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Response of P, K, Mg and NO_3-N contents of carrots to irrigation, soil compaction, and nitrogen fertilisation

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Soils ploughed in autumn were loosened by different tillage tools, or compacted to a depth of 25–30 cm by a tractor weighing 3 Mg (once or three times) before seed bed preparation for carrot under moist soil condition. Sprinkler irrigation was also applied to mineral soils when the soil moisture in top soil was 50% of plant-available water capacity, and the response of additional N application of 30 kg ha^{-1} was studied in an organic soil. Higher soil moisture tended to promote nutrient uptake, as the P content of carrot tap roots was increased by irrigation in loam. Compaction of organic soil low in P increased P and K contents and uptake by carrot roots and shoots. In severely compacted clay soil, the nutrient use decreased by increasing soil compactness. NO_3-N contents were the highest in early season (25–30 mg kg^{-1} fresh matter) and decreased with advancing season. In loam, NO_3-N content was increased by irrigation or loosening. Increasing the N fertilisation of organic soil from 30 kg ha^{-1} to 60 kg ha^{-1} increased the NO_3-N content 30%. Soil type and its nutrient status, weather conditions, and growth stage had much more significant influence on the P, K, and Mg contents of carrots than soil treatments.

Key words: clay soils, loam soils, nutrient uptake, organic soils, quality, soil management, tillage

Introduction

Loose soil conditions can contribute greatly to the production of carrots of optimal shape (White 1978, Taksdal 1984). The developmental stages of carrots have a major influence on the carotene and sugar contents of the vegetables (Platenius 1934, Hole and McKee 1988, Evers 1989a, c), although Rosenfeld (1998) and Suojala (1999) reported that they could find no definable stage of biological development which indicates maturity using these chemical variables. Altered soil conditions by fertilisation practices or soil tillage, however, have no or only slight effects on carotene and sugar contents (Evers 1989a, c, Pietola 1995). This indicates that variations in chemical quality are either caused by climate

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(Rosenfeld 1998) or by genetical factors (Nilsson 1984).

Moderate soil compaction and irrigation increase the fibrous root length and surface area of carrots (Pietola 1995), suggesting a higher efficiency of nutrient use (Lipiec et al. 1988, 1992, Veen et al. 1992). The positive effect of soil density or moisture on fibrous root growth and root-to-soil contact could, in turn, affect the mineral composition and NO_3-N contents of carrot, and thereby the quality. This study focused on the response of soil compaction and irrigation on the P, K, Mg and NO_3-N contents of carrot plants, collected mainly from the field experiments for three soil types presented by Pietola (1995). As carrot is very efficient in utilising soil N (Evers 1989b, Salo 1999), the effect of both soil compactness and N fertilisation on plant NO_3-N (mg kg^{-1} fresh weight) were studied in a separate field experiment in organic soil. To better understand the role of irrigation and soil compaction on nutrient uptake by carrots, nutrient uptake (kg ha^{-1}) was calculated using the data of carrot biomass accumulation (Pietola 1995).

Material and methods

The data for this paper were collected from field experiments established on Eutric Cambisols (FAO 1988) at the Agricultural Research Centre of Finland in Jokioinen (60°49,N; 23°28,E, 85 m above sea level) in 1989–91. The soil types were loam (topsoil sandy loam with 13% clay, subsoil clay loam with 31% clay), clay with 5.8% organic C, and a clay soil with an organic plough layer, a histic H horizon (later called an organic soil). Loam was studied in 1989–91, clay in 1989 and organic soil in 1990–91.

All the soils were quite clayey with good nutrient contents, except P in organic soil. In loam (pH_{H2O} 6.8), soil P content, analysed in acid ammonium acetate (pH 4.65) (Vuorinen and Mäkitie 1955), was very high (80 mg dm^{-3}) in 0–25 cm soil depth and 20 mg dm^{-3} in 25–50 cm, decreasing to 70 and 6 mg dm^{-3}, respectively, by the end of the experiment. Mg content in the loam was only fairly good, 100–150 mg dm^{-3}, but it increased to 650 mg dm^{-3} in subsoil (= soil depth of 25–50 cm) by the end of the experiment. The nutrient status of clay soil was very good (pH_{H2O} = 6.8, P = 19 mg dm^{-3}in topsoil and 3 mg dm^{-3} in subsoil, Mg = 750 mg dm^{-3} in topsoil and 1150 mg dm^{-3} in subsoil, K = 450 and 270 mg dm^{-3} respectively). In organic soil, both P (4–7 mg dm^{-3}) and B contents were fairly low. The K content of organic soil was 290 in topsoil and 260 in subsoil, decreasing to 235 and 190 mg dm^{-3} to the end of the experiment. Mg contents were over 200 mg dm^{-3}. Organic soil pH_{H2O} was 5.5 (Pietola 1995). Soil N contents were not determined. Organic C contents for the topsoils (0–25 cm) for loam, clay and organic soils were 2.4, 5.8, and 18.1%. The C contents for subsoils were 0.9, 0.7, and 6.9, respectively (Pietola 1995).

The treatments were irrigation (on mineral soils only), soil loosening and moderate soil compaction. The field experiments were set up in a split-plot design with four replicates. The effects of irrigation were studied in the main plots:

A_0= no irrigation
A_1= irrigation

Sprinkler irrigation was applied to the mineral soils when the soil moisture in top soil decreased to 50% of plant-available water capacity (Elonen et al. 1967), determined by the gypsum block method (Bouyoucos 1954). Mineral soils were irrigated twice each year, the yearly amount of water varied from 49 mm to 70 mm (Pietola 1995).

