

Effects of different fertilization practices on the carotene content of carrot

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Abstract. The effects of different fertilization practices on the carotene content of carrot cv. Nantes Duke Notabene 370 Sv were studied in field experiments in southern Finland. Unirrigated and irrigated placement and broadcast fertilization, NPK fertirrigations without basic fertilization, NPK fertirrigations with NPK basic fertilization, and PK placement with N fertirrigations were compared. Further, single application was compared to split applications. Carotene determinations were done at harvest in 1985 and 66, 88 and 121 (at harvest) days from sowing in 1986. The results were studied by contrast analysis.

Weather conditions had a strong effect on the carotene content and in both years the carotene content increased with the length of the growing season. At harvest in 1985, PK placement with N fertirrigations had a tendency to yield a higher carotene content than did broadcast fertilization, irrigated single application, and NPK fertirrigations. The carotene content was higher when P and K were placement fertilized as compared to treatments where P and K were broadcast fertilized or fertirrigated ($p=0.1$). At the first sampling date in 1986, fertilization increased the carotene content ($p=0.1$). PK placement with N fertirrigations had a tendency to increase the carotene content as compared to placement fertilization, single application and irrigated single application. At the second sampling date and at harvest in 1986 no statistically significant differences could be found.

The results indicate that the placement of PK-fertilizer or NPK-fertilizer was favourable to carotene production. Besides the fertilization experiment, samples from two organically cultivated fields were collected to obtain data concerning organically cultivated carrots.

Index words: carrot, placement fert., broadcast fert., fertirrigation, carotene, organic cultivation

Introduction

Carrot (*Daucus carota* L.) contains many carotenoids, mainly tetraterpenes of the isoprenoid group. About 60 % of the total carotene content in carrot is β -carotene (GABELMAN 1974). The variation in carotene

content is dependent on genotype (GABELMAN 1974) and climate (SIMON et al. 1982). The developmental stage of a plant (BANGA et al. 1963, PHAN & HSU 1973, FRITZ & HABBEN 1975) and temperatures during the growing

season (BARNES 1936, BANGA et al. 1955) also have a considerable effect on the carotene content. In addition, soil moisture (BANGA & DE BRUYN 1964, DRAGLAND 1978), the intensity of photosynthesis, shoot size, and plant density (BANGA & DE BRUYN 1964) affect the carotene content of carrots.

The literature contains reports about the influence of macronutrients on the carotene content the results of which are contradictory. FREEMAN & HARRIS (1951) and HABBEN (1973) found that increasing the amounts of nitrogen increased the carotene content. On the other hand, DRAGLAND (1978) reported that increasing nitrogen amounts did not affect the carotene content, and SOUTHARDS & MILLER (1962) obtained the highest carotene contents with low nitrogen levels. The same contradiction has been observed for potassium. In some studies, increasing amounts of potassium had no significant influence on carotene content (GALLAGHER 1966, HABBEN 1973), whereas others (SOUTHARDS & MILLER 1962) reported that high

potassium and magnesium levels increased the amount of carotene in carrots. NILSSON (1979) found no differences in carotene contents resulting from fertilizer levels or the use of organic versus inorganic fertilizers. The effects of different fertilization practices and the split application of nutrients have been studied very scarcely. The aim of the present study was to investigate whether unirrigated or irrigated placement and broadcast fertilization, fertirrigation and their combinations as well as the split application of nutrients affect the carotene content of carrots.

Material and methods

Field experiment

The field experiment was done on the Kotkaniemi Experimental Farm of Kemira Oy. in Vihti, southern Finland, in the summers of 1985 and 1986. Carrot cv. Nantes Duke Notabene 370 Sv was grown as described by EVERS (1988). The experiment was arranged in four

Table 1. The fertilization treatments

Treatment	Number and time of fertilizer applications	Macronutrient amounts in 1986 ³ kg/ha			Irrigation water amounts in 1985 and 1986 mm
		N	P	K	
No fertilization					
No irrigation	0	0	0	0	0
Irrigation	0	0	0	0	3 × 10
NPK placement					
No irrigation	1 before sowing	80	35	133	0
Irrigation	1 before sowing	80	35	133	3 × 10
NPK broadcast					
No irrigation	1 before sowing	80	35	133	0
Irrigation	1 before sowing	80	35	133	3 × 10
NPK fertirrigations					
Without basic fertilization	• 3 during season	80	29	160	3 × 10
Half the NPK basic fertilization ¹	1 before sowing and 3 during season	80	32	142	3 × 10
PK placement ²	1 before sowing and 3 during season	81	56	133	3 × 10
3N-fertirrigations	3 during season				
4N-fertirrigations	1 before sowing and 4 during season	155	56	133	4 × 10

¹ Half of the nutrients were given by basic placement fertilization and half by NPK fertirrigations.

