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// THE INFLUENCE OF PHOSPHORUS FERTILIZERS, POPULATION
DENSITY AND VARIETY ON GROWTH, YIELD AND ROOT QUALITY
OF CARROT (Daucus carota Linn.) //

BY

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Declaration

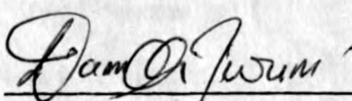
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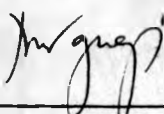

Dr. D.N. Ngugi

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SUMMARY

The effects of phosphorus fertilizers (0, 92 and 184 kg P_2O_5 /ha) and population density (666,666, 444,444 and 333,333 plants/ha) on the growth yield and root quality of Nantes and Chantenay carrots were evaluated on the field plots of the University of Nairobi, Kabete, Kenya during the short and long rainy seasons of 1978 and 1979 respectively.

The dry matter content of whole plants in the two cultivars increased as phosphorus fertilizer increased and population density decreased. However, the rate of dry matter accumulation in roots was faster than in shoots. Nantes generally accumulated a greater amount of dry matter than did Chantenay. The Efficiency of Storage Root Production (ESRP) increased as phosphorus levels increased and population density decreased. Nantes was more efficient in ESRP than Chantenay.

Root yield (Plants⁻¹ and ha⁻¹) increased as phosphorus levels increased. Root yield plant⁻¹ increased but root yield ha⁻¹ decreased with a decrease in population density. Root yield (plant⁻¹ and ha⁻¹) was higher in Nantes than in Chantenay.

Population density did not have any effect on

root length and diameter in the two cultivars. However, root length and diameter increased as phosphorus levels increased. Root length was longer in Nantes than in Chantenay but root diameter of the latter cultivar was larger than that of the former.

All the two cultivars accumulated larger amounts of β - carotene in 1978 than in 1979. The amount of β - carotene produced in Nantes was greater than in Chantenay. Root β - carotene ha^{-1} decreased but the amount root $^{-1}$ increased as the population density decreased during the two years. Phosphorus fertilizers did not affect the accumulation of β - carotene in roots.

Phosphorus fertilizers had no effect on the amounts of total and reducing sugars which accumulated in roots except that it increased the amount of total sugars per unit root fresh weight. Population density also had no effect on total and reducing sugars except that the amount root $^{-1}$ decreased with an increase in population density.

Phosphorus fertilizers when applied to carrots grown in phosphorus - deficient soils containing high levels of soil moisture increased plant growth and root yield since phosphorus is an essential constituent of nucleic acid, phytin and phospholipids.

Root yield beyond the optimum population density declined as a consequence of increased competition between plants.

Efficiency of Storage Root Production (ESRP) in Nantes was greater than in Chantenay, since lower population densities and higher phosphorus levels resulted in the accumulation of greater amounts of dry matter in the former cultivar than in the latter. As a consequence, the root yield of Nantes was higher than that of Chantenay.

Higher atmospheric temperature increased the amount of β - carotene in roots probably by influencing the biosynthetic pathway of carotenoids (Yu-Heuy Chang et al., 1977).

The **size** of roots was controlled by population density, cultivar and phosphorus fertilizers.

Nantes, the 30 x 10 cm spacing and the 184 kg P_2O_5 /ha produced the largest roots.

Nantes at a population density of 444,444 plants/ha was found to be the best for the Central Province. Application of phosphorus fertilizers are recommended if only the level of this element in the soil is very low and when adequate soil moisture is available.

CHAPTER 1

INTRODUCTION

Carrot (Daucus carota Linn), which is a native of Europe (MacGillivray, 1961) and a member of the umbelliferae family, is a very important root crop (Thompson and Kelly, 1957).

It is very vital in the human diet because it is rich in carotenes (α -, β -, σ - carotenes and cryptoxanthin), precursors of vitamin A. These precursors are converted by chemical processes in the intestinal walls of animals into more complex substances. One of these complex substances is vitamin A (Fleck, 1976).

Vitamin A concentration in carrot is about 3000 international units per 100g of fresh root. It also contains appreciable amounts of thiamine (0.05 mg per 100g fresh root), riboflavin (0.05 mg per 100g fresh root) and carbohydrates (7 g per 100 g fresh root) (Tindall, 1975).

Vitamin A is important for the formation of teeth and bones, for building up the body's resistance against infection and for normal vision. It's deficiency causes night blindness in humans (Fleck, 1976).

Since carrot root contains a fairly large amounts of sugars (4 to 9%), it was used as a source of sugar in Europe until sugar beet replaced it as the leading sugar producing root crop (Herklots, 1972). The carrot plant has also been very important for its medicinal properties for many centuries (Greensill, 1968).

Carrot is grown in Kenya for either the local market as fresh roots or for export in the dehydrated form. Fresh carrots have been produced in Lake Naivasha, Kinangop and Upper Kiambu districts and processed into the dehydrated form in a factory at Naivasha, since 1968 (Pan African Vegetable Products Ltd, Personal Communication).

Carrot yield in Kenya ranges from 15 tonnes/ha. on peasant's farms to 45 tonnes/ha on commercial farms (Anonymous, 1974). Although Kenya produces a total of 100,000 tonnes per annum (Anonymous, 1974), this amount is inadequate for the factory and for the fresh market. As a consequence, the factory has been operating under its full capacity. There is, therefore, the need to increase the production of the crop in the country.

Phosphorus is important during the early stages of plant growth when the limited root system is not

able to draw sufficient amounts of nutrients from the soil. Phosphorus usually accumulates in meristematic tissues in which cell division is actively proceeding. Thus, this element is important for root growth and development.

Dry matter yield in crops generally increased to a maximum as population density increased. Further increase in population density beyond the optimum level resulted in a decrease in dry matter yield due to the competition between plants (Arnon, 1972).

There is a paucity in the literature regarding the effects of population density and phosphorus fertilizers on the growth and yield of carrots in Kenya. There are good reasons to suspect that carrot will respond to phosphorus fertilizers in Kiambu district. The soil at the University Farm, Kabete has a pH of 5.2 to 7.7 and it is generally deficient in phosphorus (Nyandat and Michieka, 1970). Experiments, were, therefore, conducted to study the effects of phosphorus fertilizers and population density on the growth, yield and the amount of β - carotene and sugars in the roots of the two commonest cultivars grown in Kenya.

Apart from variety trials carried out at the National Horticultural Research Station at Thika, there

CHAPTER 2

LITERATURE REVIEW

A. Effect of population density on growth and yield

Population density has a direct influence on carrot growth and yield. Dry matter generally increases linearly to a maximum as population density is increased (Holliday, 1960; Donald, 1963). Further increase in population density beyond the optimum level increased the competition between plants for the available environmental factors such as soil nutrients, soil moisture, carbon dioxide and light. When there was a maximum exploitation of the available resources, as a result of an increase in population density, inter-plant competition increased. This resulted in a reduction in dry matter production (Donald, 1954).

Light is very frequently the most important factor limiting productivity of densely populated crop plants under field condition. Yield, therefore, ultimately depends on the efficiency with which these plants intercept adequate light (Arnon, 1972). The amount of light intercepted by canopies increases as population density is increased. However, there was an optimal leaf area index beyond which an increase in population density resulted in an increase in the proportion of foliage which was below the compensation

point (Arnon, 1972).

The optimum population density for carrot plants varies widely and it depends on the soil type, weather conditions, seed quality and the purpose for which the crop is being grown. Significant differences in carrot yield occurred when the intra-row spacing was varied but there were no significant differences between inter-row spacing treatments. (Lipari, 1976). Since the carrot root grows downwards rather than laterally, there is more competition within rows than between rows (Hadfield, 1967).

Population density influences root yield, size, shape, splitting, maturity and dry matter accumulation in carrot plants. Root size decreased (Franken et al., 1972; Lipari, 1976; Robinson, 1969), yield increased (Frohlich et al., 1971; Abdel-Al, 1973), splitting decreased (Bienz, 1965) and root length decreased (Bussell, 1976) in carrot as population density increased. There was an increase in competition for nutrients, moisture, carbon dioxide and light among densely populated plants. As a consequence, root size and length decreased as population density increased. Root splitting in carrots results from over-stretching of cell walls caused by excess water absorption and reduced rates of transpiration. Any factor such as high population density which increases the rate of

transpiration would minimize carrot root splitting.

B. Effect of fertilizers on growth and yield

Carrot requires rapid and continuous growth of the vegetative parts, at early stages of growth, so as to enhance high bulking rate in the root. It should, therefore, be supplied with adequate amounts of nutrients. Fertilization of the crop depends on the level of soil fertility. Carrot plants removed about 134.3 kg K_2O /ha, 35.8 kg N/ha and 46.2 kg P_2O_5 /ha from the soil to produce 24.7 tons of roots per hectare in one season (Thompson and Kelly, 1957).

Fertilizers (nitrogen, phosphorus and potassium) affect the growth and yield of carrots in various ways: high levels reduced the rate of seedling emergence and ultimately reduced yield (Halland, 1975; Hegarty, 1976); carrot root yield increased significantly in response to normal or high levels of nitrogen, phosphorus and potassium, but the higher doses were less effective and caused bolting and root splitting (Kanwar and Malik, 1971). However, Green (1973) in another study reported that the final yield of carrots was not significantly affected by fertilizers. He also reported that the interaction between phosphorus and nitrogen at their highest levels was significant and the relationship between nitrogen levels and root yield was quadratic.

Lipari (1976) reported that although fertilizers significantly affected root yield, their effects on root quality were not significant. He further reported that the weight of individual roots increased as the levels of fertilizers increased but the percentage of unmarketable roots also increased. Matev (1971) reported that equal amounts of nitrogen and potassium were absorbed by carrot plants during the vegetative phase but larger amounts of potassium were required later on during the season. The requirement for phosphorus remained constant throughout the growing season in Matev's study.

Phosphorus is one of the major elements needed by plants. Plants absorb it mainly in the form of primary superphosphate ions (H_2PO_4^-) and smaller amounts of secondary superphosphate ions (H_2PO_4). Plants might also absorb certain soluble organic phosphates which occur as a result of decomposition of soil organic matter (Tisdale and Nelson, 1966).

Phosphorus is mostly fixed in the kaolinitic clays which are predominant in Kenyan soils. Hence, it is frequently the most unavailable element (Nyandat and Michieka, 1970). Kaolinitic soils (1:1 clays) retained larger quantities of added phosphorus than those containing 2:1 clays (Tisdale and Nelson, 1966).

The presence of hydrous oxides of iron and aluminium contributed greatly to the retention of added phosphorus. Most of the soils on the Kenyan highlands contain these two compounds (Ballestrem and Holler, 1977).

Phosphorus is an essential constituent of nucleic acid, phytin and of phospholipids. It has been associated with the early maturity and increased rate of crop growth (Arnon, 1972).

The availability of phosphorus depends on soil temperature and moisture. Arnon (1972) reported that plants are more capable of absorbing phosphorus from a warm soil than from a cold one. More phosphorus became available at high moisture levels (Haddock, 1949).

There was a high correlation between carrot root yield and the amount of phosphorus in leaves. Pankov (1976) reported that the optimal phosphorus level in leaves in relation to plant growth and yield was 0.25 to 0.26 per cent. He also reported that phosphorus deficiency caused a reduction in carrot yield.

The method of application of phosphorus also influences carrot yield. Split application in which one half of the phosphorus fertilizer was applied at planting time and the other half was applied as a top

dressing later on during the season produced higher yields than when all the fertilizers were applied during planting time (Borisov et al., 1975). However, in East Africa where moisture is quite often limiting, split application of phosphorus would most probably not have a positive effect.

Phosphorus fertilizers affect carrot root shape. It was reported by Starikov (1973) that phosphorus fertilizers increased root width but influenced the roots to grow shorter in cv. Chantenay.

Nitrogen has been reported to be essential for growth and yield in carrots. It had an optimum effect on root yield (Habben, 1973; Green, 1973; Pankov, 1976). Otani (1975) reported that nitrogen increased plant height, fresh weight of roots and shoots and leaf number in carrots. Higher levels of nitrogen influenced carrot roots to mature earlier (Marter, 1971). Nitrogen was also responsible for better root shape and quality in carrots, since it promoted vigorous top growth (Giardini and Pimpini, 1966).

In comparison with other major elements, potassium had relatively little effect on carrot root yield and quality (Giardini and Pimpini, 1966). However, Gallagher (1968) reported that carrot grown in potassium deficient soils responded to potassium fertilizers in

experiments conducted over a wide range of soils.

The minor elements also have considerable effects on the growth and yield of carrots. Kanwar and Malik (1971) reported that boron increased the root yield when it was applied in combination with lower levels of nitrogen, phosphorus and potassium. Boron and zinc (Homutescu et al., 1964, Kanwar and Malik, 1971) and copper (Campell and Gusta, 1966) increased carrot root yield. Magnesium deficient soils responded to magnesium fertilizers (Bertrand and De Wolf, 1964). Nantes seeds treated with manganese or boron (0.02 and 0.01% respectively) resulted in higher germination percentage, larger roots and higher root yield under field conditions (Shishkina and Galeev, 1976).