The main plots were divided into subplots according to different mechanical treatments of soil. The treatments of spring tillage were set up on autumn ploughed land, by loosening (B_1–B_2) or compacting (B_4–B_5) the experimental field area before sowing:

B_1 = soil harrowing to the depth of 5 cm, and ridge preparation to the height of 10 cm

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B_2 = soil loosening by rotary harrowing to the soil depth of 20 cm
B_3 = untreated, only soil harrowing to the depth of 5 cm
B_4 = soil compaction by one pass of the tractor wheel
B_5 = soil compaction by three passes of the tractor wheel

The rear axle load of the tractor was 3030 kg. The ground pressure for the rear wheel was 120 kPa and that for the front wheel 60 kPa, resulting in only moderate soil compaction: The degree of soil compactness D (Håkansson 1990) to a soil depth of 20 cm averaged 80, 82 and 92% for the clay soil, in the treatments of B_2, B_3 and B_5. For loam, the D-values were 76, 78, and 88% of the maximum soil compactness for these treatments, respectively. For organic soil, the degrees of soil compactness were 76, 80, and 92%, respectively. The distance of both rear and front wheels was adjusted to 2 m which was the width of the subplots, and thereby the wheels were never allowed to compact the experimental area in treatments B_1–B_3. Mechanical treatments B_1–B_5 and the effects on soils have been presented in detail by Pietola (1995).

Soil loosening by large ridge preparation (B_0) was included in the experiment on organic soil in 1991, with B_2- and B_5-treatments. In this separate field experiment, the effect of nitrogen fertilisation during the growing period was studied in the main plots (A_2 = 0, A_3 = 30 kg ha^{-1}) which were divided into the three different mechanical treatments (B_0, B_2, B_5). Extra nitrogen fertilisation (30 kg ha^{-1}) was applied to organic soil in late July during the vigorous shoot growth. Treatment B_0 was carried out by the rotary harrow combined with the ridge former (ridge height 30 cm). The row distance of this treatment was 60 cm, as in the other treatments the distance was 45 cm.

After soil compaction, fertilisers (N 80, P 50, K 160 kg ha^{-1} to mineral soils and N 30, P 70, K 170 kg ha^{-1} to organic soil) were drilled according to general recommendations in Finland. For each subplot, seeds were sown in four row beds 10 m long. The cultivar of carrot (*Daucus carota* L.) was Nantes Duke Notabene, which has been used in the fertilisation and soil compaction experiments in the Nordic countries (Taksdal 1984, Evers 1989a, b, c). In the separate nitrogen fertilisation experiment on organic soil in 1991, the cultivar was, however, Narbonne F1 which is commonly used by Finnish farmers. Seeds (in 1990 coated) were sown in 1 cm deep and 6 cm wide bands. Later plants were thinned to 40 plants per 1 m. To be able to look more closely at the effects of soil compactness on the shape of carrots, only 20 plants were left per rowmeter in 1989.

For the chemical analyses, carrots were sampled three times a season (for clay soil and loam in 1989 only once at harvest). The first sample was collected when the tap roots began to swell, i.e. 7–8 weeks before harvest. The second sampling was performed 3–4 weeks before harvest, when tap roots were almost full size, but the internal quality was still developing. The third sampling was done at harvest:

loam 1989–1991:	137, 158 and 145 days after planting (DAP)
clay 1989:	140 DAP
organic soil 1990–1991:	165 and 146 DAP

For the determination of mineral elements in tap root and shoot materials, 2 g dried matter (60°C 48 h, 105°C 24 h) of the grated and frozen (–20°C) tap roots or dried shoots were ashed at 450°C and dissolved with 100 ml 0.2 M HCl. Phosphorus was determined colorimetrically with the modified ammonium-vanadate-molybdate method (Gericke and Kurmies 1952), and K and Mg were determined by atomic absorption methods (PERKIN-ELMER 1976). The mineral contents in tap root were analysed from all experiments, but the contents in shoot only from loam and organic soil experiments in 1990–91. The NO_3-N content was analysed from fresh tap root material (grated and frozen) with a nitrate electrode (ORION 1983, Aura 1985), from field experiments on loam and organic soils in 1990–91. Weather data was obtained from the Finnish Meteorological Institute.

The results were analysed using the analysis of variance by a split-plot design, and Tukey's HSD (Honestly Significant Difference) test, or standard errors of the means (2 × SE) at the same A level, was used to determine any statistically significant differences ($P < 0.05$) between group means. Mineral contents were multiplied with dry matter accumulation of cv. Nantes Duke determined by Pietola (1995), and with the dry matter accumulation of cv. Narbonne, and the resulting nutrient uptake was also analysed statistically. For a dimension kg ha^{-1}, 200 000 row meters was used for one hectare, including 40 plants per one rowmeter (except in 1989 only 20 plants m^{-1}).

Results and discussion

Mineral contents and uptake in tap roots

Differences between the soils

Different soil types of different nutrient status affected the mineral contents of the tap root. In loam of very high soil P, well developed tap roots contained about twice as much P as those in the organic soil, or in sandy soils reported by Dragland (1978). The K and Mg contents of carrots differed more due to weather conditions than due to soils (Table 1, Figs. 1–3).

