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Modified Transplant Production Techniques to Increase Yield and Improve Earliness of Brussels Sprouts

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Abstract. **Field studies were conducted to determine the effects of row covers (no row cover or Agryl P-17), seeding date, and seeding method (seeding in a furrow or into a smooth soil surface) on the development, harvest date, and yield of brussels sprouts *[Brassica oleracea* L. (Gemmifera Group)] grown in southwestern British Columbia. The treatments were applied to the plants in the seedbed after which the plants were transplanted in the field and grown to horticultural maturity. In both years, row covers increased soil temperatures and advanced seedling development and transplanting dates compared with uncovered treatments. Leaf weight ratio (LWR) decreased, specific leaf area (SLA) increased, and leaf area ratio (LAR) was unaffected by the application of row covers. Early seeding also promoted early transplanting. In 1987, plots were harvested when plants reached horticultural maturity. There was a linear effect of seeding date on harvest date, early seeding promoted an early harvest, and row covers advanced the sprout harvest of plants seeded earliest (24 Mar). In 1988 all treatments were harvested from 17 to 19 Oct. and marketable yield was improved by early seeding and by row covers. Seeding method did not influence plant growth or yield.**

Brussels sprouts require relatively long growing seasons, which ean limit their production in southwestern British Columbia. Therefore, the crop is started early in the season in outdoor seedbeds from which transplants subsequently are taken for stand establishment in production fields. Late-season harvesting of sprouts may result in frost damage (Maurer, 1964) or an increased incidence of internal browning (Lewandowska, 1985). Earlier seeding, transplanting, and harvesting could improve the quality and yield of sprouts (Kronenberg, 1975).

Floating row covers have been used successfully to advance the production of many crops by elevating soil and air temperatures (Bonanno and Lament, 1987; Decoteau et al., 1986; Hemphill and Mansour, 1986; Nelson and Young, 1987; Wilson et al., 1987). Most reports are concerned with transplanted crops or crops with relatively short growing seasons. Row covers placed over direct-seeded crops may abrade developing seedlings; thus, seeding into furrows has been recommended to avoid seedling damage (Gerst, 1985). The advantages of promoting earlier plant development by using transplants or row covers may not be sustained with long-season crops.

This study was initiated to determine if earliness and yield of brussels sprouts could be manipulated by modified transplant production techniques. We examined the effects of variations in seeding date and seeding method as well as the use of row covers over the seedbed.

Materials and Methods

All experiments were conducted at the Agriculture Canada Research Station, Agassiz, B. C., in 1987 and 1988. Each trial was a 2 x 3 x 2 factorial arranged in a randomized complete block design with three blocks. The treatments were seeding method (seeds drilled into 12-cm-deep, 18-cm-wide furrows or into a smooth soil surface); seeding date (24 Mar., 3 and 13 Apr. 1987 and 28 Mar., 11 and 26 Apr. 1988); and row cover [no row cover or spunbonded polypropylene (Agryl P-17, IPC, New York)]. Seeding dates in 1988 were as close to those in 1987 as the weather permitted. Each trial had a transplant production stage and a crop production stage.

Transplant production stage. The field [medium textured, stone free, moderately well-drained, flood plain soil (Luttmerding, 1981), Eutrochrept, pH 6.2] was fertilized with cattle manure at 20 $t \cdot ha^{-1}$ and with a broadcast, preseeding-incorporated application of 70N–21P–70K ($kg \cdot ha^{-1}$) following commercial practices (B.C. Ministry of Agr. and Fisheries, 1987). An application of 2,6-dinitro- *N,N*- dipropyl-4-(trifluoro-methyl)benzenamine (trifluralin) at 1.14 $kg \cdot ha^{-1}$ was made before seeding in 1987 to control weeds. Plots were 4 m^2 with six rows spaced 30 cm apart. The outer two rows and plants within 30 cm of the ends of each row were guards. Furrows were constructed manually in the appropriate treatments. Seeds of 'Lunet' were direct-seeded using a manual seeder (Stanhay Ltd., Ashford, England). Floating row covers were applied over the appropriate treatments immediately after seeding. The edges of the fabric were secured with 5 × 10-cm boards. Rowcovers were removed 3 to 6 days before transplanting. Banded *O,O*- diethyl *O*- (4-(methylsulfinyl)phenyl) phosphorothioate (fensulfothian) at 3.02

Table 1. Mean ambient temperature and hours of sunshine during the 6 weeks following each seeding date, 1987 and 1988.

