all the leaf parameters were zero.

Number and sizes of pods clearly depend upon the number of open flowers. However, number of open flowers exceed the number of pods which reach maturity. This is because pod formation and development is largely determined by the supply of assimilates. If the plant can support the pods, flowers develop into pods otherwise either flowers or even pods shed or pods do not develop fully. Shedding of pods was shown by a drop in inflorescence weight at W12 and W14. A significant increase in all the parts was however shown by across both fertilizer and row spacing treatments. The nutrients from applied fertilizer increase the amount of assimilates and wide row spacing increases light to the parts of the plant and enhances the production of photosynthetic assimilates. As a consequence significant effects on top dry weight per plant on growth were observed from higher fertilizer input and wider row spacing after W8 and W6 onward respectively . With high fertilizer input canopy closes rapidly due to fast growth of plants. Canopy area is a major factor in determining net photosynthesis. As similar effect as that of fertilizer would be expected due to wide row spacing as there

is more space for canopy development due to increase space available to individual plant. It thus seems that both fertilizer application and width of rows and for that matter space between plants within a row should be considered in manipulation of the growth of the crop.

It is well known that nitrogen application increases total dry weight and pod weight per plant (Allen and Morgan, 1972, 75; Scott, Ogunremi, Ivins and Mendham 1973b; Scarisbrick, Daniels and Chapman 1981). Similar effects were observed for dry weight with decreasing density (seed rate) by Degenhardt and Kondra (1981) who reported that an increase in seeding rate resulted in mature stands in effects of density on mean plant dry weight but no effect on total dry weight per unit area. Similar effects of decreasing seed rate were reported by Kondra (1975, 77) in oilseed rape and of wide row spacing by Bahn, Balaraju and Ram (1980) in B. campestris.

It is suggested that leaves at anthesis mainly determine final seed yield (Allen and Morgan 1972, 75). In the present experiment Bronowski had a consistently higher leaf weight than both Orpal and Erglu. The fact that Bronowski did not ultimately have a greater seed yield than Orpal or Erglu suggests either that its leaves were less efficient, or that alternative sources of photosynthates must have been available to Orpal or that these sources were more efficient in Orpal. It is clear that pods on the inflorescence and the branches were such a source. This is emphasized by the fact that at the time when leaf weight was declining total plant dry weight was increasing. Pods are nowadays considered the prime, if not the only source of assimilates for pod filling (Inanaga et al 1979). This is borne out by the data presented here, Orpal having much higher inflorescence weight than Bronowski from anthesis to maturity. The stem of an oilseed

rape plant is also green before maturity and potentially a source of photosynthates (Major and Charnetski 1976). Stem weight was similarly greater in Orpal than in Bronowski and may have also made some contribution to increased seed yield in Orpal. It is suggested, therefore, that both inflorescence (pods and branches) and stem weight contributed to the higher dry matter and seed yield.

Occurrence of component compensation, similar to that reported in Chapter 4, was again clear from these data. Orpal produced a significantly greater seed weight per plant than Bronowski and Erglu. Varieties did not differ significantly for pod number per plant, but differed for seed number per pod, and also for 1000-seed weight. Bronowski had more seeds per pod but a lower 1000-seed weight. Orpal in contrast had fewer seeds per pod but a greater 1000-seed weight. The fact that component compensation was taking place was supported by the high negative correlation between seed number per pod and 1000-seed weight ($p < 0.001$). Adams (1967) postulated that compensation is inevitable when sequentially developing yield components share a common metabolic pool. In the present study pod number per plant did not change significantly but there were compensatory (interactions) effects between number of seeds per pod and 1000-seed weight. Pod number is established early in the life of the plant, but seed number per pod and seed development occur later, and almost at the same time. It is thus more likely for compensation to occur involving these two characters. Similar compensation between seed weight and seed number per pod in B. napus was reported by Clarke and Simpson (1978).

In spite of component compensation the higher 1000-seed weight of Orpal compared with Bronowski resulted in a significant increase in seed yield per plant in Orpal. This is evident from the fact that 1000-seed weight showed significant positive correlations with

by crushing the seed, finds a variety of uses, both in food and in industry. Increasing annual production of oilseed rape for the last twenty years (Table 1.2) reflects the growing demand for it throughout the world. The specific technical usage of oilseed rape depends on the amount of large chain fatty acids or those fatty acids with double bonds it contains. Traditionally rapeseed oil was used as an illuminant and lubricant. As the industry has become more complex and industrial chemistry more advanced, so rapeseed oil and its derivatives have found a multiplicity of uses.

Rapeseed oil was previously typified by its high erucic acid (C^1_{22}) and oleic acid (C^1_{18}) contents, and by a low linoleic acid (C^2_{18}) content. A high percentage of long chain erucic acid makes it valuable as an industrial oil, whereas erucic acid is known as being toxic to animals. Current plant breeding aims to produce zero erucic acid for human and animal consumption on the one hand but high erucic acid for other industrial uses on the other hand.

1.4 Production

World production of rapeseed has been increasing steadily over the past twenty years (Table 1.2). It is apparent from Table 1.2

Table 1.2 Annual world and U.K. production of rapeseed (ooo tonnes)

	1961-65	1969-71	1973	1974	1975	1976	1977	1978	1979	1980
World	4775	6617	7132	8119	9636	7557	7981	10186	10556	10574
U.K.	3	10	30	56	61	111	142	157	194	270

Source: F.A.O. Production Year Books 1975,1978,1980 and Johnson (1981) for U.K.

seed weight per plant and seed number per pod did not. This was also shown from seed weight per pod as Orpal had higher seed weight per pod than Erglu and Bronowski.

The occurrence of yield component compensation was supported by an examination of the data for correlation between yield components (Table 5.14). Seed yield was positively correlated with pod number per plant and 1000-seed weight, but showed a negative correlation with seed number per pod and there was a very high negative correlation ($p < 0.001$) between seed number per pod and 1000-seed weight.

Again in parallel with the situation in cereals (Austin et al 1980) Orpal, being a new variety, has a higher harvest index reflecting its greater capacity to transform dry matter into seeds than either Bronowski or Erglu (Table 5.12).

The sum total of the effects of the plant characters in which Orpal is superior to Erglu and Bronowski, consistent and short height, greater total dry weight mainly inflorescence, greater stem weight, and higher harvest index, would suggest that Orpal would have a significantly higher seed yield per plant than the other two varieties. This yield rating of the three varieties is evident from the NIAB list of recommended oilseed rape varieties, Bronowski and Erglu being outclassed varieties and no longer appear on such lists.

In oilseed rape (B. napus)the number of pods per plant that develop is considerably less than the number of flowers that open (Tayo and Morgan 1975). In addition there is strong environmental control over pod number demonstrated in this study, and also reported by Allen and Morgan (1972) and Clarke and Simpson (1978). Similarly, seed number per pod is reduced due to seed abortions. As a result, selection for number of pods per plant and seed number per pod would probably be of little value in improving seed yield. Selection

for increased seed size would be more beneficial because 1000-seed weight shows significant positive correlation with seed yield per pod, dry weight per pod, harvest index and seed yield per plant and also because this character is less affected by environmental variation, as observed here, and as reported by Kondra (1975), Clarke and Simpson (1978), Bahn, Balaraju and Ram, (1980) and Scarisbrick, Daniels, Chapman and Parr (1981), although the consequence of yield component compensation would have to be taken into account. High correlations between top dry weight and seed yield however indicated again that plant size was the major determinant of seed yield per plant. Similar results have been reported by Thurling (1974b) and Campbell and Kondra (1978).

Bronowski responds to fertilizer quite differently from Erglu and Orpal which is shown by variety - fertility level interaction terms of total dry weight, stem weight and inflorescence weight per plant (Table 5.2, 5.4, 5.8) and plant height (Table 5.10). Dry weights in Bronowski gradually increased from low to high fertility treatments and the increases were considerably greater than in Erglu and Orpal. There was little change in total dry weight in Erglu and Orpal from low to medium fertility levels but had higher weights in high fertility level.

CHAPTER 6

A Comparison of Variation in Yield and Yield Components in Forage and Winter Oilseed Rape

6.1 Introduction

The area under winter oilseed rape in the United Kingdom has greatly increased from 15-25% of the total crop in the late sixties (Bunting 1969) to 95% in 1981 (Scarisbrick, Daniels and Alcock 1981). The increased area sown to the winter crop is due to its higher seed yield and higher oil content compared with spring varieties (Moore 1976), and also due to availability of contractor direct drilling at the time when permanent farm staff are needed for winter wheat land preparations (Scarisbrick, Daniels & Alcock 1981).

As in the spring sown crop, fertilizer input and row width are the main agronomic variables which are controlled by the grower, and greatly affect seed yield per hectare. Allen and Morgan (1972) showed that nitrogen application in spring oilseed rape increased growth and seed yield by increasing leaf area, number of pods, and number of seeds per pod, whereas seed weight was little affected by increasing nitrogen. Scott, Ogunremi, Ivins and Mendham (1973b) examined fertilizer response in winter oilseed rape and reported that increments of nitrogen from zero to 300 Kg ha^{-1} increased leaf area, and dry weight of leaves and stem, all at higher nitrogen levels, number of seeds per pod was increased, but seed weight was increased only in one autumn sown experiment.

Seeding rate, which can be manipulated by changing row width or plant to plant distance, has a significant but variable effect on seed yield per hectare in spring *B. napus* (Kondra 1975, 1977).

Kondra (1975) found that narrow row spacing produced the highest seed yield per hectare in the spring oilseed rape variety Zephyr. On the other hand in B. campestrus cultivar Toria 60cm row spacing gave significantly greater seed yield than 30cm row spacing, 1000-seed weight being unaffected (Patil and Rajat De 1978).

Dry weight and seed yield production both depend on the growth of the plant during its developmental stages. It is therefore important to understand the inter-relationships of morphological characteristics of plant growth, the way in which top dry matter is allocated to different parts of the plant, and the influence of environmental factors, e.g. fertilizer and density upon plant growth.

Experiments which examined the way in which environmental factors affected growth of spring oilseed rape are described in Chapter 4 and 5. The purpose of this experiment was to evaluate the effects of two fertilizer levels and two row spacings in field conditions on four winter varieties of B. napus. It was assessed by using dry matter and seed production per plant and their inter-relationships to the yield components, pod number per plant, seed number per pod, and 1000-seed weight.

6.2 Materials and Methods

The experiment was set up in the field, at the University of Liverpool Botanic Gardens, Ness. Three winter varieties of oilseed rape (B. napus) were used, Jet Neuf, Rapol, Rapora, as well as the forage rape variety Nevin. The experiment was set out as a randomised complete block design with three replications. There were two fertilizer treatments: (1) 0 Kg ha^{-1} and (2) at

the rate of 210 Kg ha^{-1} Nitrochalk. A basic fertilizer 100 Kg ha^{-1} of ICI No. 10 was applied to the seed bed of all plots before sowing. Nitrochalk application was split in two doses, firstly 75 Kg ha^{-1} in the seed bed with the basic fertilizer and a second dose of 135 Kg ha^{-1} in late March.

The experiment had two row spacings, 15cm and 7.5cm between the rows. Seed of the varieties was sown with a Stanhay precision drill placing 3 seeds 2.5cm apart. Six 4.9m long rows of each treatment were sown in the last week of September 1979. The experiment thus consisted of four varieties, 2 N fertilizer levels and 2 row spacings. The treatments were applied at random to the plots in each replication.

After germination rows were thinned to plants approximately 2.5cm apart. Spare plants from $1m^2$ plots sown at the same date as the experiment, were transplanted into gaps in rows caused by a failure of germination. This gave a uniform stand in every plot. The two cultivars Rapol and Rapora showed extremely poor germination throughout the experiment and the plots of these two varieties had to be abandoned leaving two varieties in the experiment. Overall germination in one replication was very poor and it also had to be discarded.

Six harvests of 45cm length from the two central rows of each plot (30 plants) were taken starting from 25.3.80. Winter rape is normally sown and germinates in autumn and this is followed by a small amount of growth during the winter. Plants begin growth again in spring and complete their reproductive phase in the summer. Vegetative plant growth mainly takes place during spring and early summer. The first harvest (H_1) was therefore made when

the plants started growth in early spring. The subsequent four harvests (H_2 on 14th April, H_3 on 6th May, H_4 on 27th May and H_5 on 17th June 1980) were taken at three weekly intervals and the final harvest (H_6) which was at maturity (30th July 1980), was taken six weeks after harvest 5 (H_5). Each block of plants to be harvested was separated from previously harvested material by 30cm of rows at the ends of the block, and by two rows on either side as guard rows.

At each harvest plants were cut at ground level and their number counted. Plants were then separated into leaf (less than 50% senesced), stem, inflorescence branches, flower, and pod fractions. Inflorescence branches included branches from all inflorescences, terminal and axillary, after removing flowers and pods. Leaf area was measured on a Hayashi Denko leaf area scanner. All plant parts were then dried at 38°C for 7 days, and dry weight measurements taken. Top dry weight per plant was obtained by summing the dry weights of all the plant fractions. After pod set, the plots were protected from bird damage with a cage of 3cm plastic netting erected over the experiment.

At maturity measurements of seed yield and its components were made. Number of pods was counted and a sample of forty pods was taken from which seed number per pod and 1000-seed weight were determined after drying. Seed from the remaining pods was harvested by hand, weighed and the total seed weight was determined by summing this seed weight and the 40 pod subsample. Hull weight per pod was calculated from seed weight, pod weight and pod number per plant. Harvest index was determined by dividing mean seed weight per plant by top dry weight per plant.

Measurements of mean leaf area per plant (AL), mean leaf weight per plant (WL) and mean top dry weight per plant (W) were used to calculate mean values for relative growth rate (RGR), net assimilation rate (NAR), leaf area index (LAI) and leaf area ratio (LAR) following the method given in Section 2.2. Analyses of variance were carried out on these characters and simple correlation coefficients determined between the characters at maturity, to examine relationships between them.

6.3 Results

The allocation of total dry weight per plant into its component parts i.e. leaf, stem, inflorescence branches, flower and pod weights during the experiment is shown in Fig. 6.1. The analyses of variance of different harvests showing variance ratios for varieties, fertilizers, row spacings, and the interactions between the parameters for the following plant characters are given in separate tables: leaf weight, stem weight, inflorescence branches weight, flower weight, pod weight and top dry weight, per plant, the growth characters, relative growth rate, net assimilation rate, leaf area index and leaf area ratio. The analyses are described individually in their respective sections. The means of the parameters for which significant differences are shown by analyses of variance are also given in tables next to the analyses tables. As the parameters showed non-significance at most of the times and there was a very large body of data, the means only for those parameters which were significant are given. Complete data are given in Appendix 9, page 206. The data will be considered in detail below.

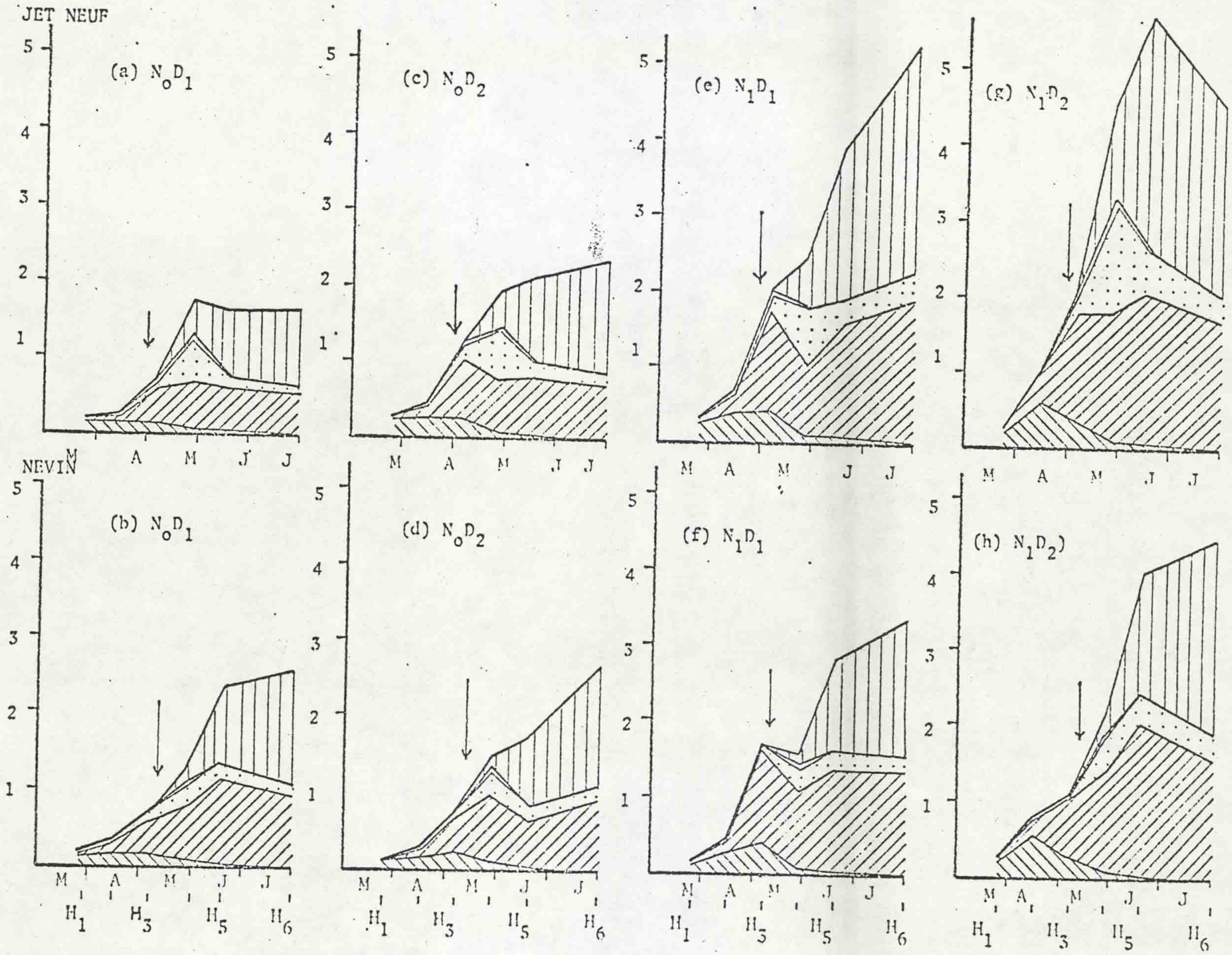

Fig.6.1. Dry matter distribution in winter rape. ▨, leaves; ▨, stem; ⁝⁝, inflorescence branches; ▭ flower; ▥ pod; Arrow show 50% anthesis; H_1 to H_6, Harvest 1 to harvest 6, N_o 0 Kg N ha^{-1}; N_1 55 Kg N ha^{-1}, D_1 7.5cm, D_2 15cm between rows.

Top dry weight per plant

Analyses of variance for top dry weight per plant are given in Table 6.1, and the means for significantly different parameters are given in Table 6.2. Jet Neuf produced significantly more top dry weight per plant than Nevin($p<0.05$ [H_1, H_2, H_4 and H_5] and $p<0.01$ [H_3]) but dry weight per plant at maturity of both the varieties was not significantly different, probably reflecting the lack of non-significant differences in component dry weights. Nitrogen fertilizer had a significant effect ($p<0.001$[H_2,H_3 and H_5] and $p<0.05$ [H_4, H_6]) on top dry weight per plant from H_2 to maturity. Plants in rows 15cm apart had significantly greater dry weight than those in rows 7.5 cm apart only at H_2 and H_5 ($p<0.001$ and $p<0.01$ respectively).

At H_1 Jet Neuf in the no N fertilizer added treatments produced more dry weight per plant in rows 15cm than 7.5cm apart. On the other hand Nevin produced more dry weight per plant in 7.5cm than 15cm row spacing. This pattern of varieties was reversed with addition of N fertilizer. At H_2 dry weight per plant with added N was greater in both 7.5cm and 15cm row spacings. The increase was greater in rows 15cm apart than in rows 7.5cm apart. At H_3, Jet Neuf produced more dry weight per plant in 15cm than in 7.5cm row spacing. In contrast Nevin produced more dry matter in 7.5cm than in 15cm row spacing. At H_3 there was a significant effect of added nitrogen in rows 7.5 and 15cm apart. There was a greater increase when rows were 7.5cm apart than in rows 15cm apart. At H_5 both Jet Neuf and Nevin produced significantly higher dry weight per plant with added nitrogen than without nitrogen addition but the increase in Jet Neuf was much higher than in Nevin.

Table 6.1 Variance ratios and significance of differences from analyses of variance for top dry weight per plant for B. napus cv. Jet Neuf and Nevin, at two N fertilizer levels with 7.5cm and 15cm between rows.

Item	df	Harvest H_1 (25.3.80)	H_2 (14.4.80)	H_3 (6.5.80)	H_4 (27.5.80)	H_5 (17.6.80)	H_6 ((at maturity, 30.7.80)
Blocks	1	4.31	27.17**	10.23*	0.26	7.28*	0.04
Fertilizer(F)	1	1.25	116.66***	84.55***	6.15*	115.30***	8.35*
Density(D)	1	1.25	32.64***	0.22	3.12	12.82**	0.16
F x D	1	0.05	11.61*	8.70*	1.88	15.04**	0.01
Variety (V)	1	8.65*	9.20*	23.85**	5.97*	8.88*	0.05
F x V	1	1.03	5.28	4.72	1.89	14.34**	1.16
D x V	1	0.14	1.67	9.61*	0.74	4.51	0.15
F x D x V	1	6.27*	1.93	0.21	0.85	0.50	0.70
Error	7						

that world production of rapeseed experienced a period of steady growth from 4,775,000 tonnes in 1961-65 to 9,636,000 tonnes in 1975, followed by a slight drop in production for the next two seasons, it reached the peak level to 10,574 thousand tonnes in 1980.

India occupied the first position in regard to the acreage and production of rapeseed (FAO, Production Year book 1980). The other major rapeseed producing countries are China, Canada, Poland, West Germany, USSR and Pakistan. Most of this production is consumed locally and only a small fraction of the total production goes to world trade.

In the United Kingdom oilseed rape cultivation has a long history, although it was until the early 1950's only a crop of minor importance (Fussell 1955). The growing of rape for seed was revived in the early 1950's, but only 2,000 to 3,000 hectares of the crop were grown. Indeed until 1968 oilseed rape was such a minor crop that it was not recorded in the Annual Review of Agriculture (MAFF 1972). Between 1968 and 1971 approximately 5,000 hectares were grown annually, largely as a break crop, in the main barley producing areas. In 1974 production reached 56,000 tonnes. Since then the area under oilseed rape has risen dramatically to 94,000 hectares in 1980 producing 270,000 tonnes. For the last few years the area under oilseed rape has been increasing by over 20% annually and the United Kingdom is now the third largest producer in the EEC after West Germany and France (Johnson 1981).

Price support for the crop under the EEC Agriculture policy has given an impetus, and it has thus become an attractive cash crop. A further advantage is that cereal growers can produce it with little extra capital expenditure. The introduction of high yielding varieties

Table 6.2 Means for top dry weight per plant (g) for B. napus cv. Jet Neuf and Nevin at two N fertilizer levels with two row spacings, where significant differences for the factors and their interactions were found in analysis of data (Table 6.1).

Factors

Harvest	Variety		N Fertilizer		row spacing	
	J. Neuf	Nevin	0 $Kgha^{-1}$	55 $Kgha^{-1}$	7.5cm	15cm
H_1	0.25a	0.19b	NS		NS	
H_2	0.58a	0.47b	0.34b	0.71a	0.43b	0.62a
H_3	1.52a	1.05b	0.84b	1.72a	NS	
H_4	2.68a	1.62b	1.61b	2.69a	NS	
H_5	3.32a	2.72b	1.94b	4.11a	2.66b	3.38a
H_6	NS		2.30b	4.42a	NS	

Interactions

H_1 variety x density x fertilizer

without N fertilizer

		Jet Neuf	Nevin	LSD p = 0.05
row spacing	(7.5cm	0.20	0.20	
	(15.cm	0.26	0.17	0.07

with N fertilizer

		Jet Neuf	Nevin	
row spacing	(7.5cm	0.29	0.14	
	(15 cm	0.26	0.24	

H_2 density x fertilizer

	row spacing		LSD
	7.5cm	15cm	p = 0.05
(without N fertilizer	0.30	0.38	0.12
(with N fertilizer	0.55	0.87	

Contd...

Table 6.2 contd.

Interactions

Harvest

H_3 variety x density

		Varieties		LSD
		Jet Neuf	Nevin	p = 0.05
row spacing	(7.5cm	1.35	1.18	0.33
	(15 cm	1.69	0.93	

H_3 fertilizer x density

		row spacing		LSD
		7.5cm	15 cm	P = 0.05
N fertilizer	(without	0.68	1.01	
	(with	1.84	1.60	0.33

H_5 variety x fertilizer

		Varieties		LSD
		Jet Neuf	Nevin	p = 0.05
N fertilizer	(without	1.85	2.02	
	(with	4.79	3.42	0.70

H_5 fertilizer x density

		row spacing		LSD
		7.5cm	15 cm	p = 0.05
N fertilizer	(without	1.97	1.91	0.70
	(with	3.35	4.86	

At H_5, dry weight per plant at both row spacings was higher with nitrogen addition than when no N fertilizer was added but in rows 15cm apart the increase was much greater than in rows 7.5cm apart.

Leaf dry weight per plant

Varieties differed significantly for leaf dry weight per plant ($p < 0.05$) only at H_1 (25.3.80, Table 6.3), when Jet Neuf produced significantly more leaf dry weight per plant than Nevin (Table 6.4). This difference did not persist however, and there were no significant differences in leaf weight at subsequent harvests. Differences in leaf weight per plant due to nitrogen application were significant at H_2 ($p<0.001$) and H_3 ($p<0.01$) only. Plants in rows 15cm apart had a greater leaf weight per plant than plants in rows 7.5cm apart at H_2 only ($p<0.01$).

At H_1, in the no N fertilizer treatments, Jet Neuf produced a greater leaf weight per plant in 15cm than 7.5cm row spacing. In contrast Nevin produced more leaf weight per plant in 7.5cm than 15cm row spacing. This behaviour of varieties was reversed with N fertilizer treatments. At H_2, in both fertility levels plants in rows 15cm apart had a greater leaf weight than in rows 7.5cm apart, but this increase was greater in 15cm than 7.5cm row spacing. At H_3, plants in rows 15cm apart had more leaf weight in no N fertilizer treatments than in rows 7.5cm apart. In contrast the order for row spacing was reversed in with N fertilizer treatment.

The trend in leaf production was similar for both varieties (Fig. 6.1) and in all treatments, being significantly greater at

Table 6.3 Variance ratios and significance of differences from analyses of variance for leaf dry weight per plant for B. napus cv. Jet Neuf and Nevin, at two nitrogen fertilizer levels with 7.5cm and 15cm between rows

Item	df	Harvests					
		H_1	H_2	H_3	H_4	H_5	H_6
		(25.3.80)	(14.4.80)	(6.5.80)	(27.5.80)	(17.6.80)	(30.7.80)
Blocks	1	4.62	14.17**	1.70	0.15	0.88	
Fertilizer(F)	1	1.35	94.65***	27.51**	1.25	2.64	
Density(D)	1	1.62	29.05***	0.02	0.77	0.20	
F x D	1	0.05	13.20**	8.35*	0.30	0.07	
Variety	1	7.73*	2.51	0.04	1.73	0.79	
F x V	1	1.05	1.81	0.71	0.74	2.68	
D x V	1	0.23	0.30	0.67	0.07	0.03	
F x D x V	1	5.75*	4.05	0.05	0.07	0.41	
Error	7						

Table 6.4 Means for leaf dry weight per plant (g) for B. napus cv. Jet Neuf and Nevin at two N fertilizer levels with two row spacings, where significant differences for the factors and their interactions were found in analysis of data (Table 6.3).

Factors

Harvest	Variety		N fertilizer		row spacings	
	Jet Neuf	Nevin	0 Kgha^{-1}	55 Kgha^{-1}	7.5cm	15cm
H_1	0.23a	0.17b	NS		NS	
H_2	NS		0.21b	0.46a	0.27b	0.41a
H_3	NS		0.21b	0.38a	NS	

Interactions

H_1 Variety x density x fertilizer

without N fertilizer

		varieties		LSD p = 0.05
		Jet Neuf	Nevin	
row spacing	(7.5cm	0.17	0.17	
	(15 cm	0.23	0.16	0.07

with N fertilizer

row spacing	(7.5cm	0.26	0.12	
	(15 cm	0.23	0.21	

H_2 Density x fertilizer

		row spacings		LSD p = 0.05
		7.5cm	15 cm	
N fertilizer	(without	0.18	0.23	0.09
	(with	0.34	0.58	

H_3 Density x fertilizer

		row spacings		LSD p = 0.05
		7.5cm	15 cm	
N fertilizer	(without	0.16	0.26	0.07
	(with	0.42	0.33	

the higher fertilizer level. Leaf weights reached a maximum just before anthesis and declined afterwards so that there were no leaves at maturity.