Dynamics of accumulation

The developmental stage of carrot plant had an influence on P, K, and Mg contents of tap roots, as reported earlier by e.g. Evers (1989a, c). The mineral contents of carrots were, however, differently affected by the growth stage in 1990–1991, indicating an effect due to different weather conditions (Table 1). In the dry and sunny summer 1990, the P content was highest (4.7 mg g^{-1} dry matter) at the second sampling (120 = DAP) in loam, and at harvest in the organic soil (3.1 mg g^{-1}). In 1991, the contents decreased towards the end of season. In that year, June was more rainy than in 1990. Overall, the contents were within or close to the range of P-, K- and Mg-contents of carrot tap roots reported by Jansson et al. (1985) under typical Finnish soils and growing conditions.

Effect of irrigation

Higher soil moisture tended to promote nutrient uptake, as the P content of carrot tap roots increased by irrigation in loam (Fig. 1). This appeared to be a response of better growth of both tap and fibrous roots under moister soil conditions (Pietola 1995). Irrigation slightly increased P content in clay soil, on an average from 2.8 to

Table 1. Weather conditions in Jokioinen in 1989–1992 and 30-year averages. Data provided by the Finnish Meteorological Institute.

Month	Mean air temperature (°C)				Precipitation (mm)			
	1989	1990	1991	1961–91	1989	1990	1991	1961–91
April	5.3	5.6	3.4	2.4	40	35	14	31
May	10.4	9.3	7.2	9.4	41	22	29	35
June	15.4	14.4	12.1	14.3	30	20	69	47
July	16.3	15.2	16.6	15.8	85	85	55	80
August	13.7	15.0	16.2	14.2	92	90	92	83
September	11.0	8.0	9.1	9.4	51	62	80	65
October	4.7	4.9	5.4	4.7	49	48	49	58
	Mean:				Sum:			
	11.1	10.3	10.0	10.0	388	362	388	399

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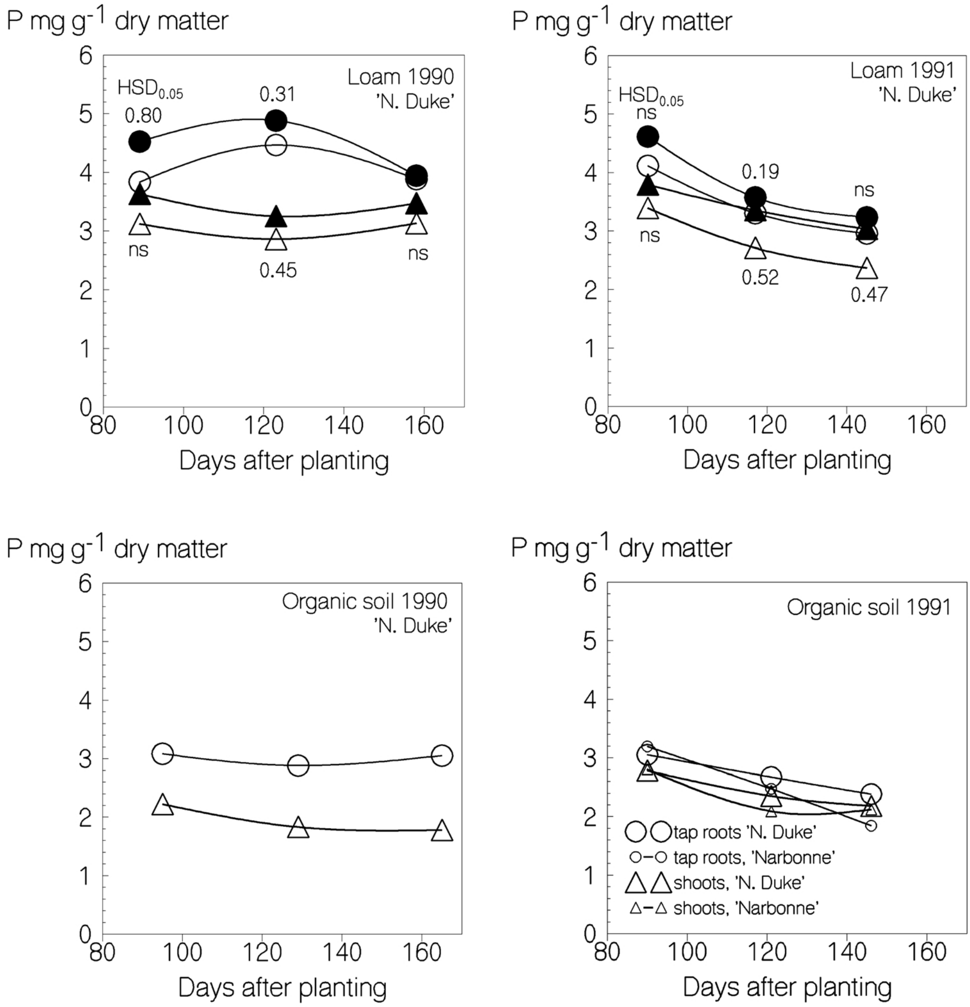

Fig. 1. P contents of carrot tap roots (O) and shoots (Δ) at different times of the season in loam, where irrigation was also applied, and in organic soil. Open symbols indicate non irrigated and black symbols irrigated soils. $HSD_{0.05}$ indicates Tukey's honestly significant difference ($P<0.05$).

2.9 mg kg^{-1} ($P < 0.05$). Irrigation also promoted P uptake in loose clay soil (B_2) from 14.5 kg ha^{-1} to 18.1 kg ha^{-1}, and also in slightly compacted loam (B_4) in 1991, from 28.1 kg ha^{-1} to 36.5 kg ha^{-1}. Under more compacted soil conditions (B_5) irrigation had negative effects. Even in loam, P uptake decreased from 27.2 kg ha^{-1} to 21.9 kg ha^{-1} by irrigation and compaction in 1989 ($P < 0.05$).