Seeding date[z]	Mean ambient temp (°C) 1987	Mean ambient temp (°C) 1988	Sunshine (hr) 1987	Sunshine (hr) 1988
1	11.4	10.2	222	215
2	12.3	9.2	238	238
3	15.2	13.0	325	227

[z]Seeding dates 1, 2, and 3 are 24 Mar., 3 and 13 Apr. 1987; and 28 Mar., 11 and 26 Apr. 1988.

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Abbreviations: LAR, leaf area ratio; LWR, leaf weight ratio; SLA, specific leaf area.

Table 2. Means and summaries of analysis of variance (ANOVA) results for height, leaf area, leaf dry weight, and total dry weight of brussels sprouts, 1987 and 1988 at the transplant production stage.

Treatment		Ht (cm)		Leaf area (cm^2)		Leaf dry wt (g)		Total dry wt (g)	
		1987	1988	1987	1988	1987	1988	1987	1988
Row cover									
None (NC)		13	9	56	27	0.23	0.13	0.32	0.18
Covered (C)		19	15	110	51	0.45	0.20	0.70	0.32
Seeding date (SD)[z]									
1		14	9	57	18	0.19	0.07	0.29	0.11
2		18	15	100	57	0.35	0.26	0.52	0.40
3		17	12	98	42	0.52	0.16	0.77	0.24
				ANOVA[y]					
Source	df	Mean square values							
Blocks	2	31**	159***	7,958**	8,198***	0.21**	0.09***	0.50***	0.23***
NC vs. C	1	3186***	3642***	253,348***	51,750***	4.15***	0.39**	11.38***	1.58**
SD_{linear}(L)	1	297***	643**	65,541***	35,093**	4.85***	0.41**	9.86***	0.99**
$SD_{nonlinear}$(NL)	1	520***	1434***	52,240***	58,056***	0.002	1.62***	0.02	3.85***
(NC vs. C)(SD_L)	1	82*	19	32,103***	5,298	1.30***	0.03	3.03***	0.10
(NC vs. C)(SD_{NL})	1	115**	11	20,045**	983	0.73***	0.04	1.37**	0.01
Experimental error	22	14***	57***	2,218*	3,584***	0.05	0.05***	0.11*	0.12***

[z]Seeding dates 1,2, and 3 denote 24 Mar., 3 and 13 Apr. 1987; and 28 Mar., 11 and 26 Apr. 1988, respectively.
[y]Method of seeding was not significant and is not presented.
*,**, *** Significant at P = 0.05, 0.01, and 0.001, respectively.