Stem weight per plant

Jet Neuf had significantly greater stem weight per plant than Nevin at H_1 ($p<0.05$), H_2 and H_3 ($p<0.01$, Table 6.6). Nitrogen application had a significant effect ($p<0.001$ [H_2, H_3, H_5] and $p<0.05$ [H_4, H_6]) on stem weight production from H_2 till maturity. Plants from plots with 15cm row spacing had significantly greater ($p<0.01$) stem weight per plant than with 7.5cm row spacing only at H_2.

At H_1 in no N fertilizer treatments Jet Neuf produced more stem weight per plant in 15cm than 7.5cm row spacing. In contrast Nevin produced more stem weight in 7.5cm than 15cm row spacing. In contrast with N addition the behaviour of Jet Neuf and Nevin for stem weight production was reversed in row spacings. At H_2 both Jet Neuf and Nevin produced a greater stem weight per plant in rows 15cm apart than in rows 7.5cm apart. The increase in Jet Neuf was higher than in Nevin. At H_2 both Jet Neuf and Nevin produced more stem weight per plant in with N fertilizer treatments than in the no fertilizer treatments, but the increase in Jet Neuf was higher than in Nevin. At H_2, plants in both fertilizer treatments had more stem weight per plant in rows 15cm apart than in rows 7.5cm apart but the increase was higher with added N fertilizer than in the no N treatment. At H_3 , Jet Neuf had a greater stem weight per plant in 15cm than 7.5cm row spacing. In contrast Nevin had a greater stem weight in 7.5cm than 15cm row spacing. At H_3, plants in plots with no N fertilizer treatment

Table 6.5. Variance Ratios and significance of differences from analyses of variance for stem dry weight per plant for B. napus cv. Jet Neuf and Nevin, at two N fertilizer levels with 7.5cm and 15cm between rows.

Item	df	Harvests H_1	H_2	H_3	H_4	H_5	H_6
Blocks	1	0.40	34.44***	13.79**	0.76	2.39	0.02
N Fertilizer(F)	1	0.09	101.87***	104.70***	5.86*	64.95***	11.86*
Density(D)	1	0.53	12.55**	0.00	2.30	4.91	0.01
F x D	1	0.02	5.78*	8.11*	1.02	8.00*	0.02
Variety (V)	1	11.40*	21.58**	21.22**	0.03	0.58	0.000
F x V	1	0.29	7.79*	4.12	0.69	1.27	1.51
D x V	1	0.49	7.75*	13.00**	0.30	0.95	0.05
F x DxV	1	6.67*	0.08	1.13	0.36	1.91	0.29
Error	7						

Table 6.6. Mean for stem dry weight per plant (g) for B. napus cv. Jet Neuf and Nevin at two N fertilizer levels with two row spacings, where significant differances for the factors and their interactions were found in analysis of data (Table 6.5).

Factors

Harvest	Variety		N fertilizer		row spacing	
	Jet Neuf	Nevin	0.Kg ha^{-1}	55 Kg ha^{-1}	7.5cm	15cm
H_1	0.03a	0.02b	NS		NS	
H_2	0.20a	0.14b	0.11b	0.23a	0.15b	0.19a
H_3	0.99a	0.71b	0.54b	1.17a	NS	
H_4	NS		0.72b	1.23a	NS	
H_5	NS		0.78b	1.71a	NS	
H_6	NS		0.76b	1.63a	NS	

Interactions

H_1 variety x density x fertilizer

without fertilizer

	Varieties		LSD
	Jet Neuf	Nevin	p = 0.05
row spacing (7.5cm	0.025	0.026	
(15 cm	0.030	0.017	0.007

with fertilizer

row spacing (7.5cm	0.032	0.019	
(15 cm	0.027	0.022	

H_2 varietyxdensity

	Varieties		LSD
	Jet Neuf	Nevin	p = 0.05
row spacing (7.5cm	0.16	0.14	
(15 cm	0.24	0.15	0.04

H_2 variety x fertilizer

	Varieties		
	Jet Neuf	Nevin	p = 0.05
N fertilizer (without	0.12	0.10	
(with	0.28	0.19	0.04

Contd..

Table 6.5 contd.

H_2 fertilizer x density

	N fertlizer		LSD
	without	with	p = 0.05
row spacing (7.5cm	0.10	0.19	0.04
(15 cm	0.12	0.27	

H_3 variety x density

	Varieties		LSD
	Jet Neuf	Nevin	p = 0.05
row spacing (7.5cm	0.89	0.82	
(15cm	1.10	0.60	0.22

H_3 fertilizer x density

	N fertilizer		LSD
	Without	with	p = 0.05
row spacing (7.5cm	0.45	1.26	
(15 cm	0.62	1.08	0.21

H_5 fertilizer x density

	N fertilizer		LSD
	Without	with	p = 0.05
row spacing (7.5cm	0.82	1.42	
(15 cm	0.75	2.00	0.40

had more stem weight in 15cm than 7.5cm row spacing. In contrast where N fertilizer was added there was a greater stem weight in 7.5cm than 15cm row spacing. At H_5, stem weight of the plants in no N fertilizer treatment was more in 7.5cm than 15cm row spacing. In contrast the plants in with N fertilizer treatment had greater stem weight in 15cm than in 7.5cm row spacing.

Dry weight of inflorescence branches per plant

Jet Neuf produced a significantly greater dry weight of inflorescence branches per plant than Nevin at H_3 ($p<0.001$), H_4 ($p<0.01$) and H_5 ($p<0.05$, Table 6.7). Nitrogen fertilizer produced a significant increase in dry weight of inflorescence branches at H_3 ($p<0.01$), H_5 ($p<0.001$) and at H_6 (maturity, $p<0.05$). Plants in 15cm row spacing had significantly greater ($p<0.01$) inflorescence branch weight than 7.5cm row spacing only at H_5.

At H_3, both Jet Neuf and Nevin had more dry weight allocated to inflorescence branches per plant in with N fertilizer treatment than in no N fertilizer treatment but Jet Neuf had a greater response to N than Nevin. At H_3, Jet Neuf had a greater inflorescence branch weight in 15cm than 7.5cm row spacing. In contrast Nevin had a greater inflorescence branch weight in the 7.5cm than the 15cm row spacing. At H_5, both Jet Neuf and Nevin produced a greater inflorescence branch weight with added N fertilizer than in the no N fertilizer treatment, Jet Neuf showing a greater increase than in Nevin. At H_5 both Jet Neuf and Nevin had more inflorescence branch weight in rows 15cm apart than in rows 7.5cm apart, but the increase in Jet Neuf was greater than in Nevin. At H_5, plants in with N fertilizer treatment, both row spacings had more dry weight

of Brassica napus with low erucic acid has made the extracted oil more useful for human consumption and this has increased product demand.

1.5 Cultivation

The rapeseed crop is widely adapted and is cultivated in temperate and warm temperate to subtropical climates. It is grown from New Zealand in the South to Finland in the North and from Canada in the West to Japan in the East.

Both annual and biennial forms of B. napus and B. campestris are grown. The annual form of B. campestris predominates in Canada and is widely grown in India and Pakistan. The biennial form of B. campestris is important in Sweden and Finland where it is found to be more winter hardy than winter B. napus (McNaughton 1976a). Winter oilseed rape (B. napus subsp. oleiferavar. biennis) is almost exclusively produced in Europe (E and W) and in some countries of South America e.g. Chile (Appelqvist & Ohlson 1972). Summer oilseed rape (B. napus sub.sp. oleifera var. annua) is grown on some areas of Western Europe and Canada.

Seeds of winter rape are sown in autumn and harvested the following summer, whereas those of spring rape are sown in spring and harvested the same summer. In Britain winter rape is best drilled in August, at the latest by early September while mid March to mid April is ideal for spring sowing. In the U.K. winter oilseed rape has over recent years largely replaced the spring crop. In the late sixties and early seventies 75-85% of the oilseed rape acreage was sown to varieties of spring rape (Bunting 1969), whereas in 1978/79 spring rape occupied less than 10% of the U.K. rapeseed area (Thompson and Capitain 1979). The average yield of winter oilseed rape is highest

Table 6.7. Variance Ratios and significance of differences from analyses of variance for inflorescence weight per plant for B. napus cv. Jet Neuf and Nevin, at two N fertilizer levels with 7.5cm and 15cm between rows.

Item	df	Harvests					
		H_1 25.3.80	H_2 14.5.30	H_3 6.5.80	H_4 27.5.80	H_5 17.6.80	H_6 30.7.80
Blocks	1		2.06	3.66	0.01	11.85**	0.45
Fertilizer(F)	1		0.03	26.43**	5.25	136.15***	8.56*
Density (D)	1		3.24	4.13	3.47	22.34**	0.31
F x D	1		0.51	1.41	2.30	21.59**	0.01
Variety (V)	1		0.92	139.66***	17.50**	7.81*	0.27
F x V	1		1.82	12.18**	2.67	13.65**	1.87
D x V	1		0.15	5.66*	1.16	7.73*	0.21
F x D x V	1		0.98	1.51	1.20	0.61	0.89
Error	7						

Table 6.8. Means for inflorescence weight per plant (g) for B. napus cv. Jet Neuf and Nevin at two N fertilizer levels with two row spacings, where significant differences for the factors and their interactions were found in analysis of data (Table 6.7).

Factors

Harvest	Variety		N fertilizer		row spacing	
	Jet Neuf	Nevin	0 Kg ha^{-1}	55 Kg ha^{-1}	7.5cm	15cm
H_3	0.18a	0.04b	0.08b	0.14a	NS	
H_4	0.88a	0.33b	NS		NS	
H_5	0.29a	0.24b	0.17b	0.37a	0.23b	0.31a
H_6			0.14b	0.31a		

Interactions

H_3 Variety x fertilizer

	Varieties		LSD
	Jet Neuf	Nevin	p = 0.05
N fertilizer(without	0.13	0.03	
(with	0.23	0.05	0.04

H_3 Variety x density

	Varieties		LSD
	Jet Neuf	Nevin	p = 0.05
row spacing(7.5cm	0.16	0.05	0.04
(15 cm	0.21	0.04	

H_5 Variety x fertilizer

	Varieties		LSD
	Jet Neuf	Nevin	p = 0.05
N fertilizer(without	0.16	0.17	0.06
(with	0.43	0.31	

H_5 Variety x density

	Varieties		LSD
	Jet Neuf	Nevin	p = 0.05
row spacing(7.5cm	0.23	0.23	
(15 cm	0.36	0.26	0.06

H_5 Fertilizer x density

	row spacing		LSD
	7.5cm	15 cm	p = 0.05
N fertilizer(without	0.17	0.17	0.06
(with	0.29	0.45	

of inflorescence branches than in with no N fertilizer treatment but the increase in plants in 15cm row spacing was greater than in 7.5cm row spacing.

Flower weight per plant

The time at which 50% anthesis occured in all the treatments is shown in Fig. 6.1. Flowering occured across all treatments at the end of April in Jet Neuf, 10 days earlier than in Nevin, which began flowering in early May. Jet Neuf, as a consequence produced a significantly greater dry weight of flowers ($p<0.001$) than Nevin at H_3 (Table 6.9). Nevin completed flowering later than Jet Neuf, so that at H_4 Nevin produced a significantly greater flower weight per plant ($p<0.001$) than Jet Neuf. Nitrogen fertilizer caused the production of a greater flower weight per plant in both varieties at H_3. Plants in 15cm row spacing produced significantly more flower weight per plant ($p<0.05$) than in 7.5cm row spacing at H_3.

At H_3 varietyxrow spacing interaction was significant ($p<0.05$). Jet Neuf in both row spacings produced greater weight of flowers than Nevin. Nevin was just starting to flower and flowering started in 15cm rowspacing but not in 7.5cm row spacing.

Pod dry weight per plant

The earlier flowering of Jet Neuf allowed the production of a significantly greater pod weight per plant ($p<0.001$) than in Nevin at H_4 and H_5 but at maturity there was no significant difference in pod dry weight per plant between Jet Neuf and Nevin. Significant nitrogen effects for pod dry weight per plant ($p<0.05$ [H_4, H_6] and $p<0.01$ [H_5]) were present throughout the pod growing period. Plants at a spacing of 15cm had a significantly greater

Table 6.9. Variance ratios and significance of differences from analyses of variance for flower weight per plant and pod weight per plant for B. napus cv. Jet Neuf and Nevin, at two N fertilizer levels with 7.5cm and 15cm between rows.

Item	df	Flower weight Harvest		Pod weight Harvest		
		H_3 (16.5.80)	H_4 (27.5.80)	H_4 (27.5.80)	H_5 17.6.80)	H_6 (30.7.80)
Blocks	1	3.20	1.34	0.02	8.65*	0.02
Fertilizer(F)	1	5.90*	0.41	6.40*	84.66***	6.23*
Density(D)	1	10.52*	0.14	3.68	12.84**	0.31
F x D	1	0.13	0.04	3.41	11.48*	0.01
Variety (V)	1	66.72***	31.85***	33.92***	32.49***	0.12
F x V	1	4.90	0.45	4.14	24.42**	0.86
D x V	1	9.16*	0.11	1.82	6.11*	0.21
F x D x V	1	0.02	0.00	1.80	0.13	0.95
Error	7					

Table 6.10. Means for flower weight (g) and pod weight per plant(g) for B. napus cv. Jet Neuf and Nevin at two N fertilizer levels with two row spacings, where significant differences for the factors and their interactions were found in analysis of data (Table 6.9).

Factors

Harvest	variety		N fertilizer		row spacing	
	J. Neuf	Nevin	0 Kg ha^{-1}	55 Kg ha^{-1}	7.5cm	15cm
Flower weight per plant						
H_3	0.051a	0.001b	0.02b	0.03a	0.02b	0.04a
H_4	0.001b	0.037a	NS		NS	
Pod weight per plant						
H_4	0.73a	0.19b	0.34b	0.58a	NS	
H_5	1.79a	1.16b	0.97b	1.98a	1.28b	1.67a
H_6	NS		1.39b	2.48a	NS	

Interactions

Flower weight per plant

		Varieties		LSD
		Jet Neuf	Nevin	p = 0.05
H_3 Variety x density				
	row spacing (7.5cm	0.032	0.000	0.022
	(15cm	0.071	0.001	

Pod weight per plant

		Varieties		LSD
		Jet Neuf	Nevin	p = 0.05
H_5 Variety x fertilizer				
	N fertilizer(without	1.01	0.93	0.38
	(with	2.57	1.40	
H_5 Variety x density				
		Varieties		LSD
		Jet Neuf	Nevin	p = 0.05
	row spacing (7.5cm	1.46	1.10	0.38
	(15cm	2.12	1.22	
H_5 Density x fertilizer				
		row spacing		LSD
		7.5cm	15cm	p = 0.05
	N fertilizer (without	0.96	0.98	0.38
	(with	1.60	2.37	

pod dry weight per plant ($p<0.01$) than plants in rows 7.5cm apart only at H_5.

Both Jet Neuf and Nevin produced more pod weight per plant at H_5 with added nitrogen than with no N fertilizer addition, but the increase in Jet Neuf was greater than in Nevin. At H_5 again both varieties produced more pod weight per plant in 15cm than 7.5cm row spacing but the increase in Jet Neuf was greater than in Nevin. At H_5 again plants with added nitrogen had a greater pod weight per plant than with no N fertilizer addition but the increase in rows 15cm apart was greater than in rows 7.5cm apart.

Mean relative growth rate and mean net assimilation rate

There were no significant differences between Jet Neuf and Nevin for mean relative growth rate throughout the experiment (Table 6.11). Jet Neuf had a significantly greater net assimilation rate ($p<0.01$) than Nevin (Table 6.12) during the interval between H_2 and H_3 ($H_{\overline{23}}$). Nitrogen fertilizer showed significant effects on both relative growth rate and net assimilation rate during $H_{\overline{12}}$. Relative growth rate during $H_{\overline{23}}$ for rows 15cm apart was significantly higher ($p<0.05$) than in rows 7.5cm apart .

The interaction term fertilizer x row spacing at $H_{\overline{23}}$ was significant for both relative growth rate ($p<0.001$) and net assimilation rate ($p<0.01$). Plants in rows 7.5cm apart had higher $\overline{RGR}$ and $\overline{NAR}$ in the with N fertilizer treatment (Table 6.12). In contrast plants in rows 15cm apart had higher $\overline{RGR}$ and $\overline{NAR}$ in no N fertilizer treatment.

Mean leaf area index

There was no significant difference between Jet Neuf and Nevin in mean leaf area index during the experiment (Table 6.13, 6.14).

Table 6.11. Variance ratios and significance of differences from analyses of variance for relative growth rate (RGR) and net assimilation rate (NAR) for B. napus cv. Jet Neuf and Nevin, at two fertilizer levels with 7.5cm and 15cm between rows.

Item	df	Harvests				
		H_1 25.3.80	H_2 14.4.80	H_3 6.5.80	H_4 27.5.80	H_5 17.6.80	H_6 30.7.80
Relative growth rate						
Blocks	1	4.00	3.65	0.03	0.01	1.03
Fertilizer(F)	1	32.65***	0.19	2.22	2.33	0.52
Density(D)	1	2.76	9.46*	1.41	0.37	0.00
F x D	1	0.39	20.63**	4.94	0.02	1.23
Variety(V)	1	1.26	4.43	0.38	3.01	0.70
F x V	1	0.01	0.19	0.07	0.28	0.00
D x V	1	1.85	2.05	0.88	0.21	0.65
F x D x V	1	0.62	2.83	0.53	1.72	0.02
Error	7					
Net assimilation rate						
Blocks	1	5.81*	1.55	0.43	2.44	
Fertilizer(F)	1	16.23**	2.97	1.29	2.36	
Density(D)	1	4.63	1.80	0.72	0.11	
F x D	1	0.63	10.23*	4.46	0.14	
Variety(V)	1	0.58	14.16**	4.71	0.73	
F x V	1	0.04	1.73	0.09	0.33	
D x V	1	1.17	2.21	0.35	0.38	
F x D x V	1	0.25	1.49	1.29	0.51	
Error	7					

Table 6.12. Means for relative growth rate (mg $mg^{-1}day^{-1}$) and net assimilative rate (mg $cm^{-2}day^{-1}$) for B. napus cv. Jet Neuf and Nevin at two N fertilizer levels with two row spacings, where significant differences for the factors and their interactions were found in analysis of data (Table 6.11).

Factors	Varieties		N fertilizers		row spacings	
Harvest	J. Neuf	Nevin	0 Kg ha^{-1}	55 Kg ha^{-1}	7.5cm	15cm
Relative Growth Rate						
H_1	NS		0.021b	0.054a	NS	
H_2	NS		NS		0.05a	0.037b
H_3						
Net Assimilation Rate						
H_1	NS		0.172b	0.368a	NS	
H_2	0.712a	0.450b	NS		NS	
H_3						

Interactions

RGR

$H_{2,3}$ density x fertilizer

	row spacing 7.5cm	row spacing 15cm	LSD p = 0.01
N fertilizer (without	0.041	0.047	
(with	0.059	0.027	0.021

NAR

$H_{2,3}$ density x fertilizer

	row spacing 7.5cm	row spacing 15cm	LSD p = 0.05
N fertilizer (without	0.57	0.70	
(with	0.67	0.36	0.240

Nitrogen fertilizer treatments had significantly greater LAI at H_2 ($p<0.001$) and H_3 ($p<0.01$, Table 6.14). Rows 15cm apart had significantly less leaf area index than rows 7.5cm apart at H_1 ($p<0.001$), H_2 and H_3 ($p<0.01$).

At H_3 density x fertilizer interaction was significant ($p<0.05$) when plants at both 15cm and 7.5cm row spacing had greater LAI in the with N fertilizer treatments than in the no N fertilizer treatments. The increase in 7.5cm row spacing was higher than 15cm row spacing.

Leaf area ratio

The Analysis of variance LAR data is given in Table 6.15 and the mean for significant items in Table 6.14. Nevin had significantly greater leaf area ratio ($p<0.01$) than Jet Neuf at both H_3 and H_4. Nitrogen application (N fertilizer) increased LAR significantly ($p<0.05$) over no N fertilizer at H_2 only. No significant effects due to row spacing were found in LAR except at H_1 when LAR was significantly greater ($p<0.05$) in 7.5cm than 15cm row spacing.

Seed yield and yield components

The analyses of variance for seed yield data and its components taken at maturity are given in Table 6.16 and their means are given in Table 6.17.

There were no significant differences between Jet Neuf and Nevin for any of the variables except 1000-seed weight and harvest index. Jet Neuf had a significantly greater 1000-seed weight ($p<0.001$) and harvest index ($p<0.01$) than Nevin.

Increasing nitrogen level had a significant effect in increasing pod number per plant, harvest index and seed weight per plant ($p\leq0.05$). No significant effects were found due to

Table 6.13. Variance ratios and significance of differences from analyses of variance for leaf area index (LAI) for B. napus cv. Jet Neuf and Nevin, at two N fertilizer levels with 7.5 and 15cm between rows.

Item	df	Harvests					
		H_1	H_2	H_3	H_4	H_5	H_6
Blocks	1	2.23	4.85	0.28	0.13	1.08	
Fertilizer (F)	1	1.26	50.68***	17.78**	2.50	1.17	
Density(D)	1	28.35*	23.28**	16.06**	4.39	1.55	
F x D	1	0.18	4.11	7.96*	0.05	0.05	
Variety(V)	1	2.53	1.52	1.03	2.31	0.18	
F x V	1	2.18	4.36	0.01	0.52	1.93	
D x V	1	0.17	0.14	0.75	0.01	0.14	
F x D x V	1	4.85	1.95	0.01	0.01	1.31	
Error	7						

followed by winter turnip, spring oilseed rape, and spring turnip rape (Appleqvist & Ohlson 1972).

Oilseed rape is grown on heavier soil types but is successful on moisture retentive soils with good drainage. It is sensitive to acidity, therefore soil pH should be at least 6.00 (Moore 1976). Traditionally the crop is sown in 35.5 cm rows but drilling 18.00 cm rows with a standard corn drill can also be done. Some farmers prefer corn drills with narrow rows i.e. 12.0 cm. A row width 35.5 cm is best for direct combining whereas close drilling 12.0 - 18.0 cm gives the best protection against predation by pigeons. A seed rate of 6.7 - 9.0 Kg ha^{-1} is normally used although for fine quality seed beds a lower seed rate can be used (Moore 1976). The crop is sown 1.2 cm (0.5 inch) deep.

Nitrogen fertiliser is applied to spring rape at the rate of 188 Kg ha^{-1} either solely as a seed bed dressing or in split applications, first into the seed bed and later as a top dressing during the post-emergence period. ADAS recommendations for winter oilseed rape are 225 Kg N ha^{-1} on sandy soils and 200 Kg of N ha^{-1} on medium and heavy soils where rape follows a cereal. All nitrogen should be applied at the start of spring growth, in the last week of February or early March (Long 1981). The current recommendation for phosphate fertilizer is 40 Kg ha^{-1}. Potash should be applied to maintain soil levels for which 40 Kg ha^{-1} of potash is recommended.

Experiments have shown that harvesting for optimum yield should be mid July for autumn sown and mid August for spring sown crops. The crop may be either swathed or windrowed, or combined direct. The former is necessary for uneven ripening crop and is normal treatment for winter rape in the U.K. The crop is cut when the bulk of the pods in the middle of the stalk are turning yellow and seed is

Table 6.14. Means for leaf area index (LAI) and leaf area ratio (cm^2/g) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with two row spacings, where significant differences for the factors and their interactions were found in analysis of data (Table 6.13, 6.15).

LAI						
Harvest	Varieties		N Fertilizers		row spacings	
	Jet Neuf	Nevin	0 $Kgha^{-1}$	55 Kg ha^{-1}	7.5cm	15cm
H_1	NS		NS		1.19a	0.66b
H_2	NS.		1.10b	2.91a	2.61a	1.39b
H_3	NS		1.17b	2.52a	4.49a	1.21b

Interaction

H_3 density x fertilizer

	row spacing 7.5cm	row spacing 15cm	LSD p = 0.05
N fertilizer (without	1.36	0.98	
(with	3.61	1.43	1.11

LAR

Factors

H_1	NS		NS		151.38a	144.82b
H_2	NS		114.20b	146.85a	NS	
H_3	39.80b	61.16a	NS		NS	
H_4	6.77b	16.18a	NS		NS	

Table 6.15. Variance ratios and significance of differences from analyses of variance for leaf area ratio (LAR) for *B. napus* cv. Jet Neuf and Nevin, at two N fertilizer levels with 7.5cm and 15cm between rows.

Item	df	Harvests					
		H_1	H_2	H_3	H_4	H_5	H_6
Blocks	1	3.68	1.45	0.05	0.23	1.02	
Fertilizer(F)	1	0.55	9.63*	0.07	0.04	0.51	
Density (D)	1	8.88*	3.15	0.57	1.45	0.91	
F x D	1	0.01	0.37	0.32	0.32	0.01	
Variety (V)	1	0.00	0.12	24.22**	29.16**	0.00	
F x V	1	0.52	0.12	1.63	1.48	2.70	
D x V	1	2.10	0.33	0.13	0.15	0.04	
F x D x V	1	0.03	0.02	0.10	0.01	1.19	
Error	7						

Table 6.16. Variance ratios and significance of differences from analyses of variance for seed yield and its components at maturity for B. napus cv. Jet Neuf and Nevin grown at two N fertilizer levels with two row spacings.

Item	df	Seed wt. per plant	Pod no. per plant	Seed no. per pod	1000-seed weight	Hull wt. per plant	Harvest index
Block	1	0.03	0.00	3.58	0.60	0.17	0.73
Fertilizer(F)	1	5.50*	11.38*	2.38	0.73	3.23	8.26*
Density(D)	1	0.23	1.03	0.54	0.33	0.33	0.45
F x D	1	0.04	0.00	0.82	0.01	0.03	0.00
Variety (V)	1	0.65	2.21	1.69	80.01***	1.23	21.15**
F x V	1	0.82	0.73	0.27	2.48	0.97	5.03
D x V	1	0.20	0.02	0.23	0.00	0.29	0.26
F x D x V	1	0.95	1.68	1.30	0.61	0.11	0.88
Error	7						

Table 6.17. Table of mean seed yield per plant and its components, at maturity for B. napus cv. Jet Neuf and Nevin grown at two fertilizer levels and two row spacings.

	Seed wt. per plant (g)	Pod no. per plant	Seed no. per pod	1000-seed weight (g)	Hull wt. per plant (mg)	Harvest index
Cultivar						
Jet Neuf	1.14	14.03	16.43	5.68a	58.4	0.34a
Nevin	0.94	16.88	15.69	4.11b	53.2	0.29b
LSD	NS	NS	NS	0.43	NS	0.03
Fertility levels						
No fertilizer	0.75b	12.22b	15.62	4.82	51.6	0.33a
with fertilizer	1.33a	18.68a	16.49	4.97	60.0	0.29b
LSD	0.60	4.67	NS	NS	NS	0.02
Row spacing						
7.5cm	0.98	14.48	16.26	4.85	54.4	0.31
15cm	1.10	16.43	15.85	4.95	57.1	0.32
LSD	NS	NS	NS	NS	NS	NS

increased row spacing or to any of the interaction terms.

Correlations between seed yield characters

Simple correlation coefficients between seed yield and other mature plant characters are given in Table 6.18. Seed yield per plant, pod weight per plant, and pod number per plant showed significant positive correlations ($p<0.001$) with mean dry weight per plant. Seed number per pod and 1000-seed weight were positively correlated with dry weight per plant, whilst harvest index was negatively correlated with dry weight per plant but not significantly so. Correlations of seed weight per plant with pod number and pod weight per plant were positive and significant ($p<0.001$). Whilst seed weight per plant and both seed number per pod and 1000-seed weight were positively correlated , and seed weight per plant and harvest index were negatively correlated, these relationships were not significant. No clear relationship was found between pod number per plant and seed number per pod or 1000-seed weight. None of the correlations of both seed number per pod and 1000-seed weight with any other character were significant except that between 1000-seed weight and harvest index, which was positive and significant ($p<0.01$).

Leaf area at anthesis has an important influence on dry and seed weight of the mature plant (Allen and Morgan 1975). Therefore correlations between leaf area index and leaf weight at H_3 (anthesis) were also calculated with other characters at maturity. As expected correlation between leaf area index and leaf weight at anthesis (H_3) was positive and significant ($p<0.001$). Both leaf area index and leaf weight at H_3 showed a significant and positive correlations with dry weight per plant ($p<0.05$ and $p<0.001$)& seed weight

Table 6.18. Correlation coefficient between yield and yield components in two varieties of winter B. napus.

	Seed wt. per plant	Pod wt. per plant	Pod no. per plant	Seed no. per pod	1000-seed weight	Harvest index	Leaf wt. at H_3	LAI at H_3
Dry wt. per plant	0.97***	0.99***	0.89***	0.31	0.30	-0.22	0.74***	0.56*
Seed wt. per plant		0.99***	0.82***	0.32	0.45	-0.01	0.68**	0.49*
Pod wt. per plant			0.88***	0.28	0.34	-0.12	0.55*	0.39
Pod no. per plant				0.08	-0.06	-0.42	0.69**	0.49*
Seed no. per pod					0.28	-0.01	0.35	0.31
1000-seed weight						0.66**	0.14	-0.03
Harvest index							-0.33	-0.37
Leaf wt. at H_3								0.76***

and pod number per plant ($p<0.05$ and $p<0.01$ respectively) at maturity.

