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Fertilizer Additives within or around the Gel for Fluid-drilled Cabbage and Lettuce[1]

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Abstract. **Three glasshouse experiments were conducted in which "starter" N, P, and K fertilizers were incorporated either within or below gel used for fluid sowing pregerminated seed of 'Avondefiance' lettuce (*Lactuca sativa* L.) and 'Derby Day' cabbage (*Brassica oleracea* L. Capitata group). Addition of nutrients to the gel at salt concentrations between 384 and 1893 mg-ion/liter inhibited emergence of the pregerminated seeds. Additions to the gel at concentrations between 9 and 21 mg-ions/liter were too low to affect the growth of the plants. Nutrient solutions applied to the base of the furrow immediately prior to fluid drilling the seeds allowed higher concentrations of salts to be used without reducing emergence. Solutions that contained factorial combinations of 0.84 g/liter N, 1.86 g/liter P, and 2.34 g/liter K applied at the rate of 0.5 ml/cm of furrow increased lettuce dry matter production by up to 44% after 20 days growth, although there was no significant effect on the growth of cabbage. The increase in lettuce growth was mainly in response to P 'starter' fertilizer but the largest response was achieved with the N + P + K 'starter' treatment.**

Fluid drilling involves germinating seeds in a controlled environment and then suspending them in a protective gel prior to sowing (1). This technique has led to faster and more even emergence, and more uniform, earlier, and greater yields of a number of vegetables (7). These benefits have been sufficient to encourage the use of fluid drilling commercially. The technique also offers an excellent opportunity for placement of materials including starter fertilizer (4, 5, 9) in the immediate vicinity of the seed. The starter nutrients could be added either in the gel to provide an immediate source of nutrients, or in the soil around the gel. The latter would allow the gel to act as a protective barrier against high salinity during this highly salt-sensitive growth stage.

Three experiments are described in which both of these techniques were used to determine the effects of applying starter nutrients to fluid-drilled lettuce and cabbage.

A sandy loam soil of the Wick Series (8) that contained 24.5 μg/g sodium bicarbonate extractable P and 83 μg/g ammonium nitrate extractable K was collected, partially air-dried, and pulverised to produce crumbs up to 1 cm in diameter. The soil was fertilized at rates equivalent to 125–100–50 kg/ha (N–P–K). N and K were applied as solutions of ammonium nitrate and potassium sulphate and P as granular triple superphosphate. The soil was then mixed and placed in 27 plastic trays (25 × 34 cm) to a 9-cm depth. Four parallel seed rows 5 cm apart and 30 cm long were formed on the soil surface in each tray.

'Avondefiance' lettuce and 'Derby Day' cabbage seeds were germinated for 16 and 24 hrs., respectively, by placing seed on absorbent paper soaked in deionized water in covered nylon trays. Pregerminated seeds were then suspended in a gel made from guar gum (Hercules Powder Co., London, U.K.—Development Product 433). A 3% suspension of the powdered gum in deionized water was used, rather than the more usual 1% suspension, to enable the colloid to hold the fertilizer salts without losing its viscosity.

Three experiments were conducted using different rates, sources, and methods of applying starter fertilizer but all with the same experimental design. There were 8 factorial combinations of treatments with and without N, P, and K starter fertilizer applied with pregerminated seed. A ninth treatment with ungerminated seed and no starter fertilizer was sown in the gel. Treatments were arranged in a randomized block design with 3 replications with 1 plot of each vegetable per tray. Experiments were conducted in England in an air conditioned glasshouse at 17° ± 3°C in May, June, and July, 1980. Water was applied through holes in the base of the trays by means of capillary matting with occasional applications from above.

Experiment 1. Starter fertilizers were added to the gel at the rate of 7.5 g/liter of N (as NH_4NO_3), 15 g/liter of P as (NaH_2PO_4) and 10 g/liter of K (as K_2SO_4) each alone and in factorial combinations. Fifty seeds of each species suspended in 15 ml of gel were sown in each tray and covered with 1 cm of soil. A count of emerged seedlings was made 5 days later. The weakest seedlings were then removed to reduce competition. Plants were harvested 15 days after sowing. Dry weights were determined on the 10 largest plants in each treatment or on all plants where less than 10 plants emerged.