Irrigation increased the K content of tap roots in early season (Fig. 2). Mg content in carrots was, however, negatively affected by irrigation in the dry summer of 1990 (Fig. 3). Irrigation also increased the K uptake on loam from 18 to 23 kg ha^{-1}, at the second sampling in 1990, and promoted Mg uptake in 1991 at the second sampling, from 1.74 to 2.11 kg ha^{-1} ($P < 0.05$).

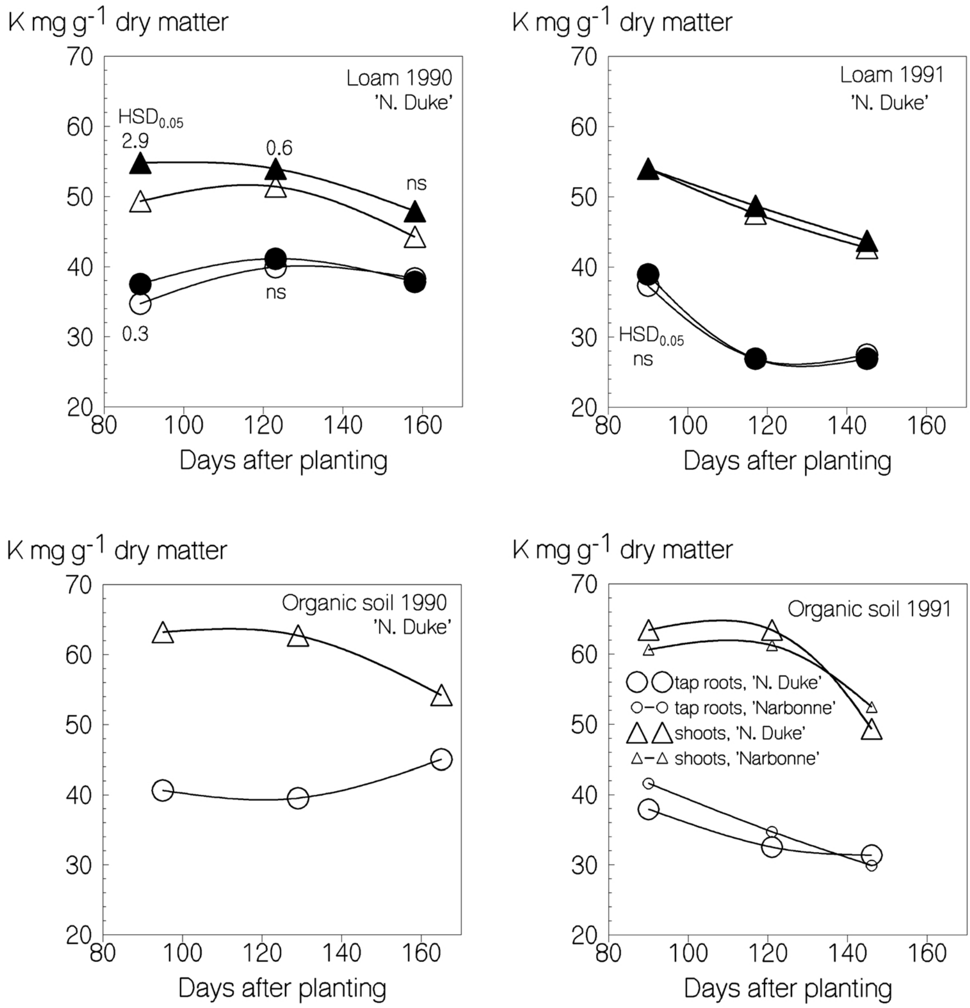

Fig. 2. K contents of carrot tap roots (O) and shoots (Δ) at different times of the season in loam, where irrigation was also applied, and in organic soil. Open symbols indicate non irrigated and black symbols irrigated soils. $HSD_{0.05}$ indicates Tukey's honestly significant difference ($P<0.05$).

Effect of soil compaction

The effect of soil compaction on K and Mg contents was minor. Also P was unaffacted on loam of high P status. The uptake of kg ha^{-1} in the organic soil of low P status, was, however, promoted by compaction as follows, for cv. N. Duke:

Treatment	129 DAP	Harvest 1990
B_5	15.4	23.9
B_1	12.2	20.7
	121 DAP	Harvest 1991
B_5	15.2	25.5
B_1	13.1	19.7