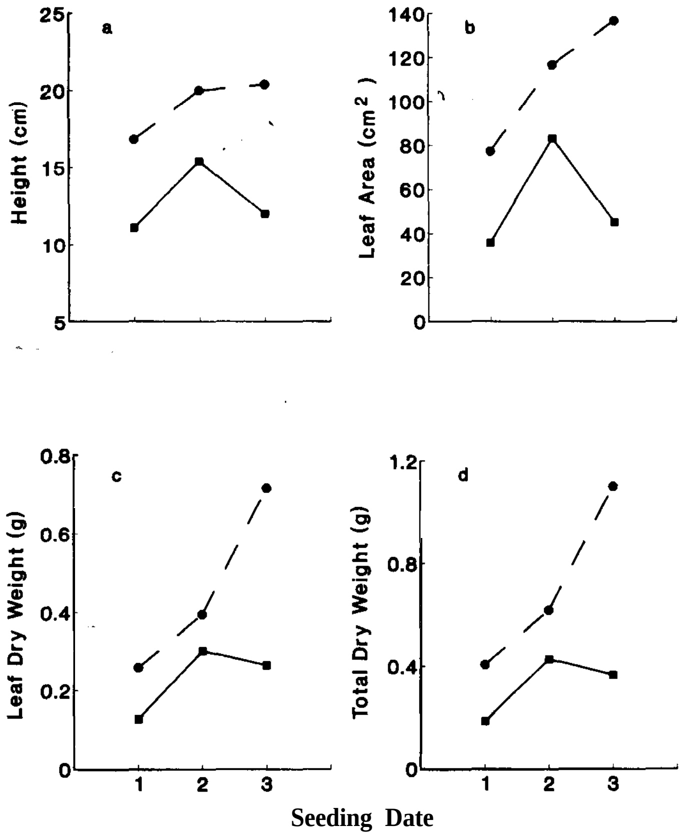

Fig. 1. Effect of row covers and seeding date on brussels sprout plants after 6 weeks of growth, 1987. **(a)** Height, **(b)** leaf area, **(c)** leaf dry weight, **(d)** total dry weight, Seeding dates 1, 2, and 3 are 24 Mar., 3 Apr. and 13 Apr., respectively. — not covered; — — — covered.

kg·ha^{-1} was used to control soil insects in the 1988 experiment. Plots were hand-weeded as required.

Ten randomly selected plants were sampled from each plot 6 weeks after seeding and plant height, leaf area, leaf dry weight, and total dry weight recorded. A LI-3000 area meter (LI-COR, Lincoln, Neb.) was used to determine leaf area. Plant components were oven-dried to a constant weight at 70C. LAR, SLA, and LWR were calculated for each plant. LAR is the ratio of leaf area to total plant dry weight and expresses the extent of photosynthesis; SLA is the ratio of leaf area to leaf dry weight and is an indication of leaf thickness; and LWR is the ratio of the leaf dry weight to plant dry weight and reflects leafiness. These indices can be expressed as: LAR = SLA × LWR.

Monthly air temperature and hours of bright sunshine were recorded at the research station's weather station, within 1 km of the trials (Table 1).

Crop production stage. Seedlings of each treatment were transplanted to the field to determine long-term effects on yield. The soil was prepared with a broadcast, preplant-incorporated application of 75N–90P–165K-4.5B (kg·ha^{-1}) according to commercial practices (B.C. Ministry of Agr. and Fisheries, 1987). Trifluralin, at 1.14 kg·ha^{-1}, was applied each year before transplanting. Transplanting data differed between treatments because each treatment was transplanted when plants were ≈24 cm high. The experimental design was the same as that used in the transplant production stage except that the plots were rerandomized. Plots consisted of five rows with six plants in each row. Plants were spaced 45 cm within rows and 90 cm between rows. Plants in the outside rows and the end plants in the remaining three rows were guards. A post-transplant banding of fensulfothian at 3.02 kg·ha^{-1} was applied to control soil insects. Sidedressed N at 45 kg·ha^{-1} was applied and plants were ridged on 15 July 1987 and between 8 and 12 July 1988. Insecticides were applied as necessary throughout the season using commercial standards (B.C. Ministry of Agr. and Fisheries, 1987).

The apical meristem was hand-pruned when the basal sprouts at the eighth node had reached a diameter of ≈2 cm on ≈50% of the plants in the plot. In 1987, each plot was harvested when the sprouts on ≈50% of the plants in the plot had reached a marketable stage (2.0 cm in diameter), to assess earliness. Treatments were harvested from 17 to 19 Oct. 1988 to enable

Table 3. Means and summaries of ANOVA results for LAR, LWR, and SLA of brussels sprouts, 1987 and 1988 at the transplant production stage.

Treatment		LAR ($cm^2 \cdot g^{-1}$) 1987	LAR 1988	LWR 1987	LWR 1988	SLA ($cm^2 \cdot g^{-1}$) 1987	SLA 1988
Row cover							
None (NC)		179	159	0.70	0.71	256	225
Covered (C)		177	165	0.65	0.64	275	271
Seeding date (SD)[z]							
1		202	162	0.66	0.68	306	254
2		198	151	0.67	0.66	294	229
3		128	174	0.69	0.67	185	261
		ANOVA[y]					
Source	df	Mean square values					
Blocks	2	3,461**	11,405**	0.00	0.00	5,385*	52,442*
NC vs. C	1	912	2,638	0.24***	0.46***	56,054***	172,003**
SD_{linear}(L)	1	298,920***	7,384	0.06***	0.01	805,707***	3,313
$SD_{nonlinear}$(NL)	1	82,817***	22,994**	0.00	0.01	188,801***	59,679
(NC vs. C)(SD_L)	1	803	1,957	0.00	0.01	4,882	8
(NC vs. C)(SD_{NL})	1	2,744	1,916	0.00	0.00	1,092	12,283
Experimental error	22	1,059*	1,835	0.00***	0.01	2,164*	17,023

[z]Seeding dates 1, 2, and 3 denote 24 Mar., 3 and 13 Apr. 1987; and 28 Mar., 11 and 26 Apr. 1988, respectively.
[y]Methodof seeding was not significant and is not presented.
*, **, *** Significantat P = 0.05, 0.01, and 0.001, respectively.

