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The effect of planting date and plant density on phosphorus uptake and phosphorus harvest by Brussels sprouts

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Abstract

The effects of planting date, plant density and their interaction on phosphorus (P) uptake during the season and on phosphorus harvest by Brussels sprouts (*Brassica oleracea* var. *gemmifera*) were studied in field experiments. Plant density in the range of 2.7 to 4.4 plants per m^2 had no or only a limited effect on crop phosphorus concentration and no effect on final crop phosphorus uptake. A delay in planting reduced the final uptake of phosphorus, but increased phosphorus concentration in the crop and in the product at harvest. Mainly depending on planting date, 33 to 50 kg of phosphorus was taken up by the crop at harvest. Forty to 60 per cent of this amount was removed from the field with the product. There were no interactions between the effects of planting date and plant density. The effect of planting date on phosphorus uptake has no consequences for phosphorus fertilizer recommendations. Currently recommended phosphorus fertilizer amounts are likely to be in excess of the amount of phosphorus harvested with the product.

Keywords: Brussels sprouts, *Brassica oleracea* var. *gemmifera*, planting date, plant density, phosphorus concentration, phosphorus uptake, phosphorus harvest.

Introduction

In two experiments in which the effects of planting date and plant density on growth, development and yield of Brussels sprouts were studied (Everaarts & De Moel, 1994), also the phosphorus (P) uptake pattern during crop growth and final uptake by the crop was observed. The first aim was to establish whether soil fertility recommendations would need to take account of demand of the crop as possibly influenced by the date of planting or by the plant density. Especially planting date may have an effect, as planting late in the season results in a lower final amount of dry matter accumulated and a lower marketable yield (Everaarts & De Moel, 1994).

Secondly, only limited information was available on the amount of phosphorus harvested with the product of Brussels sprouts. This type of information may become increasingly important, as in The Netherlands there is discussion about developing legislation which, within certain restrictions, will limit phosphorus fertilization to the amount of phosphorus harvested with the crop product, plus an amount for unavoidable losses. The present paper describes the effects of planting date and plant density on phosphorus uptake and phosphorus harvest with the product by Brussels sprouts.

Materials and methods

General

The experiments were carried out in 1989 and 1991/92, on a marine loam soil, with the Brussels sprouts (*Brassica oleracea* var. *gemmifera*) variety Kundry at the research station at Lelystad, The Netherlands. In both years the crop was planted at three dates and at each date in three plant densities, resulting in nine treatments. Planting dates were May 2 (P1), May 30 (P2) and June 27 (P3) for 1989 and April 29 (P1), May 28 (P2) and July 8 (P3) for 1991/92. In both years the distance between the rows was 0.75 m with within row planting distances of 0.50, 0.40 and 0.30 m respectively, resulting in plant densities of 26,700 (D1), 33,300 (D2) and 44,400 (D3) plants per hectare. Details of the experiments have been described by Everaarts & De Moel (1994). Statistical analysis was carried out with the GENSTAT 5 package (Genstat 5 Committee, 1993).

Crop husbandry

Soil available nitrogen (0–60 cm) at planting was 31, 48 and 68, and 37, 50 and 47 kg per hectare for P1, P2 and P3 in 1989 and 1991/92 respectively. Nitrogen fertilizer was given at planting as calcium ammonium nitrate at a rate of 300 kg nitrogen per hectare at each planting date. Phosphorus and potassium fertilizer had been applied during the preceding winter season, according to site requirements based on soil analysis. Soil phosphorus status expressed as Pw in mg l^{-1} P_2O_5 (Sissingh, 1969) was 21 and 31 for 1989 and 1991/92 respectively. Soil potassium status in mg 100 g^{-1} K_2O (Anonymous, 1992) was 19 for both years. The soil phosphorus status is classified as 'sufficient' and soil potassium status as 'more than sufficient' (Anonymous, 1992). During dry periods the experiments were sometimes sprinkler irrigated.

Plant sampling

The above-ground part of the crop was sampled five times during the crop growth period, for each planting date at the same number of days after planting. The final sampling was at the latest date of determination of the marketable yield. Plants were separated in leaf blades, petioles, yellow leaves, stem and buds (diameter ≥ 1 cm). Details of the plant sampling are given by Everaarts & De Moel (1994). The phosphorus concentration in the dry crop material was determined by the molybdenum-blue method (Walinga *et al.*, 1995).