6.4 Discussion

Leaf weights for both Jet Neuf and Nevin reached a maximum at the full flowering stage. Leaf weights and leaf areas declined thereafter. This behaviour of oilseed has been reported by Allen, Morgan and Ridgman (1971) and Major (1977) in spring oilseed rape and by Scott, Ogunremi, Ivins and Mendham (1973a) in winter oilseed rape. As leaf area was declining after anthesis, dry weight was increasing mainly due to an increase in pod weight. Similar results have been reported by Mendham and Scott (1975) in winter rape and by Allen , Morgan & Ridgman (1971) and Allen and Morgan (1972) in spring oilseed rape.

Although Jet Neuf and Nevin have been bred for contrasting plant characters, the former for seed and the latter for vegetative growth, there were no significant differences in seed yield per plant between the two cultivars. Seed yield per plant is determined by the number of pods per plant, the number of seeds per pod and seed weight. Since no differences were found between the varieties for either pod number per plant or seed number per pod, it is clear that seed yield per plant would be similar in the two varieties. Although Jet Neuf had a significantly greater 1000-seed weight than Nevin, the lack of any significant differences between the varieties in pod number per plant, which mainly determines plant yield (Olsson 1960, Clarke and Simpson 1978), or seed number per pod meant that there was no significant effect of 1000-seed weight on seed weight per plant. Although pod number per plant is a major component controlling seed yield per plant, as shown by

the highly significant positive correlation between seed yield and pod number, it is strongly influenced by environmental factors. This was shown by the data in this study where only pod number per plant and thus seed weight ($p = 0.05$), was affected by fertility out of all the recorded characters. It has also been shown in the data in previous chapters. In contrast, number of seeds per pod and 1000-seed weight have less influence on seed yield and it has also been suggested (Olsson 1960), that they are less influenced by environmental factors. Similar results to those observed here, were reported for spring oilseed rape by Allen and Morgan (1972) for turnip rape by Krogman and Hobbs (1975).

Final plant dry weight and seed yield are functions of the photosynthetic efficiency of the plant, and this influences growth rate. It is not surprising therefore in view of the lack of consistent significant differences between plant dry weight and seed yield at maturity that the growth parameters leading to the production of plant biomass did not differ significantly. There were essentially no differences in leaf area indices or relative growth rate between varieties during the experiment.

The fact that this experiment revealed no significant difference in seed yield between Jet Neuf and Nevin is at once disappointing and interesting. These two varieties are grown for quite different purposes. Jet Neuf, which appears on NIAB recommended lists, is grown for its high seed yield with its high oil content. It is thought that Jet Neuf was mainly responsible in boosting the oilseed rape yields in the U.K. (Johnson 1981). Nevin by contrast is a fodder variety grown for its dry matter

(vegetative) production rather than its seed production. Although dry weight per plant and its components tended to be greater in Jet Neuf during the experiment, there were no significant differences between varieties in these components or seed yield per plant at maturity. However, varietal interactions with density and fertilizer did show that Jet Neuf exploited the resources more efficiently than Nevin.

The lack of yield difference between these two contrasting varieties is difficult to explain. However, some factors may have influenced the performances of the varieties. The experiment was sown in the last week of September and the evidence of Mendham and Scott (1975), from their experiments with spring, winter, and intermediate varieties of oilseed rape shows that a substantial loss in seed yield occurs when oilseed rape is sown later than mid September. This may arise because all plants irrespective of their size initiate inflorescences during the winter, thus determining at an early stage the number of potential sites for leaf and primary branch development. This will limit the yield potential of late sown plants, which are still very small when the change from the vegetative to the reproductive phase occurs. The growth pattern in the experiment reported here is similar to that in their experiment of Mendham and Scott (1975) sown on September 28, 1972. The data suggest that late sowing did not allow Jet Neuf show its full potential for growth and seed yield. This view is supported by the correlation studies. High correlations (Table 6.18) between dry weight, seed weight and pod number suggest that plant size gives rise to more pods and

hence more seed yield and thus determines seed yield. These data agree with Thurling (1974b) and Clarke and Simpson (1978). Similarly higher leaf area and higher leaf weight at anthesis, which is very important for high seed yield (Allen and Morgan 1975), also showed high correlations with dry weight, seed weight and pod number at maturity, suggesting that more leaf area and leaf weight give rise to more pods which produce more dry weight and seed yield. Both varieties were affected from delayed sowing but Nevin appears to have suffered much less than Jet Neuf, and this may be a consequence of a greater phenotypic stability in Nevin than in Jet Neuf.

Another factor which may have been important in reducing seed yield in Jet Neuf was the dry weather from late March to Mid May 1980 (Appendix 1). This drought occurred at the time of maximum flowering and early pod formation. This period is a critical one in plant growth and is mainly responsible for final seed yield. Though no data on flower and pod shedding was taken, it may be that the dry weather affected fruit set adversely and led to the shedding of unfertilized flowers and newly formed pods.

Nitrogen fertilizer effects on dry weight and its components (leaf, stem and pod weight etc.) were quite clear, although insufficient to enable Jet Neuf to exploit its full yielding potential, during the experiment. Nitrogen also had a significant effect on seed yield and pod number per plant at maturity. Similar results showing that nitrogen application increases leaf area, dry weight, leaf, stem, pod and seed weights per plant have been reported by Allen and Morgan (1972, 1975) and Scarisbrick, Daniels, Chapman, and Parr (1981) in spring oilseed rape and by

chocolate brown, firm and pliable when rolled between the finger and thumb. Over-ripeness leads to pod shatter and consequent seed loss. Maturation in windrowed crops usually takes 7-10 days at which time the crop is combined, the seed having become hard and black. Direct combining is used for evenly ripened crops, usually spring rape on light soils. Usually winter oilseed rape yields from 2500 to 3000 Kg ha^{-1} and spring rape 1875 to 2000 Kg ha^{-1}, though good crops produce more. In Britain the winter oilseed rape variety, most commonly grown is Jet Neuf, other varieties are Primor, Elvira and Rapol. The summer oilseed rape varieties commonly grown are Brutor, Cresus, Maris Haplona and Gulle.

Objective and Scope of work in this thesis

As a result of increasing role of oilseed rape in European agriculture in particular, and in the world in general, efforts are being made to breed varieties with improved yield and with the desirable characteristics. In the oilseed rape crop intensive plant breeding activity is a relatively recent development. This reflects the dramatic increase in the crop's importance in recent years. It is therefore important to provide comprehensive background information about physiological and genetical aspects of the oilseed rape plant especially seed yield and its components, and varietal stability in differing environmental conditions.

The present work was therefore carried out with the objective of analysing the growth of the plant particularly dry matter partitioning, the genetic basis of yield components, correlations between yield and yield components, and the behaviour of different varieties in different density and fertility levels. Comparison of older and newly released varieties was undertaken in the expectation of maximising differences in yield and its components in the experiments carried out.

Scott, Ogunremi, Ivins and Mendham (1973b) in winter oilseed rape.

There were no significant differences for seed yield per plant and its components due to row spacing. It is known that there is an optimum seed rate for every crop depending upon optimum plant size. If the plant population per hectare is increased to that optimum there follows an increase in seed yield per hectare. At seed rates above that optimum, seed yield may again be affected. Similar behaviour in response to row spacing have been reported by several workers. Singh and Yadva (1972) found in spring B. campestris row spacing of 30cm, 45cm and 60cm had an effect on pod length, seeds per pod, 1000-seed weight, but the seed yield per hectare with 30cm row spacing was significantly better than a row spacing of 45cm. Rows 45cm and 60cm apart did not differ from each other. Kondra (1975) reported that narrow row spacing of 30cm in spring oilseed rape resulted in the highest yield in his experiment over two years and two locations compared with row spacing of 45cm or 60cm. Seeding rate, however, did not affect 1000-seed weight, as this tends to be a more phenotypically stable character (Bradshaw 1973), in general and has also been reported in oilseed rape (Degenhardt and Kondra 1981). The results of this experiment show that rows 7.5cm apart give a greater seed yield per hectare than rows 15cm apart, since there was no significant difference in seed yield per plant between the two row spacings.

CHAPTER 7

Growth of Spring Oilseed Rape in Response to Thinning During the Vegetative Growth Period.

7.1 Introduction

The expression of an individual genotype can be modified by different environments (Bradshaw, 1965). A common cause of environmental heterogeneity is variation in population density, which affects the availability of nutrients, water and light, for the growth of individual plants. Shortage of these resources caused by increased plant density can affect plant morphology (Khan and Bradshaw, 1976).

The effects of density on different plant characters in oilseed rape has been reported by several workers. Clarke and Simpson (1978) found that number of pods per plant and seed number per pod were reduced, whilst 1000-seed weight and seed yield per unit area increased with increased plant density. Increasing plant density in spring oilseed rape caused a decrease in seed yield per plant (Degenhardt and Kondra, 1981), whereas Kondra (1975), and Degenhardt and Kondra (*loc. cit.*) found that 1000-seed weight was stable in spring oilseed rape. The above studies were made on plants grown and kept at constant density. However, the distance separating neighbouring plants (i.e. plant density) and their presence or absence during the plant growth cycle can profoundly affect the growth and development of individual plants (Ross and Harper, 1972).

The stage at which competition is most intense is very important for optimising crop production. Hodgson and Blackman (1957) reported an experiment with *Vicia faba*, grown under close spacing in which they carried out thinning at different developmental stages. They found that the intensity of competition between plants even at

relatively close spacing did not become marked enough to affect ultimate seed production until plants were at an advanced stage of vegetative growth, and it did not reach a maximum until the post flowering phase. Different characters of the plant showed differences in their response to thinning and some characters were little affected by it.

Spring and winter oilseed rape exhibit considerable phenotypic variation as shown in previous chapters and the experiment reported here was set up to assess the degree of phenotypic plasticity shown by spring oilseed rape in response to the removal of stress, by thinning plants in stands of a single fixed density at regular intervals during the growth period. The stage at which competition has its maximum effect on yield and yield components should thus be revealed, and also whether the extra space made available due to thinning is utilized. Finally, any differences should be apparent between varieties in their ability to utilize the space provided by thinning, i.e. it should be clear whether varieties differ in the extent of the plasticity of their phenotypes.

7.2 Materials and Methods

The experiment was carried out in a heated and lit greenhouse at the Department of Botany, University of Liverpool. The greenhouse was heated and kept at 25.5°C. Natural day length was supplemented with artificial light to give 16 hours day length using 400 watt mercury vapour lamps. The experiment was sown on 9.12.80.

Two varieties of spring oilseed rape (*B. napus*) were used, Bronowski, released in Poland in 1955, and Orpal, released in France

in 1978. Twenty plants were grown in a 17.8cm plastic pot , from seed planted 3.5cm apart in a hexagonal pattern, each seedling being equidistant from its immediate neighbours. The plants were grown in John Innes potting soil. Two to three seeds were placed at each position and seedlings were thinned to one plant per position after germination. The experiment consisted of three replications, each replication being a randomised block containing 15 pots of each variety.

There were two sets of thinning treatments where the number of plants per pot was reduced from 20 to 10, and two controls in which the number of plants per pot remained at 20 and 10 throughout. In set 1, thinning took place at 2, 4, 6, 8 and 10 weeks from germination and the plants which remained after thinning were harvested and their dry weights measured after 12 weeks growth. In set 2, thinning took place 2, 4, 6, 8 and 10 weeks from germination as in set 1, but additional thinning was carried out 12, 14 and 16 weeks from germination. The plants remaining after thinning in set 2 were harvested at maturity on 8.5.81, 18 weeks from germination and their dry weights measured. Thinning was carried out by cutting plants at soil level in alternate rows leaving 10 plants per pot. All harvested plants were oven dried at 38°C for seven days and dry weights recorded. In addition to data for plant dry weight, set 2 plants were used to provide data for number of pods per plant, seed weight per plant, seed number per pod and 1000-seed weight. To avoid pod shattering the plants were harvested when the majority of pods were ripe. This meant that some of the pods were still green and it was noticed at seed collection that in some pods seeds were not fully developed.

However, since the number of unripe pods did not differ between varieties, they would have minimal effect on the data and its interpretation. Seed was separated by hand and a sample of up to 400 seeds taken from each plant to determine 1000-seed weight. For most of the plants all seeds were counted and number of seeds per pod and 1000-seed weight determined. For those plants which had more than 400 seeds, seed number per pod was determined from seed weight per plant, pod number per plant, and 1000-seed weight, obtained from the 400 seed sample. Harvest index was calculated by dividing seed weight per plant by dry weight per plant.

Analyses of variance were carried out on the data for all characters at both harvests. Simple correlation coefficients between the characters at maturity were also calculated.

7.3 Results

Data for the two varieties for mean dry weight per plant after 12 weeks growth, thinned to 50% density at 2, 4, 6, 8 and 10 weeks, are given in Table 7.1. The differences for dry weight per plant due to thinning are significant ($p < 0.05$). It can be seen that, as the time of thinning is delayed , there is a corresponding decrease in mean plant dry weight. Orpal accumulates significantly more dry matter per plant during the 12 weeks growth than Bronowski ($p < 0.05$).

Data for dry weight per plant, seed weight per plant, pod number per plant, seed number per pod, and 1000-seed weight at maturity, and harvest index, are given in Table 7.2 and analyses of variance for these characters are summarised in Table 7.3. These data show that differences due to thinning treatments for dry weight per plant, seed weight per plant, and pod number per plant are significant ($p < 0.05$), whereas seed number per pod, 1000-seed weight and

Table 7.1. Dry weight per plant for Bronowski and Orpal spring oilseed rape harvested 12 weeks after germination.

Variety	Weeks after germination 2	4	6	8	10	Mean
Bronowski	1.23	0.85	1.89	0.78	0.78	1.11b
Orpal	2.14	2.37	1.18	1.21	1.10	1.60a
Mean	1.69a	1.61a	1.54a	1.00b	0.94b	

LSD at p = 0.05 between

Variety (V) = 0.32

Treatment (T) = 0.51

V x T interaction = 0.71

Table 7.2. Total dry weight per plant and its components at maturity.

Weeks from germination	Dry weight per plant (g)			Seed weight per plant (g)			Pod number per plant			Seed number per pod			1000-seed weight (g)			Harvest index		
	Bronowski	Orpal	Mean	Bronowski	Orpal	Mean	Bronowski	Orpal	Mean	Bronowski	Orpal	Mean	Bronowski	Orpal	Mean	Bronowski	Orpal	Mean
(10 plants control)	3.20	4.12	3.66ab	0.77	1.21	0.99ab	19.00	24.33	21.67ab	14.13	11.89	13.01	2.81	4.02	3.41	0.24	0.29	0.26
2	3.15	5.48	4.31a	0.84	1.62	1.23a	19.00	30.00	24.50a	19.64	11.70	15.67	2.42	4.58	3.50	0.26	0.31	0.28
4	2.48	3.67	3.11abc	0.72	1.02	0.87abc	14.79	20.67	17.73abc	14.24	11.67	12.96	2.83	4.23	3.53	0.25	0.26	0.26
6	2.88	2.71	2.79bc	0.79	0.72	0.75bc	18.00	16.00	17.00abc	15.06	11.43	13.24	2.89	3.62	3.23	0.27	0.25	0.26
8	3.02	3.57	3.30abc	0.76	0.93	0.85abc	17.67	20.67	19.17abc	15.18	11.24	13.21	2.68	4.08	3.38	0.24	0.28	0.26
10	2.20	2.35	2.27c	0.40	0.65	0.53c	9.67	12.67	11.17c	14.39	12.50	13.44	3.22	3.92	3.57	0.20	0.28	0.24
12	3.02	2.45	2.73bc	0.76	0.69	0.72bc	20.33	15.67	18.00abc	12.68	11.23	11.95	2.82	3.90	3.36	0.25	0.28	0.27
14	1.72	2.81	2.27c	0.34	0.73	0.54bc	8.00	14.00	11.00c	14.67	12.76	13.76	3.18	4.03	3.60	0.20	0.27	0.23
16	1.67	2.41	2.04c	0.36	0.63	0.49c	10.00	12.67	11.33c	10.76	12.33	11.54	3.00	3.89	3.44	0.20	0.25	0.22
No thinning (20 plants control)	1.89	2.87	2.38bc	0.36	0.82	0.59bc	9.33	16.33	12.83c	12.08	11.67	11.87	3.22	3.86	3.54	0.19	0.27	0.23
Variety Mean	2.52b	3.25a		0.61b	0.90a		14.58b	18.30a		14.29a	11.84b		2.91b	4.01a		0.23b	0.27a	

LSD at p = 0.05 between

Variety (V) mean	0.62	0.20	3.55	1.33	0.25	0.03
Treatment (T) mean	1.38	0.45	7.94	NS	NS	NS
T x V mean	NS	NS	NS	NS	NS	NS

Table 7.3. Analyses of variance of the effects of thinning treatments on plant characters at maturity.

Item	d.f.	Plant character					
		Dry wt per plant	Seed wt per plant	Podno. per plant	Seed no. per pod	1000-seed wt.	Harvest index
Treatments(T)	9	2.54*	2.27*	2.95**	1.31	0.33	0.71
Varieties(V)	1	5.84*	8.69**	4.58*	14.22***	84.86***	8.36**
T x V	9	0.73	0.66	0.67	1.47	1.50	0.42
Error	37						

harvest index are not significantly affected by thinning. This suggests that, measured by their effect on mature plant characters, later thinnings cause significant reductions in dry weight per plant, seed weight per plant and pod number per plant ($p<0.05$). No significant effects of later thinnings were found, however, for seed number per pod, 1000-seed weight or harvest index, these features of plant growth remaining stable regardless of the time of thinning.

When compared with the 20 plants per pot control, early thinning allowed an increase in dry weight per plant, seed weight per plant, and pod number per plant. No similar increase as a consequence of early thinning was, however, found for seed number per pod ,1000-seed weight or harvest index.

Orpal again is superior to Bronowski at harvest 2 (Table 2) in dry weight per plant, seed weight per plant, pod number per plant, 1000-seed weight and harvest index. However, Bronowski had a significantly greater number of seeds per pod than Orpal.

No significant variety x treatment interaction was found at maturity, thinning affecting both varieties in the same way.

Correlations between yield components and their level of significance are given in Table 7.4. Significant positive correlations ($p<0.001$) were found between dry weight per plant, seed weight per plant and pod number per plant. Correlations of dry weight per plant with 1000-seed weight and harvest index were positive and significant ($p<0.01$ and $p<0.05$ respectively). Seed weight per plant was positively and significantly correlated ($p<0.001$) with pod number per plant, 1000-seed weight and harvest index. The correlations of pod number with 1000-seed weight ($p<0.05$) and harvest index ($p<0.001$) were positive and significant. Seed number per pod and

Table 7.4. Correlation coefficients between yield and yield components

	Seed wt. per plant	Pod no. per plant	Seed no. per pod	1000-seed wt.	Harvest index
Dry weight per plant	0.95***	0.94***	0.13	0.41**	0.32*
Seed weight per plant		0.95***	0.19	0.43***	0.59***
Pod number per plant			0.08	0.29*	0.50***
Seed number per pod				- 0.40**	0.28*
1000-seed weight					0.26*

CHAPTER 2

Partition of Dry Matter in Oilseed Rape

2.1 Introduction

Interest in oilseed rape in Britain has grown rapidly over the past two decades. From its place as a break crop in cereal producing areas till late sixties (Bunting 1969), oilseed rape has become a valuable cash crop in its own right (Johnson 1981). The importance of oilseed rape seems bound to grow further because the crop is regarded by the EEC as a means of reducing the community's dependence on imported oilseeds particularly soya. Subsidies to crushers from the EEC underpin market prices, and make oilseed rape attractive to grow. As a consequence the areas in which it is being grown are expanding westwards and northwards from the traditional cereal and rapeseed as a break crop growing areas.

Since biological yield and seed yield both depend on the growth of the oilseed rape plant during its developmental stages, (Thurling 1974a), an understanding of the interrelationships of morphological characteristics and plant growth and the way in which total dry matter is apportioned to different parts of the plant will be useful in defining growing strategies and plant breeding objectives. An initial series of experiments, both in greenhouse and field conditions, were therefore carried out to examine growth and dry matter accumulation, and seed yield and its components.

Since considerable studies have been made in improving yield in oilseed rape over the past twenty years, older and recently bred varieties were compared in order to try and assess, in terms of plant growth strategy, how yield differences have been brought about, since such information might reveal areas in which selection could bring about further improvements in yield.

1000-seed weight were negatively and significantly correlated ($p < 0.01$). Harvest index was positively correlated with seed number per pod and with 1000-seed weight ($p < 0.05$).

7.4 Discussion

The time at which plant number per pot was reduced by thinning from 20 to 10 had a significant effect upon dry weight produced after 12 weeks growth (Table 7.1). Thinning effects on mature plant dry weight, seed weight and pod number were also significant (Table 7.3). Earlier thinning gave greater responses, reflected in higher values for these characters compared with delayed thinning treatments and with the unthinned 20 plant per pot control (Table 7.2). Increase in these characters showed that plants successfully exploited the space made available to them by removal of the thinned plants, the enhanced growth of the remaining plants compensating for the removal of the thinned individuals. Plant density is known to affect dry weight and seed weight in oilseed rape (Clarke & Simpson, 1978; Degenhardt and Kondra, 1981). These workers' observations were made on plants sown and maintained at a single density, whereas in the present study plant density was changed during the course of the experiment. This will therefore reveal the dynamic nature of the response of the oilseed rape plant to density change. The data from this experiment clearly show that different plant characters respond to the thinning treatments imposed at different times (growth stages) and in different ways, confirming the data of Khan and Bradshaw (1976) in Linum.

The weight of seed produced by an oilseed rape plant is the product of three yield components; number of seed bearing pods,

number of seeds produced per pod and individual seed weight, usually expressed as 1000-seed weight. Pod number per plant is the main determinant of seed yield and exhibits a high degree of phenotypic plasticity, being considerably affected by environment (Olsson 1960; Thurling 1974b; Clarke and Simpson 1978). In contrast, seed number per pod and 1000-seed weight in B. napus are relatively less plastic (Olsson 1960, Thurling 1974b) and tend therefore to be characteristic of a particular variety.

The ability of the component parts of the oilseed rape plant to respond to the thinning treatments imposed, i.e. their phenotypic plasticity, can be related to the growth cycle of the plant. After the seedling stage dry matter accumulation takes place at a rapid rate. Flowering normally begins some 7 to 10 weeks from germination, and at this point leaf area index and crop growth rate reach maxima (Allen and Morgan 1975, Major 1977). After flowering, total plant dry weight continues to increase and crop growth is still high even though leaf area is declining rapidly. Inanaga, Kumura and Murata (1979) have shown from studies of photosynthesis and respiration in oilseed rape, that whilst leaves are the major photosynthetic organs until flowering, once flowering begins, photosynthesis by pods becomes increasingly important in contributing to the production of dry matter in both pods and seeds. Although pod photosynthesis makes a major contribution to pod and seed development, the role of leaves, in contributing to yield by way of flower bud formation (Thurling 1974b) cannot be overlooked. This is confirmed by the $^{14}CO_2$ assimilation experiments of Brar and Thies (1977) and of Major and Charnetski (1976) who have shown that photosynthates from

the upper leaves and the stem are received by pods. Leaves, thus, have an important function in determining, through flower bud formation, the number and sizes of pods (Tayo 1974; Clarke and Simpson 1978). Thurling (1974a) also observed that growth in B. napus prior to anthesis had a much greater influence on seed yield than post anthesis growth. Clarke (1978) found in oilseed rape that leaf removal at the start of flowering had a very pronounced effect on seed yield and yield components due to a reduction in the number of pods as a consequence of leaf removal at anthesis. He argued that this was due to a reduction in the supply of assimilates to pods at that time.

In summary then the growth of oilseed rape prior to anthesis is mainly the production of leaves, and this has a considerable influence on seed yield since it determines, by fixing the number of flower buds initiated, the number and, to some extent, sizes of pods on the plant. Once pods become macroscopic they synthesize, to a greater extent than leaves, their own assimilates and those for the seeds they contain. The results of the thinning treatments confirm this conclusion.

During the vegetative period density affects the number and sizes of leaves formed, reflected in reduced dry matter production per plant in the high density control, and these in turn determine the potential numbers and sizes of pods. Pod number per plant in the thinning treatments up to 8 weeks after germination, was not significantly different from pod number per plant in the 10 plant per pot control, but was significantly greater than for thinnings done after 10 weeks and the control 20 plants per pot. This suggests that pods are initiated early in the vegetative phase and thinning up to 8 weeks

allows the pods already initiated to mature in larger numbers. Density stress experienced in the post vegetative period brings about shedding of flowers and/or pods and a reduction in the size of those pods that have already been initiated and this may explain why the number of pods per plant in this experiment was significantly lower in the 20 plants per pot control than in the 10 plant per pot control. Plants which reached the post anthesis stage (after 10 wks) at a density of 20 plants per pot were unable to compensate for plant thinning by maturing pods in excess of the number produced by the 20 plant per pot control. Subsequent density stress may have caused abortion of flowers and/or pods, and once flowering finishes the number of pods per plant remains stable. According to Clarke and Simpson (1978) the number of seeds per pod is determined by the ability of the individual pod to supply assimilates when seed number is being determined, a feature which is governed by late vegetative growth (mainly leaves). The data presented here show that the number of seeds per pod does not vary with density, and hence the absence of effects due to the time of thinning are to be expected. Seed size within each variety reflected by 1000-seed weight, is similarly unaffected by density, or time of thinning. Constancy of seed weight is well documented for many crops and wild species (Bradshaw 1965) and has been related to the high fitness which attaches to this character. Varietal differences in seed weight have been found, Bronowski having significantly smaller seeds ($p < 0.001$) than Orpal, but having significantly more seeds per pod.

High correlations between dry weight, seed weight and pod number per plant suggest that early growth, i.e. dry matter accumulation leads to the production of a greater number of pods

which is the main factor controlling seed yield per plant. The absence of any significant correlation between pod number per plant and seed number per pod suggests that the number of pods per plant does not adversely affect the number of seeds per pod and that the pods themselves support the seeds within them. The negative correlation between seed number and 1000-seed weight is the product of a fixed assimilate pool being distributed to a number of seeds, during the development of which competition may develop so that compensation of one against the other takes place, resulting in a negative correlation between seed weight and number.

The lack of any variety x treatment interaction at maturity shows that both Bronowski and Orpal respond to thinning in the same way, both having the ability to utilise to a certain extent the extra resources made available to them by thinning during the growth period. The data show that seed number per pod, 1000-seed weight and harvest index are unaffected by changed environment, but they do differ between varieties. In contrast, plant dry weight, seed weight per plant, and pod number per plant are affected both by plant density, and by the thinning treatments imposed, and hence are highly plastic components of yield in B. napus.

CHAPTER 8

General Discussion and Conclusions

Maximising seed yield per hectare is the main aim of oilseed rape production. Seed yield depends upon the variety grown and the environment including agronomic practices used to grow the crop. Seed yield per plant is the result of plant growth during its developmental stages and it is therefore very helpful to understand the inter-relationships of morphological characters and plant growth. This points to an adoption of the ideotype (Donald 1968), a concept well known and used in cereal breeding. It defines a plant model by evaluating a number of attributes such as foliage, stout stem and presence of awns on the florets, which influence biological and economical yield. An ideotype is therefore a biological model which is expected to perform or behave in a predictable manner within a defined environment, such as at a particular crop density or nutrient level, and which will give maximum yield under those conditions. A knowledge of these characters such as dry matter production and the way it is allocated to different seed yield and its components, would clearly be very useful in planning growing strategies and plant breeding objectives in oilseed rape.

The experiments carried out here were planned to examine

1) yield and its components in oilseed rape to gain information on the basic physiology of yield;

2) the genetic basis of such variation with view to assessing potential for improvements, and

3) the stability of yield and yield components in spring and winter oilseed rape in response to density and fertility.

The experimental work carried out in Chapter 2 was designed to examine the crop growth behaviour in spring oilseed rape as a first step to start the investigation. A survey of growth and dry matter and its allocation to different plant parts suggested that the development of the crop growth could be considered in three main phases (1) Seedling and vegetative phase, is a period of vegetative growth, leaf areas reach the maximum.(2) Flowering and early pod formation, this phase is of short duration. Anthesis takes place in this period and pods are formed. Leaf area and relative growth rate, which are at a high rate previously, slow down. (3) Pod growth and ripening, in this phase rapid pod growth takes place, RGR again becomes high, dry weights continue to increase to near maturity. During this stage leaves senesce and die.