Table 4. Date of transplanting (1987 and 1988) and date of harvest of brussels sprouts (1987) as influenced by row covers and seeding date.

Treatment		Transplanting date 1987	Transplanting date 1988	Harvest date (1987)
Row covers				
None (NC)		25 May	14 June	29 Oct.
Covered (C)		20 May	6 June	28 Oct.
Seeding date (SD)[z]				
1		16 May	6 June	20 Oct.
2		21 May	6 June	30 Oct.
3		30 May	19 June	6 Nov.
		ANOVA[y]		
Source	df	Mean square values		
Blocks	2 (0)[x]	1	3	2
NC vs. C	1	80**	30***	0
SD_{linear}(L)	1	421***	49***	31***
$SD_{nonlinear}$(NL)	1	6	16***	0
(NC vs. C)(SD_L)	1	5	4	3
(NC vs. C)(SD_{NL})	1	1	2	7*
Experimental error	22(11)		21	51

[z]Seeding dates 1, 2, and 3 are 24 Mar., 3 and 13 Apr. 1987; and 28 Mar., 11 and 26 Apr. 1988.
[y]Method of seeding was not significant and is not presented. Analysis was performed on Julian dates.
[x]Indicates df for 1987 transplanting date. Furrowing treatments and replications pooled for the analysis.
*,**,*** Significant at P = 0.05, 0.01, and 0.001, respectively.

yield comparisons at a harvest date considered early for a mid-season cultivar. Plant height was recorded and sprouts were removed from the stem, graded, and counted. Sprouts were graded as small, < 2.2cm; medium, 2.2 to 2.5cm; large, >2.5 to 3.2 cm; or culls (>3.2 cm, overmature, diseased, or insect damaged).

Statistical analysis. All yield data were subjected to analysis of variance with the GLM procedure of Statistical Analysis System (SAS Institute, 1985) and the sum of squares partitioned using single-degree-of-freedom orthogonal contrasts. Growth data from the 6-week-old plants were analyzed using several (maximum 10) observations per experimental unit (Steel and Torrie, 1980). All other data (transplanting dates, harvesting dates, and yield data) were analyzed using one observation per experimental unit, the mean of subsamples that were combined during data collection. The main effect of seeding method and its interactions were never significant; therefore, the data and analysis are not presented. These data were not combined for reanalysis, with the exception of the analysis concerning 1987 transplanting dates. In this analysis there was also no variability between blocks, so these were combined in the analysis.

Results and Discussion

Transplant production. Six-week-old seedlings were generally larger in 1987 than in 1988 (Table 2), probably due to the higher air temperatures and more hours of sunshine that occurred in 1987 (Table 1). In both years, row covers elevated mean soil temperature 1 to 6C and promoted plant growth compared with bare soil. Plant height, leaf area, leaf dry weight, and total dry weight were greater from treatments with row covers than uncovered plots (Table 2). In 1987, the size of covered plants increased with later seeding dates while that of uncovered plants decreased after the second seeding date (significant cover and nonlinear seeding date interaction) (Fig. 1). Heavy precipitation followed the 13 Apr. 1987 seeding (79 mm in 4 days compared to 15 mm following the 26 Apr. 1988 seeding) and poor seed germination and slow plant growth were observed in uncovered treatments. Row covers protected the soil, inhibiting surface crusting. Plants seeded on 13 Apr. 1987 were also exposed to more sunshine hours than any other treatment in the 2-year study (Table 1). The larger plants from the covered treatments seeded at this time probably resulted from the microclimatic changes effected by the row covers and the higher irradiance.

Row covers did not influence LAR but enhanced SLA in both years (Table 3). The effect of seeding date on LAR was nonlinear in both years. Plants seeded on the last seeding date had

Table 5. Effect of row covers and seeding date on yield of brussels sprouts, 1988: means and summary of ANOVA results.