C. Vegetative development of carrot

Phan and Hsu (1973) described the anatomical and morphological changes which occur in a developing carrot plant. They reported that the first organs which grew actively were the leaves and they grew 13 to 18 cm long within two weeks. During the same period, the stem did not grow but numerous roots developed. They also reported that the rate of root growth was slow during the first month but it subsequently became faster than that of the leaves. Furthermore, they reported that root growth

simultaneously reached a maximum with the carotene and sugar contents in the roots. The authors reported that the growth of the leaves and roots ceased when they were 26 to 39 cm long while the roots began to enlarge laterally when they reached about half of their maximum length. They also reported that although the rate of root thickening was slow at the initial stages of plant growth, it subsequently increased rapidly with time. Then it slowed down again towards the end of the growing season.

The morphological features of Chantenay are distinct from those of Nantes. Chantenay has a smooth, tapered and reddish orange roots but Nantes is cylindrical and has a bright orange flesh and inconspicuous core (Thompson and Kelly, 1957).

Boerboom (1978) proposed a model for estimating the Efficiency of the plant at Storage Root Production (ESRP) in root crops. This model was based on the assumption that the relation between the dry weight of the storage roots (Y) and the dry weight of the whole plants (X) can be represented by the linear regression equation: $Y = a + bx$. (Where the regression coefficient $b = \text{ESRP}$; $a =$ the intercept of the regression line with the X axis). By using cassava as an example of a root crop, he showed that the regression coefficient (b or ESRP) quantitatively

represented the portion of the carbohydrates that were diverted to the storage root.

D. Carotenes and the factors affecting their syntheses.

Carotenes are believed to have derived their names from "Carrot" since they constitute the major pigment in the carrot root (Bauernfeind, 1972). They are precursors of vitamin A. Their functions include the absorption and transport of light energy and prevention of chlorophyll oxidation during photosynthesis (Goodwin, 1961; Bauernfeind, 1972).

Carotenoids are manufactured only in plants (Bauernfeind, 1972). They can be divided into hydrocarbon pigments or carotenes and carotenols (xanthophylls) which also contain oxygen in their molecules. About 95% of the total carotenoids are beta - and alpha - carotenes in commercial carrot cultivars. Other carotenes include phytoene, phytofluene, zeta - carotene, lycopene, gamma-carotene and delta-carotene (Umiel and Gableman, 1972). The orange colour of carrots is mostly due to the occurrence of alpha -and beta - carotenes in the roots. Since carotenes are precursors of vitamin A, the darker the colour of the root, the higher is its nutritive value (Thompson and Kelly, 1957).

The age of carrot root influences its carotene

content. There was an increase in the carotene content of roots as the roots grew older (Platenius, 1934; Barnes, 1936; Werner, 1941; Lantz, 1967; Yamaguchi et al., 1952; Bradley and Dyck, 1968; Sirtautaje, 1970). Habben (1973) reported that the age of plants was more responsible for the amount of carotene in roots than were the effects of environmental factors. Toul and Popisilova (1964) reported that significant differences in β - carotene were due to differences in variety, maturity and changes in the ratio of the outer cortex to the inner one in the root.

The roots are colourless at the seedling stage. The orange colour appears after one month of seedling growth (Phan and Hsu, 1973). Root carotene increased steadily to a maximum about three months after sowing and decreased slightly thereafter (Pepkowitz et al., 1944; Mosorinski et al., 1970; Phan and Hsu, 1973). However, Gomoljako and Sazonova (1966) reported that the carotene content increased only slightly during the period of most intensive growth and it increased by 35 to 81% when the root was in storage.

Environmental factors influence the rate of carotene accumulation in carrot. However, there are conflicting reports regarding the effects of temperature on the accumulation of carotene in roots. Whereas there was an increase in the rate of carotene synthesis and accumulation in roots, as temperature

increased during the growing season (Hansen, 1945; Yamaguchi et al., 1952; Banga and De Bruyn, 1969), Bradley and Smittle (1965), Coleman (1965), Bradley and Dyck (1968), Bradley and Rhodes (1969) and Krylov and Baranova (1967), on the other hand, reported that cool temperatures during the growing season increased the rate of carotene production. However, no specific ranges for high or cool temperatures were reported above. Carrot roots develop the best colour (deep orange) when it is grown in a temperature regime of 15.6 to 20°C (Thompson and Kelly, 1957; Coleman, 1965). Bradley and Rhodes (1969) reported that β -carotene was the only factor which showed significant and positive correlation with colour.

Jacob et al. (1970) reported that the content of β -carotene in ripe mango fruits was greater than in unripe ones. The degree of ripeness increased as temperature also increased. β -carotene content of tomato fruits treated with 2-(4-chlorophenylthio)triethylamine hydrochloride was higher at higher temperatures than at lower temperatures (Yu-Heuy Chang et al., 1977).

Temperature influences carotene development by changing the biosynthetic pathway of carotenoids and by favouring the accumulation of one pigment at the

expense of the others (Yu-Heuy Chang et al., 1977). The conversion of one form of carotenes to another depends on the enzymatic activity which is also affected by temperature (Porter and Anderson, 1967).

Moderate levels of soil moisture influenced carrot plants to produce a maximum amount of root β - carotene (Banga and Others, 1964; Seckarev and Lukovnikova, 1966). Schuphan (1963) reported that the rate of carotene synthesis in carrots was greater during a low rainfall season than during a high rainfall season. This is to be expected, since either excessive or deficient soil moisture inhibits plant growth.

Kulikova (1973) reported that the concentration of carotene in carrot roots increased with an increase in photoperiod. Godnev et al. (1968) reported that intermittent light applied twice for five minutes each time, during the dark period, increased the chlorophyll and carotene contents in carrot tissue. The rate of carotene synthesis was greater in high light intensities than in lower light intensities (Schuphan, 1963).

Pepkowitz et al. (1944) reported that an inverse relationship existed between the size of carrot root and its carotene content ($r = -0.861$). This indicates

that the strains which have larger roots contain smaller amounts of carotene than do the smaller roots. Schuphan (1963) reported that plants originating from larger seeds developed more rapidly and began carotene synthesis earlier. They, therefore, accumulated carotenes at a faster rate.

The amount of carotenes in carrot roots increased to a maximum as the level of soil nitrogen increased but further increases in the levels of soil nitrogen did not result in any concomitant increase in carotenes (Pftuzzer and Pfuff, 1937; Habben, 1973; Otani, 1975; Habben, 1974). Habben (1974) reported that nitrogen had a greater effect on carotene synthesis in carrot shoots than in carrot roots. Higher levels of nitrogen particularly favoured alpha and beta - carotene synthesis (Florescu and Cernea, 1964).

Potassium fertilizers had little effect on root carotene (Nehring, 1965; Habben, 1974). Although Ziegler and Bottcher (1968) reported that high potassium levels increased the carotene content of carrots, they concluded that the weather conditions during the vegetative phase were more responsible for the accumulation of carotenes than were the potassium fertilizers.

It seemed probable that phosphorus inhibited carotene synthesis in carrot roots (Nehring, 1965). Pftuzzer and Pfuff (1937) and Pankov (1977) reported that phosphorus deficiency resulted in an increase in the carotene content in carrot roots.

Most of the minor elements (magnesium, boron, zinc and copper) seem to have favourable effects on carotene synthesis. Florescu and Cernea (1964) and Lukovnikova and Kuliev (1977) reported that magnesium had the greatest effect in stimulating carotene synthesis in carrot roots. Seed treatment with manganese (0.02%) and boron (0.01%) solutions also resulted in an increase in carotene syntheses in carrot roots (Shishkina and Galeev, 1976). Dusting carrot seeds with zinc powder or soaking them in 0.05% zinc sulphate solution increased the amount of chlorophyll in leaves and the translocation of carotene from the leaves into the roots (Tkacuk, 1968). Many of these minor elements activate some enzymes and they may indirectly influence carotene syntheses in plants.

E. Factors affecting the syntheses of sugars in carrots

The amount of sugar and the rate of its synthesis in carrot root depends on the age of plants, temperature and the level of soil nutrients. The sugar content of carrot roots increased steadily to

a maximum about three months after sowing (Phan and Hsu, 1973). However, Gomoljako and Sazonova (1966) reported that the sugar content of carrots increased only slightly during the period of most intensive growth.

The ratio of non-reducing sugars to reducing sugars increased in the xylem to a level similar to that in the phloem in carrot roots towards the end of the growing season (Phan and Hsu, 1973). The xylem of carrot (cv. Chantenay) contained a higher ratio of sucrose to reducing sugars than in the phloem but the opposite was the case in Nantes. The sucrose/reducing sugars ratio was almost constantly greater in Chantenay than in Nantes (Werner, 1941).

Seckarev and Lukovnikova (1966) reported that lower temperatures increased the sugar content of carrot roots. However, Habben (1973) reported that the weather hardly had any influence in the sugar levels in carrot roots.

Although phosphorus deficiency resulted in reduced carrot root yield, the sugar content of the root increased (Pankov, 1977).

Nitrogen increased the amount of reducing sugars but decreased the amount of non-reducing sugars

in carrot roots (Habben, 1973).

The total and reducing sugars in carrot plants decreased as soil potassium decreased and the total and reducing sugars deficiency was more pronounced in the shoots than in the roots (Habben, 1973). He also reported that potassium had very little effect on the sucrose content of the roots.

The minor elements generally tend to promote sugar production in carrots. Magnesium, manganese, boron, copper, zinc and molybdenum stimulated sugar synthesis in carrots with magnesium having the greatest influence on sugar production (Florescu and Cernea, 1964, Shishkina and Galeev, 1976). Neljubova and Dorozkina (1969) reported that boron at 1mg/1kg soil in pot experiments resulted in an increase in sugar translocation from the leaves to the conducting tissues and the other root tissues in carrots.

CHAPTER 3

MATERIALS AND METHODS

A. The experimental site

The experiments were carried out during the short and long rainy seasons of 1978 and 1979 respectively. They were conducted on the experimental plots of the Field Station, Department of Crop Science, University of Nairobi, Kabete Campus.

The area lies at a altitude of 1,940 m above sea level, latitudes $1^{\circ} 14' 20''$ S to $1^{\circ} 15' 15''$ S and longitudes $36^{\circ} 44'$ E to $36^{\circ} 45' 20''$ E. The predominant vegetation is Kikuyu grass. The rainfall is bimodal and evenly distributed with peaks in April and November. The details of the temperature, rainfall and relative humidity during the experimental period are presented in Appendix Table 6.

The soils which have been fully described by Nyandat and Michieka (1970), are dark reddish brown clays overlying on dark red clays. They are deep, well drained and have fairly high water holding capacity. They have a blocky structure which allows good root development. They are depleted of soluble bases and silica but are rich in iron oxide, haematite goethite and aluminium in the form of clay

minerals, metahalloysite and hydrated halloysite, as a consequence of excessive leaching.

Although the clay minerals are predominately kaolin (a metahalloysite), they contain about 15% illite. The pH of the top soil and the sub soil ranges from 5.2 to 7.2 and 5.2 to 7.7 respectively. The results of soil analyses performed prior to planting, are presented in Table 1.

B. Soil analyses.

Five random samples of soil were collected from the entire experimental sites at a depth of 0-30 cm from the surface of the soil on 30 November, 1978 and 15 March, 1979 during the 1978 and 1979 experiments respectively.

The soil was air dried for about 96 hours and passed through a 2mm sieve. The fraction which passed through the sieve was used for all soil analyses.

Soil pH was determined with a pH meter (PYE UNICAM, U.K.) on one part of soil: one part of water or 0.01M CaCl_2 (W/V).

Cation exchange capacity was determined in neutral normal ammonium acetate (B.D.H. chemicals, Ltd., U.K.) by the method described by Peech (1945).

The exchangeable calcium and magnesium were

Table 1. Results of soil analyses.

Chemical constituent	1978 Experiment	1979 Experiment
PH in H ₂ O	6.40	5.80
PH in CaCl ₂	5.90	5.00
% N	0.32	0.27
% C	2.40	2.75
Mg m.e/100g	5.80	2.87
Ca m.e/100g	11.80	10.06
Na m.e/100g	0.75	0.45
K m.e/100g	1.50	4.17
P(mgP ₂ O ₅ /100g)	6.98	53.80
CEC m.e%	20.34	22.53

extracted in neutral normal ammonium acetate and determined by the versenate titration method as described by Piper (1947) and Richards (1954). The exchangeable potassium and sodium were also extracted in neutral normal ammonium acetate and determined with a flame photometer (Evans Electro Selenium LTD, U.K.) by the method described by Fieldes et al., (1951).

Organic carbon was extracted in potassium dichromate (Mayer and Baker) and determined by the method described by Walkley-Black (1946).