Results

Phosphorus concentration

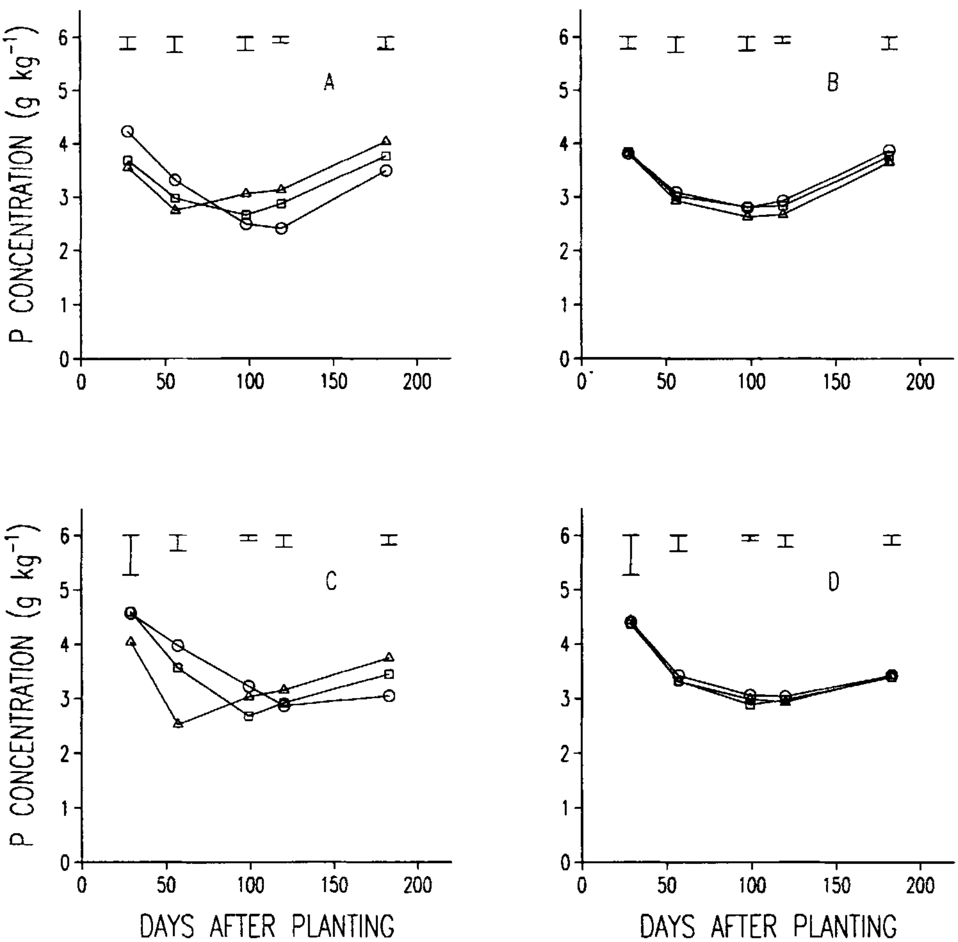
The date of planting and plant density influenced the average phosphorus concentration of the crop during the season in 1989 (Figure 1). Effects were small however and absent in 1991/92. In general the phosphorus concentration of the crop after planting initially decreased, but increased again towards harvest. In both years the phosphorus concentration of the crop during the season was influenced by the date of planting. After planting it initially was highest with the first planting date, but at harvest phosphorus concentration was highest with the third planting date. There was no interaction between the effects of planting date and plant density.

Phosphorus uptake

The amount of phosphorus in the standing dry matter increased until harvest (Figure 2). The date of planting had a strong effect on phosphorus uptake in both years. Despite the high phosphorus concentration in the crop at harvest, final uptake of phosphorus was lowest with the third planting date (Table 1). The reason for this is the lower final amount of standing dry matter when planting is delayed (Figure 3). Considering both experiments, in the period from around 30 to 100 days after planting the average rate of increase in the amount of phosphorus present in the crop was 0.38 kg per hectare per day. In the period from around 100 days to harvest, this rate decreased to an average of 0.15 kg per hectare per day. Final uptake of phosphorus ranged between 33 and 50 kg per hectare, mainly depending on planting date. Plant density had no significant effect on final uptake of phosphorus. This is consistent with the only small difference in phosphorus concentration, or absence of difference, at final harvest and the absence of effects of plant density on final dry matter accumulation (Everaarts & De Moel, 1994). No interaction was observed between the effect of planting date and plant density.