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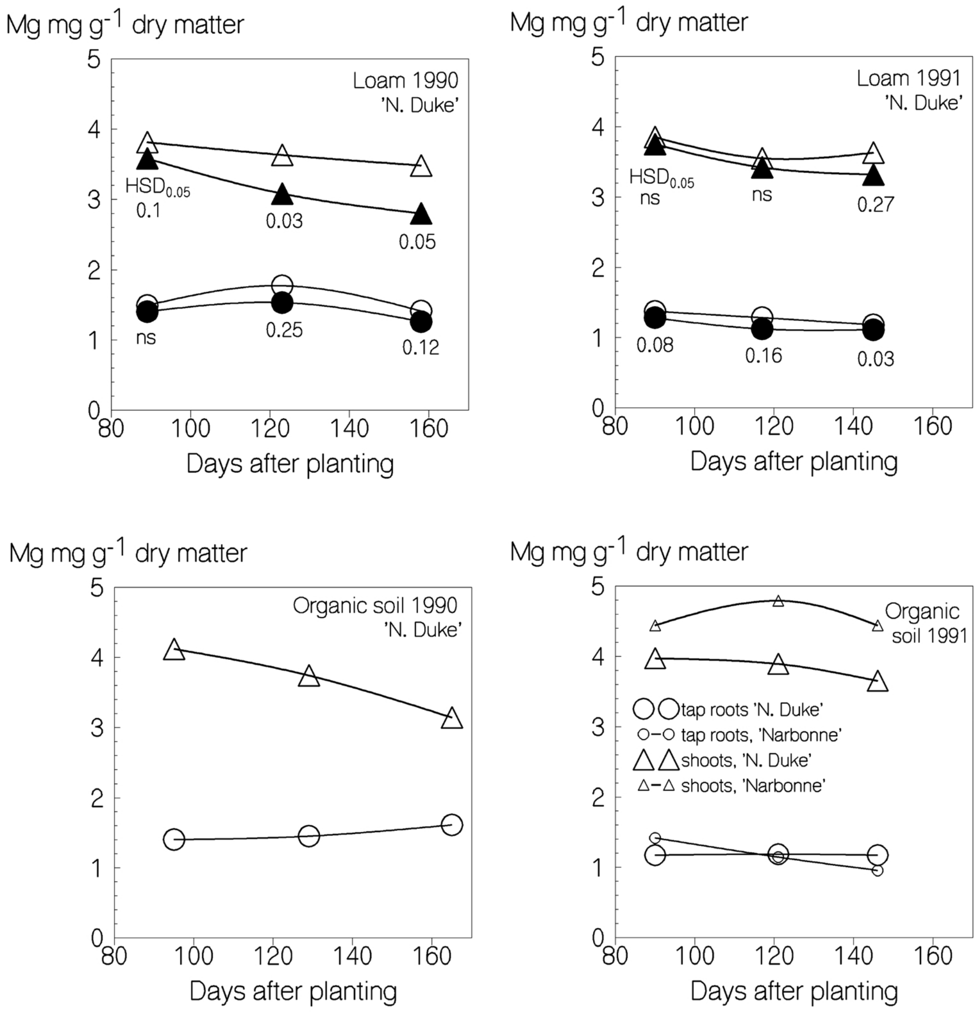

Fig. 3. Mg contents of carrot tap roots (O) and shoots (Δ) at different times of the season in loam, where irrigation was also applied, and in organic soil. Open symbols indicate non irrigated and black symbols irrigated soils. $HSD_{0.05}$ indicates Tukey's honestly significant difference (P<0.05).

The P uptake (kg ha^{-1}) was promoted by compaction of organic soil also for cv. Narbonne (Table 2). Also the positive effect of soil compaction on K and Mg uptake was obvious in early and middle season (Table 2). The results are explained by the data presented by Pietola (1995) and Pietola and Smucker (1998) showing better growth of tap roots and stimulation of fibrous root systems for compacted soils. No effects of extra nitrogen application (30 kg ha^{-1}) on mineral uptake was found on organic soil in 1991.

In clay soil, on the contrary, compaction significantly reduced the growth and mineral uptake, since the impact of tractor wheel traffic

Table 2. Effect of soil loosening, compaction and ridge cultivation on P, K and Mg -uptake by carrot tap roots in cv. Narbonne (n=4), kg ha^{-1} in 1991: B_0= large ridge cultivation, B_2=soil loosening by rotary harrowing, B_5=soil compaction by three passes of the tractor wheel. $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		Mineral uptake by tap roots, kg ha^{-1}		
Days after planting Treatment		90	121	146
			P	
60 + 0 kg/ha N	Large ridges B_0	1.24	9.4	15.7
	Loose bed B_2	2.22	11.3	14.0
	Compacted soil B_5	2.24	12.6	20.2
	$HSD_{0.05(B)}$	*0.61*	*1.50*	*ns*[1)]
	mean			16.6
			K	
60 + 0 kg/ha N	Large ridges B_0	17.7	137	270
	Loose bed B_2	30.0	164	237
	Compacted soil B_5	30.4	164	300
	$HSD_{0.05(B)}$	*9.9*	*28*	*ns*
	mean			269
			Mg	
60 + 0 kg/ha N	Large ridges B_0	0.55	4.52	8.72
	Loose bed B_2	0.92	5.48	7.46
	Compacted soil B_5	0.95	5.36	9.58
	$HSD_{0.05(B)}$	*0.33*	*0.95*	*ns*
	mean			8.59

[1)] non significant at P<0.05

on increasing soil bulk density and mechanical impedance was much stronger in clay than in the other soils (Pietola 1995). As the growth decreased, the K uptake was 12.5 kg ha^{-1} in compacted treatment (B_5) compared to 15–18 kg ha^{-1} in other treatments. In more dense stands in 1990–1991, the K uptake was much higher, e.g. in 1991 on loam at harvest 33.3 kg ha^{-1} in B_2 and 29.7 kg in B_5 ($P < 0.05$). Among different soils, also Mg uptake was affected by soil compaction most remarkably on clay soil, decreasing from 6.7 kg ha^{-1} in B_2 to 5.1 kg ha^{-1} in B_5 ($P < 0.05$).

Mineral contents and uptake in shoots

Differences between the soils

In the plants cultivated in organic soil, the K contents of shoots were 20% higher than those collected from loam (Fig. 1). This appears to reflect the higher K contents in organic soil (250 mg dm^{-3}) as compared with loam (150 mg dm^{-3}). The importance of soil nutrient status on nutrient content of carrot shoots was also shown by P contents: the P content of plough layer in organic soil was around 70 mg dm^{-3} lower than in loam. Such a difference in soil P was clearly shown in shoot P levels, being 2 mg g^{-1} in organic soil and over 3 mg g^{-1} in loam carrots (Fig. 2).