Soil nitrogen was determined by the Kjeldahl method followed by distillation and titration as described by Ahn (1973).

Available soil phosphorus was extracted in a mixture of 0.1 N HCl (B.D.H. chemicals Ltd, U.K) and 0.025N H_2SO_4 (B.D.H. chemicals Ltd, U.K) and determined by the vanadium yellow method as described by Mehlich (1953).

C. Experimental design and treatments.

A 3 x 3 x 2 factorial arrangement in a Randomized Complete-Block Design with 3 replications was used for all experiments. The treatments consisted of the effects of 3 levels of phosphorus fertilizer and 3 levels of population densities on the growth, yield and root quality of 2 carrot cultivars.

The 3 levels of phosphorus fertilizer were: (1) 0kg P_2O_5 /ha (control), (2) 92kg P_2O_5 /ha, (3) 184 kg P_2O_5 /ha, applied as double superphosphate (46% P_2O_5) at planting time.

The population density treatments were: (1) 666,666 plants/ha (2) 444,444 plants/ha (3) 333,333 plants/ha. These population densities corresponded with a constant inter-row spacing of 30 cm for all treatments by an intra-row spacing of 5, 7.5 and 10cm respectively.

The 2 cultivars used were Chantenay and Nantes, obtained in Nairobi from Kirchhoff's East Africa Ltd.

Each experimental unit measured $8.4 m^2$, consisted of 7 rows of plants and was boarded on all sides by a row of guard plants. All the experimental plants within each plot were also boarded on all sides by guard plants. The 18 treatment combinations were allocated to the plots at random.

D. Cultural Practices

Plots were tractor-ploughed and disc-harrowed. Each plot received 200 kg N/ha as calcium ammonium nitrate (26% N) and the appropriate level of the double superphosphate fertilizer treatment at planting time. Since the soil was rich in K_2O

(Table 1) it was not deemed necessary to apply any potassium fertilizers. The plots were then raked into a fine tilth prior to sowing.

The carrot seeds were drilled in rows spaced 30 cm apart at a rate of about one seed per 2 - cm run on 2 December, 1978 and 17 March, 1979. The seedlings were thinned out to straight line one week after emergence and finally to the various population density treatments one month after emergence. Hoeing and irrigation by overhead sprinkler were performed as needed.

Dithane M-45 (4kg in 600 litres H₂O/ha) and 40% Aldrin Dust (5.38 kg/ha) were used, from 2-11 weeks after seedling emergence, at 2-weekly intervals, to prevent the attack of Alternaria dauci and cut-worms respectively. Throughout the two experiments the plots were observed closely. No serious diseases and pests were noticed on plants and were not considered to be a factor in affecting growth or yield of the treatments.

E. Growth studies.

Changes in dry matter accumulation in plants were determined from 7 to 12 weeks after emergence, at one - weekly intervals, during 1978 and 1979 experiments. All the plants in a randomly selected

60-cm row were removed from each plot on each sampling date. The plants were washed in water to remove soil and separated into shoots and roots. The dry weights of each plant part were determined on materials dried in a ventilated oven at 100°C for 48 hours.

The model suggested by Boerboom (1978) was used to estimate the Efficiency of the plant at Storage Root Production (ESRP) under each treatment.

F. Determination of root yield and its components

All the roots in a 40-cm row were finally harvested from each plot 14 weeks after sowing, during the two experiments. The roots were washed in water after the leaves had been detached, air-dried for a day and weighed. The data was expressed as root yield per plant and per plot. Five randomly selected plants per plot were used to determine mean root length and diameter. Root length was measured from the tip to the top of each root. The diameter of roots was measured at the largest portion on the shoulder of each root.

G. Determination of sugars and β - carotene *

A random sample of 6 harvested roots was selected from each plot for the determination of total soluble carbohydrates, total reducing sugars and

β - carotene.

All the 6 roots were cut into small pieces. An aliquot sample (5g) was then randomly selected from each plot and boiled in 30 ml 80% ethanol for 5 minutes. The samples were very finely homogenized in the alcohol with a pestle in a mortar. The homogenate was centrifuged at 14,500 x g for 15 minutes at room temperature. The pellet was successfully resuspended with 20 ml hot 80% ethanol, 20 ml deionized water and 20 ml 80% ethanol and centrifuged. The four supernatants were combined and taken to a volume of 100 ml (alcohol-water extract).

Another aliquot sample of root pieces (2g) was randomly selected for the extraction of β - carotene. The samples were finely homogenized with a pestle in a mortar containing 50 ml acetone. The homogenate was filtered through a glass wool plug placed in the stem of a glass funnel. The pellet was washed thrice with 10 ml acetone. The four supernatants were combined and made up to 100 mls (Acetone extract).

A 20-ml aliquot of the acetone extract was taken into dryness in a rotary thin film evaporater (A. Gallenkamp and Co. Ltd., London) at 60^oC and then dissolved in 2 ml petroleum ether. The petroleum ether extract was then passed through a chromatographic

column containing a 4-cm layer of alumina in 30 ml ethanol: petroleum ether (8:92 V/V). A 1-cm layer of anhydrous Na_2SO_4 was placed on top of the alumina (Methods of Analysis, Ed. W. Horwitz, 1970). The β -carotene was retained by the column and the filtrate was discarded. The β -carotene was then eluted from the column with 20 ml petroleum ether and the eluate was made up to 25 ml (Petroleum ether extract).

For all calorimetric determinations a Beckman DB GT spectrophotometer was used. All readings were carried out at room temperature (17°C).

Total soluble carbohydrates were determined from the ethanol - water extract with 0.1% anthrone reagent (B.D.H. Chemicals Ltd., U.K) by the method of Hassid and Neufeld (1964). Glucose (B.D.H. Chemicals Ltd., U.K.) was used as a standard. The optical densities (OD's) of samples were determined at a wave length of 620 nm.

Reducing sugars from the ethanol-water extract was determined by the method of Nelson (1944). Glucose was used as a standard. The OD's of samples were read at a wave length of 540 nm.

β - carotene was determined from the petroleum ether extract by the method of Liaaen-Jensen and Jensen (1971) and Davies (1976). β -carotene (B.D.H.

Chemicals, Ltd., U.K.) was used as a standard. The OD's of samples were determined at a wave length of 450 nm.

H. Statistical analyses

Duncan's New Multiple Range Test (Steel and Torrie, 1960) was used to compare significant differences between means. No statistical significance lower than 0.05 is reported.

CHAPTER 4

RESULTS

A. Effects of phosphorus, population density and variety on vegetative development

The dry matter accumulation pattern in the various plant parts as influenced by phosphorus fertilizer was similar in all treatments during the two years. It generally increased as the levels of phosphorus increased. Dry matter increased from a minimum 7 weeks after emergence and reached a maximum 12 weeks after emergence in all treatments. The dry matter accumulation in roots increased slowly during the initial stages of plant growth but it thereafter increased rapidly. The rate of dry matter accumulation in shoots and whole plants was relatively constant during the sampling period (Figure 1).

Dry matter accumulation in roots and whole plants generally increased as population density decreased (Figures 2A, 2B, 2E and 2F). Dry matter of the roots reached a maximum 12 weeks after emergence in all treatments as population density decreased (Figure 2). Population density also influenced dry matter content of the roots

Figure 1. The influence of phosphorus fertilizers (Δ — Δ , 0kg P_2O_5 /ha; \circ — \circ , 92kg P_2O_5 /ha; \square — \square , 184 kg P_2O_5 /ha) on dry matter accumulation in carrot plants.

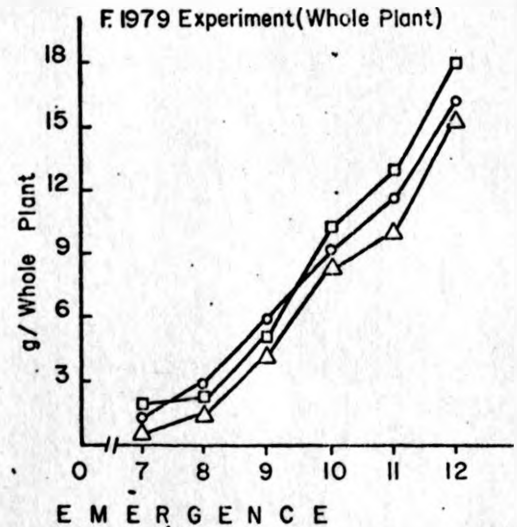
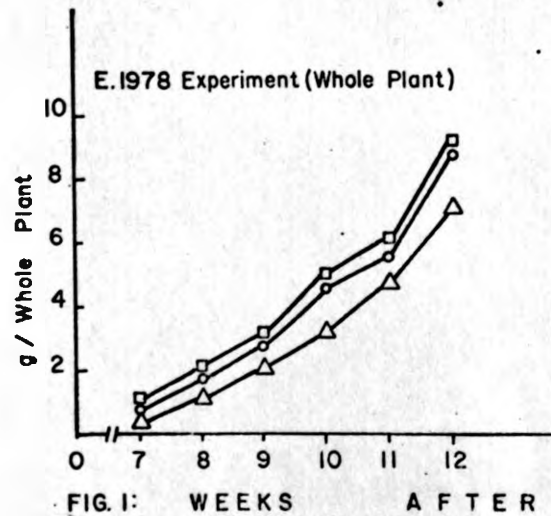
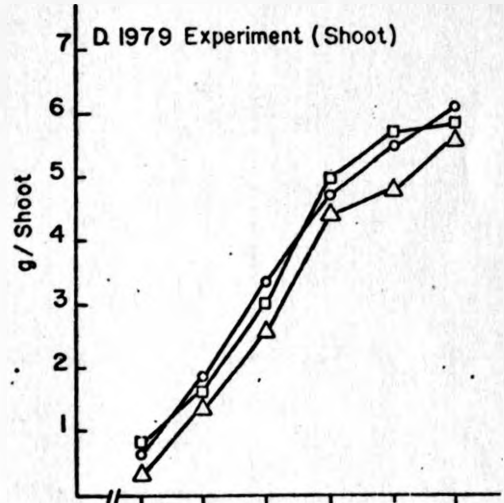
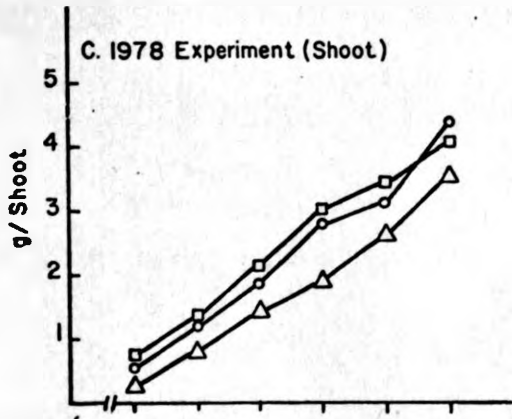
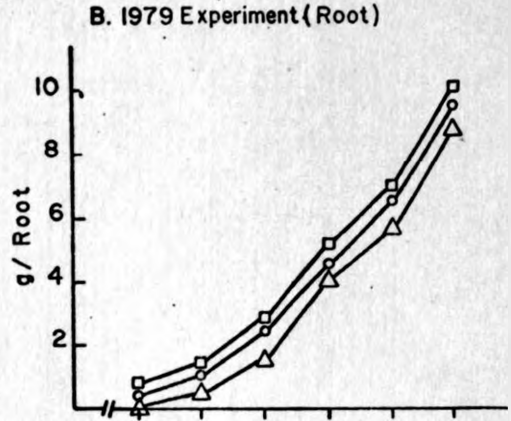
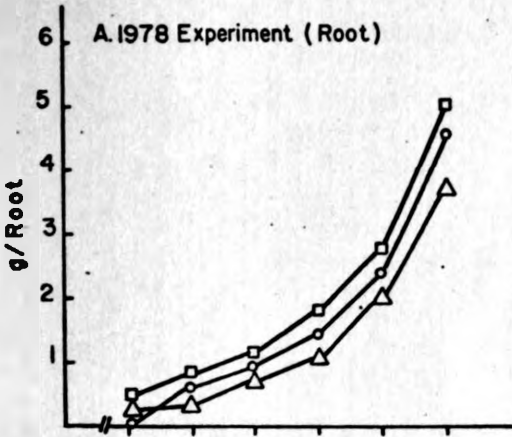


FIG. I: WEEKS

AFTER

EMERGENCE

FIG. I

Figure 2. The influence of plant population (\blacktriangle — \blacktriangle , 666,666 plant/ha; \bullet — \bullet , 444,444 plants/ha; \blacksquare — \blacksquare , 333,333 plants/ha) on dry matter accumulation in carrot plants.