The crop showed a great deal of plasticity and it was a remarkable and consistent feature of the experimental work. No significant differences for seed yield per m^2 were found between varieties selected from a wide range of backgrounds (Chapter 2). This apparently arose due mainly to compensation between two yield components, pod number per plant and 1000-seed weight. These components changed in such a way that decrease in one was compensated for by increase in the other and was thus responsible for lack of seed yield differences. The same result was indicated by high negative correlations between pod number per plant and 1000-seed weight. As nutrient supply in the experiments was low, it was not clear whether the compensation was due to low nutrients or for assimilates needs fluctuating in an oscillatory manner.

Genetic variation and the mode of inheritance of seed yield and its components is of fundamental importance for selection and

breeding of desired genotypes. Diallel analysis tests in diallel 1 and 2 showed additive-dominance model to be inadequate for the presence of reciprocal differences and epistatic effects of the genes. Though the additive-dominance model was found adequate for pod weight, seed weight, and dry weight per plant data for Brutor and Cresus (diallel 3), no additive genetic variation was found and the characters were found to be under complete dominance, dominance being ambidirectional (Chapter 3).

The presence of reciprocal effects in diallel analyses are indicated if some individual variation remains in the parental plants used. This can arise where several individuals derived from selfing one of the parental lines are used in crosses. It was not clear whether these results shown were due to the parental lines not being highly homozygotes or to phenotypic plasticity in the characters examined.

In situations where epistasis is suspected, the most appropriate test to establish its presence is the triple test cross (TTC) or North Carolina Model III (NCM III) cross. However, this requires extremes of expression of characters in parental lines plus the F_1 hybrid between such extreme individuals. Clearly one individual is unlikely to show extreme expression of more than one character and hence in such a situation as here presented, the crossing method would have been extremely difficult to carry out.

Strong directional selection will tend to reduce free additive variation, since this will become fixed. In such circumstances the dominance component remains to be detected. It may be that more diverse and completely homozygous genotypes should be used in the diallel analysis under optimum fertility conditions.

Fertilizer input and row spacings are the two main factors controlled by the grower and of interest to plant research workers. The experiment was designed to investigate the response of six variaties of spring oilseed rape to three fertility levels and two row spacings in greenhouse (Chapter 4). Again no varietal differences were found for seed yield, dry weight and pod number per plant. However, for two yield components, seed number per pod and 1000-seed weight significant varietal differences were shown. These two components therefore undergo compensation and seem likely to have been responsible for the absence of significant seed yield differences between the varieties. Density and densityxsoil fertility level interactions for seed yield per plant were significant and Finlay-Wilkinson joint regression analysis was carried out. The data showed that Janetski, an old variety, was stable and adapted to low fertility environments, whilst Brutor, a newly bred variety was much less stable and adapted to high fertility conditions. This is similar to the findings of Finlay and Wilkinson in that they found Provost adapted to high fertility conditions, had a high regression coefficient and had very low yield stability. In contrast Bankuti Korai adapted to low fertility conditions had a low regression coefficient indicating high stability of yield across environments. Provost gave high yield in best environment whilst Bankuti Korai gave low yield in all environments but performed better than rest in poor environment .

The field experiment examined the performance of spring varieties, three fertilizer treatments and two row spacings (Chapter 5). The data showed that Orpal had a greater seed yield per plant than

Erglu and Bronowski due to its having a greater pod number per plant and higher seed weight. Seed yield and other plant characters were also affected by the environmental factors, fertilizer and density. This indicated that both density and fertilizer levels are important factors which may limit oilseed rape yields.

The experiment described in Chapter 6, was carried out in order to assessthe response of winter varieties to the soil fertility levels and two densities. It was surprising to again find no significant differences due to varieties between Jet Neuf and Nevin, particularly since Jet Neuf has been bred for high seed production. It is possible that late sowing and drought conditions at anthesis were responsible for lack of variation in seed yield.

After observing a great deal of plasticity for seed yield and other characters, in the previous experiments with both spring and winter oilseed rape varieties in both greenhouse and field conditions, an experiment was planned to study the dynamic relationship between increased space made available during vegetative plant growth by thinning plants at fortnightly intervals on the two varieties Orpal and Bronowski. Thinning treatments had significant effects on seed yield, dry weight and pod number per plant but no effect was observed on seed number per pod , and 1000-seed weight. This indicated that during the vegetative period density affects the number and sizes of leaves formed which determine the number and sizes of pods. The density stress after this period results in the shedding of flowers and/or pods and reduction in pod size, and once the pods became macroscopic they manufacture their own assimilates to a greater extent and thus support the seeds

2.2 Materials and Methods

Three pairs, one old and one recent, of varieties were compared. The six varieties used in this experiment with their country of origin and year of release, are given in Table 2.1. The experiment was carried out at the University of Liverpool Botanic Gardens, Ness, Wirral , Cheshire on soil classified as a fine sand with silt.

Table 2.1. Origins and years of release of cultivars used in the experiment.

Variety	Country of Origin	Year of Release
Nugget	Canada	1961
Tower	Canada	1974
Cresus	France	1964
Brutor	France	1978
Zollerngold	West Germany	1952
Erglu	West Germany	1969

The experiment was laid out in a randomized complete block design with four replications. Seed was hand sown in hills, 1 cm deep and 2.5 cm apart, in rows which were 45 cm apart. Each row was 90 cm long. There was a total of four rows per variety. Three to four seeds were sown per hill to ensure the survival of one plant per hill. A basic fertiliser (0 N:24% P_2O_5:24% K_2O) was applied before sowing at a rate of 120 Kg ha^{-1}. Nitrochalk (26% N) was given in two doses: 90 Kg ha^{-1} with the basic dressing before sowing, and 70 Kg ha^{-1} as a top dressing applied just before anthesis. Sowing was carried out on 22.4.80.

Hand watering of the plots was carried out to encourage germination and growth as April and May were very dry months in 1980 at Ness,

withih them. The data indicated that if density stress is relaxed after the plant reaches the post-vegetative phase, no improvement in individual plant performance are found. However, if the space is provided by thinning before that period the extra resources are used effectively and seed yield per unit area can be compensated to a larger extent due to an increase in mean seed yield per plant.

Throughout this series of experiments, the oilseed rape crop showed a great deal of plasticity in all the characters. The relationship between yield and its components in the experiment also varied suggesting strong environmental influences. Component compensation was also observed which was mainly responsible for this plasticity. Thus selection for high seed yield is likely to be very difficult in a crop like this and manipulation of the different yield components by selection would have to be carried out with considerable caution.

In such a situation and at this stage in the development of the crop it is probably desirable to keep as the objective of plant breeding programmes the isolation of lines which have an optimum combination of yield components, rather than an extreme expression of one or other components.

Thus the work has provided useful information and useful experience in many ways about the oilseed rape crop. It has indicated that the crop presents a number of challenging problems which have intricate inter-relationships. Attempts to solve them will involve a knowledge of several diverse fields - physiology, genetics, plant breeding, agronomy and statistics. The position of oilseed rape as a crop which is a valuable source of vegetable

oil and protein for animal feed seems to have become established. This position needs to be maintained and improvements can be brought about only by breeding higher yielding, more disease resistant, and better quality varieties adapted to wide range of environments. This will involve effort in several fields. There is great scope for work on this crop, which needs more extensive studies to provide the plant breeder with conclusive information about yield and yield components and their stability.

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total rainfall being 2.1 mm for April, 41.5 mm for May, of which 18 mm fell on May 31st. (Monthly climatic data for April 1979 to September 1980 are given in Appendix 1, page 188). When germination was complete plants were thinned to one plant per hill keeping plant to plant distance at 2.5 cm. Where there was no germination plants were carefully transplanted from spares, also sown on 22.4.80 to fill the gap. Irrigation was continued until the end of May after which regular rainfall allowed good plant establishment. Hand weeding was done three times during the growth season. Basudin 56 (Diazinon) pesticide was applied for the control of cabbage root fly (Erioischae brassicae) twice. The first application was made when germination was complete and the second 6 weeks later. Soon after pod formation, the whole area of the experiment was covered with 3 cm plastic netting on poles of 2.5 m high in order to prevent bird damage.

Seven harvests were taken during the experiment. Harvest 1 was taken four weeks after germination, harvests 2 to 6 were taken at two weeks intervals and harvest 7 at maturity after a further four weeks growth. The harvests were denoted W4, W6, W8 ... and W18, indicating weeks after germination. A 45 cm long sample of row containing 18 plants was taken at each harvest except for the final one (W18) which was 90 cm long and contained 36 plants.

The procedure followed for each group of plants at each harvest was as follows. The plants in the sample were separated into their component parts - stem, living leaves (less than 50% senesced), flowers, flowering branches or inflorescences (main and axillary inflorescence without pods) and pods. No attempt was made to recover roots. Leaf area was

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Appendix 1

Climatic monthly data April 1979 to September 1980.

	Av. Max. Temp. (°C)	Av. Min. Temp (°C)	Total Rainfall (mm)	Total Sunshine (hours + tenth)
1979				
April	10.7	4.2	78.1	147.1
May	13.2	5.3	91.7	155.0
June	17.7	9.8	18.4	142.1
July	19.8	12.0	21.4	155.2
August	18.9	11.0	52.0	168.0
September	17.4	9.6	19.7	127.2
October	14.7	7.8	64.3	87.8
November	10.6	4.1	81.5	56.8
December	8.5	3.3	137.3	57.6
1980				
January	5.2	-0.3	60.4	54.4
February	8.6	2.7	98.5	31.3
March	7.6	1.9	93.6	81.5
April	12.5	5.4	2.1	175.4
May	16.8	6.4	41.5	231.4
June	17.1	10.1	88.1	142.1
July	18.7	11.2	49.1	139.8
August	19.6	12.4	62.7	118.9
September	18.5	11.1	39.2	129.3

Appendix 2

Variance ratios and significance of differences from analyses of variance for different plant characters at different harvests during the experiment for six varieties of spring Brassica napus L.(Chapter 2)

Item	df	Weeks after germination						
		4	6	8	10	12	14	18 (maturity)
Dry weight per m^2								
Blocks	3	1.73	0.69	0.93	0.23	0.89	0.55	2.04
Variety	5	0.59	0.07	0.93	0.83	3.67*	0.60	0.72
Error	15							
Leaf weight per m^2								
Blocks	3	1.49	0.67	2.35	0.52	1.22	1.99	-
Variety	5	0.61	0.18	2.21	1.99	12.11***	5.06	-
Error	15							
Stem weight per m^2								
Blocks	3	2.29	0.75	0.41	0.48	0.65	0.15	0.77
Variety	5	0.95	0.11	0.48	1.77	11.12***	1.30	1.10
Error	15							
Inflorescence branches weight per m^2								
Blocks	3	-	0.88	1.34	0.42	0.93	0.99	2.45
Variety	5	-	4.15*	11.02***	1.81	2.69	0.70	0.84
Error	15							
Flower weight per m^2								
Blocks	3	-	-	0.49	0.32	5.50**	-	-
Variety	5	-	-	16.31***	2.90*	0.90	-	-
Error	15							
Pod weight per m^2								
Blocks	3	-	-	1.04	1.60	2.91	0.74	2.36
Variety	5	-	-	4.43*	26.66***	6.73**	0.53	0.70
Error	15							
Leaf Area index (LAI)								
Blocks	3	3.29*	1.55	0.74	0.36	1.55	2.45	-
Variety	5	0.90	0.40	4.37*	2.71	20.06***	1.49	-
Error	15							

Contd..

Item	df	Weeks after germination 4	6	8	10	12	14	18
Leaf Area Ratio (LAR)								
Blocks	3	1.07	1.16	0.00***	0.89***	2.78***	3.60*	-
Variety	5	0.83	1.01	9.45	8.56	22.59	1.79	-
Error	15							
Relative Growth Rate (RGR)								
Blocks	3		1.06	0.95	0.85	0.39	1.08	1.73
Variety	5		0.31	0.23	1.09	1.48	1.65	0.30
Error	15							
Net Assimilation Rate								
Blocks	3		1.11	1.40	0.56	0.38	2.73	
Variety	5		0.24	0.73	1.04	1.50	3.06*	-
Error	15							

Appendix 3

Variance ratios and significance of differences from analyses of variance for different plant characters at maturity for six varieties of spring Brassica napus (Chapter 2).

Item	df	Character: Seed wt. per m^2	Pod no. per m^2	Seed no. per pod	1000-seed weight	Harvest index
Blocks	3	1.57	1.95	0.40	2.92	0.09
Variety	5	0.60	3.76*	1.05	20.29***	0.92
Error	15					

Appendix 4

Variance ratios and significance of differences from analyses of variance for different plant characters at maturity for 6 x 6 diallel (1): Tower x Nugget: three genotypes from each variety (Chapter 3).

Item	df	Dry wt. per plant	Stem wt. per plant	Inflorescence branches wt. per plant	Pod wt. per plant	Seed wt. per plant	Pod no. per plant	Seed no. per pod	1000-seed weight
Blocks	1	11.23**	8.83**	8.25**	7.35*	8.04**	9.61**	3.60	0.04
Family	35	7.36***	5.20***	14.04***	4.71***	4.41***	8.41***	1.10	2.50**
Error	35								

Appendix 5

Variance ratios and significance of differences from analyses of variance for different plant characters at maturity for 6 x 6 diallel (2): Zollerngold and Englu : three genotypes from each variety (Chapter 3).

Item	df	Dry wt. per plant	Stem wt. per plant	Inflorescence branches wt. per plant	Pod wt. per plant	Seed wt. per plant	Pod no. per plant	Seed no. per plant	1000-seed weight
Blocks	1	3.62	11.17**	3.62	1.93	0.06	2.88	1.60	0.23
Family	35	4.06***	3.50***	6.14***	3.11***	10.11***	3.74***	2.53*	3.49***
Error	35								

Appendix 6

Variance Ratios and significance of differences from analyses of variance for different plant characters at maturity for 6 x 6 diallel (3): Cresus x Brutor: three genotypes from each variety (Chapter 3).

Item	df	Dry wt. per plant	Stem wt. per plant	Inflorescence branches wt. per plant.	Pod wt. per plant	Seed wt. per plant	Pod no. per plant	Seed no. per pod	1000-seed weight
Blocks	1	0.61	5.73*	0.20	0.07	0.47	0.56	0.01	3.70
Family	35	1.74*	1.42	1.55	1.93*	2.11*	1.42	3.00***	1.44
Error	35								

Appendix 7

Variance ratios and significance of differences from analyses of variance for seed yield and yield components for six varieties of summer oilseed rape grown at three soil fertility levels and two densities (Chapter 4).

Item	df	Seed yield per plant	Dry wt. per plant	Pod no. per plant	Seed no. per pod	1000-seed weight	Harvest index	Seed wt. per pod
Block	1	0.23	0.02	0.12	7.44	0.05	10.66	0.41
Soil(S)	2	3.10	5.88	2.02	5.72	1.39	1.73	0.83
Error I	2							
Density (D)	1	4.50*	11.59**	2.84	0.15	3.49	0.10	1.22
Variety (V)	5	0.39	0.56	0.27	9.44***	15.13***	0.84	0.74
D x V	5	1.65	1.93	1.47	0.74	0.56	0.87	1.07
D x S	2	3.79*	5.04*	2.37	1.42	0.84	0.95	1.62
V x S	10	1.34	1.76	1.11	1.62	0.45	0.54	1.29
D x V x S	10	0.75	1.11	0.70	1.04	0.97	0.42	0.53
Error II	33							

Appendix 8

Means for data Chapter 5

8.1 Mean top dry weight per plant (g) for three oilseed rape varieties at three fertilizer levels and two row spacings harvested during the experiment.

H_1 (6 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	1.12	2.41	1.66	2.06	2.46	1.78
medium	2.37	2.58	1.57	2.57	2.60	1.73
high	2.33	2.72	1.85	2.08	2.68	2.43

H_2 (8 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
Low	2.64	2.74	2.01	4.22	3.32	3.98
medium	2.80	5.47	2.38	4.45	3.90	3.37
high	3.55	5.11	3.19	6.22	3.12	4.68

H_3 (10 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	3.05	4.68	4.88	6.51	5.87	6.84
medium	5.40	7.57	4.75	5.76	5.96	6.25
high	5.86	9.73	5.69	9.04	7.05	9.39

measured on a Hayashi Denko leaf area scanner. Plant parts were then dried in an oven at 38°C for seven days and weighed. The final harvest was taken when the stem and pods had reached maturity but not all the pods had ripened, so as to avoid excessive shattering and seed loss. At the final harvest pod number was counted and seed number per pod was estimated from a random sample of 40 intact pods threshed by hand and the number of seeds counted using an electron seed counter in the Department of Plant Biology, University College of North Wales, Bangor. One thousand seed weight was calculated from this sample of seeds. The remaining pods were threshed on a thresher designed for small grain crops at the Plant Breeding Institute, Cambridge and seed weighed. Total seed yield was obtained by adding these two values. Total top plant dry weight was determined by summing all the dry matter components recorded at each harvest. Because of the impossibility of adequately removing root material in extensive field (and greenhouse) experiments data for roots has not been obtained. Therefore top dry weight per plant has been used in place of total dry weight per plant throughout the thesis.

Each plot was 0.209 m^2 in area, but all the data were converted to per m^2 to facilitate interpretation.

Measurements of recorded variates, leaf area (AL), leaf weight (WL) and top plant dry weight (W) during the growth period were used to calculate the following morphological and growth parameters, after Radford (1967), and as used by Thurling (1974a).

The Mean Relative Growth Rate ($\overline{RGR}$) of a plant at an instant in time (t) is defined as 'the average increase of plant material per unit of material present per unit of time', and was calculated by the formula

H_4 (12 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	4.02	2.33	3.40	6.35	4.99	8.12
medium	4.90	8.97	5.60	5.02	3.53	7.32
high	7.45	9.09	6.06	10.72	5.36	11.52

H_5 (14 weeks after germination, at maturity)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	4.36	5.80	5.76	5.13	4.91	6.82
medium	5.62	7.56	5.74	7.37	6.46	7.47
high	5.96	8.34	6.96	8.40	6.04	9.64

8.2 Mean leaf weight per plant (g) for three oilseed rape varieties at three fertilizer levels and two row spacings harvested during the experiment.

H_1 (6 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.45	1.29	0.45	0.69	0.93	0.56
medium	0.91	1.03	0.58	0.99	1.51	0.55
high	0.89	1.26	0.47	1.05	1.07	0.83

H_2 (8 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.46	0.53	0.19	0.51	0.40	0.37
medium	0.39	0.72	0.31	0.59	0.54	0.49
high	0.68	1.13	0.38	0.75	0.52	0.73

H_3 (10 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.20	0.31	0.06	0.09	0.23	0.10
medium	0.33	0.46	0.18	0.30	0.30	0.35
high	0.22	0.46	0.22	0.41	0.44	0.42

8.3 Mean stem weight per plant (g) for three oilseed rape varieties at three fertilizer levels and two row spacings harvested during the experiment.

H_1 (6 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.54	0.94	0.93	1.09	1.24	0.95
medium	1.08	1.15	0.71	1.20	0.88	1.00
high	1.05	1.22	0.96	1.42	1.27	1.26

H_2 (8 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	1.04	1.17	0.75	1.69	1.23	1.66
medium	1.03	1.93	1.07	1.76	1.41	1.40
high	1.17	1.77	1.18	2.13	1.30	1.93

H_3 (10 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.78	1.28	1.18	1.81	1.81	1.86
medium	1.23	2.14	1.15	1.42	1.60	1.60
high	1.66	2.12	1.31	1.99	1.57	2.35

H_4 (12 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.98	1.16	1.01	1.31	1.36	1.76
medium	1.41	2.13	1.31	1.57	1.76	1.57
high	1.55	1.82	1.13	1.96	1.78	2.33

H_5 (14 weeks after germination, at maturity)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	1.13	1.49	1.48	1.46	1.47	1.53
medium	1.42	1.80	1.27	1.79	1.59	1.68
high	1.58	1.43	1.42	1.80	1.52	1.99

8.4 Mean inflorescence weight per plant (g) for three oilseed rape varieties at three fertilizer levels and two row spacings harvested during the experiment.

H_1 (6 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.12	0.18	0.27	0.28	0.29	0.27
medium	0.38	0.39	0.28	0.38	0.21	0.17
high	0.38	0.23	0.41	0.60	0.33	0.34

H_2 (8 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	1.13	1.03	1.06	2.01	1.68	1.94
medium	1.38	2.82	0.99	2.10	1.94	1.47
high	1.70	2.20	1.62	3.33	1.29	2.01

H_3 (10 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	2.06	3.09	3.64	4.61	3.83	4.87
medium	3.83	4.97	3.42	4.03	4.05	4.30
high	3.98	7.15	4.16	6.63	5.03	6.61

H_4 (12 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	3.04	1.16	2.39	5.01	3.63	6.36
medium	3.48	6.84	4.29	3.45	1.76	5.75
high	5.87	7.27	4.93	8.75	3.58	9.19

H_5 (14 weeks after germination, at maturity)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	3.23	4.31	4.27	3.67	3.44	5.29
medium	4.19	5.76	4.47	5.57	4.86	5.78
high	4.38	6.91	5.54	6.60	4.51	7.65

8.5 Mean plant height (cm) for three oilseed rape varieties at three fertilizer levels and two row spacings harvested during the experiment.

H_1 (6 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	44.51	53.27	64.44	56.49	54.91	57.29
medium	56.43	56.45	48.12	63.08	38.94	58.13
high	54.89	57.47	63.29	65.38	53.58	60.18

H_2 (8 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	79.36	76.43	69.94	84.60	71.19	83.70
medium	81.26	96.86	78.82	88.49	76.87	80.20
high	77.52	95.64	81.76	92.75	77.79	83.83

H_3 (10 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	68.64	77.54	78.90	90.68	79.74	84.00
medium	81.92	99.39	79.12	80.14	76.80	76.18
high	91.64	98.23	84.05	86.39	79.24	87.56

H_4 (12 weeks after germination)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	69.36	75.95	77.42	81.87	73.02	85.88
medium	86.81	98.09	85.79	82.73	81.22	83.32
high	85.05	94.45	77.00	88.78	80.51	89.20

H_5 (14 weeks after germination, at maturity)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	78.10	83.45	80.26	87.63	81.55	89.95
medium	85.72	96.78	79.85	87.20	74.81	90.69
high	91.30	96.96	83.41	85.18	84.26	91.06

8.6 Table of mean seed yield per plant and its components at maturity for three oilseed rape varieties at three fertilizer levels and two row spacing.

8.6.1 Seed weight per plant (g)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	2.37	2.95	2.56	2.49	2.55	3.49
medium	2.77	3.38	2.81	3.53	3.27	3.83
high	2.83	4.28	3.42	4.36	3.46	4.83

8.6.2 Pod number per plant

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	34.75	45.10	44.75	42.05	35.00	50.75
medium	41.05	55.05	49.10	58.85	47.20	58.10
high	42.00	63.65	55.60	69.80	45.90	68.90

8.6.3 Seed number per pod

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	27.18	26.09	21.48	21.64	20.91	19.40
medium	26.32	22.88	22.59	24.01	20.43	18.92
high	25.90	23.91	21.40	22.94	18.42	20.92

8.6.4 1000-seed weight (g)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	2.64	2.50	2.83	2.89	3.73	3.94
medium	2.66	2.82	2.67	2.77	4.05	3.67
high	2.63	2.62	2.94	2.92	4.37	3.66

8.6.5 Seed weight per pod (mg)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	70.45	66.70	59.60	60.55	77.60	75.80
medium	71.55	66.45	59.75	66.15	76.60	67.70
high	71.40	62.80	63.80	64.70	81.45	73.15

8.6.6 Dry weight per pod (mg)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	136.80	131.45	114.40	116.60	144.20	141.55
medium	138.10	129.50	120.80	125.60	140.15	128.20
high	140.60	129.70	120.65	115.85	147.95	133.65

8.6.7 Hull weight per pod (mg)

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	66.35	64.75	54.80	56.05	66.60	65.75
medium	66.55	63.05	61.05	59.45	63.55	60.50
high	69.20	66.90	56.85	51.15	66.50	60.50

8.6.8. Harvest index

Fertilizer level	Bronowski		Erglu		Orpal	
	7.5cm	15cm	7.5cm	15cm	7.5cm	15cm
low	0.54	0.51	0.45	0.48	0.52	0.53
medium	0.49	0.45	0.49	0.48	0.50	0.51
high	0.47	0.51	0.49	0.52	0.57	0.50

$$\overline{RGR} = (\log_e W2 - \log_e W1) / (t_2 - t_1)$$

where $\overline{RGR}$ is Mean Relative Growth Rate

$\log_e W1$ and $\log_e W2$ are $\log_e$ of total plant weight at time t_1 and t_2 respectively.

$t_2 - t_1$ interval (days) between two harvests.

The mean Net Assimilation Rate ($\overline{NAR}$) of a plant at an instant in time (t) is defined as 'the average increase of plant material per unit of assimilatory material (usually leaves) per unit of time', and was calculated by the formula

$$\overline{NAR} = \frac{(W2 - W1)}{(A2 - A1)} \cdot \frac{(\log_e AL2 - \log_e AL1)}{(t_2 - t_1)}$$

where $\overline{NAR}$ is Mean Net Assimilation Rate

W1, W2; AL1, AL2; $\log_e$ AL1, $\log_e$ AL2 are total plant dry weights, leaf areas, $\log_e$ of leaf areas at time t_1 and t_2 respectively.

Leaf Area Ratio (LAR) of plant at an instant in time (t) is defined as 'the ratio of assimilatory material per unit of plant material present', and was, at every harvest, calculated by the formula

$$LAR = AL/W$$

The Leaf Area Index (LAI) was expressed in terms of total leaf area (cm^2) per square centimeter of land surface.

Harvest Index is the ratio of an economic product to total biological yield and was obtained by dividing seed weight by total top plant dry weight.

An analysis of variance was carried out for each variable at each harvest. Simple correlation coefficients were calculated between characters at maturity.

Appendix 9

Means for data Chapter 6

9.1 Mean top dry weight per plant (g) for B. napus cv. Jet Neuf and Nevin at 2N fertilizer levels with 2 row spacings harvested during the experiment.

H_1 (25.3.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.20	0.29	0.20	0.14
15 cm	0.26	0.26	0.17	0.23

H_2 (14.4.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.26	0.65	0.33	0.45
15 cm	0.44	0.96	0.32	0.78

H_3 (6.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.69	2.01	0.68	1.67
15 cm	1.26	2.11	0.75	1.10

H_4 (27.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	1.77	2.45	1.28	1.56
15 cm	1.91	4.59	1.48	2.15

H_5 (17.6.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	1.60	3.89	2.33	2.81
15cm	2.11	5.69	1.70	4.04

H_6 (30.7.80, at maturity)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	1.63	5.25	2.57	3.38
15cm	2.35	4.55	2.64	4.49

9.2 Mean leaf weight per plant (g) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with 2 row spacings harvested during the experiment.

H_1 (25.3.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.17	0.26	0.17	0.12
15cm	0.23	0.23	0.15	0.21

H_2 (14.4.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.15	0.40	0.22	0.29
15cm	0.27	0.60	0.19	0.56

H_3 (6.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.12	0.42	0.19	0.42
15 cm	0.25	0.35	0.26	0.31

H_4 (27.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.05	0.08	0.09	0.09
15 cm	0.04	0.12	0.11	0.13

H_5 (17.6.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.010	0.072	0.031	0.015
15 cm	0.006	0.055	0.011	0.026

9.3 Mean stem weight per plant (g) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with 2 row spacings harvested during the experiment.

H_1

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.02	0.03	0.03	0.02
15 cm	0.03	0.03	0.02	0.02

H_2

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.09	0.22	0.11	0.16
15cm	0.14	0.33	0.09	0.21

H_3

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.45	1.32	0.45	1.20
15cm	0.78	1.43	0.46	0.73

H_4

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.60	0.95	0.73	0.97
15cm	0.70	1.72	0.84	1.26

H_5

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.57	1.47	1.06	1.38
15cm	0.78	2.00	0.72	2.01

H_6

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.54	1.89	0.93	1.39
15cm	0.68	1.68	0.91	1.57

9.4 Mean inflorescence branches weight per plant (g) for B. napus cv. Jet Neuf and Nevin at 2N fertilizer levels with 2 row spacings harvested during the experiment.

H_2 (14.4.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.01	0.02	0.01	0.01
15cm	0.02	0.04	0.04	0.01

H_3 (6.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.09	0.22	0.04	0.05
15cm	0.17	0.24	0.03	0.05

H_4 (27.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.60	0.78	0.26	0.29
15cm	0.65	1.51	0.31	0.45

H_5 (17.6.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.13	0.33	0.20	0.25
15cm	0.19	0.53	0.14	0.38

H_6 (30.7.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.08	0.39	0.16	0.20
15cm	0.15	0.33	0.17	0.30

9.5 Mean flower weight per plant (g) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with 2 row spacings harvested during the experiment.

H_3 (6.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.019	0.045	0.0	0.0
15cm	0.055	0.087	0.0	0.003

H_4 (27.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.001	0.001	0.030	0.040
15cm	0.002	0.001	0.036	0.043

9.6 Mean pod weight per plant (g) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with 2 row spacings harvested during the experiment.