² Phosphorus and potassium were given by basic placement fertilization and nitrogen by fertirrigations.

³ The nutrient amounts were 30 % bigger in 1985 than in 1986.

randomized blocks, with ten treatments per block and plots of 25 m² (Table 1).

Determination of carotene

The carrot samples for the determination of carotene were collected on September 30, 1985 (117 days from sowing) and August 12, 1986, on September 3, 1986 and October 6, 1986 (66, 88 and 121 days from sowing, respectively). Six consecutive carrots were sampled from each plot, from a randomized place, and two analyses were made for each sample. In 1985 samples were collected from two blocks, in 1986 from four blocks. Carotene was determined by high-performance liquid chromatography (HPLC) on SPHERISORB 10 ODS2 250 × 4.6 mm I.D. column, a bonded octadecylsilane stationary phase with visible photometric detection at wavelength 450 nm (LANGER 1976). This method measures the added α and β carotene content. In the text it is termed carotene for short. 60 grams of fresh carrot tissue was crushed in a blender

containing 100 ml CH₂Cl₂ and was mixed for 10 minutes, filtered and analyzed immediately by HPLC. The samples were protected from light and oxygen because these can destroy carotene. The data was studied statistically by contrast analysis (STEEL & TORRIE 1980).

Organically cultivated carrots

Simultaneously with those for the fertilization experiments, samples from two organically cultivated fields were collected. These organically cultivated carrots were grown with the same seed material, but the geographical locations (Varkaus and Rantasalmi) and soil characteristics differed from those of the fertilization experiments. In any case, these samples gave information of organically cultivated carrots. The compost and soil analyses as well as the amounts of compost used are given in a previous study (EVERS 1988).

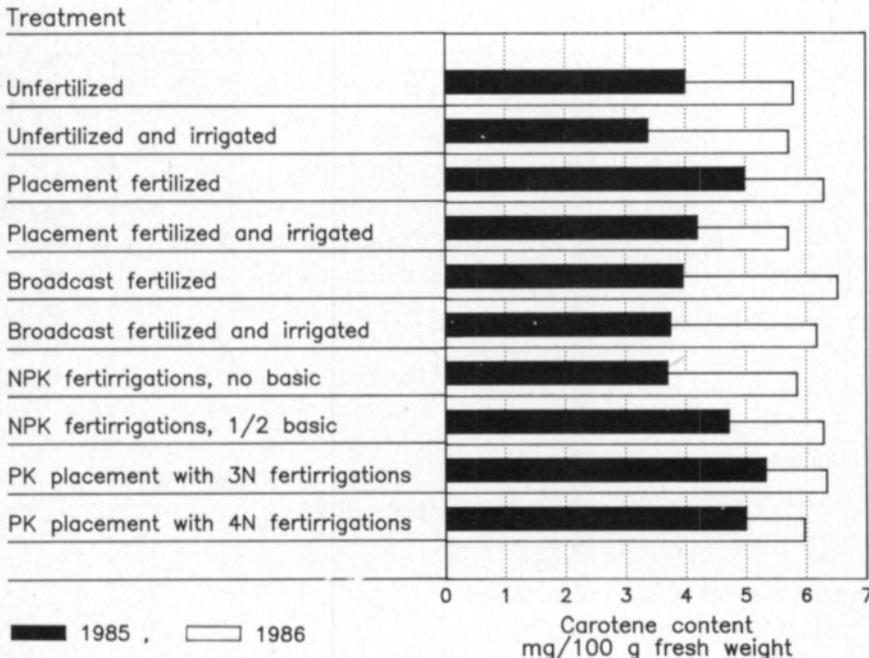


Fig. 1. The effect of different fertilization practices on the carotene content of carrots at harvest in 1985 and 1986.