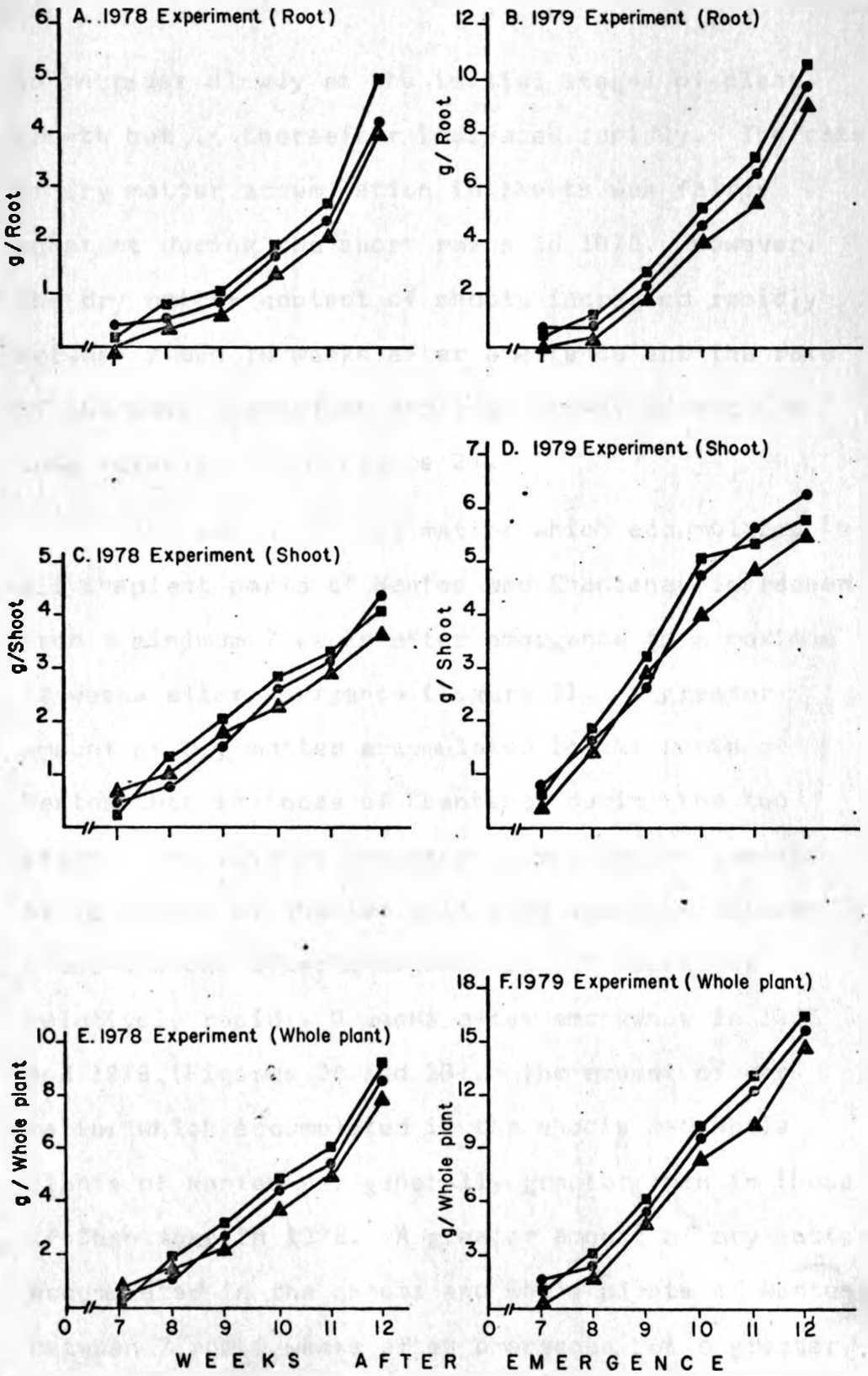


FIG. 2

to increase slowly at the initial stages of plant growth but it thereafter increased rapidly. The rate of dry matter accumulation in shoots was fairly constant during the short rains in 1978. However, the dry matter content of shoots increased rapidly between 7 and 10 weeks after emergence but the rate of increase thereafter declined slowly during the long rains in 1979 (Figure 2).

The amount of dry matter which accumulated in all the plant parts of Nantes and Chantenay increased from a minimum 7 weeks after emergence to a maximum 12 weeks after emergence (Figure 3). A greater amount of dry matter accumulated in the roots of Nantes than in those of Chantenay during the two years. The rate of increase in dry matter content of the roots of the two cultivars was slow between 7 and 9 weeks after emergence but it increased relatively rapidly 9 weeks after emergence in 1978 and 1979 (Figures 3A and 3B). The amount of dry matter which accumulated in the shoots and whole plants of Nantes was generally greater than in those of Chantenay in 1978. A greater amount of dry matter accumulated in the shoots and whole plants of Nantes between 7 and 9 weeks after emergence but a greater amount accumulated in the shoots and whole plants of

Figure 3. The influence of variety (●—●, Chantenay
■—■, Nantes) on dry matter accumulation
carrot plants.

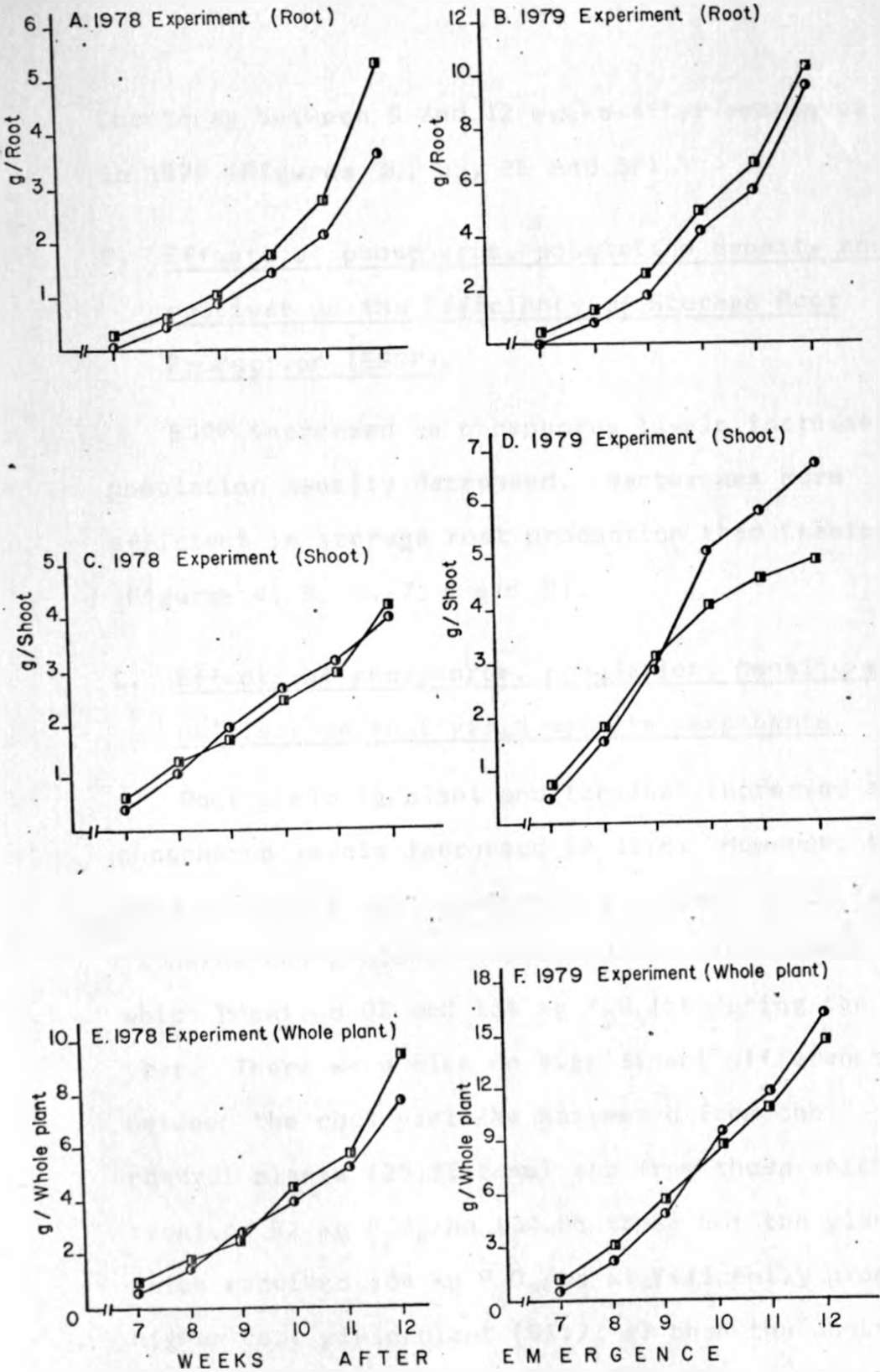


FIG.3

Chantenay between 9 and 12 weeks after emergence in 1979 (Figures 3C, 3D, 3E and 3F).

B. Effects of phosphorus, population density and cultivar on the Efficiency of Storage Root Production (ESRP).

ESRP increased as phosphorus levels increased and population density decreased. Nantes was more efficient in storage root production than Chantenay (Figures 4, 5, 6, 7, 8 and 9).

C. Effects of phosphorus, population, density and cultivar on root yield and its components.

Root yield (g/plant and tons/ha) increased as phosphorus levels increased in 1978. However, there were no significant differences between root yield (tons/ha and g/plant) harvested from the plants which received 92 and 184 kg P_2O_5 /ha during the same year. There were also no significant differences between the root yield/ha harvested from the control plants (29.31 tons) and from those which received 92 kg P_2O_5 /ha (34.05 tons) but the plants which received 184 kg P_2O_5 /ha significantly produced higher root yield/plant (91.71 g) than the control plants (66.99 g) (Table 2). Although root yield/plant increased as the levels of phosphorus increased, phosphorus had no significant effect on either root-yield/plant or root yield/ha in 1979 (Table 2).

Figure 4. The relationship between the dry matter in whole plants and the dry matter in storage roots in carrot as influenced by phosphorus fertilizers (●—●, 0kg P₂O₅/ha; ○—○, 92kg P₂O₅/ha; x—x, 184 kg P₂O₅/ha) (1978 Experiment).

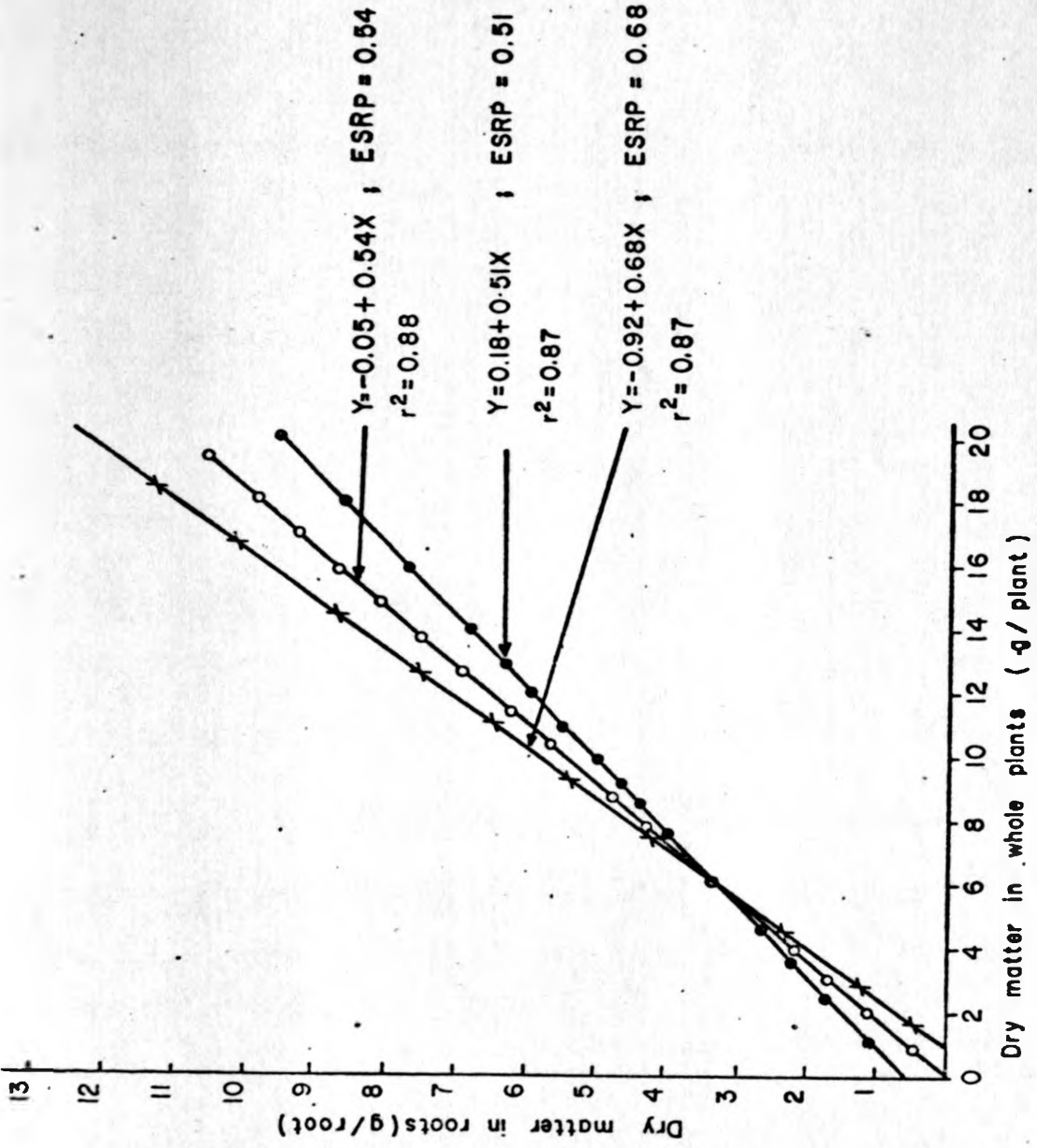


FIG. 4

Figure 5. The relationship between the dry matter in whole plants and the dry matter in storage roots in carrot as influenced by phosphorus fertilizers (●, 0kg P₂O₅/ha; ○, 92 kg P₂O₅/ha; X, 184 kg P₂O₅/ha). (1979 Experiment).