Seedling emergence was severely retarded by adding fertilizer salts to the gel, particularly with lettuce (Table 1). The salt concentrations of the fertilized gels are shown in Table 1. Poor seedling emergence was related directly to salinity rather than to toxic effects of any particular ion. At harvest, there were no beneficial effects of starter fertilizer on plant dry weight. Most of the fertilizer treatments added to the gel significantly reduced growth of the seedlings to below that with the control treatments.

Experiment 2. Six mg-ions/liter of N, P, and/or K (equivalent to 0.84 g/liter, 0.186 g/liter, and/or 0.234 g/liter, respectively) were added to the gels as salts selected to minimize salinity (Table 2). These concentrations were chosen because preliminary laboratory germination trials had shown that they were low enough to have no deleterious salinity effects on lettuce germination. The conductivities of the fertilized gels were determined using a Wayne Kerr B221A conductivity bridge with a probe standardised against 0.1M KCl at 20°C. Seeds were sown as in experiment 1. Plants were thinned after emergence and the 10 largest plants from each plot were harvested 17 days after sowing.

The NK treatment significantly reduced cabbage seedling emergence below the control treatment (Table 2). With lettuce, the salts added to the gel had no effect on seedling emergence. Once again, the starter fertilizer had no beneficial effect on plant growth, however, at these salt concentrations there were no detrimental effects.

Experiment 3. Starter fertilizer was not added to the gel, but was instead applied by pipette to the base of the furrows immediately before seeds in the gel were sown. The combinations of salts were the same as those used in experiment 2 (Table 2), but they were applied at the rate of 0.42 mg/cm of N, 0.93 mg/cm of P, and 1.17 mg/cm of K in a solution applied at 0.5 ml/cm of furrow. Seeds were sown as in experiment 1, but the sowing rate was increased to 70 seeds per plot.

Seedlings were counted after 7 days and the first harvest was made at 14 days. The remaining plants were spaced 3 cm apart and were harvested 20 days after sowing. The harvested plants were oven-dried at 105° C, digested with sulfuric acid–hydrogen peroxide mixture with 0.1% selenium for 1 3/4 hours at 330°. The digest was analysed for N by indophenol-blue colorimetry, P by vanadomolybdate colorimetry, and K by flame photometry.

Starter fertilizer applied below the gel had no significant effect on seedling emergence (Table 3). In lettuce, after 14 days growth, dry weights were increased between 24 and 44% over the control by treatments that included P or K. The addition of N had no

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dition of N had no effect on lettuce growth (Table 3). However, after 20 days, the early growth advantage conferred by most of the treatments had been lost and only the N + P + K treatment maintained its advantage; the plants at that time were 44% heavier than those from the control treatments.

The nutrient content of the lettuce at the second harvest is shown in Table 4. The plant concentration of N was not affected by the starter fertilizers. Plant concentration of P was increased by the N + P + K treatments over that with the control treatments. Plant centration of K was increased by the N + K treatment and reduced by the N + P treatment. The benefical growth effect of the starter fertilizer seems to have been largely a response to increased P uptake, although the presence of N in the starter was effective in increasing P uptake, an effect noted elsewhere (2,6). The combination of N + P treatments produced plants with a low K content, possibly because of competition or antagonisms between K and NH_4 uptake. Therefore, a starter fertilizer that contained NH_4, P, and K was necessary to produce a lasting improvement in crop growth.

In cabbage, none of the treatments provided any improvement in growth at either harvest. Cabbage nutrient concentration data at harvest (Table 4) showed a different pattern of response than that obtained with lettuce. As in lettuce, there was no significant difference in N concentration between any of the starter treatments and the control. There were also no significant effects of individual treatments on P concentration, although an analysis of variance showed a reduction of 14.0% ($P<5\%$) in P content in the presence of N starter fertilizer. There were also significant increases in K concentration of the cabbage in response to starter applications of N + K, P + K, or N + P + K, although these produced no improvement in plant growth.

It seems that the application of starter fertilizers, particularly P salts, which ensure that each seed is near a nutrient rich zone, can significantly improve early growth and establishment of fluid-drilled lettuce. The starter fertilizer can be applied within the gel or through a separate nozzle during drilling. The former is mechanically simpler but the intimate association of the seeds with the gel requires careful control of the concentrations of fertilizer, as pregerminated seeds are very sensitive to osmotic damage (3). Although no benefits were achieved by such a technique in this study, it is possible that incorporation of nutrients into the gel at a total ionic concentration between 400 mg-ions/liter, which caused salinity damage, and 21 mg-ions/liter, which was ineffective, may produce benefits.