Dynamics of accumulation

P, K and Mg contents in shoots varied differently during the growing season, but mostly decreased towards the end. This is in agreement with the data presented by Evers (1989c).

Effect of irrigation

Irrigation increased P contents of shoots. Mg

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Table 3. Effect of soil loosening, compaction and ridge cultivation on P, K and Mg -uptake of carrot shoots in cv. Narbonne (n=4), kg ha^{-1} in 1991: B_0= large ridge cultivation, B_2=soil loosening by rotary harrowing, B_5=soil compaction by three passes of the tractor wheel. $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		Mineral uptake by carrot shoots, kg ha^{-1}		
Days after planting Treatment		90	121	146
			P	
60 + 0 kg/ha N	Large ridges B_0	1.31	4.41	6.89
	Loose bed B_2	2.12	5.82	8.97
	Compacted soil B_5	2.19	7.66	11.4
	$HSD_{0.05(B)}$	*0.4*	*1.60*	*2.71*
	mean			9.07
			K	
60 + 0 kg/ha N	Large ridges B_0	25.7	132	183
	Loose bed B_2	48.5	179	213
	Compacted soil B_5	50.1	209	268
	$HSD_{0.05(B)}$	*10.1*	*14*	*49*
	mean			221
			Mg	
60 + 0 kg/ha N	Large ridges B_0	2.04	10.3	15.7
	Loose bed B_2	3.44	13.5	18.7
	Compacted soil B_5	3.49	17.0	21.7
	$HSD_{0.05(B)}$	*0.7*	*2.1*	*5.2*
	mean			18.7

[1)] non significant at P<0.05

contents, however, decreased with increasing soil moisture, while K was unaffected (Figs. 1–3). Also P uptake by shoots was promoted by irrigation on loamy soil at 2nd sampling, in 1990 (123 DAP) on average from 7.0 to 10.9 kg ha^{-1} and in 1991 (117 DAP) from 12.2 kg to 18.0 kg ha^{-1} ($P < 0.05$). By harvest, no differences were found in 1990, but in 1991 irrigation promoted P uptake from 11.6 to 16.1 kg ha^{-1} ($P < 0.05$).

Irrigation also increased Mg yield in 1991 from 1.6 to 1.8 kg ha^{-1} ($P = 0.01$), measured four weeks before harvest (117 DAP). Despite lower K contents, irrigation also increased the K yield by enhancing the biomass accumulation (Pietola 1995). In 1990, the increase was from 12.5 to 18.0 kg ha^{-1}($P = 0.001$) at the second sampling (123 DAP), and from 15.1 to 18.9 kg ha^{-1} at harvest. Similarly in 1991, the increase was from 21.5 kg ha^{-1} to 25.9 kg ha^{-1} at the 2nd sampling ($P < 0.05$) and at harvest from 20.8 kg ha^{-1} to 23.2 kg ha^{-1} ($P = 0.07$).

Effect of soil compaction

On loam, compaction did not remarkably affect K or Mg content or uptake by shoots. However, most P in the middle and late season of 1990 was found in shoots of carrots grown in compacted loam, supporting the fact that soil nutrient absorption increases with increasing root to soil contact in moderately compacted soils (Lipiec et al. 1988, 1992, Kooistra et al. 1992, Veen at al. 1992). Also the P uptake was somewhat improved, most (4 kg ha^{-1}) by the 2nd sampling in 1991. By harvest, the most significant effect for cv. Narbonne was found in organic soil (Table 3). In organic soil, the promoting effect of soil compaction on K and Mg uptake was clearly shown only by cv. Narbonne (Table 3). No

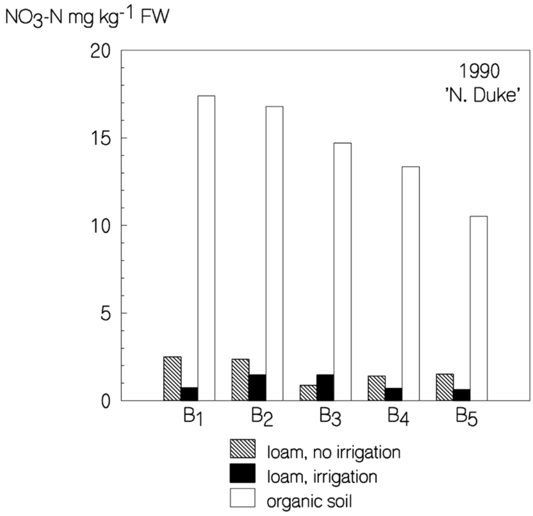

Fig. 4. Effect of soil mechanical treatments, irrigation and soil type on NO_3-N contents in well developed carrot tap roots on 1990. B_1=soil loosening by ridge preparation, B_2=soil loosening by rotary harrowing, B_3=untreated, B_4=soil compaction by one pass of the tractor wheel, B_5=soil compaction by three passes of the tractor wheel.

effect of extra nitrogen application (30 kg ha^{-1}) on mineral uptake by shoots was found.

Nitrate-N content in tap roots

Differences between the soils and dynamics of accumulation

The NO_3-N contents in tap roots cultivated in loam were much lower than in tap roots grown in organic soils (Fig. 4), indicating the high nitrogen mineralization capacity of organic soils. Also the higher K content in organic soil appeared to increase NO_3-N, as compared to loam. This is explained by Miedzobrodzka et al. (1993) who found an increased accumulation of nitrates in carrot roots grown in soils with high K levels. Only in the early growth stages of tap roots, were the NO_3-N contents over 25 mg^{-1} kg fresh weight in both soil types (Fig. 5), but this clearly decreased toward the end of the season, which agrees with the findings of Evers (1989c).

