# FERTILITY STUDIES ON IRRIGATED CABBAGE AND CARROTS IN SASKATCHEWAN

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## TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# INTRODUCTION

Fertility studies play an important part in determining how crop yields can be increased. Many vegetables grow rapidly and have high demands for plant nutrients.

With the development of the Gardiner Dam in Saskatchewan, interest is being shown in the commercial growing of vegetables under irrigated conditions. During 1970 about 334 hectares of potatoes were grown commercially in the area, and some increase in this acreage is expected in 1971. Very little research on the nutrient requirements for vegetables grown in Saskatchewan has been done, and there is a need for further studies. The Department of Horticulture Science at the University of Saskatchewan, Saskatoon has conducted fertility studies since 1962 on a number of crops including the present study on cabbage and carrots, with financial assistance from the Saskatchewan Research Council. The latter experiments were carried out on Asquith Fine Sandy Loam at Saskatoon and Outlook, Saskatchewan.

All measures and weights reported in this thesis have been expressed according to the metric system and the precision of these figures does not necessarily indicate the high degree of accuracy, but rather are the result of conversions to the metric system.

# REVIEW OF LITERATURE

## Cabbage

### The effects of nitrogen

Yield - Betzema and Commandeur (7) reported that an application of 1729.63 kilograms of nitrogen per hectare gave the best yields of cabbage when compared to rates of zero and 3459.26 kilograms per hectare, and the latter caused plant losses in the field. Woodman (104) reported that reduced nitrogen resulted in diminished yields and later maturity. Ziegler and Böttcher (109), however, stated that nitrogen gave no significant increase in total yield. In contrast, Haworth (36) found that high nitrogen applications gave yields three times that of the check treatments, and Hensel (42) found that both rates and methods of application significantly affected yield and head weight. According to him, the lowest rate of fertilizer applied as a liquid in split applications gave the highest yields. Haworth (37) noted that increasing nitrogen applications up to 312.70 kilograms of nitrogen per hectare in very early spring progressively increased the yield of spring cabbage. In studies on autumn-sown cabbage, Iwata and Utada (44) found that withholding nitrogen applications in early April to early June when outer leaf growth was more rapid reduced head weight, while there was no significant effect if this was done after early June. Burleson et al (17) found that an application of nitrogenous fertilizer increased the yield of medium size cabbage and reduced the yield of small cabbages. Highest yield was obtained with an application of 201.74 kilograms of nitrogen per hectare.

This rate also gave the highest total fresh yield and marketable yield in an experiment conducted by Heilman et al (40). Man and Sandhu (59) obtained optimum yields with applications of 168.12 kilograms of nitrogen per hectare and found that applications of 224.16 kilograms depressed yields, whereas Ram and Sharma (76) found that 148.25 kilograms of nitrogen per hectare gave the greatest yield and head diameter, as well as greatest plant height, spread, stem girth, leaf number and compactness of plant. According to them, rates of 49.42, 98.84 and 197.67 kilograms per hectare gave lower yields. Studies by Volk et al (98) indicated a general positive correlation between nitrate-nitrogen in the soil just prior to harvest and the yield of marketable cabbage. They found that the critical point was about 16.81 kilograms of nitrate-nitrogen per hectare, and that above this value the response to larger amounts of nitrogen dropped rapidly.

Quality - According to Arnon (1), nitrogen reduced the ascorbic acid content of cabbage. He indicated that the reduction might be due to the role of ascorbic acid in the chemical reduction of nitrites in the leaf tissue, during which process part of the ascorbic acid itself was reduced. Heintze (41) noted that an increase in soil nitrogen, along with an increase of phosphorus and potassium gave an increased level of total nitrogen in cabbage, but the potential content of pure protein-nitrogen was limited because any excess of nitrogen was stored in the amide form. Janes (47) reported that the main effect of using a sodium nitrate side-dressing on cabbage was an increase in sodium content. Kimbrough (51) studied the effect of the source of nitrate-nitrogen and found that when $NaNO_3$ was used a physiological breakdown occurred and normal heads were not formed in many cases. He found, however, that this problem was overcome by adding a mixture of minor plant nutrients. Thomas and Namken (91) reported that the cation and anion content of cabbage was significantly affected by the application of ammonium nitrate, but did not indicate the direction of the significance.

Deficiency symptoms and nutrient uptake - According to McMurtrey (63), nitrogen deficiency in cabbage could be detected visually by pale green young leaves, and older leaves that were colored orange, red or even purple, and were sometimes shed by the plant. Under low temperature conditions, purpling was often quite evident (75). Goodall and Gregory (30) reported that nitrogen deficiency could be detected visually when cabbage had 78 ppm of nitrate-nitrogen in fresh matter and that no deficiency symptoms could be detected visually when cabbage had 518 ppm of nitrate-nitrogen. They suggested that the optimum level for nitrate-nitrogen in the sap of cabbage was 300 ppm.

According to Halliday (34), "nutrient uptake proceeds at a uniformly high rate from about two and one-half months after sowing (usually one month after planting out) until maturity". He noted that for a yield of 44, 832 kilograms of fresh weight and 7,285.20 kilograms of dry matter per hectare, a cabbage crop would take up 218.56 kilograms of nitrogen per hectare. Shaw (84) noted that the safe level of nitrate-nitrogen was above 8000 ppm and the deficiency range was below 5000 ppm in the cabbage midrib, on a dry weight basis.