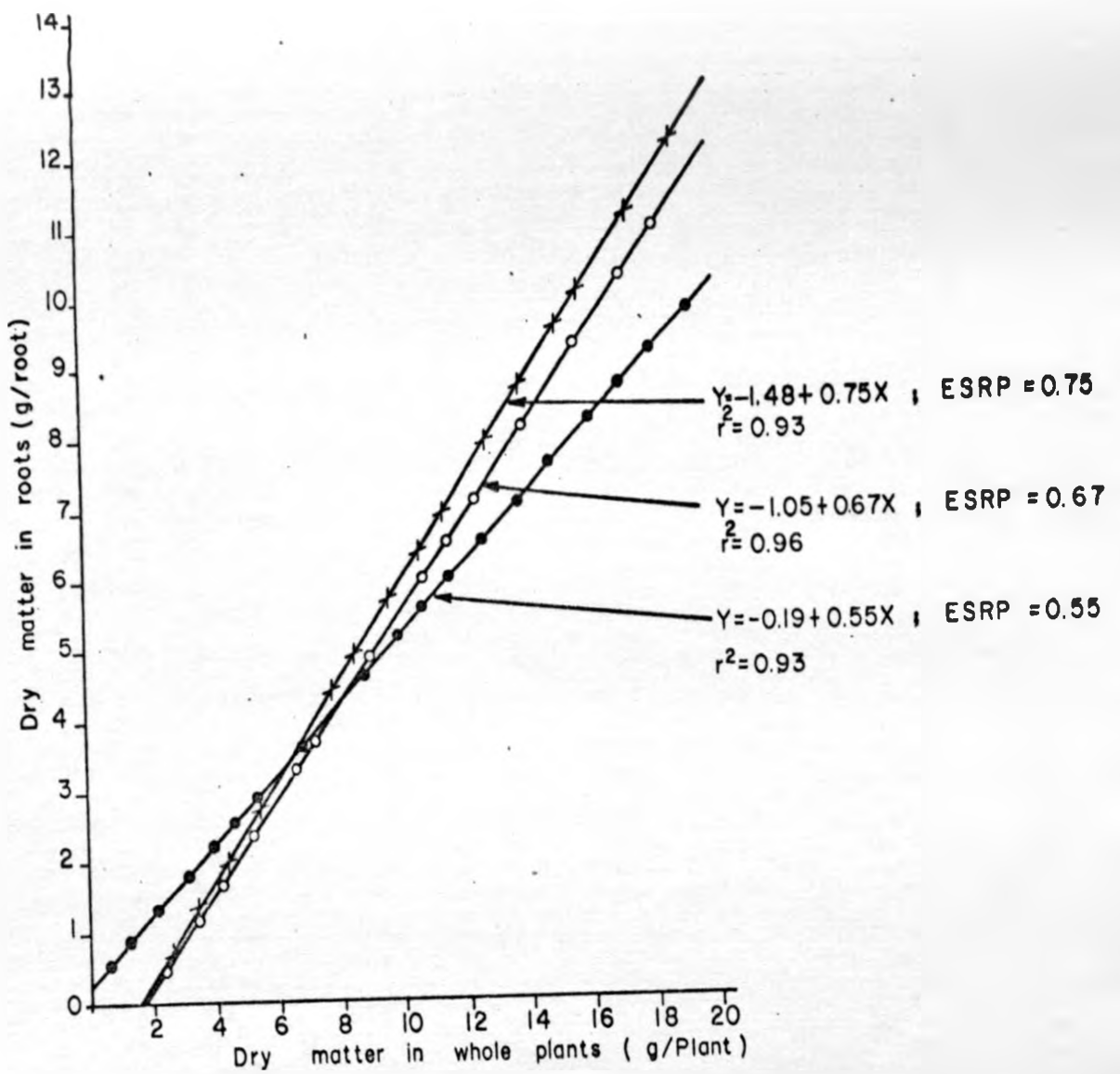


FIG. 5

Figure 6. The relationship between the dry matter in whole plants and the dry matter in storage roots in carrot as influenced by population density (●—●, 666,666 plants/ha; ○—○, 444,444 plants/ha; x—x, 333,333 plants/ha) (1978 Experiment).

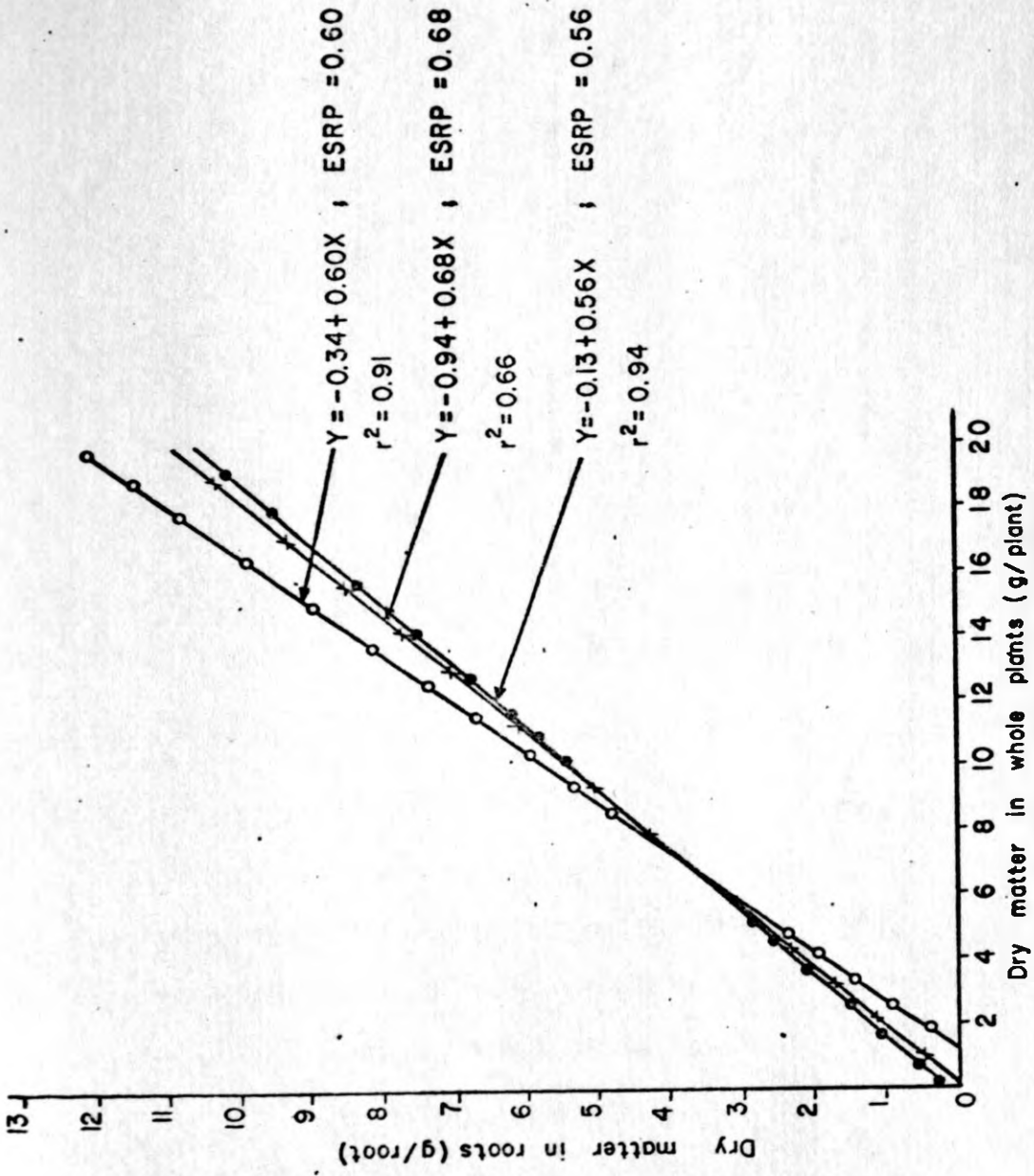


FIG. 6

Figure 7. The relationship between the dry matter in whole plants and the dry matter in storage roots in carrot as influenced by population density (●—●, 666,666 plants/ha, ○—○, 444,444 plants/ha, x—x, 333,333 plants/ha) (1979 Experiment).

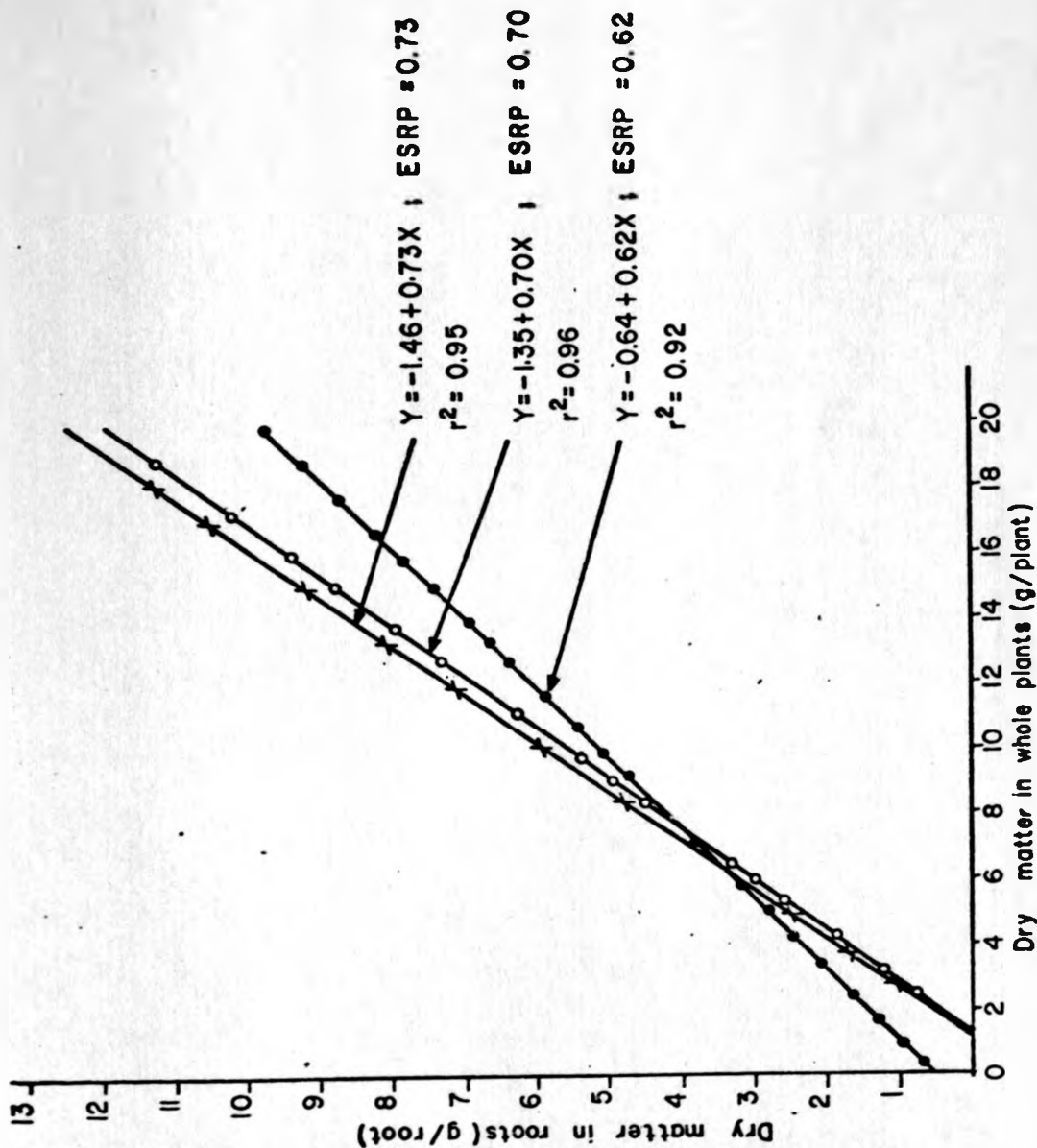


FIG. 7

Figure 8. The relationship between the dry matter in whole plants and the dry matter in storage roots in two carrot cultivars (●—●, Chantenay; x—x, Nantes). (1978 Experiment)