H_4 (27.5.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.51	0.64	0.17	0.16
15 cm	0.52	1.24	0.17	0.26

H_5 (17.6.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.89	2.03	1.03	1.17
15 cm	1.14	3.11	0.82	1.62

H_6 (30.7.80)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	1.01	2.97	1.48	1.79
15 cm	1.52	2.54	1.56	2.61

9.7 Mean relative growth rate (mg mg^{-1} day^{-1}) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with 2 row spacings harvested during the experiment.

H_{23} (Mean RGR during H_2 and H_3 period)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.047	0.055	0.035	0.062
15 cm	0.052	0.037	0.043	0.017

H_{34} (Mean RGR during H_3 and H_4 period)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.045	0.007	0.027	-0.003
15 cm	0.020	0.036	0.033	0.030

H_{45} (Mean RGR during H_4 and H_5 period)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	-0.007	0.025	0.033	0.028
15 cm	0.002	0.012	0.008	0.032

H_{56} (Mean RGR during H_5 and H_6, maturity)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5 cm	0.002	0.004	0.003	0.003
15 cm	0.003	-0.005	0.010	0.003

9.8 Mean net assimilation rate (mg cm^{-2} day^{-1}) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with 2 row spacings harvested during the experiment.

H_{23} (mean NAR during H_2 and H_3 period)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5 cm	0.744	0.669	0.409	0.688
15 cm	0.891	0.542	0.519	0.183

H_{34} (mean NAR during H_3 and H_4 period)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5 cm	2.928	0.562	0.805	- 0.101
15 cm	1.421	2.327	1.042	1.120

H_{45} (mean NAR during H_4 and H_5 period)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	-3.950	4.853	3.649	5.360
15 cm	1.694	4.490	1.965	5.521

9.9 Mean leaf area index for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with 2 row spacings harvested during the experiment.

H_1

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	1.03	1.55	1.20	0.98
15cm	0.72	0.71	0.53	0.67

H_2

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	1.22	4.42	1.69	3.13
15cm	0.77	2.23	0.72	1.84

H_3

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	1.06	3.31	1.67	3.91
15cm	0.92	1.44	1.05	1.41

H_4

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.51	0.96	0.89	1.05
15cm	0.20	0.52	0.57	0.70

H_5

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.07	0.81	0.41	0.17
15cm	0.03	0.24	0.07	0.18

9.10 Mean leaf area ratio (cm^2 g^{-1}) for B. napus cv. Jet Neuf and Nevin at 2 N fertilizer levels with two row spacings harvested during the experiment.

H_1

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	140.08	145.90	148.30	171.24
15cm	137.99	143.85	151.61	145.84

H_2

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	118.89	163.21	121.76	155.64
15cm	102.07	130.43	114.08	138.13

H_3

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	38.13	46.35	64.80	59.19
15cm	37.09	37.63	64.22	56.42

2.3 Results

Development of the crop can be considered in three more or less distinct phases on the basis of dry matter accumulation, (a) seedling and vegetative growth, (b) flowering and early pod formation, and (c) pod growth and ripening (Allen and Morgan 1975).

2.3.1 Seedling and Vegetative Growth: This phase extended from germination to the eighth week after germination. In this period there is predominantly vegetative growth and development of flowering branches. By week 8 flowering had commenced, and leaf area index (LAI, Table 2.8) had reached its maximum value.

2.3.2 Flowering and Early Pod Formation: This was a phase during which most of the flowers opened and it lasted for only three weeks from W8 to W10. Relative growth rate (RGR, Table 2.10) slowed down while leaf area index was still high (Table 2.8), though it was also declining.

2.3.3 Pod Growth and Ripening: This was a period of rapid growth of the pods and this phase extended from W10 to W18 i.e. maturity. The dry weight of the plants increased at a high rate, though leaf area index was declining due to senescence and death of leaves. Dry weight continued to increase upto maturity (Table 2.2), which was mainly due to pod weights (Table 2.7) and seeds in them.

The allocation of dry matter into different plant parts for the six varieties is shown in Fig. 2.1. It is apparent from the diagrams that the general pattern of growth and development in all varieties is similar and falls into the pattern described previously.

The detail of dry matter allocation with different plant parts will now be considered.

Analysis of variance for total plant weight and its components during the experiment are given in Appendix 2, page 193.

H_4

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	6.68	9.63	17.76	16.01
15cm	5.11	5.64	17.10	13.83

H_5

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.88	5.44	4.33	1.50
15cm	0.68	2.49	1.76	2.08

9.11 Table of mean seed yield per plant and its components at maturity for B. napus cv. Jet Neuf and Nevin grown at 2 N fertilizer levels and 2 row spacings

9.11.1 Seed weight per plant (g)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.60	1.69	0.75	0.91
15cm	0.90	1.40	0.79	1.33

9.11.2 Pod number per plant

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	7.98	18.45	14.65	16.85
15cm	11.97	17.71	14.29	21.73

9.11.3 Seed number per pod

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	15.90	17.64	15.24	16.28
15cm	16.37	15.79	14.97	16.27

9.11.4 1000-seed weight (g)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	5.36	5.91	4.21	3.93
15cm	5.59	5.89	4.15	4.18

9.11.5 Hull weight per plant (g)

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.05	0.07	0.05	0.05
15cm	0.05	0.06	0.05	0.06

9.11.6 Harvest index

Row spacing	Jet Neuf		Nevin	
	No N	55 Kg N ha^{-1}	No N	55 Kg N ha^{-1}
7.5cm	0.37	0.32	0.29	0.27
15cm	0.37	0.31	0.29	0.30

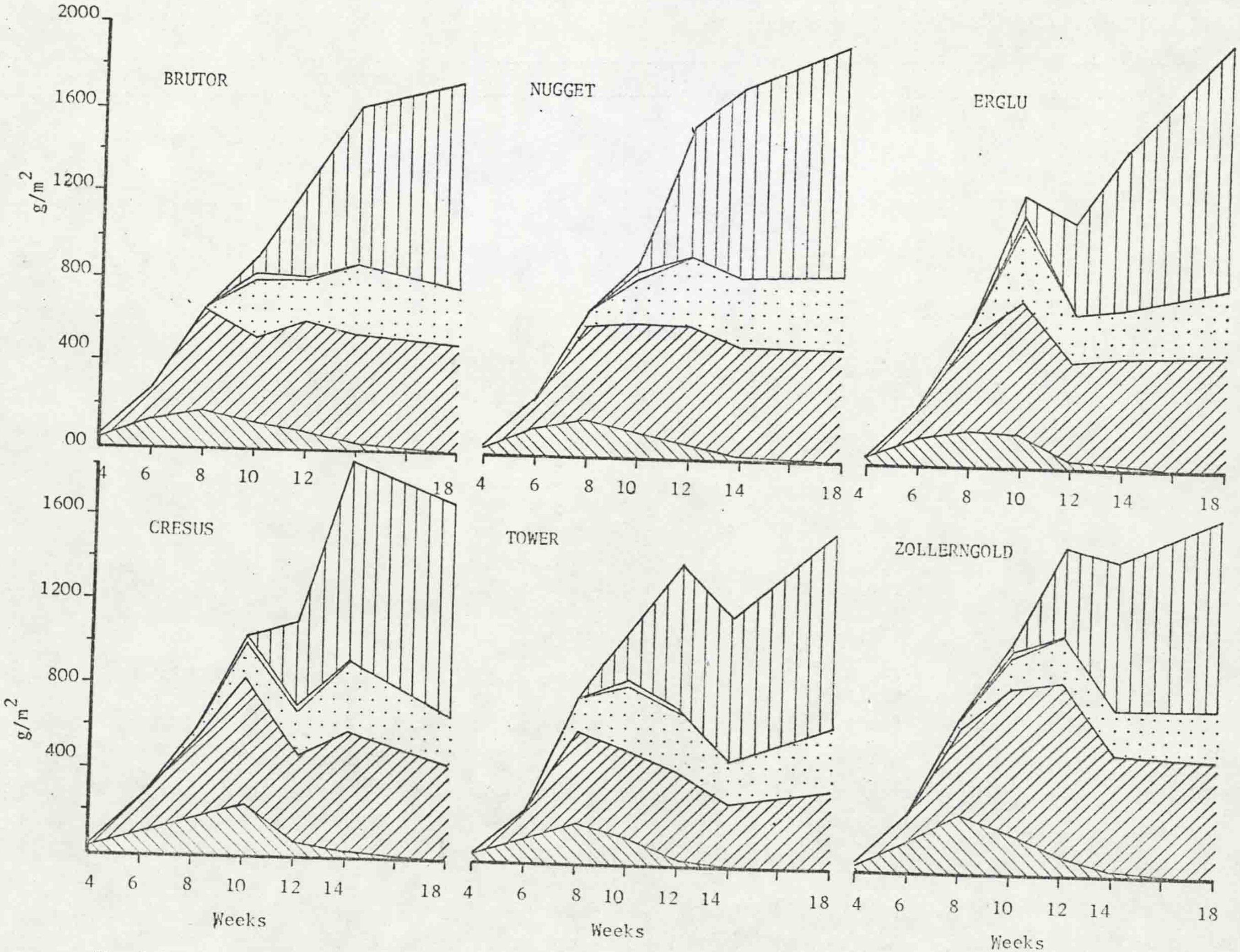

Fig.2.1 Distribution of dry matter in spring oilseed rape. ▨, leaf weight; ▨, stem weight; ⁘, inflorescence branches weight; □, flower weight; ▥, pod weight.

These characters are individually considered now.

Top plant weight per square metre

The varieties did not differ significantly from one another for top dry weight per m^2, except at W12, 12 weeks after germination (Table 2.2). At W12 Nugget had the highest and Cresus the lowest top plant weight per m^2. Tower, Zollerngold, Brutor and Erglu had significantly more dry weight than Cresus, and did not differ significantly from one another. This difference was not found in later stages (W14 and W18), so there were no significant differences between varieties at W14 and at final harvest (W18).

Leaf weight per square metre

There were no significant differences between varieties for leaf weight per m^2 upto W12 i.e. 12 weeks after germination (Table 2.3). Leaf weights increased to their maximum at W10 after which leaf weights declined reaching zero at the final harvest. Varieties differed significantly at W12 ($p<0.001$) when Zollerngold and Brutor had the highest and Tower and Erglu had the lowest leaf weights per m^2. Leaf weight of these latter two varieties being significantly ($p<0.05$) less than that of Brutor, Nugget and Zollerngold. This was the stage when leaves started senescence and there were no significant differences at W14 whilst no leaves were left at the final harvest (W18).

Stem weight per square metre

The varieties did not differ significantly for stem weight per m^2 except at W12 (Table 2.4). At W12 Zollerngold had the highest stem weight per m^2 and Tower and Cresus the lowest, the difference being significant at $p<0.05$. Erglu and Brutor, and Brutor and Nugget did not differ significantly ($p<0.05$) from each other nor did Nugget and Zollerngold differ significantly from each other.

Table 2.2. Mean top dry weight (g m^{-2}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus	50.19	239.44	563.58	1185.91	1086.91 c	1894.53	1699.92
Brutor	55.17	254.44	685.79	886.61	1295.92 bc	1525.12	1771.55
Nugget	44.93	256.43	685.40	924.32	1608.09 a	1737.77	2024.44
Tower	47.95	251.26	800.91	1131.37	1427.94 ab	1162.85	1587.23
Zollerngold	42.11	271.55	721.96	1032.60	1422.68 ab	1467.66	1830.74
Erglu	34.69	243.80	665.50	1273.43	1156.63 bc	1513.50	2012.19

Varieties do not differ significantly except where columns are lettered. Values having the same letter are not significantly different. This is followed in all subsequent tables.

Table 2.3. Mean leaf weight (g m^{-2}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus	39.09	128.38	187.09	226.04	66.08 ab	26.94	
Brutor	42.44	128.62	185.37	122.50	82.21 a	31.72	
Nugget	31.10	128.76	176.04	124.27	71.15 a	7.51	
Tower	37.13	118.19	199.10	136.37	34.40 b	0.43	
Zollerngold	33.30	144.12	269.54	159.67	90.15 a	22.54	
Erglu	27.56	127.33	166.66	158.86	29.57 b	7.23	

At W14 and W18 there were no significant differences between the varieties.

Inflorescence weight per square metre

Means of inflorescence weight m^{-2} are given in Table 2.5. Floral bud formation started between W4 and W6 and flowering started between W6 and W8 (Table 2.6). Tower started to form flowering branches early and produced significantly ($p<0.05$) more inflorescence at W6 and at W8 ($p<0.001$) than all the other varieties. In all the other varieties, Cresus, Brutor, Nugget, Zollerngold and Erglu, the formation of flowering branches began at about the same time and inflorescence branches weight m^{-2} did not differ significantly between varieties from W10 to the final harvest.

Flower weight per square metre

Flowering of varieties started between W6 and W8. No precise data were recorded on flowering date but it was observed that Tower flowered one week before Erglu, Brutor, Nugget and Cresus, which were 2-3 days ahead of Zollerngold which was the last variety to flower. Flower weight m^{-2} behaved in the same way as did the inflorescence branches weight m^{-2}. Being earlier to commence flowering than the others, Tower produced a greater number of flowers m^{-2} (significant at $p<0.001$) at W8 than all the other varieties. At W10 Nugget and Erglu had the highest flower inflorescence weights (significant at $p<0.05$) and did not differ significantly from each other. All the other varieties did not differ significantly from each other. W10 (Fig. 2.1) corresponded to the peak of flowering for all six varieties. At W12 when flowering was declining there were no significant differences between the varieties. No flowers were present at W14 or W18.

Table 2.4. Mean stem weight (g m^{-2}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus	11.10	109.10	354.19	599.80	425.39 d	575.83	441.66
Brutor	12.73	127.76	473.52	517.88	560.52 bc	526.49	493.19
Nugget	13.83	124.89	451.99	509.17	615.72 ab	515.54	523.19
Tower	10.77	127.66	435.48	429.12	416.73 d	305.95	375.72
Zollerngold	8.80	125.94	413.04	684.40	701.63 a	542.00	541.09
Erglu	7.08	114.51	448.93	618.80	468.31 cd	538.07	536.93

Table 2.5. Mean inflorescence weight (g m^{-2}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus		1.96 b	22.20 b	279.54	198.82	328.30	248.01
Brutor		2.11 b	24.93 b	160.59	200.30	217.67	277.48
Nugget		2.73 b	55.22 b	205.61	327.68	310.12	339.26
Tower		5.41 a	146.04a	298.82	274.85	193.27	285.28
Zollerngold		1.48 b	39.09 b	137.09	205.85	226.47	238.15
Erglu		1.96 b	48.19 b	354.09	224.85	217.77	311.17

Table 2.6. Mean flower weight (g m^{-2}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus				0.16 b	32.23 b	0.76	
Brutor				2.15 b	20.52 b	1.07	
Nugget				2.03 b	32.68 ab	1.75	
Tower				10.73 a	27.01 b	0.04	
Zollerngold				0.16 b	25.62 b	1.38	
Erglu				1.62 b	51.94 a	0.74	

Table 2.7. Mean pod weight (g m^{-2}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus				48.37 bc	395.88 c	963.46	1010.26
Brutor				65.11 bc	451.85 bc	749.67	1000.88
Nugget			0.16 b	52.60 bc	591.79 ab	904.17	1161.99
Tower			9.57 a	240.04 a	701.93 a	663.19	924.76
Zollerngold			0.10 b	25.78 c	423.63 c	676.64	1051.52
Erglu			0.12 b	89.68 b	433.22 c	750.47	1164.12

ABSTRACT

Munir, M. Phenotypic and genotypic plasticity for yield and yield components in Brassica napus.

The work described in this thesis was carried out to examine patterns of vegetative and reproductive growth in spring and winter oilseed rape, and the genetic basis of the differences found in the components of yield.

Partition of dry matter into its components was examined in 3 old and 3 recent spring oilseed rape varieties. The pattern of growth was similar in all six varieties. They differed however, significantly, in pod number per plant and 1000-seed weight indicating the occurrence of component compensation. This was confirmed by correlation studies.

The inheritance of seed yield and its components was investigated using the diallel analysis technique. There was evidence for the presence of reciprocal and epistatic effects for most characters. In one diallel (Brutor and Cresus) only dominance effects were detected for pod weight, seed weight and dry weight per plant. Component compensation was again evident.

Six varieties of spring oilseed rape were grown in a greenhouse experiment at three fertility levels and two densities. Using the joint regression technique of Finlay and Wilkinson, Brutor was shown to be less stable variety specifically adapted to high yielding environment, whilst Janetski had a high stability and is specifically adapted to poor environments.

A field experiment examined vegetative and reproductive growth in three varieties of spring oilseed rape at three fertilizer levels and two row spacings. Orpal gave a higher yield than Bronowski and Erglu, due to its greater seed weight. Fertilizer and row spacing effects were also significant.

Jet Neuf and Nevin, fodder rape, were compared at two nitrogen levels and two row spacings. There were no significant differences between varieties for seed yield or its components apart from 1000-seed weight. Fertilizer effects were significant for pod number and seed yield per plant.

A final experiment examined the effect of changing plant density during the growth period by reducing density per plot by half. Thinning treatments significantly affected dry weight, seed weight and pod number per plant, but seed number per pod, 1000-seed weight and harvest index were unaffected.

Oilseed rape showed a great deal of plasticity in all the characters studied and the effect of environment was also marked. The data from this work suggests that the concept of an ideotype in oilseed rape is likely to be of value in breeding studies.

Pod weight per square metre

Pod weight m^{-2} is given in Table 2.7. Pod formation started just before W8 in Nugget, Tower, Zollerngold and Erglu. Among these at W8 Tower, being again early in pod formation, had a significantly higher pod weight ($p<0.05$) than the remaining varieties. At W10 Tower still had the highest pod dry weight value, Zollerngold the least whilst the other varieties did not differ significantly from each other. At W12 Tower again had the highest pod weight. Cresus, Zollerngold and Erglu did not differ significantly from each other and produced the lowest pod weight. Brutor and Nugget were intermediate and did not differ significantly from each other. At W14 and W18 there were no significant differences between any of the varieties.

Leaf Area Index (LAI)

Leaf area indices of the varieties during the growth period are given in Table 2.8. There were no significant differences between the varieties at W4 and W6 whereas at W8 Zollerngold had significantly greater LAI ($p<0.05$) than the remaining five varieties. At W10 Cresus, Zollerngold and Erglu did not differ significantly from one another and had higher LAI than Brutor, Nugget and Tower all of which did not differ significantly from one another. At W12 Zollerngold had the highest LAI value which was significantly greater ($p<0.05$) than the remaining five varieties. Tower and Erglu had the lowest LAI values, significantly less than those of Brutor, Nugget and Cresus ($p<0.05$). Near W14 LAI was declining rapidly due to leaf senescence and death, and no differences were found between the varieties at W14.

Table 2.8. Mean Leaf Area Index (LAI) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus	0.98	3.86	4.71 b	5.36 a	1.54 b	0.62	
Brutor	1.11	4.00	4.87 b	2.85 b	1.86 b	0.72	
Nugget	1.15	4.32	4.32 b	2.88 b	1.66 b	0.27	
Tower	1.11	4.30	4.68 b	2.98 b	0.76 c	0.33	
Zollerngold	0.98	4.89	7.54 a	4.42 ab	2.37 a	0.59	
Erglu	0.75	3.99	3.92 b	3.81 ab	0.63 c	0.19	

Table 2.9. Mean Leaf Area Ratio (LAR) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination						
	4	6	8	10	12	14	18
Cresus	197.40	161.72	88.33 b	45.81 a	14.47 a	3.09	
Brutor	209.22	156.35	71.88 c	32.68 b	14.41 a	4.19	
Nugget	290.09	169.56	64.04 bc	30.92 b	10.27 b	1.66	
Tower	238.25	173.28	58.52 c	26.18 b	5.55 c	2.73	
Zollerngold	232.13	182.48	103.69 a	41.65 a	16.64 a	4.69	
Erglu	214.98	167.63	60.96 c	31.19 b	5.49 c	1.22	

Leaf Area Ratio (LAR)

The varieties did not differ for LAR at W4 and W6 (Table 2.9). At W8 Zollerngold had significantly ($p<0.05$) higher LAR than Cresus and Nugget which did not differ significantly from one another and had significantly higher LAR than Brutor, Erglu and Tower, which again did not differ significantly from one another. At W10 Cresus and Zollerngold had significantly ($p<0.05$) higher LAR than Brutor, Erglu, Nugget and Tower. At W12 Zollerngold, Cresus and Brutor had significantly ($p<0.05$) higher LAR than Nugget which in turn had a significantly ($p<0.05$) higher LAR than Tower and Erglu. At W14 there were no significant differences and at W18 LAR had declined to zero due to progressive leaf senescence and death from W10 onwards.

Relative Growth Rate (RGR) and Net Assimilation Rate (NAR)

Means of RGR are given in Table 2.10. RGR was at a maximum as expected at the earlier phase of growth, W4-W6. Thereafter it declined steadily reaching almost zero at W14-W18. There were no significant differences for RGR between varieties throughout their period of growth.

No significant differences were found between varieties in their NAR values during the whole period (Table 2.11). Although substantial differences were found within and between varieties, none of them were found to be significant.

Seed Yield and Yield Components at Maturity (W18)

Data for seed yield m^{-2}, harvest index, number of pods m^{-2}, number of seeds per pod and 1000-seed weight are given in Table 2.12 and their analyses of variance are shown in Appendix 3, page 190 .

There were no significant differences between varieties for seed yield m^{-2}, harvest index, and number of seeds per pod. Varieties differed significantly from one another only for two yield components,

Table 2.10. Mean Relative Growth Rate (g gm^{-1} day^{-1}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination					
	4	6	8	10	12	14	18
Cresus	0.112	0.063	0.051	-0.004	0.031	0.0001
Brutor	0.114	0.068	0.019	0.028	0.008	0.006
Nugget	0.127	0.076	0.023	0.040	0.003	0.006
Tower	0.120	0.084	0.023	0.018	-0.016	0.012
Zollerngold	0.132	0.071	0.024	0.026	-0.003	0.010
Erglu	0.140	0.073	0.046	0.005	0.019	0.011

Table 2.11. Mean Net Assimilation Rate (g m^{-2} day^{-1}) for six varieties of spring oilseed rape harvested during the experiment.

Variety	Weeks after germination					
	4	6	8	10	12	14	18
Cresus	6.53	5.71	8.71	-0.49	45.27	
Brutor	6.56	6.79	3.91	12.50	7.39	
Nugget	6.39	8.06	4.79	23.13	17.58	
Tower	6.19	8.92	5.85	17.76	-66.01	
Zollerngold	6.72	5.42	3.88	10.63	3.43	
Erglu	7.65	7.56	10.90	-4.96	64.74	

Table 2.12. Mean seed yield (g m^{-2}), number of pods m^{-2}, number of seeds per pod, 1000-seed weight and harvest index for six varieties of spring oilseed rape at maturity (W18).

Variety	Seed yield g m^{-2}	Number of pods m^{-2}	Number of Seeds per pod	1000-seed weight g	Harvest index
Cresus	496.68	6297.06 c	23.79	3.73 a	0.28
Brutor	503.21	7004.04 bc	22.88	3.52 a	0.27
Nugget	563.00	10102.30 a	23.61	2.63 c	0.27
Tower	424.52	7178.70 bc	22.16	3.21 ab	0.25
Zollerngold	510.12	7995.73 ab	21.67	3.27 ab	0.27
Erglu	541.72	9183.61 a	25.20	2.80 bc	0.26

Table 2.13. Correlation coefficients (r) between yield and yield components at maturity for six varieties of spring oilseed rape.

Variety	Seed weight m^{-2}	Number of pods m^{-2}	Number of seeds per pod	1000-seed weight	Harvest index
Dry wt. m^{-2}	0.996***	0.86***	0.59**	-0.46*	-0.02
Seed wt. m^{-2}		0.81***	0.63***	-0.35	0.23
Pod number m^{-2}			0.43*	-0.77***	-0.06
Seed number per pod				-0.28	0.22
1000-seed wt.					0.33

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$.

This notation is followed throughout the remainder of the thesis.

number of pods m^{-2} ($p<0.05$) and 1000-seed weight ($p<0.001$). Nugget produced the highest number of pods m^{-2} followed by Erglu, Zollerngold, Tower, Brutor and Cresus. Nugget and Erglu did not differ significantly from each other and produced a significantly ($p<0.05$) greater number of pods m^{-2} than Cresus. Cresus produced fewer pods than Brutor, Tower and Zollerngold all of which did not differ significantly from one another.

For 1000-seed wieght the order of ranking was Cresus > Brutor > Tower > Zollerngold > Erglu > Nugget.

Correlation Studies

Correlation coefficients among seed yield per m^{-2}, top plant dry weight m^{-2}, pod number m^{-2} and seed number per pod (Table 2.13) were all positive and significant (at $p<0.001$ except correlation between seed number per pod and top dry weight and between pod number m^{-2} and seed number per pod which was significant at $p<0.01$ and $p<0.05$ respectively). Correlations between 1000-seed weight and all other characters except harvest index, which was positive and non-significant, were negative. These negative correlations of 1000-seed weight were significant with dry weight per m^{-2} ($p<0.05$) and highly significant with pod number per m^{-2} ($p<0.001$). None of the correlations of harvest index with any other character was significant.

2.4 Discussion

Plant growth, divided into three stages, was similar to the model proposed by Allen and Morgan (1975). There were however differences in the duration of each stage. The seedling and vegetative growth stage extended one week more, flowering and pod formation lasted one week less and pod growth and ripening stage lasted two

more weeks than that of Allen and Morgan (1975). Such variations may simply be a reflection of environmental variations.

Leaf area at anthesis is the major determinant of yield in oilseed rape (Allen and Morgan 1975) and differences in LAI during development upto and including anthesis may reflect potential yield differences. Zollerngold in this experiment had higher LAI from W8 to W12 and it might be expected therefore that Zollerngold would have a high seed yield. However it did not show a clear seed yield superiority over the other varieties.

Leaf weight to LAI ratio in Zollerngold at W8 was smaller than any other variety, indicating that it had thin leaves. In contrast it had the highest leaf area to total dry weight ratio i.e. LAR from W6 to W14 (Table 2.9). Both these factors suggest that in Zollerngold this high leaf area could not be used to an advantage by this variety. Probably it resulted in shading of the lower leaves thus making them less photosynthetically efficient which is clearly shown from the fact that leaf weights in Zollerngold declined more quickly than in the other varieties between W8 and W10 when it was the highest. Other varieties however generally had a lower leaf area thus reducing the possibility of mutual shading within the canopy and rendering it therefore more efficient.

Another plant character of major importance in determining seed yield, is pod weight, since this reflects pod area and hence the photosynthetic potential of the plant during seed development. Pods are considered able to support themselves and the seeds in them almost entirely after they become macroscopic and until maturity. At the time when Zollerngold had higher leaf area indices (W8-W12) it had lowest pod weight suggesting that the fall in leaf area in the other varieties was being compensated by their increased pod areas.

It is suggested, therefore, with LAI, it is crucial that pod area index (PAI) is taken into account when calculating growth parameters, especially NAR in oilseed rape.

Zollerngold had the lowest pod weight at W10, possibly reflecting lateness of flowering in this variety. This was also shown by the data for inflorescence branch weight in that having been late in producing flower branches it also had lowest branch weight per plant at W10 and at W12 it was lower than Nugget, Tower and Erglu.

Pods continued to develop in Zollerngold, however, and intimately pod weight in Zollerngold reached the same level as in the other varieties at W18 (Table 2.7). By contrast Tower was the earliest to flower. This was apparent from its flower weight at W8 which was much higher than any other variety and it had almost completed flowering by W12 (Table 2.6). The earliness of Tower in flowering was also indicated by again its much greater pod weight at W10 than in any of the other varieties. However, it clearly did not maintain this large pod number and since pod shedding apparently occurred before W14 (Table 2.7) by which process it lost pod weight and by W18 it had the lowest pod weight. This resulted in its having the lowest seed weight. Pod loss at W14 was reflected in negative RGR value and very high negative value for NAR for this variety between W12 and W14.

Varieties lacked significant variation in both important growth parameters, RGR and NAR. RGR for all the varieties declined continuously throughout the harvest period, decreasing almost to zero at maturity. RGR is the product of NAR and LAR (Radford 1967). Therefore NAR is negatively correlated with LAR. In this experiment this direct

relationship was not observed for most of the data. NAR can be affected by the photosynthetic efficiency of different leaves within the canopy and weight of inflorescences (pods and branches). Had data been available for pod area and pod area index, this negative relationship could possibly have been established.

Negative RGR and NAR during W10 and W12 and W12 and W14 occurred after anthesis and were due to loss of total plant weight either from senescence of leaves or shedding of pods during the pod formation stage.