The effects of phosphorus

Yield - Woodman (104) reported that a reduction in phosphorus had no effect until a low level was reached and then a sudden drop in yield was noted. Burleson et al (17) found that phosphate alone or with nitrogen increased the yield of medium size cabbages and reduced the yield of small cabbage. These workers obtained optimum yields with an application of 134.50 kilograms of $P_2O_5$ per hectare. Application of $P_2O_5$ also gave a slight increase in average head weight. Similarly, Khupse and Kalke (50) noted that head weight and yields were significantly increased by phosphate applications. Furthermore, Odland and Cox (68) stated that tripling the rate of phosphorus doubled the yields.

Quality - Jankovskaja (49) found that the application of phosphorus to plants on soddy, podzolic soil, along with potassium, increased the dry matter content, but did not affect total sugars. Increases in dry matter content were also reported by Khupse and Kalke (50).

Deficiency symptoms and nutrient uptake - According to McMurtrey (63), as well as Purvis and Carolus (75), cabbage growing with a deficiency of phosphorus had dull leaves because of anthocyanin pigmentation on the underside or along the veins, and that otherwise, symptoms resembled those of nitrogen deficiency. McMurtrey also reported that heads were small and firm, and their leaf margins died. Halliday (34) stated that a crop yielding 44,832 kilograms of fresh weight and 7,285.20 kilograms of dry matter per hectare would take up 72.85 kilograms of phosphorus per hectare. Shaw (84) noted that the safe level of phosphate-phosphorus was above 3000 ppm in the leaf and the deficiency range was below 2500 ppm.

The effects of potassium on yield

Burleson et al (17) reported that potash caused a slight decrease in average head weight, whereas Vihtenko (95) obtained no response with the use of potassium fertilizers. Dennison and Janes (19) compared the effect of potassium chloride, potassium nitrate and potassium sulfate on cabbage, but did not obtain any significant differences in yield. Haworth et al (39), however, reported a small, but significant increase in yield with the use of potassium sulfate. Furthermore, yield increases from increased rates of potassium fertilizers were also reported by Odland and Cox (68). Haworth (36) found, however, that potash gave no response until the third year and no appreciable response until the fourth and fifth years.

The effects of fertilizer placement on root development

Weaver and Bruner (102) made extensive studies of cabbage roots and found that cabbage produced an extensive and finely branched root system, which was most abundant in the surface 30 centimeters of soil. Root development was studied by Sayre (81) also, who found that when a fertilizer band was placed near the roots, they became more fibrous and finely branched and tended to follow along the fertilizer band, filling it in completely. He noted further that using a complete fertilizer was injurious at first and that placement should be deep enough so that the soluble salt concentration would be reduced before the roots reached it.

The effects of irrigation

Yield - Many workers have shown that irrigation affected the yield of cabbage. According to Thomas and Namken (91), evapotranspiration was 2.4 times more effective than nitrogen supply in determining yields. Drew (21) and Laverton (55) found that increasing the amount of water resulted in increased yields. Drew (21) noted that, during the first nine weeks, depriving plants of rain or irrigation for up to five weeks had little effect on final yield. He found, however, that dry periods of three weeks later in the life of the plants markedly reduced yields, and irrigation in the last two to three weeks substantially reduced yields, regardless of previous moisture supply. According to Drew (21) and Laverton (55), irrigation gave earlier maturity and more uniformity, but had no effect on the ratio of marketable head weight to total head weight. Drew noted that the smaller the maximum permitted soil moisture deficit, the larger was the average head weight. Jadhav and Sreenivas (45) noted that there was a trend towards increased yields as irrigation intervals decreased from 16 days to 12 and to 8 days. Experiments by Janes and Drinkwater (48) indicated that a prolonged condition of low soil moisture on fine sandy loam occurring at any time in the growth of cabbages reduced yield and that dry conditions were most harmful during the latter part of the growing season. Somos (89), however, stated that the most crucial time for irrigation was during the early growing period in hot weather, and that yields were increased from 280 to 430 per cent by irrigation. In contrast, Laverton (55) reported that there was no moisture-sensitive stage of growth, but noted that if irrigation was limited to 2.54 centimeters of water, the nearer to harvest it was applied the greater was the weight of trimmed heads. According to Salter and Goode (80), highest yields were obtained when plants were never subjected to high stress conditions and that stress conditions, prior to and after heading, reduced yields by 14 and 36 per cent, respectively. They concluded that "maximum growth and yield can only be obtained when a plentiful supply of water is available to the plants throughout growth, but that dry conditions during head formation will cause the biggest reduction in yield".

Weaver and Bruner (102) found that cabbage roots obtained most of their water supply from the surface 30 centimeters of soil. Accordingly, on good loam soil frequent shallow irrigations eight to ten days apart, especially after heading began, resulted in larger yields than heavier irrigations at longer intervals. Vittum and Peck (97) noted that irrigating whenever available water in the upper 61 centimeters of soil dropped below 50 per cent significantly increased the yield per hectare of marketable cabbage and the average head weight, while having no effect on bursting. Reports by Vittum _et al_ (96) noted a 17 per cent increase in yield for irrigated plots and stated that tension higher than two atmospheres reduced yield, with further reductions occurring as tensions increased above this value. They suggested that soil water at tensions less than two atmospheres be made available to cabbage roots, particularly during the last few weeks of growth when the plants had the maximum water requirement. Jamison (46) and Nettles _et al_ (64), however, noted that too heavy an application of water reduced yields. Jamison attributed the reduction to the leaching of nutrients. He also noted that in the experiments conducted, non-irrigated plants were infested with aphids, whereas irrigated plants were not.