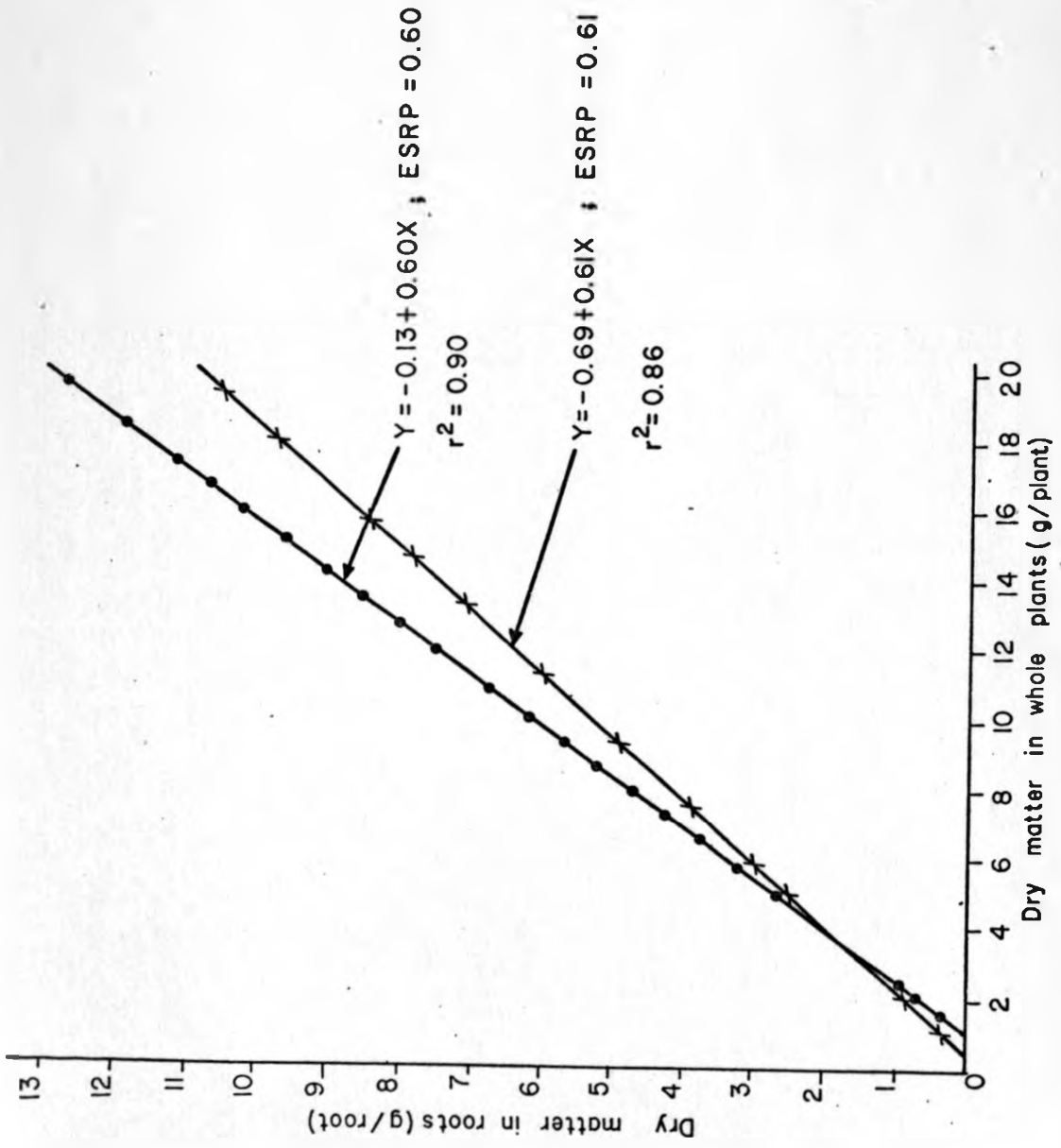


FIG. 8

Figure 9. The relationship between the dry matter in whole plants and the dry matter in storage roots in two carrot cultivars (●—●, Chantenay; X—X, Nantes) (1979 Experiment)

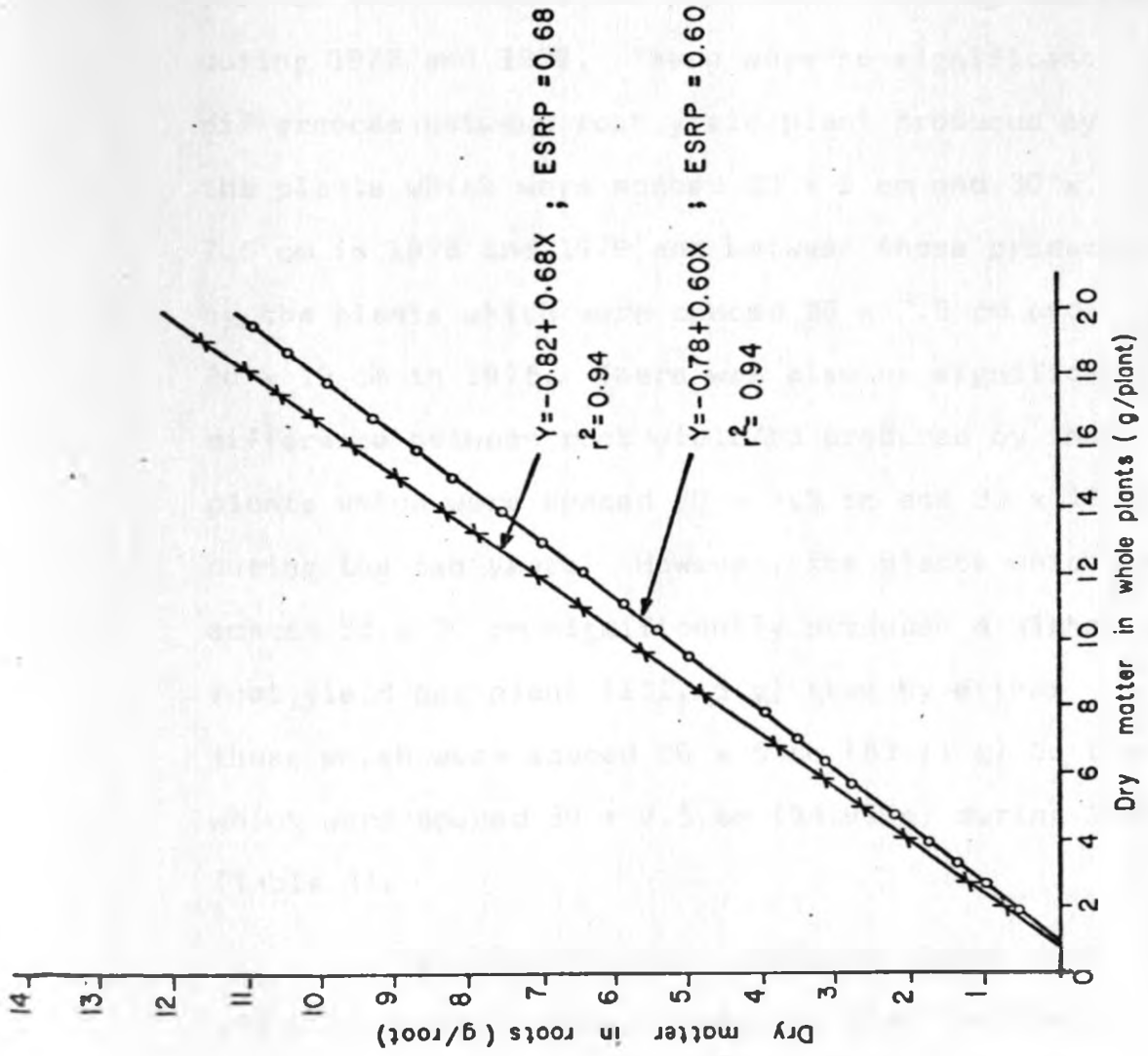


FIG. 9

Root yield per plant increased but root yield per hectare decreased as population density decreased during 1978 and 1979. There were no significant differences between root yield/plant produced by the plants which were spaced 30 x 5 cm and 30 x 7.5 cm in 1978 and 1979 and between those produced by the plants which were spaced 30 x 7.5 cm and 30 x 10 cm in 1978. There was also no significant difference between root yield/ha produced by the plants which were spaced 30 x 7.5 cm and 30 x 10 cm during the two years. However, the plants which were spaced 30 x 10 cm significantly produced a higher root yield per plant (111.25 g) than by either those which were spaced 30 x 5 cm (83.11 g) or those which were spaced 30 x 7.5 cm (94.95 g) during 1979 (Table 3).

Nantes significantly produced higher root yield (per plant and per hectare) than Chantenay during the two years (Table 4). Root yield was generally higher in 1979 than in 1978 (Tables 2, 3 and 4).

Since the effects of phosphorus, population density and cultivar on root diameter and length were assumed to be similar during 1978 and 1979, only the data in the former year is presented. Root length and diameter of the two cultivars increased as

Table 2. Root yield of carrot as influenced by phosphorus fertilizers.

Levels of phosphorus (kg/ha P ₂ O ₅)	Root yield			
	1978 Experiment		1979 Experiment	
	(g/plant)	(tons/ha)	(g/plant)	(tons/ha)
0	66.99 a	29.31 a	88.08 NS	36.70 NS
92	83.75 b	34.05 ab	99.71 NS	36.87 NS
184	91.71 b	37.23 b	101.52 NS	36.65 NS

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Table 3. Root yield of carrot as influenced by population density.

Plant spacing (cm)	Population density (plants/ha)	Root yield			
		1978 Experiment		1979 Experiment	
		(g/plant)	(tons/ha)	(g/plant)	(tons/ha)
30 x 5	666,666	73.56 a	38.69 a	83.11 a	39.53 a
30 x 7.5	444,444	77.51 ab	32.56 b	94.95 a	36.59 ab
30 x 10	333,333	91.38 b	29.34 b	111.25 b	34.09 b

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$)

Table 4. Root yield of carrot as influenced by variety.

Variety	Root yield			
	1978 Experiment		1979 Experiment	
	(g/plant)	(tons/ha)	(g/plant)	(tons/ha)
Chantenay	74.12 a	30.45 a	88.11 a	33.14 a
Nantes	87.52 b	36.61 b	104.76 b	40.33 b

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$).

the levels of phosphorus increased. However, phosphorus had no significant effect on the two parameters except that its effect on the root diameter of Chantenay was significant. There was no significant difference between the root diameter of Chantenay which received 0 kg P_2O_5 /ha and 92 kg P_2O_5 /ha and between that of those which received 92 kg P_2O_5 /ha and 184 kg P_2O_5 /ha but the plants which received the highest level of phosphorus significantly produced higher root diameter than the control (Table 5).

Population density did not have any significant effect on root length and diameter of the two cultivars (Table 6).

The root length of Nantes was significantly longer than that of Chantenay but the root diameter of the former was significantly shorter than that of the latter (Table 7).

The interaction of phosphorus and population density had a significant effect on root length of Nantes (Appendix Table 2a).

D. Effects of phosphorus, population density and cultivar on β - carotene, total sugars and reducing sugars content of carrot roots.

The amount of β - carotene produced in roots was

Table 5. Root length and root diameter of Chantenay and Nantes as influenced by phosphorus fertilizers (1978 Experiment).

Phosphorus level (kg/ha P ₂ O ₅)	Root length (cm)		Root diameter (cm)	
	Chantenay	Nantes	Chantenay	Nantes
0	11.65 NS	14.50 NS	4.24 a	4.06 NS
92	12.30 NS	14.63 NS	4.72 ab	4.15 NS
184	12.83 NS	15.47 NS	4.99 b	4.18 NS

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Table 6. Root length and root diameter of Chantenay and Nantes as influenced by population density (1978 Experiment).

Plant spacing (cm)	Population density (plants/ha)	Root length (cm)		Root diameter (cm)	
		Chantenay	Nantes	Chantenay	Nantes
30 x 5	666,666	12.07 NS	14.28 NS	4.67 NS	4.22 NS
30 x 7.5	444,444	12.81 NS	15.27 NS	4.71 NS	4.01 NS
30 x 10	333,333	11.91 NS	15.05 NS	4.56 NS	4.16 NS

NS = Not significantly different ($P \leq 0.05$).

Table 7. Root length and root diameter of carrot as influenced by variety
(1978 Experiment).