Effect of irrigation and compaction

The effect of irrigation was studied in loam where water applications increased the NO_3-N contents from 20 to 25 mg^{-1} kg fresh weight at the first sampling. The influence of soil compactness on carrot NO_3-N contents was obvious in organic soil. The contents were increased by soil loosening, particularly in the plant material collected late in the season (Fig. 5). This suggests that both soil loosening and irrigation increased the nitrogen mineralization, and leads to increased NO_3-N accumulation in tap roots. In organic soil, however, soil loosening did not significantly increase the NO_3-N values which were 52.0, 68.7 and 49.8 mg kg^{-1} in large ridges (B_0), loose beds (B_2) and compacted soils (B_5), respectively ($P = 0.16$), 121 DAP. Earlier in the season (90 DAP), all values were close to 85 mg kg^{-1}. The NO_3-N values found in this study were, however, far below the values of other vegetables, such as 150–600 mg kg^{-1} in red beet (Salo et al. 1992) or 290–1650 mg kg^{-1} in lettuce grown in greenhouses (Jokinen and Tahvonen 1991).

Effect of N application

Some influence of N application on carrot NO_3-N contents was found (Table 4). The increasing effect of nitrogen fertilisation on NO_3-N was, however, no more than 15 mg kg^{-1} indicating that nitrogen application of 30 kg ha^{-1} during the season is not harmful to the internal quality of fully grown carrots.

Conclusions

This study contributes to our understanding of the role of soil physical properties in relation to the chemical quality of carrots. Different soil mechanical treatments had little or no influence on the nutrient content of carrots. The data however show the importance of water supply on nutrient uptake by carrots. The mineral contents of shoots and roots as well as NO_3-N contents in

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Table 4. The effect of soil loosening, compaction and ridge cultivation on NO_3-N -contents of mature carrot tap root for cv. Narbonne (n=4), mg kg^{-1} in fresh matter in 1991: B_0= large ridge cultivation, B_2=soil loosening by rotary harrowing, B_5=soil compaction by three passes of the tractor wheel, without and with additional N fertlilisation. $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

	NO_3-N, mg kg^{-1}, at two fertilisation level	
Treatment	60 + 0 kg ha^{-1} N	60 + 30 kg ha^{-1} N
Large ridges B_0	51.6	57.5
Loose bed B_2	41.7	59.7
Compacted soil B_5	41.2	57.0
$HSD_{0.05(B)}$	ns[1)]	ns
mean	44.8	58.0
$HSD_{0.05(N)}$	12.2	

[1)] non significant at P<0.05

fresh root material varied according to different soil P, K, Mg, and N levels. In loose organic soils, compaction increases the P uptake (kg ha^{-1}) of carrots. In mineral soil with high clay content, compaction may decrease nutrient use due to weakened growth conditions. In soils of coarse texture, the impact of soil compactness is minor.

Soil loosening and irrigation increased NO_3-N contents, up to 30 mg kg^{-1} of fresh matter in the early growth stage. In full-size carrots, the NO_3-N contents were below 20 mg kg^{-1} in organic soil and negligible in loam. Nitrogen fertilisation (30 kg ha^{-1} in organic soil) during the carrot growing period affected the NO_3-N content of fully-grown carrots 30%.

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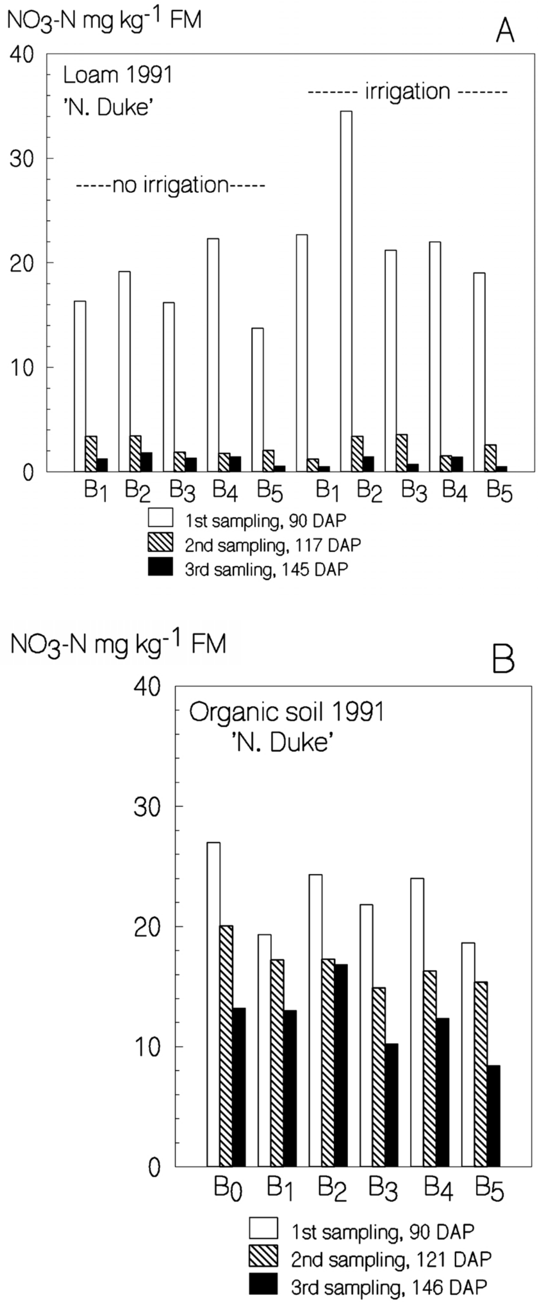

Fig. 5. Effect of soil mechanical treatments and irrigation on the development of NO_3-N contents in carrot tap root in loam (A) and in organic soil (B). B_0 = large ridge cultivation, B_1=soil loosening by ridge preparation, B_2=soil loosening by rotary harrowing, B_3=untreated, B_4=soil compaction by one pass of the tractor wheel, B_5=soil compaction by three passes of the tractor wheel.