Quality - Janes (47) reported that irrigation increased reducing sugar and hydrolysable carbohydrate levels, but reduced nitrogen, iron and manganese content on a dry weight basis. On a fresh weight basis, irrigation reduced levels of all constituents except sodium. Jamison (46) reported that generally irrigation improved quality, but did not indicate the criteria used.

The effects of spacing

Jadhav and Sreenivas (45) found that plant spacings had no significant effect on height, spread, leaf number, head density, root growth or ascorbic acid content, whereas Drew (21) reported a reduction in size and delayed maturity with close spacing. Vittum and Peck (97) stated that close spacing increased yields, but decreased the average head weight and the degree of bursting.

The effects of planting time

Some studies on the effect of planting time have indicated that earlier sowings and transplantings increased yields (8,33), although Vaidya and Patil (93) reported that transplanting date or age of seedling had no effect on yield or quality. Vaidya and Patil (93) further noted that earlier transplanted ones produced heavier shoots, as well as heavier and larger heads, but they took a longer time to mature. According to Hahn (33), earlier sowing and transplanting resulted in better quality.

Factors affecting storage and changes in storage

Some cultivars of cabbage have been found to retain quality better in storage than others. Newer cultivars, such as Houston Evergreen, were found to have marked resistance in storage to breakdown and bolting, as well as better retention of color and weight after six months, compared to the cultivar Danish Ballhead (58).

The effect of fertilizers on storage quality has been studied, and several workers have agreed that heavy nitrogen fertilization caused more breakdown in storage (1,3,83,109). Mǎskovič (61) reported that the keeping quality of cabbage was poorest for plants grown on drained peat soils, but that application of high rates of potassium plus adequate nitrogen and phosphorus considerably improved the keeping quality. Furthermore, Dennison and Janes (19) found that cabbage which had received potassium chloride maintained better quality in storage at 8.1 degrees C than those which had received potassium nitrate or potassium sulfate.

Saburov _et al_ (78) studied the cooling of cabbages in storage and noted that cooling took place more rapidly along the stem than from the lateral sides of the head. According to them, the apical bud was the most cold sensitive and could be killed if the temperature fell too low. In fact, Širokov (86) found that the apical bud was killed at temperatures of -0.8 to -1.0 degrees C and that it was less resistant to cold than the core, white leaves or green leaves.

Lemke (56) reported that heads wrapped and stored upright decreased in vitamin C content, while those wrapped and stored upside-down increased in vitamin C content. According to Širokov (85), there was a decline in dry matter, total sugars and vitamin C content of the leaves during storage, but the stalk and terminal bud increased in dry matter and total sugar content, and only declined after the terminal bud became active. He noted that reducing sugars in the stalk increased until the terminal bud became active and that the level of reducing sugar could be used to predict the time at which the terminal bud would become active. Saburov *et al* (78) continued these studies and found that the decline in dry matter, sugars and vitamin C occurred later in varieties that stored well, and they suggested that the suitability for storage might be determined by measuring the concentration of soluble dry matter by refractometric readings, with high readings being desirable. High specific gravity of the heads was also suggested as a good indicator of keeping quality. They further reported that suitable varieties produced less carbon dioxide and had a slower growing axis in storage.

Carrots

The effects of nitrogen

*Yield* - Several workers have found that yields were increased by nitrogen applications. Goodman (31,32) reported that only a moderate amount of nitrogen was necessary for maximum yields, and Dhesi *et al* (20) found that an application of 56.04 kilograms of nitrogen per hectare gave higher yields than did an application of either 28.02

kilograms or 84.06 kilograms per hectare. These same workers also found that applications of nitrogen, phosphorus and potash significantly increased leaf number, plant height, root length and diameter, as well as yield of roots and bolting habit of the plants. Bleasdale et al (10) found the greatest yield response was with an application of farmyard manure at 44,832 kilograms per hectare. Woodman and Johnson (106) reported that an addition of nitrogen increased the water content in roots, which resulted in increased yields. According to Southards and Miller (90), the smallest roots were obtained from plants given the lowest levels of nitrogen, phosphorus and potassium. They also noted that top growth was markedly limited by either low nitrogen or phosphorus, and that an application of nitrogen late in the season caused excessive production of tops. In addition, Nicolaison and Haar (65) also reported the dependency of foliage growth on nitrogen supplies. Forbes (24) studied the effects of different sources of nitrogen for carrots and reported that ammonium sulfate, urea, Aqua-humus, MagAmp, Ferram 21, Uran 32 and 5-5-8-2 gave better results than either ammonium nitrate, sodium nitrate or castor pomace. Furthermore, Niemann (66) found that the use of ammonium chloride resulted in more marked potassium deficiency than with ammonium sulfate or calcium nitrate, especially with low moisture supplies. He noted that "ammonium plants" generally produced more leaf and dry matter than did "nitrate plants".

Quality - Goodman (31,32), as well as Wallace et al (100), reported that high nitrogen applications caused root splitting, and Garner (28) also noted that nitrogen applications reduced the number of sound carrots.