Variety	Root length (cm)	Root diameter (cm)
Chantenay	12.26 a	4.65 a
Nantes	14.87 b	4.13 b

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$).

generally greater in 1978 than in 1979 (Tables 8, 9 and 10). β - carotene per unit fresh weight of roots decreased as the levels of phosphorus increased during 1978 but phosphorus had no effect on the concentration of β - carotene in roots during the two years. Although the amount of β -carotene per root and per hectare increased as the levels of phosphorus increased, it did not have any significant effect on root β - carotene during the two years (Table 8).

The amount of root β - carotene per hectare decreased but the amount per root increased as the population density decreased during the two years. Population density did not have any appreciable effect on the concentration of β - carotene in roots. However, population density significantly affected the amount of root β - carotene per hectare produced during 1978 and the amount obtained per root during 1979 but it did not have any significant effect on the amount produced per root and per unit root fresh weight during 1978. It also had no significant effect on the amount produced per hectare and per unit root fresh weight during 1979 (Table 9).

The amount of β - carotene produced per hectare and per root was greater in Nantes than in Chantenay during the two years. The amount of root β - carotene

Table 8. β - carotene content of carrot roots as influenced by phosphorus fertilizers.
Determinations were done on fresh tissues.

Levels of phosphorus (kg/ha P ₂ O ₅)	β - Carotene					
	1978 Experiment			1979 Experiment		
	(mg/100g)	(mg/root)	(kg/ha)	(mg/100g)	(mg/root)	(kg/ha)
0	11.70 NS	7.92 NS	3.53 NS	7.62 NS	6.69 NS	2.82 NS
92	11.70 NS	9.75 NS	3.97 NS	7.60 NS	7.70 NS	2.85 NS
184	10.84 NS	9.90 NS	4.03 NS	8.15 NS	8.51 NS	3.08 NS

NS = Not significantly different (P \leq 0.05).

Table 9. β - Carotene content of carrot roots as influenced by population density.

Determination were done on fresh tissues.

		β - carotene					
Plant spacing (cm)	Population density (plants/ha)	1978 Experiment			1979 Experiment		
		(mg/100g)	(mg/root)	(kg/ha)	(mg/100g)	(mg/root)	(kg/ha)
30 x 5	666,666	12.42 NS	8.23 NS	4.77 a	7.70 NS	6.52 a	3.06 NS
30 x 7.5	444,444	10.77 NS	9.11 NS	3.50 b	7.96 NS	7.68 ab	3.01 NS
30 x 10	333,333	11.04 NS	10.23 NS	3.27 b	7.72 NS	8.69 b	2.67 NS

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Table 10. β - carotene content of carrot roots as influenced by variety.

Determinations were done on fresh tissues.

Variety	β - carotene					
	1978 Experiment			1979 Experiment		
	(mg/100g)	(mg/root)	(kg/ha)	(mg/100g)	(mg/root)	(kg/ha)
Chantenay	11.49 NS	8.43 NS	3.55 NS	7.40 NS	6.69 a	2.53 a
Nantes	11.32 NS	9.95 NS	4.14 NS	8.18 NS	8.57 b	3.31 b

Means in the same column followed by the same letter are not significantly different (P \leq 0.05).

NS = Not significantly different (P \leq 0.05).

per unit fresh weight produced in Chantenay was greater than that in Nantes during 1978 but Nantes produced a greater amount than Chantenay during 1979. Cultivar had significant effects on the amount of β - carotene produced per hectare and per root in 1979 but it did not have any significant effects on the concentration of β -carotene per unit root fresh weight during the same year and on β - carotene yield per hectare, per root and per unit root fresh weight during 1978 (Table 10).

The interaction of population density and variety had a significant effect on the concentration of β - carotene in roots in both years (Appendix Table 4).

The amount of total and reducing sugars in roots were not determined in 1978 and only the data for 1979 is presented.

Although the amount of total sugars and reducing sugars in roots per hectare, per root and per unit fresh weight increased as the levels of phosphorus increased, phosphorus had no significant effect on the amount of total and reducing sugars in roots during 1979 except that it significantly affected the amount of total sugars per unit root fresh weight. There were no significant differences between the amount of total sugars per unit weight

of root fresh tissue produced by the control plants and by those which received 92 kg P_2O_5 /ha and between those produced by the plants which received 92 and 184 kg P_2O_5 /ha. However, there was a significant difference between the amounts produced by the control plants and by those which received the highest level of phosphorus (Table 11).

The amount of total and reducing sugars in roots per unit weight of fresh tissue and per hectare decreased as the population density decreased but the amounts of total and reducing sugars per root increased as population density decreased. Population density had no significant effect on the amount of total and reducing sugars in roots except that its effect on the amount of reducing sugars per root was significant. The amount of reducing sugars produced by the plants which were spaced 30 x 7.5 cm was not significantly different from that produced by those which were spaced 30 x 10 cm. The plants spaced 30 x 7.5 cm and 30 x 10 cm significantly produced more reducing sugars than those which were spaced 30 x 5 cm (Table 12).

Cultivar had no significant effect on the amount of total and reducing sugars produced in roots but Nantes generally produced a greater amount of sugars than Chantenay (Table 13).

Table 11. Sugar content of carrot roots as influenced by phosphorus fertilizers (1979 Experiment).
Determinations were done on fresh tissues.

Levels of phosphorus (kg/ha P ₂ O ₅)	Total sugars			Reducing sugars		
	(mg/g)	(g/root)	(tons/ha)	(mg/g)	(g/root)	(tons/ha)
0	46.57 a	4.71 NS	1.75 NS	17.16 NS	1.59 NS	0.62 NS
92	52.72 ab	4.80 NS	1.93 NS	18.13 NS	1.71 NS	0.65 NS
184	61.21 b	6.28 NS	2.35 NS	18.53 NS	1.86 NS	0.68 NS

Means in the column followed by the same letter are not significantly different ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Table 12. Sugar content of carrot roots as influenced by population density (1979 Experiment).

Determinations were done on fresh tissues.

Plant spacing (cm)	Population density (Plants/ha)	Total sugars			Reducing sugars		
		(mg/g)	(g/root)	(tons/ha)	(mg/g)	(g/root)	(tons/ha)
30 x 5	666,666	55.36 NS	4.88 NS	2.29 NS	19.37 NS	1.25 a	0.69 NS
30 x 7.5	444,444	54.12 NS	4.89 NS	1.88 NS	18.99 NS	1.80 b	0.63 NS
30 x 10	333,333	51.03 NS	6.02 NS	1.86 NS	15.47 NS	2.10 b	0.62 NS

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Table 13. Sugar content of carrot roots as influenced by variety (1979 Experiment).
Determinations were done on fresh tissues.

Variety	Total sugars			Reducing sugars		
	(mg/g)	(g/root)	(tons/ha)	(mg/g)	(g/root)	(tons/ha)
Chantenay	55.20 NS	5.04 NS	1.90 NS	19.14 NS	1.69 NS	0.62 NS
Nantes	51.80 NS	5.49 NS	2.12 NS	16.75 NS	1.75 NS	0.68 NS

NS = Not significantly different ($P \leq 0.05$).

The interaction of phosphorus and population density had significant effects on the total sugars per unit root fresh weight and per hectare. The interaction of phosphorus and variety had significant effects on the total sugars per unit root fresh weight, per root and per hectare and on the reducing sugars per unit root fresh weight and per root (Appendix Table 5).

CHAPTER 5

DISCUSSION

The effect of phosphorus on dry matter accumulation, as observed in the present study, is consistent with the results obtained by Pankov (1977) who reported that the rate of carrot growth increased with phosphorus levels (Figure 1). Phosphorus is an essential constituent of nucleic acids, phytin and phospholipids. It, therefore, increases the rate of crop growth and maturity (Arnon, 1972).

That the rate of dry matter accumulation in carrot plants ha^{-1} increases as population density increases (Holliday, 1960; Donald, 1963) has been demonstrated in the present study (Table 3). Further increase in population density beyond the optimum level resulted in a reduction in dry matter production in carrot, as a consequence of increased inter-plant competition. However, it seems probable that the highest population density used in the present study was not the optimum for dry matter accumulation in carrots. There was a linear increase in dry matter accumulation with population density (Table 3).

The present study shows that a greater amount of dry matter accumulated in Nantes than in Chantenay and this was apparently due to varietal differences

(Figure 3).

Since a decrease in population density and an increase in phosphorus levels resulted in a greater amount of dry matter in Nantes than in Chantenay, it is to be expected that ESRP in Nantes will be higher than in Chantenay, as population density decreased and phosphorus levels increased (Figures 4, 5, 6, 7, 8 and 9).

It has been reported by Arnon (1972) that crops do not respond to phosphorus fertilizers in soils containing high levels of this nutrient, and similar results were obtained in the present study (Table 2). Although phosphorus fertilizer significantly affected root yield during 1978, when the level of soil phosphorus was low ($6.98\text{mg P}_2\text{O}_5/100\text{g}$), it had no effect on root yield in 1979, when its level was high ($53.80\text{mg P}_2\text{O}_5/100\text{g}$), (Table 1).

Evidence arising from this work (Table 2) agrees with the results reported by Pankov (1977) that higher levels of soil phosphorus result in increased root yield. The results presented here show that carrot root yield (ha^{-1} and plant^{-1}) significantly increased in 1978 when the level of phosphorus fertilizer increased from 0 to $92\text{ kg P}_2\text{O}_5/\text{ha}$ but further increase in the level of the fertilizer did not

result in any significant increase in root yield (Table 2). Similar results were reported by Kanwar and Malik (1971). Phosphorus is an essential constituent of nucleic acids, phytin and phospholipids (Arnon, 1972). It is, therefore, apparent that higher levels of phosphorus fertilizer will result in a higher root yield and increased rates of plant growth.

The effect of population density on root yield plant⁻¹ (Table 3) is in agreement with Franken (1972) and Lipari (1976) who showed that lower population densities increased root yield plant⁻¹. It seems probable that the plants which were sparsely spaced had better chance for development resulting in larger roots. Root yield ha⁻¹ significantly increased but root size decreased with an increase in population density, as a consequence of increased competition between individual plants (Table 3). Similar results were reported by Franken (1972) and Lipari (1976).

The results of the present study show that there are varietal differences in carrot yield. Nantes consistently produced higher yields (ha⁻¹ and plant⁻¹) during the two years (Table 4). In Kenya Nantes is grown for the fresh market and for canning while Chantenay is grown only for the fresh market.

Root yield (ha⁻¹ and plant⁻¹) was higher in

1979 than in 1978 (Tables 2, 3 and 4). This seasonal difference in yield could be attributed to the higher levels of soil phosphorus (Table 1) and higher amounts of rainfall received by plants during 1979. Whereas 1979 crop received 269.6 mm rainfall during the first two months of crop growth, the 1978 one received only 191.0 mm of rainfall during the same period (Appendix Table 6). Similar results were reported by Haddock (1949) who reported that more phosphorus became available for crop growth at higher soil moisture levels. However, carrot root yield ha^{-1} in both years obtained from this study was higher than the average root yield on peasants farms (20 tons/ha). This difference could be due to differences in management of the crop.

The results of the present study have clearly demonstrated that any factor which increases ESRP will increase root yield; it will decrease root yield if it decreases ESRP. Higher levels of phosphorus fertilizer increased ESRP (Figures 4 and 5) and this resulted in a higher root yield (plant^{-1} and ha^{-1}) (Table 2). Lower population densities increased ESRP (Figures 6 and 7) resulting in a higher root yield plant^{-1} (Table 3). ESRP was higher in Nantes than in Chantenay (Figures 8 and 9) and the former cultivar produced a higher root yield

than the latter (Table 4).

Phosphorus levels (Table 5) and population density (Table 6) had no significant effects on carrot root length. The effects of population density and phosphorus on root length in the present study are at variance with the results reported by Starikov (1973) that phosphorus fertilizers decreased carrot root length and by Bussell (1976) that carrot root length decreased with higher population densities.

The present study showed that phosphorus had a significant effect on the root diameter of Chantenay (Table 5). This is in agreement with Starikov (1973) who reported that phosphorus fertilizers increased carrot root width. This is to be expected since phosphorus is an essential constituent of nucleic acid, phytin and phospholipids (Arnon, 1972).

The results obtained here show that population density had no effect on carrot root diameter within ranges of densities used (Table 6). The reason is not known.

The results reported here have confirmed the observations made by Thompson and Kelly (1957) that there are varietal differences in the thickness of carrot roots. The diameter of Chantenay roots was

larger than that of Nantes (Table 7).

Although the main effects of phosphorus and population density on root length were not significant, the interaction between phosphorus and population density significantly influenced the root length of Nantes (Appendix Table 2a). This might be due to the fact that variety which significantly affected root length might have been very effective (Appendix Table 3). However, the interaction of phosphorus and population density had no specific trend (Appendix Table 2b).