The technique of adding starter nutrients adjacent to the gel was clearly beneficial for lettuce in this study, even though N–P–K were incorporated into the soil before seeding. A more pronounced response would be expected on less fertile soil that received band placement of fertilizer (4). The gel separated

Table 1. Effects of gel additive on cabbage and lettuce emergence at 5 days and plant dry weight 15 days after sowing in experiment 1.

Gel additive		Emergence (%)[z]		Dry wt (mg/plant)[z]	
Nutrient	(mg/liter)	Cabbage	Lettuce	Cabbage	Lettuce
N	543	15.4cd	0.6ab	6.6abc	2.0ab
P	966	2.6d	0.0b	5.3bc	0.8b
K	384	62.6a	13.4a	11.0a	3.7a
NP	1509	0.0d	0.0b	2.2c	0.4b
NK	927	32.0bc	0.0b	10.5ab	1.9ab
PK	1350	7.7cd	0.0b	7.3abc	0.0b
NPK	1893	2.6d	0.0b	6.2abc	1.1b
0	0	46.6ab	16.0a	10.6ab	3.5a
0 (dry seed)	0	21.4b	14.6a	8.8ab	3.6a

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 2. Effect of gel additive on cabbage and lettuce emergence at 6 days and on plant dry weight 17 days after sowing in experiment 2.

Gel additive				Gel conductivity	Emergence (%)[z]		Dry wt[z] (mg/Plant)	
Nutrient	Salt	(mg/liter)	(mg-ion/liter)	(S/cm)	Cabbage	Lettuce	Cabbage	Lettuce
N	$(NH_4)_2SO_4$	396	9	940	74.8abc	68.8a	10.9a	8.5a
P	NaH_2PO_4	936	12	610	90.0a	68.0a	10.9a	9.8a
K	K_2SO_4	522	9	970	64.8bc	72.8a	14.9a	11.8a
NP	$NH_4H_2PO_4$	690	12	820	64.0bc	54.0ab	11.2a	10.0a
NK	$(NH_4)_2SO_4$ + K_2SO_4	396 522	18	1580	58.8c	79.2a	9.8a	9.4a
PK	KH_2PO_4	816	12	820	77.2abc	64.8a	10.3a	11.0a
NPK	$NH_4H_2PO_4$ + KH_2PO_4	690 816	21	1500	68.8abc	75.2a	11.7a	10.7a
0	---	---	0	330	84.8ab	68.0a	12.8a	9.5a
0 (Dry seed)	---	---	0	330	67.2abc	32.8b	11.9a	9.7a

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 3. Effect of nutrients added to base of furrow on cabbage and lettuce emergence at 7 days and on plant dry weight at 14 and 20 days after sowing in experiment 3.

			Dry wt (mg/plant)[z]			
	Emergence[z](%)		Cabbage		Lettuce	
Nutrient	Cabbage	Lettuce	14 days	20 days	14 days	20 days
N	84.3a	68.6a	14.0a	34.2a	3.6bc	14.2c
P	99.0a	89.6a	12.9a	26.8a	4.8ab	21.8ab
K	100.0a	68.1a	11.8a	25.2a	4.2abc	19.1abc
NP	100.0a	71.9a	12.0a	32.0a	4.4abc	17.7bc
NK	82.9a	81.4a	12.4a	32.4a	4.7ab	18.2abc
PK	83.3a	82.9a	14.0a	33.1a	4.5abc	19.8abc
NPK	82.4a	75.7a	13.4a	27.1a	4.9a	25.0a
0	87.1a	75.7a	13.6a	31.8a	3.4cd	17.4bc
0 (Dry seed)	79.0a	43.9a	10.6a	24.0a	2.4d	17.5bc

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 4. Mean N, P, and K concentrations in dry matter of cabbage and lettuce 20 days after sowing in experiment 3.