In addition, Bienz (9) found that heavy ammonium nitrate side-dressings when roots were 6.35 millimeters in diameter increased the incidence of splitting, especially for widely spaced roots, but that later applications had less effect. According to Osawa (69), ammonium forms of nitrogen also promoted forking of roots.

Studies on the sugar content of carrots by Florescu and Cernea (23), as well as by Matuura (62) and Niemann (66), have indicated that nitrogen fertilization increased sugar synthesis, except at very high rates. Other studies by Southards and Miller (90) showed that total sugar levels were highest when carrots were grown with low nitrogen and were lowest with high nitrogen. Barnes (5), however, found that the addition of nitrogen increased glucose levels, but decreased sucrose so that total sugar levels remained the same. He noted that sucrose was the major sugar in carrots, followed by glucose and then fructose.

Color has long been considered one of the principal criteria of quality in carrots. The orange color was found to be caused mainly by carotenoids in which provitamin A predominated (1,67). Matuura (62) found that maximum accumulation of carotene occurred when nitrogen was applied 80 to 90 days after sowing, whereas Wolf (103) and Pollard (74) found that manuring raised the carotene content. Studies on carotene by Florescu and Cernea (23) showed that nitrogen increased alpha and beta carotene levels except at high levels of nitrogen, and Niemann (66) observed that carrots receiving high levels of sulfates and ammonium salts had high levels of carotene. Furthermore, work by Freeman and Harris (26) indicated there was a linear relationship between the application of nitrogen and levels of carotene. According to literature reported by Tsai (92), nitrogen levels exceeding those required for high yields might still increase carotene content, whereas Southards and Miller (90) found that carotene levels were higher in roots grown at low nitrogen levels than at medium or high levels. Arnon (1) noted that the beneficial effect of nitrogenous fertilizers resulted from the close relationship between chlorophyll and carotene content. He explained that increased nitrogen affected the protein content and this promoted production of chloroplasts and their pigments. Conversely, he found that any nutrient deficiency which reduced the green color of the leaves reduced the carotene content.

Bazier et al (6) found that insoluble protein-nitrogen was affected only by severe and prolonged nitrogen deficiency which led to a decrease in arginine, while their study on free amino acids of carrots indicated that nitrogen deficiency markedly reduced glutamine and arginine. Furthermore, Heintze (41) and Niemann (66) found that high nitrogen applications, along with phosphorus and potassium, increased the total nitrogen content in carrots.

Deficiency symptoms and nutrient uptake - According to McMurtrey (63), nitrogen deficiency in carrots was indicated by weak petioles and by light green leaves which later became yellow. Goodall and Gregory (30) found that plants with 55 ppm of nitrate-nitrogen on a fresh weight basis showed visible deficiency symptoms, while those with 521 to 833 ppm of nitrate-nitrogen exhibited no visible symptoms. Smith and Salomon (88) studied the optimum soil nitrate level for carrots and found that concentrations of less than 25 ppm of nitrate-nitrogen produced yields below optimum and supplied less nitrogen than was removed by the crop. They reported that carrots needed 10 to 25 ppm of nitrate-nitrogen during the first third of the growth period and 25 to 50 ppm for the remainder. Halliday (34) reported that the peak uptake for nitrogen occurred at least one to two weeks before the peak for phosphorus and similar observations were made by Hester et al (43). In her literature review, Tsai (92) reported that nitrogen uptake during the summer was greatest in August. Osawa (69) indicated that nitrate content in the roots decreased during the vegetative period, but that nitrate content in the leaves depended on the presence of sodium chloride in the soil. According to him, the presence of sodium chloride with the ammonium form of nitrogen in the soil resulted in a decrease in the nitrate content of the leaves, whereas in the absence of sodium chloride the nitrate content increased.

The effects of phosphorus

Yield - Investigations by Woodman and Johnson (106) indicated that phosphorus fertilizers had no effect on the yield of tops or roots although Garner (28) noted that superphosphate slightly increased the yields of roots and Goodman (32) reported that phosphorus was necessary for maximum yield of roots. Džebrailov (22) found that yields were increased by 134 per cent when he applied 50 kilograms of $P_2O_5$ per hectare along with nitrogen and potash four to six days before sowing, followed by two further applications of nitrogen, phosphorus and potassium at 15 kilograms per hectare at the three- to four-leaf stage and again twenty-five days later. He also reported that similar rates of phosphorus alone increased yields by only 57 per cent.

Quality - According to Freeman and Harris (26), phosphorus had no effect on carotene content in carrot roots even though the soil was deficient, but Tsai (92) reported that other workers have found phosphorus indispensible for the attainment of maximum carotene values. Jankovskaja (49), however, noted that high rates of phosphorus and potassium reduced the carotene content, and Southards and Miller (90) found that carotene content of roots was higher with a low level of phosphorus than it was at either medium or high levels. Woodman and Johnson (106) found that phosphorus fertilizers increased the dry matter content of carrot tops, but not of the roots.

Deficiency symptoms and nutrient uptake - Phosphorus deficiency in carrots resulted in abnormal root growth, as well as bronzing, chlorosis, scorching and stunting of foliage (92,105). Goodall and Gregory (30) reported that phosphorus deficiency was visible in plants with petiole levels of 15 to 22 ppm of phosphorus on a fresh weight basis during the active growth period, but was not visible at 125 to 250 ppm of phosphorus and they concluded that reduction in yield would occur if the phosphorus level was less than 125 ppm. Furthermore, Shaw (84) reported the safe level ot phosphate-phosphorus on a dry matter basis was above 2000 ppm and the deficiency range was below 1500 ppm for leaves.