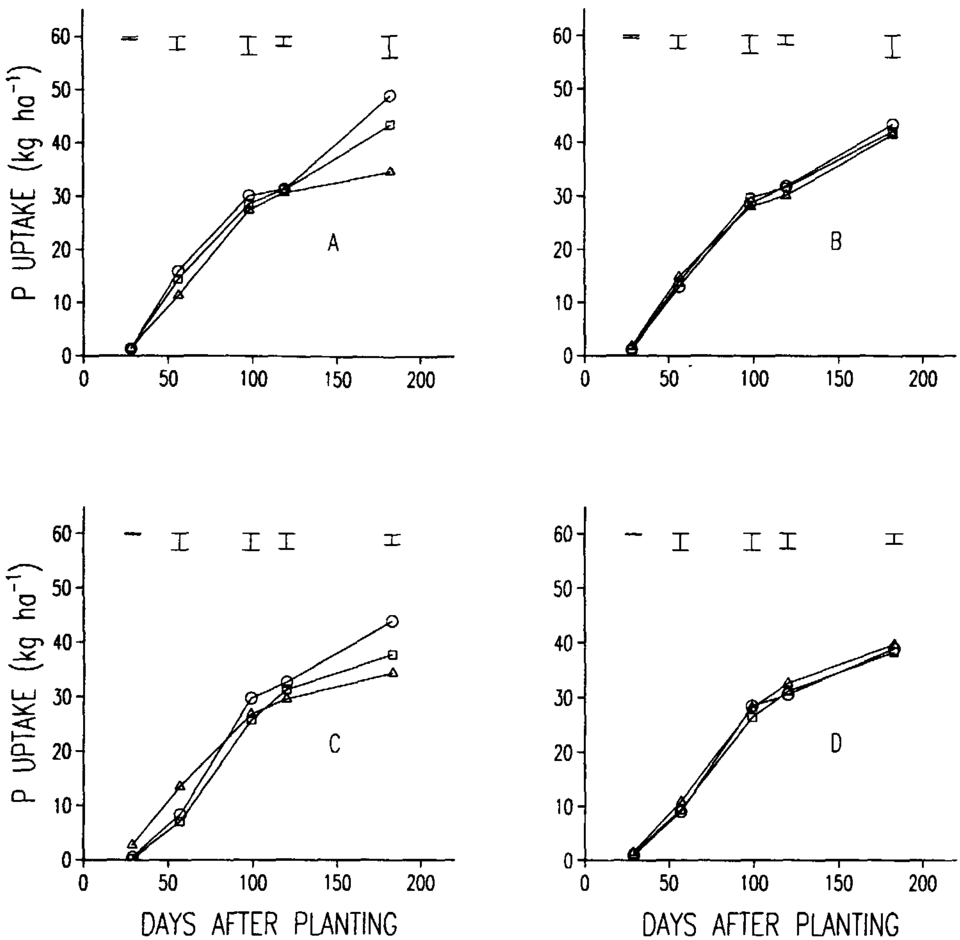
Phosphorus in the product

The amount of phosphorus harvested in 1989 decreased when planting was delayed, because of the lower amount of phosphorus taken up when planting was late (Table 2). In 1991/92 the decrease in amount of phosphorus in the crop when planting was late did not result in a lower amount of phosphorus removed from the field. Mainly



Significance	1989	1991/92
P (Planting date)	*P*=0.037	ns
D (Plant density)	*P*=0.017	ns
P × D	ns	ns
P × Days after planting	*P*<0.001	*P*<0.001
D × Days after planting	ns	ns
P × D × Days after planting	ns	ns
LSD (α = 0.05) indicated bij bars		

Figure 1. The phosphorus concentration of the crop (dry weight) in 1989 (A, B) and 1991/92 (C, D) at three planting dates (A, C), P1 (○), P2 (□) and P3 (△) and three plant densities (B, D), D1 (○), D2 (□) and D3 (△).



Significance	1989	1991/92
P (Planting date)	P=0.003	P=0.003
D (Plant density)	ns	P=0.036
P × D	ns	ns
P × Days after planting	P<0.001	P<0.001
D × Days after planting	ns	ns
P × D × Days after planting	ns	ns
LSD (α = 0.05) indicated bij bars		

Figure 2. The phosphorus uptake by the crop in 1989 (A, B) and 1991/92 (C, D) at three planning dates (A, C), P1 (○), P2 (□) and P3 (△) and three plant densities (B, D), D1 (○), D2 (□) and D3 (△).