Gel additive	Nutrient concn in cabbage[z] (%)			Nutrient concn in lettuce[z] (%)		
	N	P	K	N	P	K
N	5.28a	0.56ab	4.51de	4.95a	0.46bc	5.60b
P	5.29a	0.71a	4.69cde	4.81a	0.53abc	5.65b
K	5.21a	0.68ab	4.77cd	4.81a	0.43bc	5.85b
NP	5.38a	0.57ab	3.98e	5.08a	0.57ab	4.71c
NK	5.20a	0.60ab	5.71ab	4.93a	0.45bc	7.01a
PK	5.26a	0.64ab	5.20bc	4.89a	0.49abc	6.04b
NPK	5.08a	0.54b	6.06a	4.84a	0.60a	5.93b
0	5.27a	0.61ab	4.42de	4.85a	0.44c	5.55b
0 (dry seed)	5.36a	0.68ab	4.27de	4.77a	0.43c	5.46b

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

the seeds from the fertilizer and the addition of the nutrients to the soil itself probably allowed adsorption onto soil components which may lead to a higher nutrient availability without necessarily incurring a high salt level in the soil solution. Development of modified fluid drills would be necessary to permit starter fertilizer application in this way.

One disadvantage of using starter fertilizers with conventional sowings of ungerminated seeds is that the nutrient solutions may become concentrated to potentially damaging levels if the soil dries out. However, fluid-drilled crops, even without starter fertilizer, are already in danger of dessication so that irrigation is needed under dry conditions (7). Therefore, the use of starter fertilizer with fluid sown crops need impose no further constraints.

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Self-incompatibility Alleles in Broccoli[1]

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Abstract. **Seven self-incompatibility (*S*) alleles (S_2, S_{13}, S_{15}, S_{18}, S_{24}, S_{39}, and S_{51}) were identified in various hybrids and breeding lines of broccoli [*Brassica oleracea* L. (Botrytis group)]. The international *S*. allele collection of *Brassica oleracea* at the National Vegetable Research Station was used to assure standardized identification.**

Sporophytic self-incompatibility in *Brassica oleracea* has been used to produce hybrids. Sporophytic self-incompatibility is controlled by a series of multiple alleles at a single locus (1). With most self-incompatibility (*S*) alleles, a plant will reject its own pollen or pollen from other plants carrying the same *S* alleles. This rejection involves inhibition of pollen germination or restriction of pollen tube growth at the stigma surface (2). Both weak self-incompatibility in seed parent lines and environmental factors such as high temperatures reduce the self-incompatibility expressed by parental lines (11). Without adequate self-incompatibility, self- and sib-pollinations can result in an unacceptble level of self- and sib-progeny in hybrid seed lots (5). Self-incompatibility alleles, their dominance relationships, distribution, and frequency are well documented for kale (9, 10), Brussels sprouts (6, 7), and cabbage (3). The purpose of this study was to identify the *S* alleles in various commercial broccoli hybrids and breeding lines that might be useful in the production of hybrid broccoli.

The research was performed at Western Washington Research and Extension Center (WWREC) of Washington State in Puyallup, Wash., and the National Vegetable Research Station (NVRS) in Wellesbourne, England. The following homozygous *S* allele Brussels sprout and kale tester lines from the International S allele collection of *B. oleracea* at the NVRS were used: S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17}, S_{18}, S_{20}, S_{22}, S_{23}, S_{24}, S_{25}, S_{28}, S_{29}, S_{32}, S_{35}, S_{36}, S_{39}, S_{45}, S_{46}, S_{51}, and S_{63}. The broccoli lines and cultivars tested are listed in Table 1.

Since dominance of *S* alleles is more frequently expressed in the pollen than in the stigma (10), initial test crosses always included broccoli as the seed parent to increase the probability of detecting pollen-recessive *S* alleles. In most initial test crosses, a reciprocal cross, using broccoli as the pollen parent, was also made. This enabled identification of the stigma recessive *S* alleles, S_{14} and S_{45}, and the *S* alleles that could be either stigma-recessive or dominant, S_{13}, S_{25}, S_{28}, and S_{32}. Whenever a self-incompatible reaction was obtained in the initial test crosses, both the test and reciprocal crosses were repeated at least 3 times to verify the presence of the *S* allele, to identify plants homozygous for recessive *S* alleles, and to determine the dominance relationships of *S* alleles in both the pollen and stigma. Questionable results were always retested.

Plants were kept in a glasshouse with average daily temperatures between 14 to 20°C. Three open flowers on each plant tested were emasculated and pollinated in the morning. About 25–30 hr later, pollinated styles were removed. Johnsons' (4) staining technique was used to fix, soften, and stain pollinated styles for viewing by fluorescent microscopy. An epi-fluorescent microscope with UV wavelength of about 350–400 mμ, was used to examine styles for the presence of pollen tubes.

A fully self-incompatible test cross establishing the presence of the *S* allele being tested for was characterized by short, coiled, inhibited pollen tubes on the stigma surface,

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