No significant differences were found for harvest index agreeing with the findings of Olsson (1960). These data however indicate that top total plant weight is closely related to seed yield in spring oilseed rape as suggested by Thurling (1974b) and Campbell and Kondra (1978). This fact is confirmed by very high ($r = 0.996$) correlation between dry weight and seed weight in this

study. In the experiment described here the varieties did not differ either in top dry weight per square metre at maturity or in harvest index, and hence there was no difference in seed yield.

The data shown that the varieties did not differ significantly for most of the characters examined during growth, and even if there were significant differences between varieties, they did not affect final seed and dry matter yield i.e. at maturity.

In spring oilseed rape (B. napus) several investigators have reported similar results for seed yield per unit area. Thurling (1974b) planted three B. napus and three B. campestris varieties at three sowing dates, the analysis of variance showed no significant seed yield per hectare differences for cultivars within species. Similarly Scarisbrick, Daniels and Alcock (1981) found non-significant differences in seed yield per hectare, in three pairs of varieties, including Orpal, Maris Haplona and Loras, at three sites with five sowing dates.

The breeding of new varieties is a continuous process. The new varieties normally are better in one or more of the several characters like higher yield, better quality, resistance to insects, diseases or lodging and early maturity. The varieties chosen in this study represent years of breeding for improved yield in oilseed rape, reflecting the increased interest in the crop by farmers and breeders alike. It is therefore interesting to note that no differences for seed yield between varieties were observed.

The non-significance of seed yield differences between the varieties may be explained due to the following factors, low fertility and yield compensation.

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Austin, Bingham, Blackwell, Evans, Ford, Morgan and Taylor (1980) while comparing new and old varieties in wheat describe two main differences between new and old varieties; new varieties are resistant to prevailing insect pests and diseases whereas old ones with the passage of time become susceptible to the diseases and pests. As the level of fertilizer input has increased for the last few decades, new varieties have been selected for growth at high levels of soil fertility, and thus their increased yield may depend on high soil fertility whereas older varieties were normally grown on soils of generally lower fertility. The experiment reported here was carried out on a sandy soil with silt. It was therefore a basically poor soil and the level of fertilizer added was not great (basic fertilizer at the rate of 120 Kg ha^{-1} and Nitrochalk (26% N) at 160 Kg ha^{-1}) compared with levels used by other workers, e.g. Thurling (1974b) who applied basic fertilizer at the rate of 224 Kg ha^{-1}, potassium chloride at 112 Kg ha^{-1}, and urea at 112 Kg ha^{-1} before sowing, and further gave urea at 112 Kg ha^{-1} at monthly intervals till maturity, and compound fertilizer at 112 Kg/ha at monthly intervals till pod filling. It is, therefore, possible that the initial low soil fertility, and the relatively modest levels of fertilizer input in this experiment were less than sufficient to allow the full yield potential of the newer oilseed rape varieties to be reached. It may be for this reason that no yield differences between old and new varieties were observed.

The lack of significant differences for seed yield was largely based on two yield components, pod number per square metre and 1000-seed weight. These components varied in such a way that a decrease in number of pods was compensated for by an increase in seed weight.

Significantly greater number of pods and lower seed weight in Nugget on the one hand and smaller number of pods and greater seed

weight on the other hand in Cresus, were responsible for this to keep the yields similar. Other varieties had medium pod number and seed weight. It was therefore due to this compensatory mechanism that seed yield did not differ significantly between varieties. Component compensation has been reported by several workers in oilseed rape (Thurling 1974b, Tayo 1974, Degenhardt and Kondra 1981) and in other field crops, field beans (Adams 1967) and barley (Adams and Grafius 1971).

Environment strongly influences seed yield which is already a complex character. In Brassica napus it is further influenced by a number of morphological and physiological factors, such as leaf area index, its duration and the photosynthetic capacity of leaves and other organs, each of which acts in a more or less complicated way (Thurling 1974b). These factors can also interact in such a way that the yield components, number of pods per plant, seeds per pod, and seed size vary, which infact determine plant yield.

In B. napus the number and sizes of pods and seeds which develop, depend to a large extent on the rate of the supply of carbon assimilates (Tayo 1974, Allen and Morgan 1975). After the pod formation stage the rape plant above ground can be visualized as a structure composed of several nutritional units (pods in inflorescences), which share approximately equally the potential characteristics of the plants genotype and of the environment, within which the available input is subjected to the competitional alternatives of pod setting and/or seed setting and/or seed development which is the basis of competition.

It is evident from experiments with various grain crops including oilseed rape that yield component compensation is an inevitable consequence of the sequential development of the component characters (for discussion of component compensation see Adams (1967), Adams and

grafius 1971). Adams (1967) argues that if components share a common metabolic pool, the input of which is limited, yield component compensation would be expected to occur if the rate of input of metabolites to the component system was either limited constantly throughout its development, or fluctuated in an oscillatory manner. In the experiment reported here, yield component compensation due to both these factors seems to have occurred. The experiment was carried out in a poor soil. Thus the rate of input of the nutrients in the first place and that metabolic products in turn may well have been limiting throughout plant development.

The formation of reproductive structures in oilseed rape involves a sequential development of pods in an inflorescence and inflorescences from axils of successively lower leaves on the main stem, so that there is a steadily increasing demand for metabolic products by the expanding inflorescences. In oilseed rape, therefore, the metabolic input of the plant during flowering would be diverted to an increasing number of growing points between and within the inflorescences, with the result that there is likely to be intense intraplant competition for metabolites between pods, developing on the main stem and axillary inflorescences. Since number of seeds per pod has a similar pattern of dry matter accumulation, regardless of the pod position (Diepenbrock and Geisler 1979), and most of the pods that set seed are produced early in the flowering of the oilseed rape plant (Tayo and Morgan 1975), the limited metabolic input would have to be partitioned among a substantially greater number of growing points (pods) within the inflorescences and proportionately smaller amount will be available to seeds developing in each individual pod. As a consequence the seeds formed in each pod in Nugget and Zollerngold were lighter (in weight), than those in Cresus and Brutor and vice versa (Table 2.12). Tower

and Erglu produced intermediate pod number and seed weight and gave similar yields.

The above results are confirmed by correlation studies. High correlation ($r = 0.996$) between top dry weight and seed weight per plant shows the importance of plant size for seed yield. High positive correlations between top dry weight, seed weight and pod number suggests that the greater the plant size (dry weight), the greater the pod number and the greater the seed yield. The negative correlation between dry weight and 1000-seed weight suggests that the greater the dry weight, the greater the pod number (high correlation between dry weight and pod number) and the less the seed weight (g/1000). The same competitive relationship between pod number and 1000-seed weight is shown by the significant negative correlation ($r = -0.77$) between the two characters and therefore a great amount of compensation. None of the yield and yield components had significant correlation with harvest index, suggesting that harvest index was not a very important yield determinant in this group of varieties.

CHAPTER 3

Genetic Basis of Yield and Yield Components in Oilseed Rape

3.1 Introduction

For a successful breeding programme in a crop species it is now recognised that the information from physiological and biometrical studies of crop yield is necessary (Poehlman 1979). In the previous chapter a study was carried out to obtain information about the accumulation of dry matter and its allocation to different plant parts, yield and yield components. The second phase of this study was to obtain information about the genetic basis of the various plant characters examined in Chapter 2. This is necessary since the type of breeding programme for a particular crop, will be determined by the nature and relative magnitudes of genetic/non genetic variation associated with the plant population and the nature of gene action governing those characters of importance in selection and breeding.

The information available about the genetic basis of yield and other qualitative characters in oilseed rape is, with the exception of oil and protein contents, meagre . Singh and Yadav (1980) in a 9 x 9 diallel cross analysis of oilseed rape (B. napus L.) found prominent non-additive gene action for seed yield. In B. campestris, one of the parents of B. napus (U 1935), Duhoon, Chandra, Basu and Makhija (1979) reported additive gene action relatively more important for seed number per pod and 1000-seed weight, whilst non-additive gene action predominantly controlled siliqua number per plant and seed yield. Putnaik and Murty (1978) from generation means of five inter varietal crosses in brown sarson (B. campestris var. Sarson) reported that both additive and non-additive gene action were important for seed yield and yield components,

maturity, and developmental characters. Epistatic effects were predominant over additive and dominance effects with an important role of duplicate epistasis for most of these characters. Moreover they found that the nature of gene action for the developmental traits was similar to those for yield and its components.

In the current investigation the diallel procedure (Hayman 1954a, b, Jinks 1954) was used to examine the genetic basis of some of the characters examined in Chapter 2 using the same varieties as were used in Chapter 2.The study was made with the objectives 1) to understand the nature of gene action, 2) to suggest the implications of the mode of gene action for breeding for improvement of yield and 3) to investigate whether the type of variation present as a consequence of selection and breeding methods differ from one region to another.

3.2 Diallel Definitions and Assumptions

A full diallel cross is the set of all possible matings between several genotypes which may be individuals, clones, homozygous lines, etc. and if they are n of these there are n^2 mating combinations, counting reciprocols separately. A diallel table is an arrangement in a square of n^2 observations from a set of diallel crosses between n parental lines. Each row and column of the square correspond to the measurements on the offspring with a common parental genotype, so that the n parents form the leading diagonal of the table and each male array (row) has a common male parent, being like the female array (column) which is of the same genotype as its common female parent.

The diallel cross design is a powerful method of estimating additive effects (a), dominance effects (b) and maternal sources

of reciprocal differences (Mather and Jinks 1977).

Before proceeding to a diallel analysis however, one must perform an ordinary analysis of variance to determine whether significant variation is present between the crosses (families) for the character under study. If significant differences are found between families for the character, then the data may be subjected to the Hayman analysis of variance to get information about the type of genetic/non genetic variation governing the character.

The diallel analysis technique includes two discrete operations (Mather and Jinks 1971). Firstly, there is the formal analysis of variance which partitions family mean effects into a (additive) and b (dominance) effects, and in addition detects maternal (c) and other sources of reciprocal effects (d). The b item may be further partitioned into directional dominance (b_1) effects, the mean deviation of the F_1s from the mid-parent values, due to parents contributing varying numbers of dominance alleles (b_2) and specific gene interaction (b_3) effects. Specific gene interactions are called by Griffing (1956) specific combining ability. General combining ability is used to designate the average performance of a genotype in hybrid combinations, whilst specific combining ability designates those cases in which certain combinations do relatively better, or worse, than would be expected on the basis of the average performance of the genotypes involved (Poehlman 1979).

The second stage of a diallel analysis is the graphic representation of the variance of all components of the rth array, Vr and the covariance of all the offspring in each parental array with the non-recurring parents,Wr. From the graph of regression of Wr and Vr the following phenomena may be detected. With full

dominance at all loci the regression line passes through the origin. Partial dominance shifts the line to the left, while overdominance shifts the line to the right. Furthermore, the position of individuals on the regression line depicts the dominance order of the parents, and the distance between points provides a measurement of the genetical diversity among the parents. (Vr + Wr) indicates the order of dominance of the parental strains.

The use of the diallel procedure is based on the following assumptions (Hayman 1954b)

1. Normal diploid segregation of chromosomes.
2. Absence of maternal effects.
3. Homozygous parents.
4. Independence of gene action.
5. No multiple alleles.
6. Unrelated distribution of genes among parents.

Failure to meet some of these conditions will cause a characteristic disturbance of the array variance, array covariance regression (Jinks 1954; Dickinson and Jinks 1956) and helps in understanding the assumption not fulfilled.

The adequacy of this model, the additive-dominance model as it is called, and hence fulfilment of assumptions for the model can be determined with the help of two tests. The consequence of the failure of those assumptions makes the model inadequate. For the additive-dominance model to be adequate and hence the fulfilment of the assumptions for the model, data should satisfy both tests. Firstly, a general test of assumptions is provided by joint regression analysis of Wr on Vr. The regression coefficient is expected to be significantly different from zero but not significantly different

from unity if all the assumptions are fulfilled (Mather and Jinks 1971). Failure of this test means that either genes show non-allelic interaction i.e. are not independent in their action, or show non-random association among the parents, i.e. are non-independent in their distribution.

The second test of adequacy of this diallel analysis is the analysis of variance of Wr + Vr. If dominance (or for that matter certain types of non-allelic interaction) is present Wr + Vr must change from array to array. At the same time if there is non-allelic interaction between the alleles, Wr-Vr will vary between arrays. Although if dominance is present, Wr - Vr will not vary more than expected from error variation.

3.3 Materials and Methods

The six varieties used in the experiment described in Chapter 2 were the basis of this experiment (Table 2.1). They were Tower and Nugget (Canada), Zollerngold and Erglu (Germany) and Cresus and Brutor (France). About twenty plants of each of these varieties were raised in 11 cm pots and selfed. Four lines derived from the S_1 seed generation, were then selected at random from each of the cultivars. These S_1 lines were used as parents for an eight x eight diallel cross.

Eight plants from each parental line were raised in 5 cm pots in John Innes I compost, in a heated greenhouse under a 16 hour photoperiod (normal day light supplemented by 400 Watt mercury vapour lamps). A complete diallel cross, including reciprocals, was made between the eight parental lines. Crosses were made by hand at the green bud stage. The buds were opened and the six

unripe anthers removed using foreceps sterilised in absolute alcohol. The stigma in these buds was dusted the next day with pollen from a ripe anther from the appropriate male parent. The buds were enclosed in a 5 cm x 8 cm non moisture proof glassine bag after emasculation and again after pollination. The remaining immature buds were removed from the plants soon after emasculation. Four to six flowers from terminal inflorescence were used on one plant. One inflorescence was used for one cross and, due to the small pot size there was only one inflorescence per plant. It was, therefore, necessary to use eight parent plants from each line for the crosses. The glassine bag was removed from the crossed plants after the young siliqua began to extend, indicating that fertilization had occurred. The pods produced from crosses were left on the plant until ripe. When ripe the pods were collected from each cross separately.

Seeds from the pods of each cross (family) were separated by hand. In some of the crosses there was no seed set and seed set was very poor in others. When arranged on the diallel table the amount of crossed seeds was only enough to give complete six x six diallel crosses for the three diallels. Since there is no restriction on the number of parental lines in an undefined diallel (Mather and Jinks 1977), six parental lines were sufficient to proceed with a valid diallel analysis.

About forty seeds from each family were germinated on a petri dish on moist filter paper. Four to six days after radical emergence the seedlings were transplanted into the field at the University of Liverpool Botanic Gardens, Ness. The experiment was laid out in a randomised block design with two replicates. Fifteen to eighteen seedlings of each family were sown per

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replication. Some of the families had less than 10 plants per replication because seed set was poor in those crosses and/or some plants died due to stem rot early after transplantation. Plants were sown in rows 45 cm apart at a distance of 2.5 cm from one another within a row. Transplanting of all the plants from the three diallel sets of crosses was completed in May 1980.

A basic dressing of ICI No.10 at the rate of 120 Kg ha^{-1} as compound fertilizer was applied before sowing. Nitrochalk fertilizer was added in two doses: (i) 90 Kg ha^{-1} with the basic fertilizer at sowing, and (ii) 70 Kg ha^{-1} top dressed before anthesis. Benlate fungicide was applied for stem rot just after transplantation. Basudin insecticide was applied twice: first one week after transplanting, the second application being 8 weeks after transplanting when an attack of cabbage root fly (Erioischae brassicae) was noted. At pod filling and seed enlargement the plants were protected from bird damage by erecting a cage of 3 cm plastic netting over the experiment.

Plants were harvested before they were fully ripe to avoid pod shattering. The plants of each family were cut at ground level and brought to the laboratory and the number of plants in each family and pod number were counted. A sample of 40 pods was taken at random to take data on number of seeds per pod and 1000-seed weight. Plants were separated into pods, flowering branches and stem (there were no leaves left on the plants) and these were dried at 37°C for seven days and weighed.

The sample of 40 pods was threshed by hand and seed number counted using the electronic counter as described in Chapter 2.

From this sample seed number per pod and 1000-seed weight were determined. The remaining pods were threshed, again using the method described in Chapter 2. Seed weight per plant was calculated from these data.

The following characters were recorded for mature plants.

1. Dry weight of inflorescence weight (all flowering branches without pods) per plant.
2. Stem dry weight per plant.
3. Pod dry weight per plant.
4. Dry weight per plant was calculated by adding the above three components.
5. Seed dry weight per plant [(a)].
6. Number of pods per plant.
7. Number of seeds per pod, and
8. 1000-seed weight[(a)].

[(a)]Seed weights were measured on seeds dried at 37°C for 7 days.

The diallel analysis procedure (Hayman loc. cit., Jinks loc. cit.) was carried out for all these characters. Computer program for this analysis was very kindly supplied by Dr. M.D. Hayward, Welsh Plant Breeding Station, Aberystwyth.

3.4 Validity of Assumptions

Chromosomal segregation in B. napus is of the normal diploid type (U 1935) although it is an amphidiploid species. B. napus is a predominantly self-pollinated crop (Free and Nuttal 1968) and about 70-80 per cent selfing takes place. The parental lines were produced by selfing over one generation, so the individuals were

approximately 90% homozygous (Poehlman 1979). Moreover the assumption that parents are homozygous is, although desirable, not essential (Kempthorne 1956), it being necessary only that the parents have the same coefficients of inbreeding. Randomisation of the families in blocks minimize environmental influences, whilst maternal effects will be shown by the significance of c item from the Hayman analysis of variance. The remaining assumptions about independence of gene action, multiple alleles and unrelated distribution of genes among parents are difficult to evaluate before hand and can only be tested following completion of the diallel analysis.

3.5 Results

3.5.1 Diallel Cross 1: Tower and Nugget: 6 x 6 diallel

The 6 x 6 diallel was conducted by taking three lines from each of Tower and Nugget varieties as parents. All the characters except seed number per pod showed significant variation between families (the relevant analyses of variance for these characters are given in Appendix 4, page 191). A Hayman analysis of variance was therefore carried out on the seven characters. The results of these analyses, giving variance ratios and significant levels are given in Table 3.1.

Dry weight per plant, stem weight per plant, inflorescence branches weight per plant, pod weight per plant, seed weight per plant and pod number per plant show the same patterns, of control of variation. The a item ($p < 0.001$) indicates significant additive gene effects and the non-additive component, b, is also significant ($p < 0.001$). The b_1 component, which gives information about directional dominance, is significant ($p < 0.05$) for dry weight per plant, pod

Table 3.1

a additive effects

b general dominance effects

b_1 directional dominance effects

b_2 effects due to unequal distribution of dominance

b_3 effects due to dominance deviations unique to F_1s

c maternal effects

d non-maternal reciprocal effects.

Table 3.1. Tower and Nugget: 6x6 diallel: three genotypes from each variety. Variance ratios and level of significance from Hayman analysis of the data for the seven characters which show significant variation.

	CHARACTER						
Item	Dry weight per plant	Stem weight per plant	Inflorescence weight per plant	Pod weight per plant	Seed weight per plant	Pod number per plant	1000-seed weight
a	10.93^{***}	13.76^{***}	11.09^{***}	6.51^{***}	8.03^{***}	22.07^{***}	8.87^{***}
b	7.32^{***}	3.74^{***}	13.46^{***}	4.78^{***}	3.78^{***}	5.69^{***}	2.11^{*}
b_1	4.49^{*}	0.61	0.74	5.68^{*}	4.00	4.44^{*}	11.52^{**}
b_2	3.02^{*}	2.79^{*}	7.36^{***}	1.51	2.03	4.26^{**}	1.66
b_3	10.03^{***}	4.61^{***}	18.26^{***}	6.50^{***}	4.73^{***}	6.62^{***}	1.31
c	11.04^{***}	5.37^{**}	18.20^{***}	7.16^{***}	7.29^{***}	11.27^{***}	1.21
d	7.08^{***}	4.14^{**}	17.29^{***}	3.71^{**}	2.92^{**}	6.01^{***}	1.09
EMS	21.00	1.50	1.00	9.3	2.50	463.70	~0.0

EMS Error mean square (= block interactions, were homogeneous, so pooled interactions were used).

weight per plant and number of pods per plant suggesting the presence of directional dominance for these characters. The non-significant b_1, item for stem weight per plant, inflorescence weight per plant and seed weight per plant indicates the absence of directional dominance for these characters. The significant b_2 component ($p<0.05$) for dry weight per plant, stem weight per plant, inflorescence weight per plant ($p<0.001$) and number of pods per plant ($p<0.01$) shows that genes for these characters are asymmetrically distributed among the parents. In contrast the b_2 item is not significant for pod weight per plant and seed weight per plant suggesting a symmetrical distribution of the genes among the parents for these characters. For all the above characters there is evidence for significant specific gene action b_3 ($p<0.001$). Both maternal effects (c) and inconsistent reciprocal differences (d) are found to be significant for dry weight per plant, inflorescence weight per plant, pod weight per plant, seed weight per plant, and number of pods per plant at $p<0.001$; c and d items for stem weight per plant; d item for pod weight and seed weight per plant at $p<0.01$.

The Hayman (1954a) analysis of the diallel cross partitions variation into additive (a), dominant (b) maternal (c) and reciprocal effects not ascribable to c (d). In general (in the absence of reciprocal differences) these effects (mean squares of a, b, c and d) must be tested against their individual interactions with blocks (B x a to B x d respectively). However, if the error variance are homogeneous, they may be pooled to give a block interaction mean square as a common error variance and all items mean squares tested against it. On the assumption of no genotype x environment interaction, and no differences between reciprocal crosses the mean squares for c and d

and the block interactions are all estimates of E, the environment component of variation. If on the other hand the c and/or d items are significant, these become the appropriate error term for a and/or b respectively (Wearden 1964).

Since c is significant for all six characters, a must be retested against c rather than against the pooled interactions mean square (Wearden 1964). When this is done the a item is found to be non-significant, suggesting no additive effects (Table 3.2). Again since d is significant for all six characters, b must be retested against the d item. When this is done the b item becomes non-significant meaning that no general dominance is revealed in the diallel analysis of these data. Thus in the material used there were neither significant additive effects nor significant dominance effects for these six characters.

Following the Hayman (1954a) analysis of the diallel table one can proceed to test the assumption that an additive-dominance model is adequate for the data. To do this it is necessary to perform two tests. First is the joint regression analysis of Wr, the covariance of the families in each parental array with the non-recurrent parents and Vr, the variance of all families of the rth array. If the slope of Wr/Vr regression is significant, does not deviate significantly from unity, but significantly differs from zero, it suggests that no non-allelic interaction is present and that the genes are distributed independently among parents. The second test for the model to be adequate is the analysis of variance of Wr and Vr. Significant differences for Wr + Vr values of arrays suggests the presence of non-additive (dominance and/or non-allelic)

Table 3.2. Summary of analysis of variance of data presented in Table 3.1 using the appropriate error terms, following Wearden (1964), c and d items having been found to be significant.

Item	Dry weight per plant	Stem weight per plant	Inflorescence weight per plant	Pod weight per plant	Seed weight per plant	Pod number per plant	1000-seed weight
a	NS	NS	NS	NS	NS	NS	***
b	NS	NS	NS	NS	NS	NS	*
b_1	NS	NS	NS	NS	NS	NS	**
b_2	NS	NS	NS	NS	NS	NS	NS
b_3	NS	NS	NS	NS	NS	NS	NS
c	***	**	***	***	***	***	NS
d	***	**	***	**	**	***	NS

Mean squares determined as follows

a item tested against significant c item from Table 3.1,

b item tested against significant d item from Table 3.1.

variation, whereas non-significant difference of Wr-Vr values of arrays suggests no non-allelic variation, but variation due to dominance is present. If the tests suggest that the additive-dominance model is adequate we may proceed to the Wr/Vr regression graph which gives information about the type of variation (additive and/or dominance) and the distribution of the alleles among parents. If either or both of the requirements are not met, it suggests that data do not fulfill the assumptions of the model, and therefore the model is unsuitable forthe data analysis.

The results for 1000-seed weight indicate significant additive effects (a item, $p < 0.001$). The b ($p < 0.05$) and b_1 ($p < 0.01$) components were also shown to be significant. None of the other effects were significant however. The joint regression analysis of Wr on Vr was carried out, b was not significantly different from unity (Table 3.3) suggesting that the additive-dominance model was adequate for the data set for this character. However analysis of variance of Wr and Vr invalidated the model.

For none of the characters in this diallel, the data adequately fit the simple additive - dominance model. This being the case, it is not legitimate to produce graphs of regressions of Wr on Vr.

3.5.2 Diallel Cross 2: Zollerngold and Erglu: 6x6 diallel

The ordinary analysis of variance (Appendix 5, page 192) showed significant variation ($p < 0.05$) for all the eight characters recorded in the 6 x 6 diallel of the lines from Zollerngold and Erglu. Hayman analysis of variance (loc. cit.) were therefore carried out for all these traits. These are given in Table 3.4, and indicate the following.

Table 3.3. Tests of adequacy of the additive-dominance model (joint regression analysis and Wr/Vr analyses of variance) for the characters with significant variation for 6x6 diallel cross of the lines taken from Tower and Nugget.

Character	Joint regression analysis	Analysis of variance of arrays		Conclusions
		Wr + Vr	Wr - Vr	
Dry weight per plant	$b = 0.132 \pm 0.05$ $\underline{b}$ is significantly different from unity $\underline{b}$ is " " " zero	***	***	Model is inadequate, shown by both tests.
Stem weight per plant	$b = 0.213 \pm 0.05$ $\underline{b}$ is significantly different from unity $\underline{b}$ " " " " zero	*	*	Model is inadequate, shown by both tests.
Inflorescence weight per plant	Regression is not significant	***	***	Model is inadequate, shown by both tests.
Pod weight per plant	Regression is not significant	***	***	Model is inadequate, shown by both tests.
Seed weight per plant	Regression is not significant	*	***	Model is inadequate, shown by both tests.
Pod number per plant	$b = 0.039 \pm 0.039$ $\underline{b}$ is significantly different from unity $\underline{b}$ " " " " zero	*	***	Model is inadequate, shown by both tests.
1000-seed weight	$b = 1.020 \pm 0.159$ $\underline{b}$ is not significantly different from unity $\underline{b}$ " " " " zero	NS	**	Joint regression analysis suggests model to be adequate but analyses of Wr and Vr invalidate the model

The significant a item for stem weight per plant, seed weight per plant, seed number per pod and 1000-seed weight, ($p < 0.001$), and for dry weight per plant, inflorescence weight per plant, pod weight per plant ($p < 0.01$), and for pod number per plant ($p < 0.05$), indicates significant additive genetic effects. The non-additive component b is also shown to be significant at $p < 0.001$ for inflorescence weight per plant and seed weight per plant, at $p < 0.01$ for dry weight per plant and pod number per plant, and at $p < 0.05$ for stem weight per plant, pod weight per plant, seed number per pod and 1000-seed weight. The non-significant b_1 component for dry weight per plant, stem weight per plant, inflorescence weight per plant, pod weight per plant, pod number per plant and 1000-seed weight suggests the absence of directional dominance. However, for seed weight per plant and seed number per pod b_1 is significant ($p < 0.001$ and $p < 0.01$ respectively) and these indicate directional dominance. The significant b_2 item shows that the genes are asymetrically distributed among the parents for dry weight, stem weight, inflorescence weight, seed weight and pod number per plant. The b_2 was however non-significant for pod weight per plant, seed number per pod and 1000-seed weight suggesting symmetrical gene distribution for these characters. There is significant evidence for specific gene action (b_3 item) for all the characters except stem weight. Maternal effects (c) were found to be significant for inflorescence weight ($p < 0.05$), seed weight per plant ($p < 0.001$) and 1000-seed weight ($p < 0.01$) and inconsistant reciprocal differences (d) were found to be significant ($p < 0.001$) for all the characters except 1000-seed weight (significant at $p < 0.01$ and seed number per pod (non-significant). Again following Wearden (1964) the significance of

Table 3.4. Zollerngold and Erglu: 6x6 diallel: three genotypes from each variety. Variance ratios and level of significance from Hayman analysis of the data for the eight characters which show significant variation.

Item	Dry weight per plant	Stem weight per plant	Inflorescence weight per plant	Pod weight per plant	Seed weight per plant	Pod number per plant	Seed number per pod	1000-seed weight
	CHARACTER							
a	4.02**	6.10***	4.17**	4.06**	10.47***	2.75*	7.01***	6.32***
b	3.39**	2.52*	4.75***	2.49*	9.10***	3.19**	2.54*	2.46*
b_1	0.07	0.10	3.54	0.00	15.97***	2.58	7.55**	1.11
b_2	3.39*	4.17**	4.78**	2.33	5.68***	2.80*	2.07	2.18
b_3	3.75**	1.87	4.87***	2.85*	10.23***	3.48**	2.25**	2.77*
c	2.16	2.44	3.14*	1.76	6.74***	2.17	0.75	4.19**
d	7.37***	4.95***	11.32***	4.91***	14.18***	6.23***	1.37	3.62**
EMS	50.9	1.70	1.80	31.40	1.60	1210.3	7.80	~0.0

EMS Error mean square (block interactions were homogeneous, so pooled interactions were used).

items have to be retested against the appropriate error terms (Section 3.5.1) and the results of this modification are given in Table 3.5. For all the characters except inflorescence weight, seed weight and 1000-seed weight additive effects were present but dominance effects became non-significant for all characters except seed number per pod (significant at $p<0.05$).