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SELOSTUS

Maan tiiviyden, sadetuksen ja typpilannoituksen vaikutus porkkanan kivennäispitoisuuteen ja ravinteiden ottoon sekä nitraatin kertymiseen

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Tiedetään, että maan tiiviys vaikuttaa herkästi porkkanan ulkoiseen laatuun. Karoteeni- ja sokeripitoisuuksiin maaperätekijät vaikuttavat huomattavasti vähemmän, minkä osoittivat Maatalouden tutkimuskeskuksessa vuosina 1989–1991 tehdyt kenttäkokeet. Tämä julkaisu kattaa näiden kenttäkokeiden tulokset porkkanan kivennäisaine- ja nitraattipitoisuuksista. Ravinteiden otto analysoitiin käyttämällä hyväksi aiemmin julkaistuja naatti- ja juurisadon määriä.

Tutkimuksessa mitattiin kynnöksen kuohkeuttamisen ja tiivistämisen vaikutuksia porkkanan naattien ja juuresten P-, K-, Mg- ja NO_3-N -pitoisuuksiin kasvukauden eri vaiheissa. Kivennäismailla verrattiin lisäksi sadetuksen ja multamaalla lisätyppilannoituksen vaikutusta edellä mainittuihin tekijöihin. Lajikkeena oli Nantes Duke, paitsi lisätyppilannoituskokeessa Narbonne. Kynnöstä kuohkeutettiin kolmella eri tavalla: 1. Perunamaan multausvantailla tehtiin 2 m levyisiin koeruutuihin neljä 10 cm:n harjua 45 cm:n välein. 2. Kelajyrsimellä kuohkeutettiin 2 m levyisiä penkkejä 20 cm:n syvyyteen hieta- ja turvemaalla sekä savimaalla 15 cm:n syvyyteen, tai 3. Multamaalla tehtiin suuria korkeudeltaan 30 cm:n harjuja 60 cm:n välein. Lisäksi kynnöstä tiivistettiin 3 Mg:n akselipainolla kosteissa olosuhteissa juuri ennen kylvöä ajamalla traktorin rengas ruudun koko pinta-alan yli. Koeruutu tiivistettiin näin kertaalleen tai kolmesti. Käsittelemättömän koejäsenen kylvöalusta äestettiin suoraan kynnökselle. Kaikissa maan mekaanisissa käsittelyissä käytettiin 2 m raideväliä, jotta ylimääräinen tallaus vältettiin. Mikäli maan kosteustila laski alle 50 % hyötykapasiteetista, hieta- ja savimaan kastelukäsittelyt sadetettiin. Lisätyppilannoituskäsittelyssä multamaalla annettiin 30 kg ka^{-1} lisätyppeä heinäkuun lopussa. Tässä kokeessa olivat mekaanisista käsittelyistä mukana vain iso harju, jyrsitty penkki ja kolmesti tiivistetty tasamaa.

Kasvustonäytteet kerättiin noin 8 ja 4 viikkoa ennen sadonkorjuuta ja sadonkorjuun yhteydessä. Maalaji, maan ravinnepitoisuus, kasvukauden sääolot ja kasvun kehitysvaihe vaikuttivat huomattavasti enemmän P-, K- ja Mg -pitoisuuksiin kuin maan kuohkeuttaminen ja tiivistäminen tai sadetus. Sadetuksella oli suurempi merkitys kivennäispitoisuuksiin kuin muokkauksella; sadetus lisäsi P- ja hieman K-pitoisuuksia mutta laski Mg-pitoisuuksia hietamaalla. Myös vähän fosforia sisältävän ja luontaisesti löyhän multamaan tiivistäminen lisäsi fosforipitoisuuksia naateissa ja juureksessa sekä näiden fosforinottoa. Esimerkiksi vuonna 1990 neljä viikkoa ennen korjuuta (129 päivää kylvöstä) kolmesti tiivistetyn maan juuresten P otto oli 15,4 kg ha^{-1}, kun se kuohkeutetussa maassa oli 12,2 kg ha^{-1}. Korjuuvaiheessa fosforin määrät juurisadoissa olivat vastaavasti 23,9 ja 20,7 kg ha^{-1}, naateissa vastaavasti 6,0 ja 8,3 kg ha^{-1}. Seuraavana vuonna 1991 tiivistäminen lisäsi juuresten P ottoa lähes 6 kg ha^{-1}.

Hyvin tiiviissä savimaan olosuhteissa, joissa kasvu heikentyi, maan tiivistäminen vähensi ravinteiden ottoa. Hietamaalla mekaaniset käsittelyt eivät juuri vaikuttaneet porkkanan kivennäisten pitoisuuksiin ja ottoon. Nitraatin kertyminen porkkanaan sen sijaan lisääntyi maan kuohkeuttamisen ja sadetuksen vaikutuksesta. Tosin maalaji ja kasvuvaihe vaikuttivat