Studies on nutrient uptake by Halliday (34) have indicated that a carrot crop sown in May for harvesting in October or November took up all the nutrients at a high rate between mid-June and late August. The peak for phosphorus uptake occurred one or two weeks later than that for potassium or nitrogen and after the beginning of September only a small amount of phosphorus was taken up. A study by Hester et al (43) showed that phosphorus uptake was smaller than that for nitrogen and potassium, but uptake continued later in the season.

The effects of potassium

Yield - According to Wallace et al (100), potassium supply was much more important to carrot growth than the supply of nitrogen and phosphorus. Furthermore, Woodman (104) stated that carrots required large amounts of potassium for optimum root growth and Austin (2) reported that potassium significantly increased root yields. In addition, studies by Garner (28) showed that potassium chloride increased yields greatly. Gallagher (27) reported that maximum yields were obtained with 112.08 to 168.12 kilograms of potassium per hectare and Boschart (11) obtained maximum yields with 119.84 kilograms of potassium per hectare. In contrast, Giardini and Pimpini (29) stated that potassium had little effect on yield except to enhance the effect of nitrogen. Furthermore, Woodman and Paver (107) reported that potassium had a tendency to reduce yields and Kudzjaveca (52) also noted that heavy potassium fertilization reduced yields. Haworth and Cleaver (38) also reported that more than 224.16 kilograms of potassium per hectare adversely affected growth.

Quality - Studies by Haworth and Cleaver (38) indicated that the concentration of potassium in carrots increased during the growth period. According to these authors, as well as Roll-Hansen (77), increasing the potassium level in the nutrient medium and the soil, respectively, gave an increase in the potassium content in the plant. In addition, Penningsfeld and Forchthammer (70) found that an increase in potassium resulted in a decrease in magnesium content. Other effects of potassium were a reduction in the moisture content of leaves, but an increase of moisture content in the roots (106) and an increase in yields of split carrots (27). Ziegler and Böttcher (108), however, found that potassium applications up to 400 kilograms per hectare increased dry matter, as well as carotene content. In contrast, Freeman and Harris (26) stated that there was no effect of potassium on carotene, whereas Scharrer and Burke (82) reported that high rates of potassium were unfavorable to carotene content. Ziegler and Böttcher (108) further noted that vitamin C content remained stable above the level of 400 kilograms of potassium per hectare. They stated, however, that weather conditions were a greater factor than potassium supply in determining carrot quality.

Deficiency symptoms - Purvis and Carolus (75) reported that a deficiency of potassium in carrots resulted in curled leaves which became brown along the edges. In later stages the leaves faded to a yellowish and finally to a bronze color.

The effects of irrigation

Yield - Bradley and Smittle (13), as well as Bradley et al (15), reported that carrot yields were increased by irrigation, especially with frequent irrigation. Furthermore, Salter and Goode (80) found that the highest yield of marketable roots was obtained from plants grown at the highest plant density (not indicated) which were irrigated during the first seven weeks of growth. In their review of literature, they noted that in one experiment carrot yields were reduced by 13 per cent when a soil moisture stress of six atmospheres occurred during the period of final root development, but yields were reduced by only 1.5 per cent when a similar moisture stress extended only up to the beginning of root development. Salter and Goode also reported that other researchers found no beneficial effects of irrigation before the middle of July. Laverton (55), however, recommended that for main-crop carrots grown on light land, irrigation should be given to restore the soil to field capacity whenever the deficit reached 1.90 centimeters.

Quality - While Bienz (9) reported no significant effect of irrigation on splitting, Pew (71), as well as Salter and Goode (80), found that improper timing of irrigation resulted in splitting of roots. These workers noticed that splitting was most common when a dry period was followed by a period of ample moisture. Salter and Goode also reported that irrigation before early June often resulted in poor root development. According to Barnes (5), low moisture levels resulted in carrots which were smaller in size and more tapered than those obtaining ample moisture during growth.

Bradley et al (15) reported that irrigation had no effect on color, but Barnes (5) stated that moisture influenced color, although it was not the controlling factor. Furthermore, Tsai (92) reported in her literature review that the total amount of color decreased with an increase in soil moisture. In addition, because irrigation when the roots were nearing maturity sometimes impaired color and flavor, Laverton (55) recommended that irrigation be avoided at that time. According to Banga (4), carotene content of roots was higher when grown with a high water table.

Sistrunk et al (87) noted that water stress caused an increase in sugar levels in the roots, but Barnes (5) stated that soil moisture had little effect on sugar content.

The effects of spacing

According to Bienz (9), spacing was the most significant factor affecting splitting of carrots. He stated, along with Warne (101), that the degree of splitting was greatest with the widest spacings of six plants per thirty centimeters of row and that wide spacings promoted secondary growth as well. He observed that large roots were more likely to split and produce secondary growth and that split carrots had a larger top than normal ones. Experiments by Wagner and Beneš (99) showed that both the highest yield and best quality of roots were obtained with the greatest distance between rows and the smallest distance within the row. They reported highest yields with spacings of about 5 x 25 to 30 centimeters, while Pew (71) recommended spacing beds 91.44 to 106.68 centimeters apart with plant spacings within the row of 1.90 to 2.54 centimeters. From his experiment, Warne (101) also found that closer spacings were necessary in a field of low fertility than in a field of high fertility to produce maximum total yields, but not for marketable yields. He concluded that "the effects of close spacing in restricting growth cannot be explained solely in terms of competition for light, water or the major nutrient elements". Furthermore, Mann and MacGillivray (60) found little relationship between root diameter and spacing. They stated, that as close spacing increased competition, it would increase the variation in root size and consequently would affect the proportion of unmarketable roots. According to the review given by Tsai (92), carrots grew best on deep, loose, well drained sandy loams and heavy soils promoted leaf growth and forked roots.