Table 1. The amount of phosphorus in the crop at harvest.

Planting date	Phosphorus (kg ha^{-1})		Plant density	Phosphorus (kg ha^{-1})	
	1989	1991/92		1989	1991/92
P1	49	44	D1	43	39
P2	43	38	D2	42	38
P3	35	35	D3	41	40
LSD (α = 0.05)	4	2		–	–
Significance	1989	1991/92			
P	P=0.002	P<0.001			
D	ns	ns			
P × D	ns	ns			

depending on planting date, the total amount of phosphorus removed from the field with the product varied between 16 to 30 kg per hectare. Within the range of plant densities used, plant density had no significant influence on this amount.

The higher final phosphorus concentration in the crop of the second and third planting date as compared to that of the first planting date (Figure 1), was reflected in the phosphorus concentration in the (fresh) product (Table 3). Phosphorus concentration was significantly lower in the product of the first planting date, as compared to the phosphorus concentration in the product of the other planting dates. Plant density had no effect on phosphorus concentration in the product.

Phosphorus harvest index

The amount of phosphorus harvested from the field as a percentage of the final up-

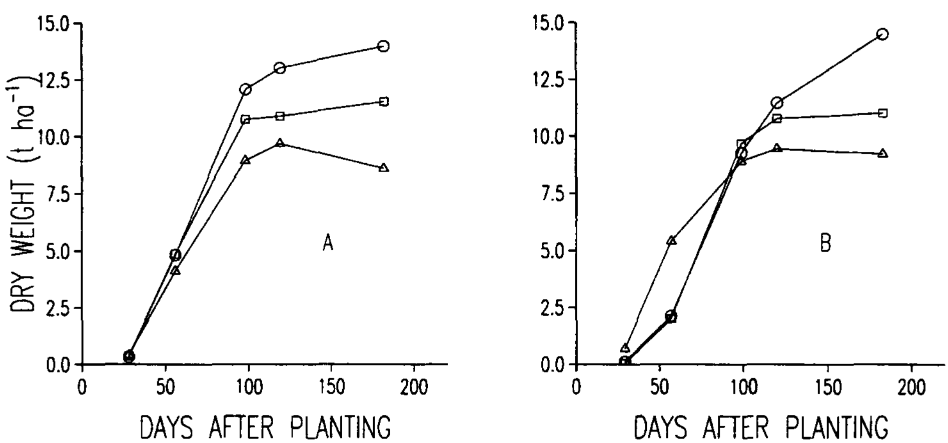


Figure 3. Dry weight of the crop in 1989 (A) and 1991/92 (B) at three planting dates, P1 (○), P2 (□) and P3 (△).

Table 2. The amount of phosphorus removed from the field.

Planting date	Phosphorus (kg ha^{-1})		Plant density	Phosphorus (kg ha^{-1})	
	1989	1991/92		1989	1991/92
P1	28	18	D1	25	18
P2	25	17	D2	23	17
P3	18	17	D3	22	17
LSD ($\alpha = 0.05$)	3	–		–	–

Significance	1989	1991/92
P	P=0.004	ns
D	ns	ns
P × D	ns	ns

Table 3. The phosphorus concentration in the (fresh) product.

Planting date	Phosphorus (kg ton^{-1})		Plant density	Phosphorus (kg ton^{-1})	
	1989	1991/92		1989	1991/92
P1	0.72	0.76	D1	0.84	0.79
P2	0.88	0.82	D2	0.81	0.79
P3	0.87	0.83	D3	0.82	0.82
LSD ($\alpha = 0.05$)	0.04	0.03		–	–

Significance	1989	1991/92
P	P<0.001	P=0.006
D	ns	ns
P × D	ns	ns

take of phosphorus, the phosphorus harvest index, was influenced in both years by planting date as well as plant density (Table 4). Between 40 and 60 per cent of the phosphorus in the crop at harvest was removed from the field with the product. The effect of planting date on the phosphorus harvest index was inconsistent between the two years of the experiments. Absolute differences in phosphorus harvest index between planting dates within one year were smaller than between year differences. The phosphorus harvest index decreased slightly with an increase in plant density.

Discussion

Greenwood *et al.* (1980) reported final crop phosphorus concentrations of *Brassicaceae* at harvest of around four g kg^{-1} and stated that for the *Brassicaceae* together the crop phosphorus concentration at harvest was almost independent of dry

Table 4. The phosphorus harvest index (PHI).