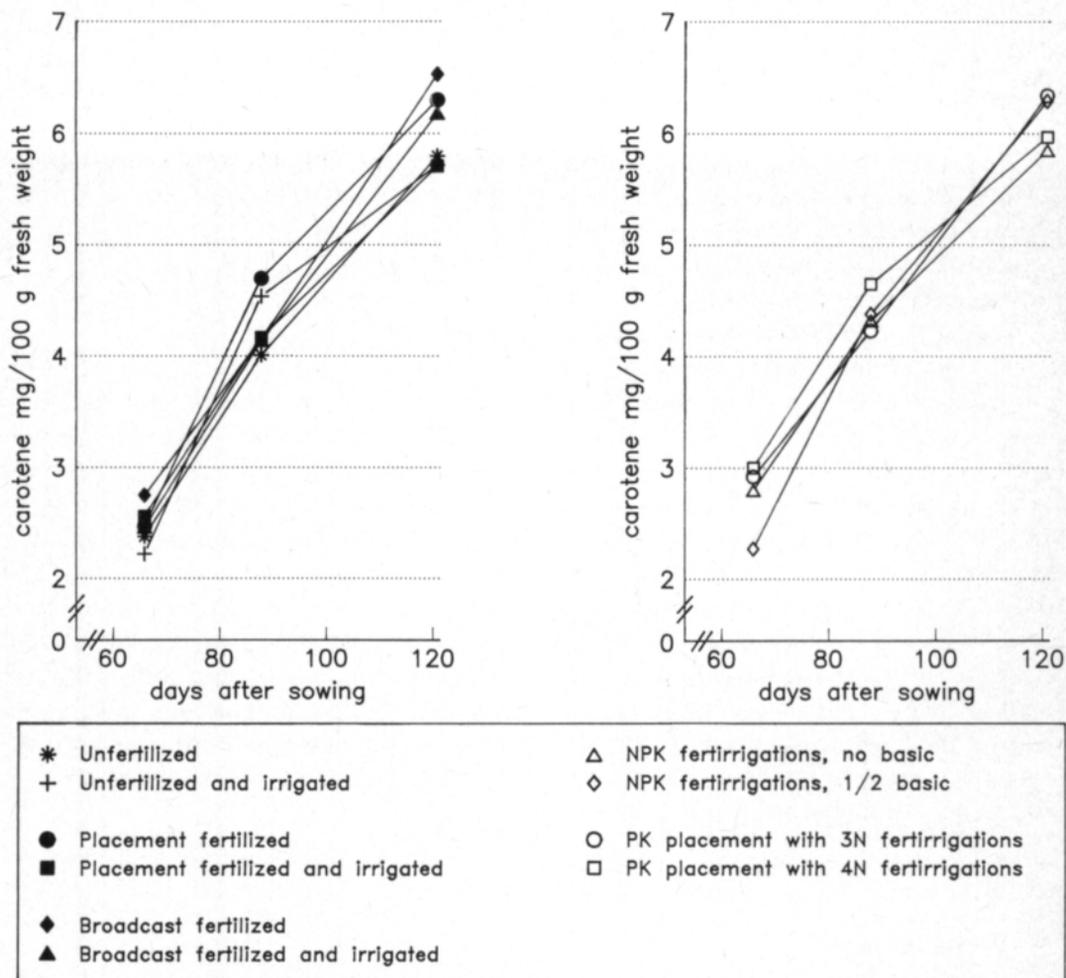


Fig. 2. The effect of different fertilization practices on the development of the carotene content of carrots in 1986.

Results

Weather conditions

Weather conditions had a strong effect on the carotene content of carrots. The carotene contents of carrots cultivated in 1985 were lower than in 1986 irrespective of the fertilization treatments ($p < 0.001^{***}$) (Fig. 1).

Developmental stage

The carotene content of carrots increased with the length of the growing season (Fig. 2). At the first sampling date, 66 days from sowing, the carrots were about 10 cm long, with

an average weight per carrot of 27.0 grams. In these young and small carrots, the carotene content was low, the average for all treatments being 2.6 mg/100 g fresh weight (FW). At the second sampling date, 88 days from sowing, the average weight per carrot was 76.5 g, the mean carotene content being 4.3 mg/100 g FW. At harvest, 121 days from sowing, the corresponding values were 106 g and 6.1 mg/100 g FW.

Fertilization

The statistical analysis method used in this study did not reveal any significant differences

between fertilization practices or between unfertilized and fertilized treatments on level $p < 0.05$. At harvest in 1985, PK placement with N fertirrigations had a tendency to yield a higher carotene content than did broadcast fertilization, irrigated single application, and NPK fertirrigation ($p = 0.1$). There was also a tendency for a higher carotene content when P and K were placement fertilized as compared to treatments where P and K were broadcast fertilized or fertirrigated ($p = 0.1$).

At first sampling date in 1986, fertilization increased the carotene content ($p = 0.1$). PK placement with N fertirrigations had a tendency to increase the carotene content as compared to placement fertilization, single application and irrigated single application ($p = 0.1$). At the second sampling date and at harvest in 1986 no statistically significant differences could be found.