Banga (4) reported that carotene content was a consequence of ripening and that close spacing increased the level of this pigment. He noted that the total carotene content increased in proportion to the root size until a maximum was reached.

The effects of planting time and length of season

Mann and MacGillivray (60) reported a relationship between the size of carrot roots at harvest and the time of germination, and suggested that early seedlings had a competitional advantage over seedlings that germinated later. As well, leaf area, chlorophyll content, respiration rate, yields, nutrient value, flavor and storage quality have been found to increase with early sowings (53). Bradley et al (15), on the other hand, suggested that planting date was the most important factor affecting the color of carrots, with later plantings being more favorable.

Several workers have studied the effects of the season and the length of the growing period on carrot quality. Lantz (54), Platenius (72) and Wolf (103) found that the carotene content of carrot roots increased as they matured, although Wolf noted that leaf carotene content declined. According to Hansen (35), carotene increased for the first 20 days and then did not change, but Barnes (5) and Brown (16) agreed that carotene levels increased for 100 days and then remained constant. Furthermore, Barnes (5) and Hansen (35) both noted that carrots continued to increase in size after maximum carotene values had been reached, and Barnes (5) found that carotene levels were always higher in larger roots. A comparison of spring- and fall-grown carrots by Lantz (54) indicated that spring-grown carrots were higher in carotene content and Hansen (35) found that winter-grown carrots were lower in carotene content than those grown between June and December. In addition, Saburov and Sirtautajte (79) reported that winter-sown carrots were higher in carotene than spring-sown carrots.

Platenius (72) and Barnes (5) both found that sweetness of carrots increased with age. They noted that while the percentage of total sugars remained fairly constant, sucrose content increased and glucose content decreased as the carrots matured. Platenius (72) also added that older carrots had a higher quality and were higher in nutritional value than younger carrots. Lantz (54), however, reported that very young carrots were higher in ascorbic acid than older ones. Sucrose, starch, cellulose and dry matter content were found by Saburov and Sirtautajte (79) to be higher in winter-sown carrots than spring-sown carrots, but invert sugar levels were lower in winter-sown carrots. According to Bradley and Smittle (13), soluble and total solids were higher for late winter-sown carrots than for summer-sown carrots. Bradley _et al_ (14) found an interaction between planting date and harvest sequence. They noted that the effects of delayed harvesting on the amount of solids were inconsistent.

Chipman (18) grew five varieties of carrots on sandy loam and harvested them at 106, 130 and 159 days after planting. He found that yield, root length, root diameter and the percentage of cracked roots all increased with the length of time to harvest, but there was no increase in the percentage of forking. According to him, the first harvest gave the greatest proportion of best grade roots. He noted that delayed harvest of the cultivar Gold Pak did not result in an appreciable increase in yield and recommended that it be harvested as early as possible to minimize losses from cracking.

The effects of temperature

Temperature effects were studied by Matuura (62) and he reported that maximum root growth occurred at a temperature of 20 degrees C. Barnes (5) found that the greatest and most normal root growth occurred between 15.5 and 21.1 degrees C. According to him, higher temperatures shortened the root, whereas lower temperatures lengthened it and increased slenderness proportionately. He added that any alteration in shape was controlled by the average temperature rather than by the range of temperature. In addition, Pew (71) found that both growth and maturity in Arizona were much slower on heavy soils than on sandy soils and attributed the difference to the cooler temperatures of the heavier soils because of their tendency to warm up more slowly. Furthermore, Barnes (5) stated that the best color in carrots was obtained at temperatures of 15.5 to 21.1 degrees C, and Banga (4) found carotene content to be higher in roots grown at approximately 17.8 degrees C than at 7.8 degrees C. Bradley and Dyck (12), as well as Bradley *et al* (14), however, both reported that temperatures below 15.5 degrees C were favorable for color formation. In addition, Bradley *et al* (14) indicated that low temperatures increased the total carotene level, whereas Bradley and Dyck (12) reported that total carotene content was reduced and there was a maximum shift from *alpha* to *beta* carotene production. Furthermore, Bradley and Smittle (13) reported that summer-sown carrots were superior in color to winter-sown carrots and suggested this was due to temperature effects preceding harvest.

## Factors affecting storage and changes during storage

Studies by Brown (16) on the quality of carrots in storage indicated that the carotene content increased, while Lemke (56) noted a rise in carotene and vitamin C content plus a slight decrease in dry matter content. While Lantz (54) noted an apparent increase in carotene for stored carrots, he found that the increase disappeared when a correction was made for loss of weight in storage. He also noted a gradual decrease of vitamin C content during storage. In addition, Lemke (56) reported that sugar levels declined greatly during storage, but Platenius (72) noted that total sugar levels at first rose as a result of sucrose being converted to glucose, but later glucose was converted back to sucrose during respiration, which re-established equilibrium. According to Barnes (5), older carrots lost much less weight in storage than young carrots and weight loss was much less at 0 degrees C than it was at 10 degrees C. He also reported that carrots were higher in sugar and original carotene levels at the lower temperature. Saburov and Sirtautajte (79) found that the storage life of carrots improved with maturity and deteriorated with the development of floral organs.