For all the characters except stem weight per plant, the regression of Wr on Vr was not significant, suggesting the failure to meet the assumption of non-allelic interaction and/or non-random distribution of genes among parents. By analysis of Wr and Vr, non-additive variation was indicated for inflorescence weight, seed wt.and stem weight per plant, seed number per pod and 1000-seed weight and it was shown as non-allelic interaction for pod weight, seed weight and seed number per pod.

Thus joint regression analyses and analyses of variance of Wr and Vr of arrays indicated that the additive-dominance model was not adequate based on one or both these tests (Table 3.6) except for stem weight per plant. In the presence of inconsistent reciprocal effects (Table 3.5), it would not give very clear picture about the inheritance of this character.

3.5.3 Diallel Cross 3: Brutor and Cresus: 6x6 diallel

Variation between family means was significant at $p<0.05$ for dry weight per plant, seed weight per plant and pod weight per plant, and at $p<0.001$ for seed number per plant (Appendix 6, page 193) out of the eight characters recorded. Hayman analysis of variance was therefore carried out for these four characters. The results of the analysis are shown in Table 3.7.

Table 3.5. Summary of analysis of variance of data presented in Table 3.4 using the appropriate error terms following Wearden (1964), c and d items having been found to be significant.

Item	Dry weight per plant	Stem weight per plant	Inflorescence weight per plant	Pod weight per plant	Seed weight per plant	Pod number per plant	Seed number per pod	1000-seed weight
a	**	***	NS	**	NS	*	***	NS
b	NS	NS	NS	NS	NS	NS	*	NS
b_1	NS	NS	NS	NS	NS	NS	**	NS
b_2	NS	NS	NS	NS	NS	NS	NS	NS
b_3	NS	NS	NS	NS	NS	NS	*	NS
c	NS	NS	*	NS	***	NS	NS	**
d	***	***	***	***	***	***	NS	**

Mean square determined as follows

a item tested against significant c item from Table 3.4.

b item tested against significant d item from Table 3.4.

Table 3.6. Tests of adequacy of the additive-dominance model (joint regression analyses and Wr/Vr analysis of variance) for the characters with significant variation for 6x6 diallel cross of the lines taken from Zollerngold and Erglu.

Character	Joint regression analysis	Analysis of variance of Wr+Vr	Analysis of variance of Wr-Vr	Conclusions
Dry weight per plant	Regression is not significant	NS	NS	Regression analysis invalidates the model
Stem weight per plant	b = 0.89±0.182 b is not significantly different from unity b is significantly different from zero	***	NS	Model is adequate shown by both tests
Inflorescence weight per plant	Regression is not significant	*	NS	Regression analysis invalidates the model
Pod weight per plant	Regression is not significant	NS	*	Model is inadequate shown by both tests
Seed weight per plant	Regression is not significant	***	*	Model is inadequate, shown by both tests
Pod number per plant	Regression is not significant	NS	NS	Regression analysis invalidates the model
Seed number per pod	Regression is not significant	*	***	Model is inadequate shown by both tests
1000-seed weight	Regression is not significant	***	NS	Regression analysis invalidates the model

Dry weight per plant, seed weight per plant and pod weight per plant show similar patterns for the genetic components of variation. The non-significant a item indicates absence of additive genetic effects. The general dominance component (b) is shown to be significant ($p < 0.01$), whilst the non-significant b_1 component ($p > 0.05$) suggests no directional dominance. The b_2 component was found to be significant ($p < 0.01$) indicating that some parents contain more dominance alleles than others. The b_3 item was significant ($p < 0.05$) and gave an indication for the presence of specific gene interaction. Maternal effects (c) were found to be non-significant and there was no evidence for inconsistent reciprocal differences.

The analysis for seed number per pod (Table 3.7) indicated additive effects (a, $p < 0.01$). The dominance (b) item and its b_1 and b_3 components were also shown to be significant. But the analysis of regression (Table 3.8, b significantly different from unity $p < 0.05$) showed that additive-dominance model was not adequate. The inadequacy of the model was verified by the analysis of variance of Wr and Vr. So no further analyses were carried out for seed number per pod.

The additive-dominance model was shown to be adequate by both the tests for dry weight, seed weight and pod weight per plant (Table 3.8). Wr/Vr regressions for these characters are shown in Figures 3.1 to 3.3. From an examination of these graphs it is clear that all these characters behave in the same manner. Regression coefficients are nearly equal and the parental points are scattered on the graph in the same positions.

The slope (b) of the regressions of Wr on Vr are not significantly different from unity for all three characters, suggesting no non-allelic

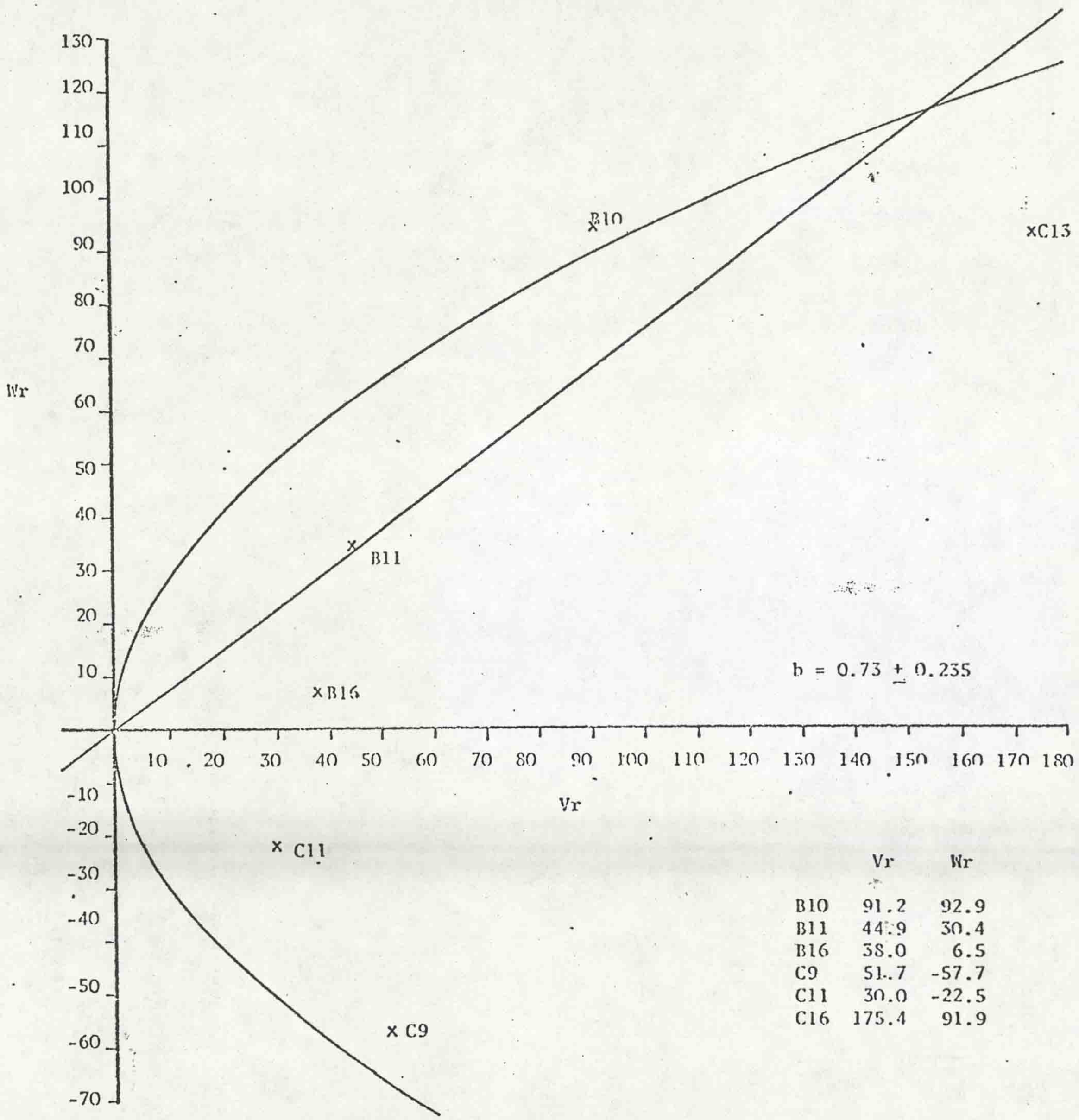
Table 3.7. Brutor and Cresus: 6x6 diallel: three genotypes from each variety. Variance ratios and level of significance from Hayman analysis of the data for the four characters which show significant variation.

Item	CHARACTER			
	Dry weight per plant	Seed weight per plant	Pod weight per plant	Seed number per pod
a	1.33	1.01	1.39	4.09^{**}
b	2.96^{**}	3.95^{***}	3.38^{**}	4.60^{***}
b_1	0.00	0.35	0.04	5.41^{*}
b_2	3.61^{**}	4.02^{**}	3.68^{**}	2.18
b_3	2.92^{*}	4.31^{**}	3.58^{**}	5.86^{***}
c	0.25	0.15	0.22	1.51
d	0.85	0.87	0.87	0.79
EMS	32.90	2.30	10.70	4.60

EMS Error mean square (were homogeneous, so pooled interactions were used).

Table 3.8. Tests of adequacy of additive-dominance model (joint regression analysis and Wr/Vr analysis of variance) for the characters with significant variation for 6x6 diallel cross of the lines taken from Brutor and Cresus.

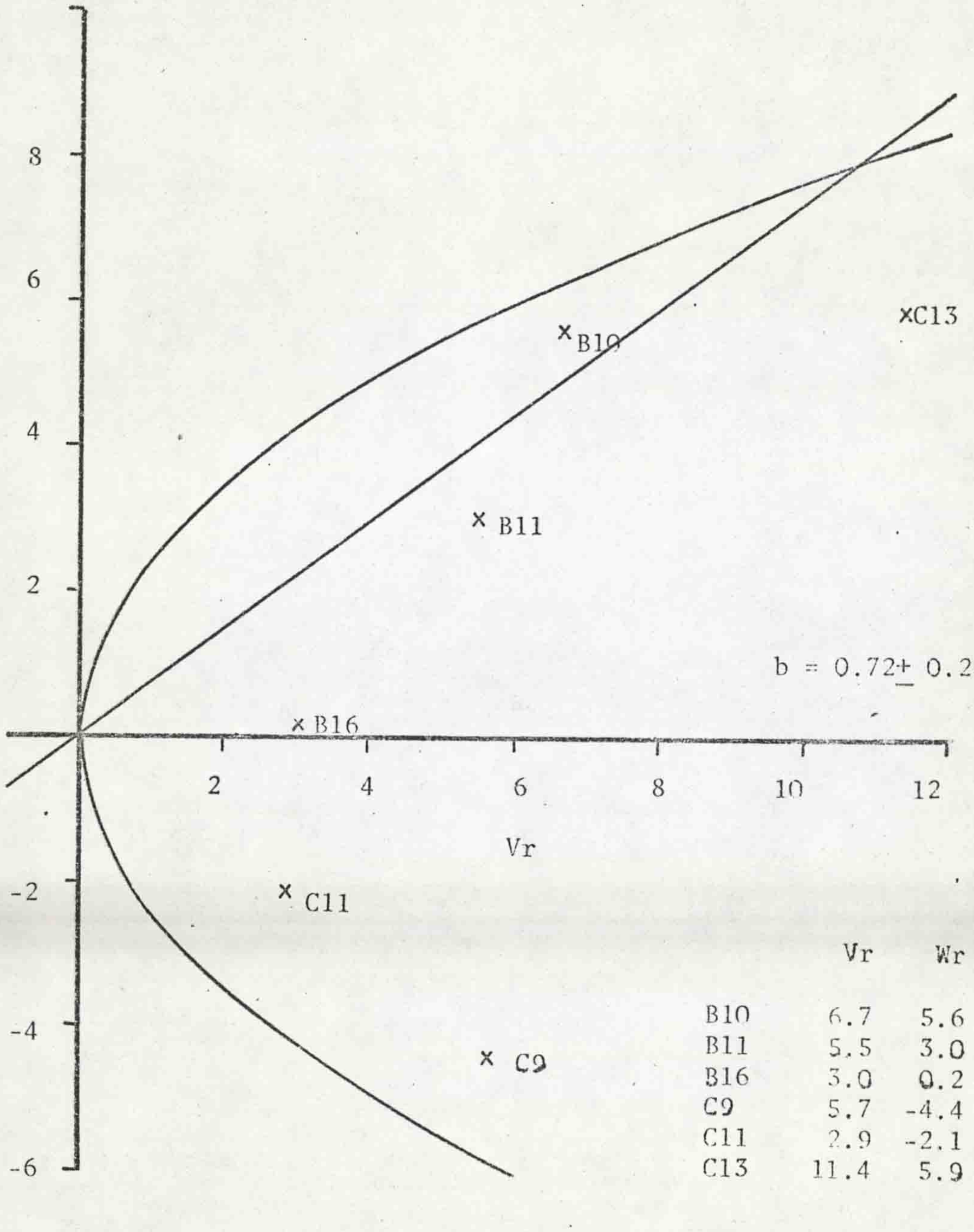
Character	Joint regression analysis	Analysis of variance of arrays		Conclusions
		Wr + Vr	Wr - Vr	
Dry weight per plant	b = 0.731 ± 0.235 b is not significantly different from unity b is significantly different from zero	*	NS	Model is adequate shown by both tests
Pod weight per plant	b = 0.734 ± 0.255 b is not significantly different from unity b is significantly different from zero	*	NS	Model is adequate, shown by both tests
Seed weight per plant	b = 0.723 ± 0.264 b is not significantly different from unity b is significantly different from zero	*	NS	Model is adequate, shown by both tests
Seed number per pod	b = 0.619 ± 0.122 b is significantly different from unity b is significantly different from zero	***	**	Model is not adequate, shown by both tests



	Vr	Wr
B10	91.2	92.9
B11	44.9	30.4
B16	38.0	6.5
C9	51.7	-57.7
C11	30.0	-22.5
C16	175.4	91.9

Fig. 3.1. Wr/Vr Graph for total dry weight per plant from the lines of Brutor (B10,B11,B16) and Cresus (C9,C11,C16) cultivars.

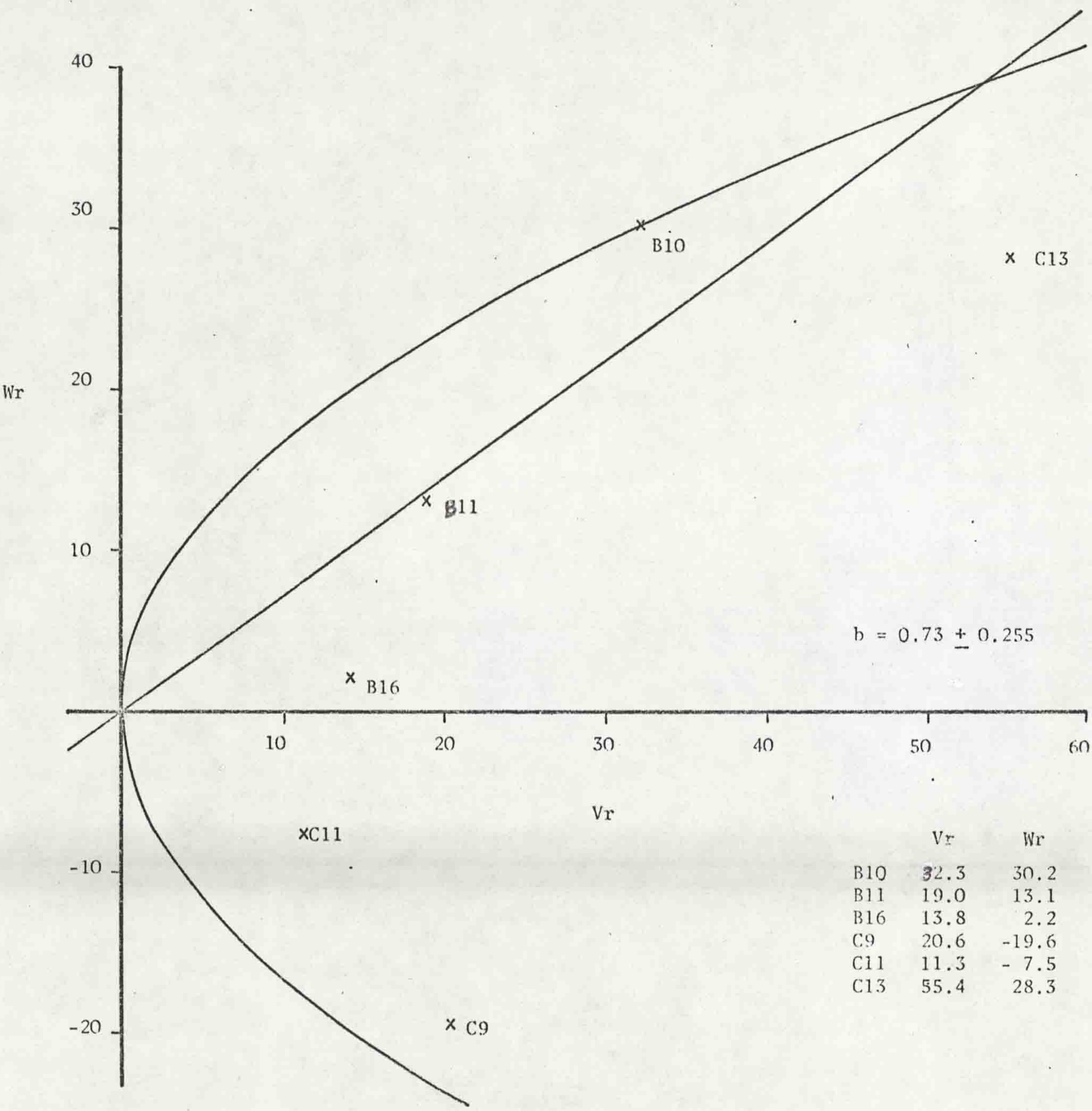
page



b = 0.72± 0.264

	Vr	Wr
B10	6.7	5.6
B11	5.5	3.0
B16	3.0	0.2
C9	5.7	-4.4
C11	2.9	-2.1
C13	11.4	5.9

Fig.3.2. Wr/Vr Graph for seed weight per plant from the lines of Brutor (B10,B11,B16) and Cresus (C9,C11, C13) cultivars.



	Vr	Wr
B10	32.3	30.2
B11	19.0	13.1
B16	13.8	2.2
C9	20.6	-19.6
C11	11.3	- 7.5
C13	55.4	28.3

Fig. 3.3. Wr/Vr Graph for pod weight per plant from the lines of Brutor (B10, B11, B16) and Cresus (C9, C11, C13) cultivars.

interaction and an independence of genes among the parents. The regression lines cut the Wr-axis at the origins suggesting the presence of complete dominance. This agrees with the Hayman analysis of variance (Table 3.7) in that there was only significant dominance effect (b) shown but no directional dominance (b_1) indicating full dominance. However the correlation of Wr + Vr of arrays with common parents is not significant (r = 0.5) suggesting an ambidirectional dominance.

If the model is shown to be adequate, the components of variation D,H_1,H_2,F and E may be estimated. D measures only additive effects, H_1 and H_2 measure only dominance effects and H_1 has the same coefficient as D (for detail see Mather and Jinks 1971), so that the square root of the ratio of H_1 to D is a measure of degree of dominance, the ratio of 1/4 H_2 to H_1 measures the average value of uv (where u is frequency of increasing allele and v = 1-u, is the frequency of decreasing allele) over all loci. In the presence of unequal gene frequencies the sign and magnitude of F determines the relative frequencies of dominant to recessive alleles in the parental population and the variation in the dominance level over loci. F is positive whenever the dominance alleles are more frequent than the recessive alleles, irrespective of whether or not the dominant alleles are increasers or decreasers. E is environmental component and is derived from the block interactions of the family means, when the interactions do not differ significantly.

The relative sizes of D and H_1 from Wr/Vr analysis (Table 3.9) indicated $H_1 > D$ suggesting the presence of (full) dominance, the same being shown by high dominance ratios (nearly 1.50) for these characters.

Table 3.9. Components of genetic variation for dry weight per plant, seed weight per plant, pod weight per plant for 6x6 diallel of the lines from Brutor and Cresus.

Item	Dry weight per plant	Seed weight per plant	Pod weight per plant
D	53.7	3.6	17.7
H_1	95.4	8.8	35.2
H_2	71.2	6.8	26.9
F	82.1	6.1	27.1
Dominance ratio $(H_1/D)^{1/2}$	1.33	1.55	1.41
Mean uv $(H_2/4H_1)$	0.19	0.19	0.19
E	32.9	2.3	10.7

D additive effects

H_1 and H_2 dominance effects

F frequency of dominance alleles

E Environmental component of variation

$H_2 < H_1$ which suggests unequal frequencies of dominant and recessive alleles. The same is suggested by uv value which is 0.19 less than its maximum value (0.25 when u = v = 0.5) suggesting unequal frequency of dominant and recessive genes.

From the position of parental lines on the Wr/Vr graph, it is possible to determine the distribution of dominant and recessive genes in the parent lines. The relative values of Wr and Vr show that C13 and B10 have the highest values and hence have the highest proportions of recessive genes. C9 has the lowest values and will therefore contain most dominant genes. The other lines fall between these extremes in the order of C13, B10, B11, B16, C11 and C9 and have the dominant and recessive alleles accordingly.

3.6 Discussion

The results for dry weight, stem weight, inflorescence weight, pod weight, seed weight and pod number per plant from the diallel Set 1 (Tower and Nugget) showed that there were significant additive effects but the presence of maternal effects made these non-significant. Similarly dominance effects were made non-significant by the presence of inconsistent reciprocal effects. This indicated thatall the variation present was masked by maternal and inconsistent reciprocal effects. These characters therefore behaved in the similar way indicating neither additive nor dominance effective effects when the appropriate tests against maternal and reciprocal effects respectively were carried out.

For the above six characters in diallel 1, failure of the joint regression analysis suggests that non-allelic interaction is present and that genes are not independently distributed among parents. The

presence of non allelic interaction was confirmed by the analysis of variance of Wr and Vr. Significant Wr + Vr values of the arrays suggested the presence of non-additive variation and significant Wr-Vr values of the arrays suggested that the non-additive variation was due to non-allelic interaction.

For 1000-seed weight in diallel 1 (Tower and Nugget), presence of additive and dominance, and absence of maternal and reciprocal effects was shown. Joint regression analysis suggested the additive-dominance model to be adequate suggesting that genes were distributed independently among parents but analysis of variance of Wr and Vr indicated the presence of non-allelic interaction and thus rendered the model inadequate.

The analysis of results from the 6 x 6 diallel set 2 (Zollerngold and Erglu) for dry weight per plant, stem weight per plant, inflorescence weight per plant, pod weight per plant, seed weight per plant, seed number per pot and 1000-seed weight showed significant additive and dominance effects. The presence of maternal effects (c item) for inflorescence weight and seed weight per plant, and 1000-seed weight made additive effects non-significant. There were inconsistent maternal effects (d) for all the eight characters except seed number per pod. Hence, the presence of these inconsistent maternal effects made dominance effects non-significant in all these characters except seed number per pod.

For seed number per pod in diallel 2 (Zollerngold and Erglu) and in diallel set 3 (Brutor and Cresus) though maternal and reciprocal inconsistent effects were absent but both the tests suggested model to be inadequate probably for the presence of non-

allelic interaction.

Thus the model was rendered inadequate largely through reciprocal effects (c and d items). The reciprocal effects may also be shown if inbreeding of the parental lines is not completely effective and some (residual) variation remains in them. This can occur if precisely the same parents have not been used in making the reciprocal crosses (Mather and Jinks 1977). In this investigation the crosses were made from plants which had been selfed for one generation only, and they were highly unlikely to have been completely homozygous. Furthermore eight different plants were used for all possible diallel crosses because of the smaller pot and therefore plant sizes and one inflorescence only being used for one cross (Section 3.3). No account in a particular cross was kept of the pollen source and hence identification of truly reciprocal crosses was not possible, and records of reciprocal differences might have arisen for these reasons.

On the other hand if reciprocal effects were in fact present, this infers that the assumption of the absence of non-reciprocal differences, which may be due to epistatic or non-nuclear factors, were not met. The presence of epistatic effects have been reported in B. campestris var. Sarson (Putnaik and Murty 1978), and may also occur in B. napus. There is however less possibility of epistatic effects in diallel set 1 because it is known that Tower and Nugget have some ancestors in common (Downey, Stringam and McGregor 1975). Whatever the cause of the failure to meet the diallel assumptions, it is clear that a more complex genetic system is involved in the control of the characters in which the model was rendered inadequate, than that described by the diallel analysis (Hayman 1954a,b, Jinks

1954). The same conclusion is reached from the analyses of Wr and Vr, for the characters in which reciprocal effects are non-significant. In this case non-allelic interaction may be responsible. It thus seems clear from these data that very complex genetic mechanism governs variation in all these characters of the diallels.

The additive-dominance model was shown to be adequate for dry weight, seed weight and pod weight per plant in diallel set 3 (Brutor and Cresus) and there were only significant dominance effects. The presence of dominance effects without additive variation means that no progress can be made by selection suggesting no genetic variation which can be exploited. Non-significant additive effects for these characters in the diallel cross may however be due to the lack of genetic variability for the characters in question, and it may be that all the parents have more or less the same genes for the characters. This would mean that there would be no genetic variation to detect.

The parents in the diallel set of Brutor and Cresus were chosen from a pair of varieties bred in France. It has not been possible to ascertain the direct relationship between cultivar Cresus and cultivar Brutor. However it may well be that the varieties are quite closely related, the use of better performing parents and parents with good general combining ability tending to be preferred in breeding programmes. Hence the diallel analysis may have been invalidated for seed number per pod and no additive variability was shown for dry weight, seed weight and pod weight per plant because of the low genetic variability between parental lines.

It is surprising to note however that no additive variation was found, and that the parents showed ambidirectional dominance . Ambidirectional dominance would be expected for characters under stabilizing selection (Mather 1973) in a situation in which no additive variation is left. Cresus is an old, and Brutor the newly evolved variety. New varieties have been selected for higher yields which should have under directional selection and should have altered the constitution of yield and yield components in the new variety. Though strange, it was noted in Chapter 2, that Cresus and Brutor did not differ significantly in seed and dry yield, and the three lines were selected from each of these two varieties. Experiment was sown in same soil, at the same season and the similar cultural and fertilizer inputs were given as in the experiment described in Chapter 2, it was probably no significant differnces between the parental lines used (significant variation observed may have been shown significant by large error degree of freedom). Perhaps the inclusion of more parents (more variable varieties) would provide data more adequately fitting the diallel model.

For two diallel sets (Tower and Nugget, and Zollerngold and Erglu) out of the three 6 x 6 diallels carried out the additive-dominance model was found to be inadequate and for the third set (Brutor and Cresus) data for dry weight, seed weight, and pod weight per plant . adequately fitted the model, but no additive effects were found. This may be a further reflection of the extreme phenotypic plasticity, observed in Chapter 2 in oilseed rape.

The failure of the three diallel analyses to show significant additive genetic variation may be due to a number of factors.

Firstly, component compensation is a phenomenon widely reported in oilseed rape (Tayo 1974, Thurling 1974b, Degenhardt and Kondra 1981) and was noticed in the experiments described here. The correlation coefficients between yield and yield components are shown in Table 3.10. Correlation coefficients between seed yield per plant and dry weight, pod number and pod weight per plant are positive and significant ($p < 0.001$) and negative between 1000-seed weight and yield and all other components, i.e. component compensation, which is discussed in Chapter 2 and it may have masked the mechanisms which govern gene action for characters showing compensation.

Secondly, the nature of the genetic material used in these diallel sets may be such that there were not sufficient differences between the lines. In each set the lines were selected from two varieties produced in the same country. It is possible that differences between lines were not big enough to be detected by the Hayman analysis of variance. It can be inferred that in most of the characters studied a more specific breeding test would be necessary or the assumption of homozygous parents (advanced selfed generations) and also the use of same plants for reciprocal crosses should be attempted for these diallels.

Thirdly, the soil fertility and other environmental factors may have been responsible for hiding the genetic behaviour of the genotypes. Ness soil and fertilizer application was the same as for that of the experiment conducted in Chapter 2. It has been that one of the factors which may have been largely responsible for the lack of significant differences between variety yields was poor soil fertility and the application of low fertilizer. In such a situation, the varieties and the lines not having optimum conditions of growth could not exploit their full potential. This condition was

CHAPTER 1

Rapeseed as a World Oil Crop

1.1 Introduction

Vegetable oil has been utilized by man since ancient times. In the past it was mainly used for lighting and lubrication. Nowadays it has uses both in the food and other chemical industries. A large number of plant species are known to contain oil, but only about forty trees and plants have been used for the commercial production of vegetable oils. Most of these species are grown intensively and their oil products are largely for domestic use. Only a small number of oil crops enter world trade. At present nine crops make up about 90% of international trade in oils of vegetable origin. These crops are soybean, cotton seed, groundnut, sunflower, rapeseed, copra, linseed, palm oil and palm kernal (King 1978).