In both years, four treatments gave good results (Fig. 1). These were placement fertilization, NPK fertirrigation with NPK basic fertilization and PK placement with N fertirrigations. In both years NPK fertirrigations without basic fertilization yielded a low carotene content. Broadcast fertilization gave con-

tradictionary results in two years. As compared to the average carotene content of unfertilized treatments, placement fertilization increased the carotene content by 35 % in 1985 and by 9 % in 1986, NPK fertirrigations with NPK basic fertilization increased the carotene content by 28 % in 1985 and by 9 % in 1986, and PK placement with 3N fertirrigations increased the carotene content by 44 % in 1985 and by 10 % in 1986.

Carotene yield

The order of superiority for the treatments was roughly similar whether the carotene content was calculated on the basis of fresh matter (Fig. 1) or dry matter (Table 2). When the results were studied as the calculated carotene yield per hectare (Table 2), some differences were observed for 1986. Irrigated placement fertilization produced a relatively low carotene content, but the carotene yield calculated as g/ha was very good. On the contrary, broadcast fertilization produced a surprisingly high carotene content, but the carotene yield calculated as g/ha was low. The same was true for PK placement with N fertirrigations (Fig. 1, Table 2).

Table 2. The effect of different fertilization practices on the carotene content of carrots calculated on dry weight basis and as a carotene yield per hectare.

Treatments	Carotene content mg/100 g dry weight			Carotene yield g/ha		
	1985	1986	\bar{x}	1985	1986	\bar{x}
Unfertilized	42.5	54.2	48.3	1 620	2 760	2 190
Unfertilized and irrigated	35.1	53.4	44.2	1 190	2 620	1 900
Placement fertilized	49.7	60.0	54.9	1 850	3 190	2 520
Placement fertilized and irrigated	43.7	55.6	49.7	1 520	3 230	2 380
Broadcast fertilized	42.4	61.6	52.0	1 620	3 150	2 380
Broadcast fertilized and irrigated	38.3	60.1	49.2	1 060	2 970	2 020
NPK fertirrigations, without basic	41.4	56.8	49.1	1 190	3 050	2 120
NPK fertirrigations, half the basic	50.5	60.2	55.3	1 830	3 460	2 650
PK placement with 3N fertirrigations	55.4	58.8	57.1	2 090	3 070	2 580
PK placement with 4N fertirrigations	50.4	56.7	53.5	1 760	3 140	2 450
\bar{x}	44.9	57.7	51.3	1 570	3 060	2 320
Organically cultivated, location 1		66.7			3 240	
Organically cultivated, location 2		64.6			2 570	
\bar{x}		65.6			2 910	

Organically cultivated carrots

The carotene contents were high for carrots grown at both locations, being 7.0 mg/100 g FW at location one and 6.2 mg/100 g FW at location two. The contents were high also when calculated on the dry weight basis (Table 2). When the carotene yields were calculated (Table 2), they were lower in organically cultivated carrots than in the fertilizer experiment.

Discussion

Genotype

The main variation in the carotene content of carrots depends on genotype (GABELMAN 1974) and climate (SIMON et al. 1982). In the present study, cv. Nantes Duke Notabene 370 Sv was used; the average carotene content of all treatments and for two years at harvest was 5.2 mg/100 g FW. BAJAJ et al. (1980) studied 23 cultivars of carrot; in their study this variety contained 4.95 mg β -carotene/100 g FW. The overall mean of 23 varieties was 5.67 mg β -carotene/100 g FW (range 0.85—8.50 mg/100 g FW). Thus in the climatic conditions of southern Finland, this variety can reach the same carotene level as in India.

Weather conditions

There was a clear difference in the mean carotene content between the two years. The average carotene content for all treatments was 41.2 % higher in 1986 than in 1985. In 1985, the mean day temperature and the number of sunshine hours in June and July were lower than in 1986 and lower than the long-term averages (EVERS 1988). BARNES (1936) and BANGA et al. (1955) reported that high temperature favours carotene synthesis. HÅRDH (1975) reported that the β -carotene content of carrots is higher in southern Finland than in northern Finland, a difference that is mainly due to higher temperatures in the southern part of the country. Similar

results were also obtained in Norway and Sweden (HÅRDH et al. 1977).

DRAGLAND (1978) reported that low soil moisture content increases the carotene content of carrot roots. Also BANGA & DE BRUYN (1964) reported that the carotene synthesis increases in dry soil. They concluded that evidently in such case, primary vegetative root growth is suppressed by the low soil moisture content, causing the root to ripen at a smaller root size. This means that protein synthesis is also reduced and it is consuming less carbohydrate compounds. Consequently, most of the carbohydrate compounds available can be used for other consumption processes, such as carotenoid synthesis. BANGA et al. (1963) also studied whether the soil moisture content affected the carotenoid synthesis directly or indirectly by lowering the soil temperature. They found that the soil moisture content had a direct effect. Further BANGA & DE BRUYN (1964) concluded that an oxygen content under 6 % in the soil atmosphere reduces carotenoid synthesis.