Arnon (1), as well as Ziegler and Böttcher (108), reported that potassium fertilization improved the keeping quality of carrots.

Poapst and Phillips (73) stored carrots in perforated polyethylene bags for two months at 0 degrees C and found that the carrots were of excellent texture compared to the slightly flexible carrots which had lost moisture in bulk storage. They found that the carrots stored in polyethylene had a secondary disagreeable flavor, but this was attributed to an impurity in the plastic. Lentz (57) studied moisture loss of carrots under refrigerated storage and found that moisture loss took place at relative humidities as high as 98.5 per cent, but that 2.6 per cent per day could be regained in ice water and 3.0 per cent per day in drained, crushed ice. According to Van den Berg and Lentz (94), who stored carrots treated with maleic hydrazide for nine months, the best storage treatment was 0 to 1.1 degrees C and 98 to 100 per cent relative humidity. This treatment resulted in less quality loss and less decay. They found that increasing the temperature to a level of 3.0 to 4.0 degrees C increased the amount of sprouting and reduced table quality, but did not affect decay. They noted further that a storage temperature of 0 to 1.1 degrees C and a lower relative humidity of 92 to 96 per cent resulted in desiccation, softening and some increased decay. These authors also reported that a modified atmosphere increased the incidence of mould and rotting.

# MATERIALS AND METHODS

## Purpose, Design and Location of Experiments

In the summer of 1969 and 1970 trials were conducted to determine the fertility requirements of irrigated cabbage and carrots in Saskatchewan. During 1969 cabbage and carrots were grown on Asquith Fine Sandy Loam, located on the Canada Department of Agriculture Irrigation Research Farm, about one kilometer north of the University of Saskatchewan campus. In 1970 this area was also used for the cabbage trials. The carrot trials in 1970 were located on the land of A.A. Kroeker approximately 5 kilometers east of Outlook, Saskatchewan. The soil classification was identical to that used for carrots in 1969.

A randomized complete block design was used in both years for the fertility trials. Thus, all possible combinations of the fertilizer levels were represented in each replicate and each treatment was randomized within the replicate.

In both 1969 and 1970 the cabbage trials consisted of duplicate treatment rows 9.75 meters long, with each duplicate treatment row separated by a single guard row. The rows were spaced 0.91 meters apart, allowing 8.92 square meters per row. The plants were spaced 60.96 centimeters apart within the row. The end plant of each row was considered a guard plant and thus each treatment had a maximum of 28 plants. In 1969 the carrots were grown in duplicate treatment rows 9.75 meters long and spaced 0.76 meters apart, giving 7.43 square meters per row. As with the cabbage, each duplicate treatment row was separated by a single guard row, and the end 0.30 meters of each treatment row was considered as guard plants, thus leaving 9.14 meters of actual treatment row. The carrots in 1970 were grown in rows 10.36 meters long and the rows were spaced 0.41 meters apart, giving 4.20 square meters per row.

Fertilizer Rates

The fertilizer levels for cabbage in both 1969 and 1970 included all possible combinations of four levels of nitrogen and four levels of phosphorus to give a total of 16 treatments. The nitrogen levels applied were equivalent to 0, 56.04, 112.08 and 168.12 kilograms per hectare. The highest rate was given in two applications with 112.08 kilograms placed at transplanting time and 56.04 kilograms placed about one month later. The phosphorus levels included 0, 84.06, 168.12 and 252.18 kilograms $P_2O_5$ per hectare. The highest phosphorus level was applied as 168.12 kilograms at transplanting time and 84.06 kilograms a month later.

The fertilizer levels for carrots in 1969 included four levels of nitrogen and three levels of phosphorus in all possible combinations, to give a total of 12 treatments. The nitrogen levels used in 1969 were equivalent to 0, 87.42, 174.84 and 349.69 kilograms per hectare, and reduced slightly to 0, 84.06, 168.12 and 336.24 kilograms per hectare in 1970. In 1969, phosphorus was applied at 0, 87.42 and 174.84 kilograms of $P_2O_5$ per hectare, and in 1970 at 0, 84.06 and 168.12 kilograms of $P_2O_5$ per hectare. In both years, the highest rate was given in two equal amounts, one at seeding time and the other about one and one-half months later. The fertilizers used in both years were ammonium nitrate (34-0-0) and triple superphosphate (0-45-0). No potash was supplied in either year as soil tests (Table I) indicated that the initial levels were adequate for crop production.

Table 1: Average Initial Soil Nutrient Levels for each Field Plot in Kilograms per Hectare. (Saskatchewan Soil Testing Laboratory).

| Area | Depth | $NO_3$-N | $NaHCO_3$-P | $NH_4OAc$-K |
|---|---|---|---|---|
| 1969 Cabbage | 0-15 cm. | 36 | 32 | 695 |
| | 15-30 cm. | 118 | 38 | 466 |
| | 30-61 cm. | 58 | 25 | 583 |
| 1969 Carrots | 0-15 cm. | 30 | 38 | 749 |
| | 15-30 cm. | 99 | 38 | 439 |
| | 30-61 cm. | 58 | 20 | 547 |
| 1970 Cabbage | 0-15 cm. | 11 | 21 | 390 |
| | 15-30 cm. | 10 | 12 | 305 |
| | 30-61 cm. | 40 | 11 | 350 |
| 1970 Carrots | 0-15 cm. | 7 | 17 | 363 |
| | 15-30 cm. | 2 | 7 | 166 |
| | 30-61 cm. | 9 | 13 | 323 |

## Cultivars and Cultural Practices

Houston Evergreen cabbage, a cultivar known for its keeping quality in storage, was grown in 1969 and 1970. The carrot cultivar grown in these years was Gold Pak Improved.