Planting date	PHI (%) 1989	PHI (%) 1991/92	Plant density	PHI (%) 1989	PHI (%) 1991/92
P1	56	42	D1	58	47
P2	57	46	D2	55	46
P3	53	49	D3	54	43
LSD ($\alpha = 0.05$)	3	3		3	3

Significance	1989	1991/92
P	P=0.031	P=0.004
D	P=0.041	P=0.033
P × D	ns	ns

weight per unit area or dry weight per plant. Our values for crop phosphorus concentration of Brussels sprouts at harvest for the different planting dates are comparable to the values reported by Greenwood *et al.* (1980) and they also relate to considerably different amounts of dry matter (Everaarts & De Moel, 1994), supporting the observation of Greenwood *et al.* (1980).

Leaf blade phosphorus concentration increases with the position of the leaf towards the top of the stem (Kirkby & DeCock, 1965; Haworth & Cleaver, 1966). Leaf shedding, resulting in a lower number of leaves present towards harvest (Everaarts & De Moel, 1994), could therefore increase the average leaf blade phosphorus concentration near harvest. This indeed was found for all treatments in both years. The magnitude of the increase was small however, and given the decrease in number of leaves present towards harvest, this increase in leaf blade phosphorus concentration does not explain the increase in total crop phosphorus concentration or uptake towards harvest. The increase in average plant tissue phosphorus concentration and phosphorus uptake towards harvest is more likely related to the fact that the part of bud dry matter in total standing dry matter increased towards harvest, due to rapid bud dry matter accumulation at that stage (Everaarts & De Moel, 1994). At harvest buds had the highest phosphorus concentration compared to concentrations in other plant tissues. Averaged over all treatments phosphorus concentration at harvest in the leaf blades, petioles, yellow leaves, stem and buds was 2.7, 2.2, 1.3, 3.1 and 5.0 gram per kilogram respectively in 1989 and 2.8, 1.8, 1.2, 3.0 and 4.7 gram per kilogram in 1991/92. Also Haworth & Cleaver (1966) found average bud phosphorus concentration to be considerably higher as compared to phosphorus concentration in leaf blades or petioles. The accumulation of bud dry matter coupled with the high bud phosphorus concentration, resulted in an increase of the average crop phosphorus concentration and phosphorus uptake towards harvest.

Within the range of plant densities tested, plant density had no or only a limited effect on crop phosphorus concentration and no effect on final crop phosphorus uptake. The decrease in phosphorus uptake with a delay in planting is considered too small to have consequences for fertilizer recommendation, which is based on crop phosphorus demand, soil phosphorus fertility status and crop rotation. This especially so, as in practice this decrease will be limited, since most of the Brussels sprouts crop is planted before the end of May. This means that within the range of planting dates and plant densities used, the current phosphorus fertilization recommendation system needs no adaptation.

Alt & Wiemann (1987) mentioned a phosphorus concentration of 0.98 kg per ton (fresh) product for Brussels sprouts. Our values for the phosphorus concentration in the buds range from 0.7 to 0.9. The currently agreed value for phosphorus concentration of buds for the calculation of nutrient harvest is 0.9 kg phosphorus per ton product (Anonymous, 1996). Soil phosphorus status of clay soils in the south-western part of the Netherlands, where Brussels sprouts are an important crop, may be higher as compared to the soil phosphorus status of our experimental fields (Pothoven, 1995). It is not known in how far a high phosphorus soil fertility status may increase phosphorus concentration of the buds. If so, Alt & Wiemann (1987) argued that using a medium product concentration for the calculation of the amount of fertilizer based on removal would be beneficial in situations of low fertility and would correct in situations of high fertility. Given the limited amount of data on phosphorus bud concentrations presently available, it appears valid to use the 0.9 value, until new data show the need for reconsideration.

At the final harvest in both years the highest yields were obtained with the first planting dates. Averaged over the plant densities, the highest marketable yield was 27.1 ton in 1989 and 23.3 ton per hectare in 1991/92 (Everaarts & De Moel, 1994). With these yield levels approximately 20 and 18 kg per hectare phosphorus was harvested. With the phosphorus soil fertility status of the experimental fields, amounts of 65 and 50 kg phosphorus per hectare would have been recommended for application in 1989 and 1991/92 respectively (Anonymous, 1992). In view of the limited amounts of phosphorus harvested at the measured yield levels, it is likely that phosphorus fertilizer gifts in practice will often be considerably higher than the amount of phosphorus removed at harvest.

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