In the present field experiments, in 1985 the precipitation was equal to the long-term averages, and in 1986 the precipitation was heavier than the long-term averages except in June, which was sunny and drier than average (EVERS 1988). In both years there were heavy rains in September; the soil was very moist and perhaps also had a low oxygen content. Precipitation probably does not explain the difference in the carotene contents between years, as in both years the soil remained moist throughout the growing period (except June, 1986). It is more likely that the higher temperature in 1986 is the main reason for the higher carotene contents in 1986 than 1985.

Developmental stage

There is general agreement in the literature that the carotenoid content of carrots increases when the plant is ripening (BANGA et al. 1963, PHAN & HSU 1973, FRITZ & HABBEN 1975). Also in the present study, the carotene content increased as the growing season proceeded.

Fertilization

Because most of the variation in carotene content is genetically controlled or is dependent on climate, it is obvious that there can be no clear differences between fertilization practices. In more unfavourable year 1985 there was, however, a tendency for the placement of PK fertilizer to increase the carotene content. In future studies it would be interesting to investigate whether it is P or K that increases the carotene content and the way in which the nutrient affects the carotene content.

According to the literature, contradictory results have been obtained with increasing nitrogen amounts (FREEMAN & HARRIS 1951,

SOUTHARDS & MILLER 1962, HABBEN 1973, DRAGLAND 1978). In the present study, the surplus nitrogen in treatment PK placement with 4N fertirrigations did not significantly affect the carotene content as compared to the average of other fertilized treatments, where the N amount applied was thought to be optimal on the basis of the yield. Thus this study could find no response that depended on the nitrogen amount.

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Eri lannoitustapojen vaikutus porkkanan karoteenipitoisuuteen

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Eri lannoitusmenetelmien vaikutusta porkkanalajikkeen Nantes Duke Notabene 370 Sv karoteenipitoisuuteen tutkittiin kenttäkokeissa 1985 ja 1986 Kotkaniemen koetillalla Vihdissä. Vertailtavina menetelminä olivat sijoitus- ja pintalannoitus (ilman kastelua ja kastelun kera), NPK-kastelulannoitus ilman peruslannoitusta, NPK-kastelulannoitus, jossa puolet ravinteista annettiin peruslannoituksena, sekä N-kastelulannoitus, jossa P ja K annettiin sijoittaen peruslannoituksena. Kokeessa verrattiin myös kerta-annostelua jaksotettuun ravinteiden antoon. Porkkananäytteet karoteenimäärityksiin kerättiin sadonkorjuun yhteydessä 1985 sekä 66, 88 ja 121 (sadonkorjuu) päivän kuluttua kylvöstä 1986. Tulosten analysointiin käytettiin kontrastianalyysejä, jossa ei verrata yksittäisiä koekärsiä toisiinsa vaan voidaan verrata asiakokonaisuuksia.

Vuonna 1985 sadonkorjuun yhteydessä koekärsienissä, jotka saivat P:n ja K:n sijoittaen peruslannoituksena ja N:n kastelulannoituksena kasvukaudella, oli korkeammat

karoteenipitoisuudet kuin pintalannoituksen, kertalannoituksen kastelun kera tai NPK-kastelulannoituksen saaneissa koekärsienissä. Karoteenipitoisuudet olivat myös korkeammat koekärsienissä, jotka saivat P:n ja K:n sijoituslannoituksena, kuin koekärsienissä, joissa P:tä ja K:ta ei annettu sijoituslannoitustekniikalla. Tulokset olivat suuntaa-antavia tasolla $p=0.1$.

Vuonna 1986 vain ensimmäisellä näytteenottokerralla (66 vrk kylvöstä) lannoitus lisäsi karoteenipitoisuutta ($p=0.1$). Lannoitustapa, jossa P ja K annettiin sijoittaen keväällä ja N kastelulannoituksena kasvukaudella, lisäsi suuntaa-antavasti ($p=0.1$) karoteenipitoisuutta verrattuna sijoituslannoitukseen, yhteen antokertaan ja kasteltuun yhteen antokertaan.

Kaikkien koekärsien karoteenipitoisuus nousi kasvukauden edetessä. Vuoden säätäkijöillä oli selvä vaikutus karoteenipitoisuuksiin.