Total annual world rapeseed production amounts to over ten million tonnes and it ranks fifth among oilseed crops after soybean, cotton seed, groundnut and sunflower (FAO Production Year book, 1978). In terms of oil equivalent, rapeseed provides approximately 10% of world vegetable oil production.

Rapeseed is a common term used to describe the seed from Brassica campestris L. and Brassica napus L. (Downey 1971, King 1978). The English word "rape" is derived from the Latin word "rapum" meaning turnip. In the world market, though, rapeseed oil includes the oil from a third species, Brassica juncea L. commonly called brown mustard. In Asia the rapeseed crop is sometimes grown as a mixture of B. campestris and B. juncea, the crop being used locally and it does not enter the world market. The two species are commonly

Table 3.10. Correlation coefficients (r) between yield and yield components of 6x6 diallel crosses from lines of Brutor and Cresus varieties.

	Pod number per plant	Pod weight per plant	Seed weight per plant	1000-seed weight	Seed number per pod
Dry weight per plant	0.96***	0.99***	0.97***	-0.12	0.42***
Pod number per plant		0.95***	0.91***	-0.19	0.36**
Pod weight per plant			0.98***	-0.09	0.46***
Seed weight per plant				-0.10	0.57***
1000-seed weight					-0.28*

exaggerated by another factor. In the start of the experiment it was dry weather and after June the weather became extremely wet (Appendix 1, page 188).

These factors may well have contributed to a distortion of the expression of genetic differences in yield and yield components. Nonetheless significant variation was present in the lines as shown by analyses of variance (Appendix 4-6) and it was therefore valid to apply the diallel technique.

CHAPTER 4

Variation in Yield and Yield Components in Six Varieties of Spring Oilseed Rape

A greenhouse experiment with spring rape.

4.1 Introduction

Plant breeders work with phenotypes. The phenotype is variable and the variation in the phenotype is the product of variation in the genotype and variation caused by the environment directly, and also specific effects due to the interaction of specific genotypes and environments termed genotype environment interaction (g x e). The occurrence of genotype - environment interaction makes the task of plant breeders difficult because the environment, and therefore g x e is made up of extremely variable factors. Genotypes can be selected and controlled, but environment and thus the g x e, is very difficult to control. Variation in the environment of a plant is caused by many factors such as differences in the physical and chemical properties of soil, climatic fluctuations, and management and treatment differences (fertilizer and other agronomic practices). The examination of g x e is important for plant breeders in general but particularly in a crop like oilseed rape which is expanding.

The existence of genotype x environment interactions has long been realized. The earliest reference to the phenomenon (Fisher and MacKenzie 1923) preceeds the analysis of variance. Comstock and Moll (1963) explained the definitions, terms and symbols concerning g x e and discussed its implications for biometrical genetics and plant breeding. Allard and Bradshaw (1964) reviewed previous work, emphasizing the importance of interactions, particularly varieties x years, to plant breeders. Yates and Cochran (1938) gave a method of partitioning g x e

effects. This was modified by Finlay and Wilkinson (1963) who rediscovered and used it in modified form for an analysis of adaptation in a trial with 277 varieties of barley in seven environments. This is now commonly called the joint regression analysis, or Finlay-Wilkinson technique. In this technique, a linear regression of individual variety performance on mean performance of all varieties for each different environment (environmental mean) is computed. In this way the mean yield of a group of varieties is used to describe a complex natural environment so that the complexities of defining or analysing interacting environmental factors is avoided. The two important statistics obtained by this technique are the regression coefficient of variety mean yield on environmental mean, and individual variety mean yields over all environments. Regression coefficients approximating to 1.0 indicate average stability. Regression coefficients which are more than 1.0 indicate increasing sensitivity to environmental change. This reflects below average stability for the genotype or variety concerned and specific adaptability to high yielding environments. Regression coefficients which are less than 1.0 reflect a reduced response to environmental change, an above average stability of performance and an increased specific adaptability to low yielding environments. Variety means over all environments provide a measure of the overall performance of individual varieties. A regression coefficient of 1.0 when associated with high overall mean yield, reflects varieties with good general adaptability. A regression coefficient of 1.0 associated with low yield reflects varieties which are poorly adapted to all environments.

Eberhart and Russell (1966), and Breese (1969), extended this technique to include deviations from regression, as estimates of unpredictable irregularities of response so that a stable variety

should have deviations from the regression not significantly different from zero. In spite of some objections (Knight 1970), critical re-examination of the joint regression technique (Perkins and Jinks 1968, Kaltsikes and Larter 1970, Samuel, Hill, Breese and Davies 1970, Breese and Hill 1973), it has proved the most useful means yet available for assessing stability of plant variety or species.

The objective of this experiment was to assess the extent if any of g x e in oilseed rape by growing seven varieties from a wide range of backgrounds, on three different soils at two densities using seed yield and its components as measure of plant performance. The experiment also examined the way in which yield and yield components interact. From the data it was hoped that varieties with different degrees of environmental stability could be identified.

4.2 Materials and Methods

Seven summer type varieties of Brassica napus were used in this study, Brutor, Bronowski, Erglu, Gulle, Janus, Janetski, and Tower. The country of origin and year of release of the varieties used are given in Table 4.1.

Table 4.1. Country of origin and year of release of summer B. napus cultivars.

Variety	Country of Origin	Year of release
Bronowski	Poland	1955
Gulle	Sweden	1969
Erglu	Germany	1969
Janetski	Germany	1942
Janus	France	1969
Brutor	France	1978
Tower	Canada	1974

The experiment was carried out in a heated greenhouse under a 16 hour photoperiod (normal day light supplemented by 400 watt mercury vapour lamps) at the University of Liverpool Botanic Gardens, Ness. A split plot design with three replications was used, with soils as main plots, and varieties and density combinations randomised in subplots. A split plot design was used because it was convenient to make soil blocks in the greenhouse and randomise treatments within each block. Three soil fertility levels were used, (i) sandy soil from Ness Gardens representing low soil fertility (S1), (ii) John Innes Compost I (S2) and (iii) a high fertility soil obtained by doubling the amount of John Innes base fertilizer added to the standard John Innes mix (S3). Wooden boxes 91 cm x 320 cm x 26 cm were constructed for soil blocks. Three blocks, each with a different soil type comprised one replication. These blocks were partitioned into 46 cm x 46 cm compartments which were lined with polythene, leaving holes in the bottom for drainage. The compartments of each of the boxes were filled to within 3 cm of the top with the appropriate soil. Seed of each of the seven varieties was sown into subplots in all possible combinations of variety and density, within each block. Seed was sown at two densities, 18 and 25 seeds per 46 x 46 cm^2 plot obtained by sowing them in rows 6.5 cm and 5 cm apart respectively. Two to three seeds were sown per hill to ensure germination of one plant per hill. Sowing of the seed was completed on 23rd December 1978.

Germination of all the varieties except Janus was completed 10 days after seeding. Janus showed very poor germination, and was therefore abandoned, the experiment thus having six varieties. After germination was complete, plants were thinned to leave one seedling per hill. Where there was no germination, spares of the same age

were used to fill the gaps. During summer 1979 the greenhouse doors had to be kept open to encourage cooling of the house. This caused draughts and extensive damage to one block which had to be discarded.

At maturity the eight central plants in each subplot were harvested from each treatment by cutting at ground level and data on the following characters (each character mean of 8 plants per treatment for replication) recorded.

1. Top dry weight per plant.
2. Seed weight per plant.
3. Pod number per plant.
4. 250-seed weight.

Harvest index was calculated by dividing seed weight per plant by top dry weight per plant. One thousand seed weight was obtained from 250-seed weight x 4. Seed weight per pod, and seed number per pod were estimated from seed weight per plant, pod number per plant and 1000-seed weight. To avoid loss of seeds and pods plants were harvested before the pods were fully ripe.

Analyses of variance were carried out on the data for the characters studied. Simple correlations between seed yield and yield components were computed. Because the soil-density interaction was significant, it was felt justified to proceed to the joint regression analysis of these data following Finlay and Wilkinson (1963). The joint regression technique was carried out for seed yield per plant only.

4.3 Results

Soil fertility level, density and variety means for seed yield per plant, top dry weight per plant, number of pods per plant, seed number per pod, seed weight per pod, 1000-seed weight and harvest index are given in Table 4.2. Because items are generally not

Table 4.2. Seed yield and yield components at maturity for six summer varieties of B. napus grown at three soil fertility levels and two densities.

	Seed weight (g plant^{-1})	Dry weight (g plant^{-1})	Pod number per plant	Seed number per pod	1000-seed weight (g)	Seed weight per pod (mg)	Harvest index
Soil fertility levels							
Low	0.91	4.06	18.93	12.15	4.08	48.0	0.22
Medium	1.01	4.45	20.77	11.64	3.75	43.0	0.20
High	1.32	5.88	24.82	13.30	3.83	49.0	0.21
LSD	NS	NS	NS	NS	NS	NS	NS
Densities							
5 cm	0.92 b	4.12 b	19.29	12.25	3.77	45.0	0.21
6.5 cm	1.25 a	5.48 a	23.72	12.48	4.00	48.0	0.21
LSD	0.32*	0.82	NS	NS	NS	NS	NS
Varieties							
Bronowski	1.17	4.71	23.82	16.42 a	2.90 c	48.0	0.24
Brutor	1.06	4.67	20.48	10.14 b	4.48 a	44.0	0.19
Erglu	1.06	4.28	21.99	13.26 ab	3.48 bc	46.0	0.23
Gulle	1.19	5.24	21.42	12.36 b	4.17 ab	53.0	0.21
Janetski	1.14	5.21	22.31	11.55 b	4.07 ab	46.0	0.21
Tower	0.86	4.67	18.31	10.46 b	4.22 ab	44.0	0.18
LSD	NS	NS	NS	3.90***	0.79***	NS	NS

significant, analyses of variance tables have been placed in appendix 7, page 194. Significant effects were found due to density for seed yield per plant ($p<0.05$) and top dry weight per plant ($p<0.01$), and for varieties in seed number per pod ($p<0.001$) and 1000-seed weight.

Plants at 6.5 cm spacing between rows had significantly more top dry weight ($p<0.05$) and greater seed weight per plant than those with 5.0 cm between rows. Bronowski produced the greatest number of seeds per pod followed by Erglu, Gulle, Janetski, Tower and Brutor. Seed number in the latter five varieties did not differ significantly ($p<0.001$). On the other hand Brutor had the maximum 1000-seed weight value and Bronowski the minimum. No significant differences were found between varieties for seed weight per pod (Table 4.2).

Correlations amongst yield and yield components are given in Table 4.3. Seed yield per plant showed a significant positive correlation ($p<0.001$) with top dry weight per plant, pod number per plant, seed number per pod and harvest index. The correlation of seed weight per plant with 1000-seed weight was not significant. Dry weight per plant had a significant positive correlation ($p<0.001$) with pod number per plant, harvest index, 1000-seed weight ($p<0.05$) and seed number per pod ($p<0.001$). Harvest index and pod number per plant showed significant positive correlation ($p<0.001$) with all the other characters except 1000-seed weight, with which the correlation was not significant. The correlation of 1000-seed weight with other characters was not significant except with top dry weight per plant (positive, $p<0.05$) and seed number per pod with which it was negatively correlated ($p<0.01$).

By regarding each combination of density and soil as a different unspecified environment (Eberhart and Russell 1966, Breese

Table 4.3. Coefficients of correlation between seed yield and its components in six varieties of summer oilseed rape grown at three fertility levels and two densities.

	Seed weight per plant	Pod number per plant	Seed number per pod	1000-seed weight	Harvest index
Dry weight per plant	0.92***	0.84***	0.47***	0.25*	0.50***
Seed weight per plant		0.93***	0.53***	0.22	0.75***
Pod number per plant			0.44***	0.08	0.79***
Seed number per pod				-0.32**	0.60***
1000-seed weight					0.09

distinguished by their common names: B. napus is called rape, colza and navette in Europe and Argentine rape in Canada. B. campestris is known as turnip rape, navette and rubsen in Europe, whereas in Canada it is called Polish rape (Table 1.1).

1.2 Evolutionary Origin of Rapeseed

Information about the origin of different species is conflicting and sometimes not very well documented (Downey 1965, Prakash 1980). Although earlier records of the use of oilseed are found in ancient Sanskrit writings in Indo-Pakistan Subcontinent dating from 2000 to 1500 B.C. (Prakash 1980), other literary references are scarce until well into the middle ages. By that time rapeseed was being grown as an ancient crop in Europe but which species was grown is, unfortunately, not known (Appelqvist and Ohlson 1972).

McNaughton (1976a) describes two centres of origin for B. campestris. The Mediterranean area is thought to be the primary centre of European forms, while eastern Afghanistan and the adjoining portion of Pakistan is considered another primary centre. Anderson and Olsson (1959) recognised three main groups within B. campestris: Asiatic, Mediterranean and West European. All cultivated forms in the Indo-Pakistan subcontinent are annual types and it is probable that biennial forms arose in a more Mediterranean climate. In Southern Asia (India, Pakistan and Bangladesh) three races of B. campestris are grown, Brown Sarson, Yellow Sarson and Toria (Prakash 1980). King (1978) reports that Singh (1958) described eastern Afghanistan and North West India (now Northern Pakistan) as the centre of origin for the Brown Sarson, Brassica campestris Brown Sarson, which is believed to be the oldest type from which Toria developed, probably

1969) and using the regression technique proposed by Finlay and Wilkinson (loc. cit.) the dynamic relationship between genotype and environment can be studied. This is accomplished by obtaining for each cultivar the linear regression of its mean on the mean of all cultivars in each environment. The regression lines and their standard errors are shown in Fig. 4.1. Regression coefficients of Bronowski, Gulle and Tower did not differ significantly from 1.0, Brutor had a regression coefficient b = 2.93 significantly higher than 1.0. The regression coefficient for Erglu was significantly less than 1.0. The regression coefficient of Janetski was however negative but it did not differ significantly ($p>0.05$) from a line of zero slope.

4.4. Discussion

Soil effects were non-significant. Application of plant nutrients as fertilizer in B. napus can show considerable effects. Scarisbrick, Daniels, Chapman and Parr (1981) found a significant response to nitrogen application from 50 to 200 Kg/ha on dry weight and seed weight and, pod number per plant (from 100 to 200 Kg ha^{-1}) and seed number per pod . Differences of 100 to 200 were not markedly bigger as compared with control(s) and 50 Kg ha^{-1} doses. Allen and Morgan (1975) also found significant effects due to nitrogen for seed weight and dry weight per plant comparing rates of 0 and 211 Kg ha^{-1} of nitrochalk. Scott, Ogunremi, Ivins and Mendham (1973b)found that nitrogen had a significant effect in increasing seed yield when added at rates in excess of 100 Kg ha^{-1}. These workers used distinctly different doses of fertilizer and found significant effects (using standard errors to assess the data). Yet no effects of increased soil fertility were found in this experiment. In this investigation

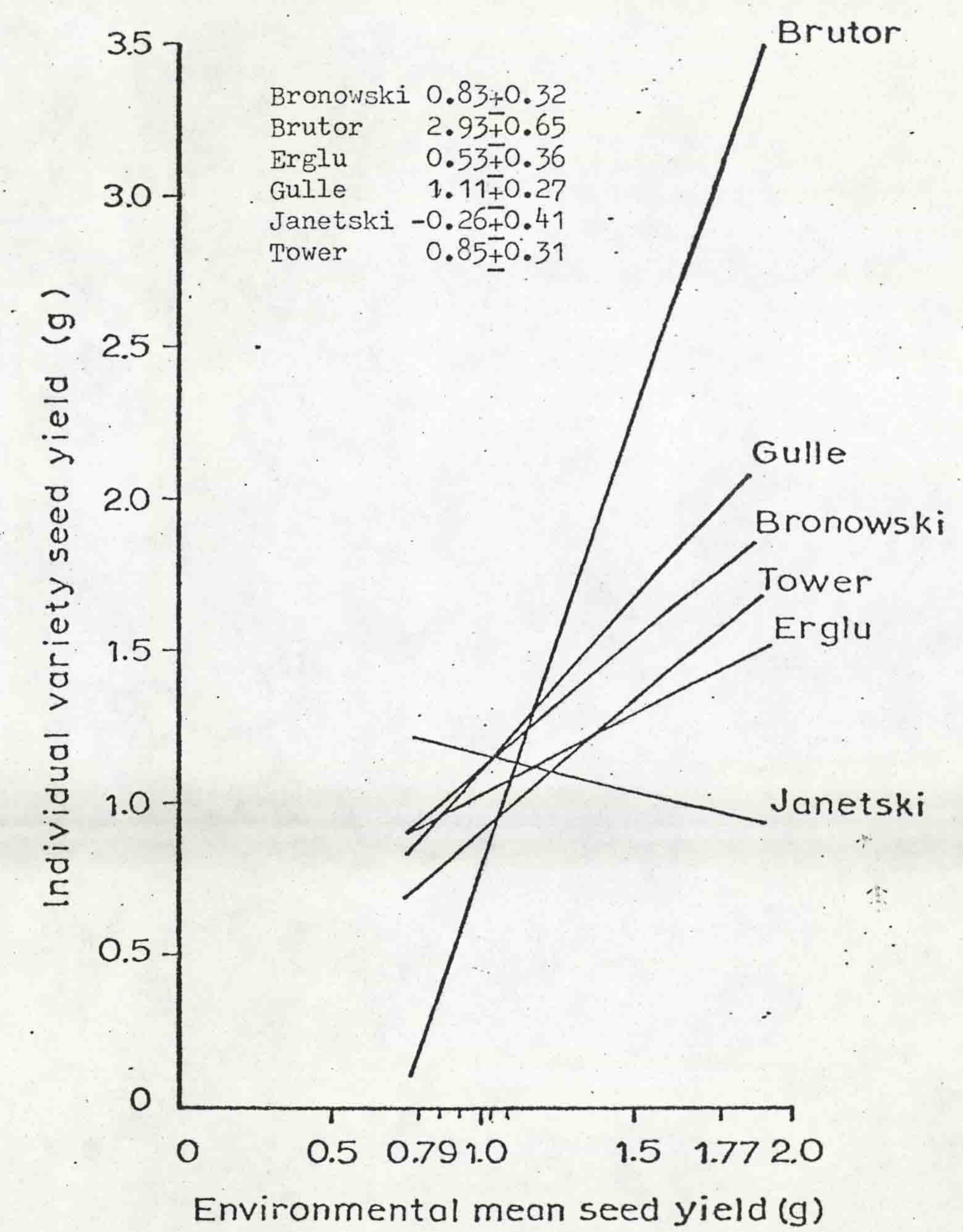


Fig. 4.1. Regressions of individual variety yields on mean yield on all six varieties in each environment for six cultivors of B.napus grown on two densities and three soil fertility levels.

the plants became larger, and it may be that the differences in levels of nutrients which would have occurred at the beginning of the experiment were not maintained until its completion, and hence yield differences did not show up.

Density effects were significant ($p < 0.05$) only for seed weight per plant and dry weight per plant (Table 4.2). These results are in agreement with those of Degenhardt and Kondra (1981) who found that increased seeding rate resulted in a significant decrease in seed yield per plant and harvest index but there was no effect on 1000-seed weight. However, density did not affect harvest index in this study.

Varieties differed significantly only in seed number per pod and 1000-seed weight which varied in opposite directions so that increase in one was accompanied by a decrease in the other (Table 4.2). Therefore these two characters in combination were responsible for the non-significance in seed weight per pod. As there were no significant differences for pod number per plant, so seed yield per plant did not show significant differences. These results were confirmed by examining correlation between the characters (Table 4.3). There was a significant negative correlation ($p < 0.01$) between the two characters, a clear example of component compensation.

Component compensation in spring oilseed rape was also observed with the experiments described in Chapter 2. But there is a difference in the mode of compensation between different components. In this experiment there were compensatory effects between seed number per pod and 1000-seed weight, whereas in the varieties examined in Chapter 2 1000-seed weight and pod number per plant were responsible for compensation. These results are in agreement with those of Clarke and Simpson (1978) who found that yield

component compensation was evident in the relationship of 1000-seed weight to pod number, and number of seeds per pod.

There is evidence from various experiments with various grain crops and with oilseed rape (Thurling 1974b) that yield component compensation is a widespread phenomenon. Yield component compensation may be expected either because the rate of supply of metabolites to the component system in which components share the common metabolic pool is limited, or because the supply of metabolites fluctuates in an oscillatory manner. These two factors are probably responsible for the yield component compensation found here. As the fertility levels were not high enough, plant nutrients and metabolites may have been limiting during their development, and so could have been favouring component compensation. Where the supply of metabolites fluctuates in an oscillatory manner the reproductive phase involves a sequential development of inflorescences and pods within an inflorescence. Therefore there is a steadily increasing demand for assimilates by the increasing number of pods and seeds in them resulting intense competition for assimilates. As the limited assimilate input would have to be partitioned among a greater number of growing points, pods and seeds within a pod, a proportionately smaller amount will be available to the seeds developing within a pod resulting in a competition and a negative correlation between these two characters (seed number per pod 1000-seed weight). Component compensation has been reported by other workers in B. napus (Tayo 1974, Thurling 1974b, Degenhardt and Kondra 1981) and has been discussed in more detail in Chapter 2.

Varieties did not differ significantly and no interaction term except density x soil for seed and dry weight was significant. However, when the analysis due to Finlay and Wilkinson (loc cit) was carried out for seed yield per plant strikingly different responses to changing experiments were found. Cultivar Gulle had an average response (b=1.11) and had

a high overall mean yield (Table 4.2). Released in Sweden in 1969, it appears from these data to have good yield potential and a stable yield over a wide range of environments. Tower and Bronowski also had an average response over a range of environments, b not significantly different from 1.0 and yield not significantly different from the environmental mean. Erglu and Janetski had a response well below the average (b not significantly different from zero) and based upon the arguments of Finlay and Wilkinson (loc cit) and Breese (1969) are specially adapted to low yielding environments. Brutor had a well above average response to environmental change and is clearly adapted only to highest yielding environments. It shows a high response to environmental change (b = 2.93), but has a comparatively low overall mean yield in this range of environments.

These data suggest that the response of varieties to changing environments can be related to their origin. Austin, Bingham, Blackwell, Evans, Ford, Morgan and Taylor (1980) gave one of the main reasons for differences in yield potential between old and new varieties in wheat as differences in fertility level. New varieties have been bred for continuously increasing fertility levels and sophisticated management practices. These conditions also seem to be applicable to the B. napus cultivars used here. Janetski is an old variety having been bred in Germany in the nineteen thirties and released in 1942. At that time fertilizer input was low, and nowadays such levels would be regarded as equivalent to poor soil fertility conditions. Its response to improving environments assessed from the Finlay-Wilkinson technique (F.W. technique) was so low that there was no change in its yield over a range of environments. Brutor on the other hand bred in the late seventies in France for high soil fertility levels currently recommended for

oilseed rape growth reaches its potential only in such high fertility levels. The remaining varieties were released in 1955, Bronowski, in Poland; 1969, Gulle, in Sweden; and 1974, Tower in Canada and showed a response to changing environments intermediate between the extremes of Janetski and Brutor.

Genotype x environment interaction has been reported for many species. Rawat and Anand (1978) reported significant ($p < 0.05$) variety x location interaction in B. campestris, (one of the parents of B. napus), for seed yield per plant but a non-significant interaction for seed number per pod and 1000-seed weight. The present data show no g x e effect for seed number per pod and 1000-seed weight. Degenhardt and Kondra (1981) using five genotypes, three sowing dates and three seeding rates found no interaction between sowing date and treatments for seed yield per plant or dry weight in B. napus cultivars, although seeding date by treatment interaction was significant for harvest index and 1000-seed weight.

The results indicate that either this crop is highly plastic and does not show g x e or the environments used were not sufficiently different to detect significant differences between varieties and interactions between varieties and environments. The fertility differences between the three soils used and the limited soil volume used per plot, may not have been sufficient to elicit differences in response. However, Allen and Morgan (1972) could not detect variety nor row width interaction with nitrogen applications in their experiment with two varieties of B. napus at three levels of nitrogen and two row widths.

The experiment reported here was of limited size, 6 varieties x 2 densities x 3 soil types, whereas Breese (1969) has suggested that a better indication of g x e may be obtained by increased number of

varieties and environmental combinations - locations and years. Nonetheless the data do suggest that genotype x environment interaction may be of importance in the crop, and may be revealed by more extensive experiments. However, it is very clear that the crop shows extreme phenotypic plasticity which makes even the detection of varietal differences difficult.

CHAPTER 5

Dry Matter Accumulation and Variation in Seed Yield Components in Spring Oilseed Rape in Field Conditions.

5.1 Introduction

Seed yield per hectare is of major importance in the production of the oilseed rape crop. Yield depends upon the characteristics of the variety sown, and the agronomic practices under which it is grown. It is a well known fact that the response of different genotypes to one environment, or of a single genotype to different environments can be quite different (Comstock and Moll 1963, Allard and Bradshaw 1964, Bradshaw 1973). Fertilizer input and row width are the main factors which can easily be controlled by the grower. Fertilizer is of critical importance for improving production on inherently poor soils, and on soils depleted of nutrients through years of removal by crops, in percolating drainage waters or by erosion. Nutrient balance is also extremely important for crops such as rapeseed (Ukrainetz, Soper and Nyborg 1975). The number of plants per hectare which depends on row spacing is another variable which can affect agronomic practices and hence, indirectly, yield. Wider row spacing is best for direct combining whilst close drilling gives protection against pigeons (Moore 1976).

An evaluation of the effect of fertilizer application and row width on seed yield per plant and yield components can improve the efficiency of a plant breeding programme in bringing about increase in production per hectare. Significant effects of nitrogen application in *B. napus* were observed for total plant dry weight and pod dry weight by Allen, Morgan and Ridgman (1971). Soper (1971) reported that rape (*B. napus*) responded to N added to soils containing less

than 100 Kg ha^{-1} N, responded to added P in soils containing less than 100 ppm P (Na HCO_3- extractable), and responded to added K when soils had 35 or less ppm of K (ammonium acetate-extractable). Kondra (1975, 1977) found that seeding rate in B. napus had a significant but variable effect on dry matter yield per plant. Degenhardt and Kondra (1981) reported that there were significant differences due to genotypes for harvest index, seed yield per plant, 1000-seed weight and plant height and that increased seeding rate resulted in a significant decrease in harvest index, seed yield per plant and plant height, but it had no significant effect on seed yield per unit area and 1000-seed weight.

On the other hand seed yield depends on its components (Olsson 1960) i.e. number of pods per plant, seed number per pod, and 1000-seed weight. So the relationships between seed yield and its components are important. In oilseed rape (B. napus) positive correlations between seed yield and yield components were found by Thurling (1974b) and Campbell and Kondra (1978).

The object of this experiment was to investigate the response of four varieties of spring oilseed rape to three levels of fertilizers at two densities (row spacings) in field conditions. Response was assessed using dry matter and seed production per plant and their relationships to yield components.

5.2 Materials and Methods

The experiment was conducted in the field at the Liverpool University Botanic Gardens, Ness, using four spring varieties of oilseed rape, Bronowski, Erglu, Gulle and Orpal. Bronowski, Erglu and Gulle were used in the experiment described in Chapter 4 (Table 4.1). Orpal

is a high yielding variety recently released (1978) in France.

The experiment was laid out as a randomised complete block design, with three replications. There were three fertilizer levels: (i) 100 Kg ha^{-1} of Nitrochalk (26% N) + 100 Kg ha^{-1} of ICI No. 10 (0 N:24 P_2O_5:24 K_2O) denoted as F1 treatment, (ii) 200 Kg ha^{-1} of Nitrochalk + 150 Kg ha^{-1} of ICI No. 10 (F_2) and (iii) 300 Kg ha^{-1} of Nitrochalk + 200 Kg ha^{-1} of ICI No. 10 (F_3). All ICI No. 10 and half of the nitrochalk was applied in the seed bed; the remainder was applied as a top dressing just before anthesis.

Seeds were sown at two row spacings, 15 cm (density D_1) and 7.5 cm (D_2) between rows. Ten 3.5 m long rows of each (variety x F x D) treatment were sown on 20.5.79 and 1 m^2 plots of spare material were sown on the same date for each variety. All the treatments were assigned at random to the plots. Sowing was done using a hand operated belt driven seed drill set to put 3 seeds per hill with 3 cm spacing within a row. Germination was completed within two weeks. Germination as a whole was poor but cultivar Gulle showed extremely poor germination throughout the treatments and therefore had to be abandoned leaving three varieties in the experiment. Plants from the plots of spare material were transplanted to fill gaps in the experiment. Even where germination was adjudged to have been adequate, one replication had to be discarded and it was only possible to maintain six adjoining rows from the ten sown in each treatment. After transplantation Basudin was applied for the control of cabbage root fly. Hand weeding was carried out three times during the experiment. In July the weather was dry (Appendix 1, page188) and the experiment was hand watered.

Five harvests of 10 plants (30 cm lengths) were taken at random from the two central rows of each plot at fortnightly intervals starting