Treatment		Plant ht (cm)	Sprouts/ha (no., $\times 10^5$)	Sprout yield ($t \cdot ha^{-1}$)[z] Small	Medium	Large	Cull	Marketable
Row cover								
None (NC)		84	22	5.9	3.6	2.1	0.4	11.6
Covered (C)		85	24	5.9	4.0	3.0	0.5	13.0
Seeding date (SD)[y]								
1		87	24	5.7	4.8	4.0	0.5	14.5
2		86	24	6.0	4.3	3.0	0.6	13.3
3		81	21	6.1	2.3	0.8	0.3	9.3
ANOVA[x]								
Source	df	Mean square values						
Blocks	2	252***	13*	1	7**	10	0.6***	12*
NC vs. C	1	9	25**	0	2	7	0.2**	17*
SD_{linear} (L)	1	246***	65***	2	36***	61***	0.2**	162***
$SD_{nonlinear}$ (NL)	1	52*	24**	0	5	3	0.2**	16*
(NC vs. C)(SD_L)	1	0	0	0	1	0	0.0	0
(NC vs. C)(SD_{NL})	1	6	5	0	1	0	0.0	0
Experimental error	22	9	2	1	1	3	0.0	3

[z]Grades determined by sprout diameter: small, < 2.2 cm; medium, 2.2-2.5 cm; and large, 2.5-3.2 cm. Culls were > 3.2 cm, overmature, diseased, or insect damaged.
Weeding dates. 1, 2, and 3 denote 28 Mar., 11 and 26 Apr., respectively.
[x]Method of seeding was not significant and is not presented.
Asterisks indicate significance at P = 0.05, 0.01, 0.001, respectively,

the lowest LAR in 1987 but the highest in 1988. SLA declined with later seeding dates in 1987 but was nit affected by seeding date in 1988. LAR and SLA were lowest in plants seeded 13 Apr. 1987 and exposed to the greatest amount of bright sunshine during the 6 weeks of growth. These indices decline with increasing irradiance (Hurd and Thornley, 1974; Smith et al., 1984; Tooze and Klapwijk, 1985). Buttery et al. (1981) suggested that a low LAR may favor high photosynthesis because the leaves have a larger sink for photosynthetic products compared with plants with a higher LAR. Low SLA is indicative of-thick leaves (Hunt, 1978). The potential for high photosynthesis (low LAR) could be greatest at seeding dates that resulted in the thickest leaves (low SLA). LWR was not affected by row covers and increased slightly with later seeding dates in 1987 but not in 1988 (Table 3).

Crop production. Row covers, applied to the seedbed, advanced transplanting dates in both years (Table 4). In 1988, the year with the cooler spring temperatures, covered plants were transplanted 8 days earlier than uncovered plants. Early seeding also promoted early transplanting (significant linear effect of seeding date in 1987 and 1988). Interactions between row covers and seeding date were not significant.

In 1987 seeding date influenced harvest date but row covers, computed as main effects, did not. However, a significant interaction between row covers and seeding dates showed that the earliest harvest was from plants seeded 24 Mar. and covered in the seedbed (Table 4). This treatment was harvested on 15 Ott., 11 days earlier than uncovered plants seeded on the same date. Row cover and seeding date treatments did not affect plant height or sprout yield in 1987 (data not presented).

Total marketable sprout yield from the once-over harvest in 1988 was enhanced by the application of row covers to the seedbed and by early seeding (Table 5). Row covers and seeding date did not affect the yield of small sprouts; however, the yields of medium, large, and culled sprouts were greatest from treatments seeded early. The larger yields were the result of more sprouts obtained from covered than uncovered plants, and from plants produced after early seeding compared to those from late seeding (Table 5). Plant height increased in a nonlinear fashion with earlier seeding dates but was unaffected by row covers.

This study demonstrates the influence of seeding date and the effect of row covers applied to seedbeds on transplanting date, harvest date, and yield of brussels sprouts. Our results can be applied to cultural management decisions in regions with climates like that of southwestern British Columbia. The effects of seeding date and row covers on plant development can last until sprout harvest. This accelerated seedling development enables commercial producers to stagger transplanting operations without extending the sprout harvest into the late fall.

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