Phosphorus had no significant effect on β -carotene content of carrot roots (Table 8). Similar results were reported by Nehring (1965). ^{Wolera's this?} However, Pftuzer and Pfuff (1937) reported that phosphorus deficiency resulted in higher levels of root β -carotene in carrot roots.

The yield of β -carotene ha^{-1} increased as population density increased during 1978 (Table 9). This is to be expected since the root yield ha^{-1} also increased with population density (Table 3).

Population density had an optimum effect on the amount of β -carotene root ha^{-1} (Table 9). Although soil moisture levels were not determined in the present study, it was more than likely that the higher

population densities depleted the soil moisture at a faster rate than did the lower population densities. Thus, moderate amounts of soil moisture were presumably available to the plants spaced 30 x 7.5 cm whilst those spaced 30 x 10 cm and 30 x 5 cm grew in soils containing high and low moisture respectively. Banga et al. (1964) and Seckarev and Lukovnikova (1966) reported that moderate levels of soil moisture influenced carrot root to produce maximum amount of root β -carotene.

Cultivar had no effect on the amount of β - carotene in roots during 1978 but it significantly affected root β - carotene yield ha^{-1} and root⁻¹ in 1979 (Table 10). It is apparent that the seasonal differences in β - carotene content in roots, as influenced by variety, were due to differences in soil moisture levels during the two years. The level of soil moisture was presumably higher during 1979 than during 1978 (Appendix Table 6). Nantes accumulated more β - carotene than Chantenay (Table 10). These results suggest that the amount of β - carotene which accumulates in cultivars may not be significantly different under low moisture levels but it may vary significantly when the soil moisture levels are high. It would seem probable that Nantes was able to maintain moderate amount of moisture

in the soil whilst Chantenay grew in soils containing high levels of moisture. Shoot dry matter was greater in Nantes than in Chantenay (Figure 3). It was, therefore, probable that the rates of transpiration were also higher in Nantes than in Chantenay. Banga et al. (1964) and Seckarev and Lukovnikova (1966) reported that moderate soil moisture levels favoured the accumulation of β - carotene in roots. Variety influenced the accumulation of β - carotene in roots (Yamaguchi et al., 1952, Toul and Popisilova, 1964).

The results of the present study on seasonal variation in β - carotene content of carrot roots (Tables 8, 9 and 10) are consistent with those reported by Hansen (1945), Yamaguchi et al. (1952) and Banga and De Bruyn (1969) that the rate of carotene synthesis and accumulation increases in roots as temperature increases. The amount of β - carotene in roots increased (Tables 8, 9 and 10) as atmospheric temperature increased in the present study (mean temperature during February and March was 18.8°C while it was 17.2°C during May and June) (Appendix Table 6). Temperature influences carotene development by changing the biosynthetic pathway of carotenoids and by favouring the accumulation of one pigment at the expense of the others (Yu-Heuy Chang et al., 1977).

The conversion of one form of carotenes to another depends on the enzymatic activity which is also affected by temperature (Porter and Anderson, 1967).

The population density and variety interaction had significant effect on β -carotene content in roots during the two years. This is to be expected, since both population density and variety significantly affected root β -carotene (Appendix Table 4).

Although the amount of total and reducing sugars in roots (concentration, root^{-1} and ha^{-1}) increased as the levels of phosphorus increased, phosphorus had no significant effect on sugars, except that the concentration of the total sugars increased as phosphorus levels increased (Table 11). Similar results were reported by Habben (1974) that the total sugars content of roots varied very little with fertilizer levels. Pankov (1977) reported that phosphorus deficiency resulted in an increase in the sugar content of carrot roots.

Population density and variety had no measurable effects on sugars except that the reducing sugars root^{-1} increased as the population density decreased (Table 12). This is to be expected since higher population density resulted in the depletion

of soil nutrients. Reducing sugars in carrot roots increased as soil nitrogen and potassium also increased (Habben, 1973).

The interaction of phosphorus and population density and that of phosphorus and variety had significant effects on the total sugars. This is to be expected since phosphorus significantly affected the total sugars.

CONCLUSION

The results of the present study has confirmed that carrots grown in phosphorus-rich soils do not require phosphorus fertilizers. Although phosphorus fertilizers enhanced the yield and root size of carrots in phosphorus-deficient soils, excess application of this fertilizer, beyond the optimum level, does not result in a concomitantly higher root yield and larger roots. Thus, excess application of this fertilizer in any type of soil may not be economic.

Population density also has optimum effect on carrot root yield. The 444,444 plants/ha was the optimum density in the present study and either higher or lower density did not significantly result in higher yields.

Cultivar is a very important factor which determines the root yield of carrots. Nantes yielded higher than Chantenay in this study.

The results of these experiments clearly show that the size of carrot roots can be controlled by population density, cultivar and phosphorus fertilizers (in deficient soils). If it is intended to produce larger roots the 30 x 10 cm spacing, the 184 kg P_2O_5 /ha and cv. Nantes (in phosphorus-deficient soil) were most satisfactory. If it is desired to produce small roots the 30 x 5 cm spacing, the 0kg P_2O_5 /ha and cv.

Chantenay gave the best results. Root length and diameter cannot be significantly influenced by either phosphorus fertilizers or population density. However, root length and diameter may be significantly different in various cultivars.

The sugar content of roots may be changed by varying the levels of phosphorus fertilizers. Higher levels of phosphorus fertilizers enhanced the accumulation of sugars in roots in these experiments. However, cultivar and population density did not have significant influence on sugars in carrot roots

Phosphorus fertilizers may not change the amount of β -carotene in roots but higher temperatures and higher levels of soil moisture favoured the accumulation of β - carotene in roots. Nantes was more efficient in the accumulation of β - carotene in roots than was Chantenay.

The current recommendations that carrots should be grown at a population density of 444,444 plants/ha is reinforced specifically for Nantes by the findings of this study. This treatment produced the highest root yield and the largest amounts and the highest concentrations of β - carotene in roots.

The amounts of phosphorus fertilizers to be applied should depend upon the fertility status of

the soil. No fertilizers are required, if the soil contains ≥ 53.80 mg $P_2O_5/100g$. On the other hand, about 92 kg P_2O_5/ha may be needed, if the level of soil phosphorus is < 53.80 mg $P_2O_5/100g$. However, if the emphasis is to produce roots containing high concentrations of total sugars, phosphorus fertilizer may be used even if its level in the soil ≥ 53.80 mg $P_2O_5/100g$.

Appendix Table 1. Mean Squares for root yield of carrot

Source of variation	D.F.	Mean squares			
		1978 Experiment		1979 Experiment	
		(g/plant)	(tons/ha)	(g/plant)	(tons/ha)
Total	53				
Blocks	2				
Total treatment	17	847.81 NS	144.14 *	928.96 *	80.68 NS
Phosphorus (P)	2	2867.86 *	286.08 *	956.56 *	0.24 NS
Population density (S)	2	1576.62 *	405.79 *	3594.23 *	133.75 *
Variety (V)	1	2424.33 *	513.62 *	3741.01 *	699.48 *
P X S interaction	4	395.48 NS	70.16 NS	110.63 NS	66.30 NS
P X V interaction	2	15.73 NS	0.17 NS	576.45 NS	9.42 NS
S X V interaction	2	138.26 NS	13.39 NS	102.96 NS	18.52 NS
P X S X V interaction	4	302.41 NS	61.31 NS	287.12 NS	20.74 NS
Error	34	528.95	54.68	387.02	51.69

* Significant ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Appendix Table 2a. Mean squares for root length and root diameter in Chantenay and Nantes
(1978 Experiment).

Source of variation	D.F	Mean Squares			
		Root length (cm)		Root diameter (cm)	
		Chantenay	Nantes	Chantenay	Nantes
Total	26				
Blocks	2				
Total treatment	8	2.46 NS	3.98 *	0.48 NS	0.09 NS
- Phosphorus (P)	2	3.14 NS	2.53 NS	1.32 *	0.04 NS
- Population density (S)	2	2.08 NS	2.43 NS	0.06 NS	0.10 NS
- P X S interaction	4	2.31 NS	5.47 *	0.28 NS	0.12 NS
Error	16	4.35	1.49	0.28	0.24

* Significant ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$)

Appendix Table 2b. Mean effects of phosphorus and population density on the root length of Nantes (cm).

Spacing (Population density) Levels of phosphorus	30 x 5 cm (666,666 plants/ha)	30 x 7.5 cm (444,444 plants/ ha)	30 x 10 cm (333,333 plants/ha)
0 kg P ₂ O ₅ /ha	14.35 NS	15.99 a	13.55 a
92 kg P ₂ O ₅ /ha	14.35 NS	13.36 b	15.78 b
184 kg P ₂ O ₅ /ha	14.15 NS	16.45 a	15.82 b

Means in the same column followed by the same letter are not significantly different (P ≤ 0.05).

NS = Not significantly different (P ≤ 0.05).

Appendix Table 3. Mean squares for carrot root length and root diameter (1978 Experiment).

Source of variation	D.F	Mean squares	
		Root length (cm)	Root diameter (cm)
Total	53		
Blocks	2		
Total treatment	17	8.41 *	0.48 *
Phosphorus (P)	2	4.97 NS	0.90 *
Population density (S)	2	3.48 NS	0.04 NS
Variety (V)	1	91.55 *	3.63 *
P X S interaction	4	2.87 NS	0.34 NS
P X V interaction	2	0.73 NS	0.46 NS
S X V interaction	2	1.02 NS	0.12 NS
P X S X V interaction	4	32.03 *	0.06 NS
Error	34	2.86	0.26

* Significant ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Appendix Table 4. Mean squares for β -Carotene content in carrot roots.

Source of Variation	D.F.	Mean squares					
		1978 Experiment			1979 Experiment		
		(mg/100g)	(mg/root)	(kg/ha)	(mg/100g)	(mg/root)	(kg/ha)
Total	53						
Blocks	2						
Total treatment	17	30.76 NS	50.16 NS	11.43 NS	7.47 NS	34.34 NS	3.79 NS
Phosphorus (P)	2	17.53 NS	87.68 NS	5.37 NS	6.98 NS	60.06 *	1.40 NS
Population density (S)	2	56.35 NS	72.26 NS	47.21 *	1.52 NS	84.41 *	3.25 NS
Variety (V)	1	1.52 NS	125.10 *	18.72 *	32.71 *	191.50 *	32.81 *
P X S interaction	4	2.63 NS	30.80 NS	4.57 NS	1.02 NS	2.49 NS	1.86 NS
P X V interaction	2	21.68 NS	28.19 NS	4.12 NS	4.76 NS	4.74 NS	0.10 NS
S X V interaction	2	115.33 *	75.44 NS	14.53 NS	27.91 *	22.97 NS	4.44 NS
P X S X V interaction	4	22.20 NS	19.31 NS	3.70 NS	1.97 NS	9.47 NS	1.47 NS
Error	34	44.93	56.45	9.17	12.92	28.08	3.36

* Significant ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Appendix Table 5. Mean squares for sugar content in carrot roots (1979 Experiment).

Source of variation	D.F	Mean squares					
		Total sugars			Reducing sugars		
		(mg/g)	(g/root)	(tons/ha)	(mg/g)	(g/root)	(tons/ha)
Total	53						
Blocks	2						
Total treatment	17	930.80 *	12.35 *	1.92 *	36.14 NS	0.79 NS	0.04 NS
Phosphorus (P)	2	972.88 *	13.92 *	1.72 *	8.95 NS	0.35 NS	0.02 NS
Population density (S)	2	89.52 NS	7.71 NS	1.05 NS	83.46 *	3.34 *	0.03 NS
Variety (V)	1	155.58 NS	2.68 NS	0.65 NS	77.21 NS	0.06 NS	0.04 NS
P X S interaction	4	905.16 *	10.52 NS	2.40 *	8.87 NS	0.16 NS	0.06 NS
P X V interaction	2	2199.13 *	30.68 *	3.43 *	81.76 *	1.65 *	0.08 NS
S X V interaction	2	89.79 NS	1.50 NS	0.08 NS	19.93 NS	0.05 NS	0.01 NS
P X S X V interaction	4	1336.18 *	11.70 NS	2.43 *	28.37 NS	0.49 NS	0.03 NS
Error	34	260.05	6.60	0.77	43.01	0.44	0.07

* Significant ($P \leq 0.05$).

NS = Not significantly different ($P \leq 0.05$).

Appendix Table 6. Weather data during 1978 and 1979 Experiments

Year	Month	Total Rainfall (mm)	Temperature ($^{\circ}$ C)			Mean Relative humidity
			Maximum	Minimum	Mean	
1978	November	105.5	22.2	13.3	17.8	73%
	December	129.7	22.5	13.8	18.2	73%
1979	January	61.3	22.5	13.6	18.1	74%
	February	205.1	23.8	13.5	18.7	69%
	March	120.6	24.6	13.4	19.0	62%
	April	209.3	23.0	14.4	18.7	76%
	May	187.5	21.9	13.9	17.9	77%
	June	40.0	21.4	11.7	16.6	74%

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