The dates of major operations carried out are given in Table II. The cabbage was sown in Jiffy pots, thinned to one good plant per pot and grown in the greenhouse until ready for transplanting to the field. They were then hardened-off for a few days and then transplanted by hand to the field. Each plant was given a starter solution of Plant-Prod (20-20-20) at a rate of 1.58 grams per litre of water to help overcome transplanting shock. In 1969 the carrots were sown in the field with a Planet Jr seeder. A self-propelled International Harvester three-row seeder was used in 1970.

Fertilizer for cabbage in both years and for carrots in 1969 was applied with a V-belt seeder in bands about 5 centimeters from each side of the row and 2.5 to 5 centimeters deep. In 1970 the first fertilizer application for carrots was applied at the same time as seeding, using the fertilizer attachment on the three-row seeder which placed the fertilizer at approximately the same location in relation to the seed as in 1969. The second fertilizer application was applied by hand in a shallow trench made with a hoe on one side of the row only, to minimize disturbance to the seedlings.

During the early growth of the crops, water was applied by means of a sprinkler irrigation system. Sprinkler irrigation was used for the entire season on carrots in 1970, but for cabbage in that year and both

Table II: Dates of Major Operations for Cabbage and Carrot Fertility Trials, 1969 and 1970

| Year | Crop | Seeding | Transplanting | Fertilizing | Furrowing | Harvesting |
|---|---|---|---|---|---|---|
| 1969 | Cabbage | May 8 | June 3-4 | June 3-4<br>July 10 | July 24 | Sept. 23 |
| 1969 | Carrots | June 2 | | May 31<br>July 10 | July 24 | Oct. 7-17 |
| 1970 | Cabbage | May 6<br>May 26* | June 17-18 | June 22<br>July 22 | July 23 | Oct. 9,13 |
| 1970 | Carrots | June 1 | | June 1<br>July 21 | | Sept. 23 |

* Damping-off of some seedlings made it necessary to make another sowing of cabbage.

crops in 1969 sprinkler irrigation was discontinued in late July. For the remainder of the season water was applied via gated pipes into furrows between the rows. Attempts were made to irrigate when the soil moisture reached a minimum of approximately 50 per cent of field capacity. Scheduling of irrigation was determined by use of tensiometers and gravimetric soil moisture samples.

Data Collection

All treatment-plants of the cabbage plots were harvested and the total weight of above-ground production was recorded. The heads were then trimmed of wrapper leaves and the malformed, immature and headless cabbages were discarded to determine marketable head weight. A record was also made of the equatorial and polar diameters of the marketable heads. Five heads from each treatment were selected for storage purposes. These were placed in perforated plastic garbage bags and placed in cold storage at approximately 1.0 to 1.5 degrees C. Leaf material of cabbage was obtained by taking cross-sectional cores through the heads after harvest. The material was air-dried, ground in a Wiley mill and packaged for later analysis.

In 1969 the entire carrot row of each treatment was harvested and washed to remove most of the soil from the roots. The data collected included total weight of plants, total root weight and number, total oversized root weight and number, total undersized root weight and number, as well as total forked or split root weight and number. Criteria used in grading for marketable carrots were a minimum length of 8.89 centimeters and a diameter between 1.90 and 4.44 centimeters. Twenty-five carrots from each treatment were selected, re-washed, trimmed of crown and packaged in a polyethylene bag for cold storage observations. The temperature of the storage room was the same as that for cabbage. The carrot harvest in 1970 consisted of only 6.1 meters of row because of the uneven stand of the plants. Data were collected as in the previous year with the exception of total plant weight. Leaf samples of carrots were taken just prior to harvest in 1969. Five plants of various sizes were selected from each treatment and the entire tops were harvested, washed, dried and ground as with the cabbage samples. Selection of carrot tops in 1970 was made on July 30. Carrot root samples were taken from cross-sections of selected carrot roots at the end of the storage period for the 1969 growing season, and in October of 1970.

Total nitrogen determination was carried out using the semi-micro Kjeldahl method. Potassium content was determined using a wet ash combustion method followed by analysis with a flame photometer (I L Model 143) using 15 meq of lithium as an internal standard. Phosphorus content was determined using a wet ash combustion method followed by analysis in an Auto-Analyser using the molybdo-phosphoric blue method. The above techniques were suggested by the staff of the Saskatchewan Soil Testing Laboratory and the final analyses for phosphorus and potassium were conducted by them.

## Method of Statistical Analysis

The various measurements made were first subjected to an Analysis of Variance test to determine whether there were significant differences in the measurements. Where significant differences were found, a Duncan's Multiple Range test was conducted to determine which treatments were significant.

# RESULTS AND DISCUSSION

## Cabbage

### The effects of nitrogen

The levels of nitrogen reported in this discussion are given as total available nitrogen which includes the initially available nitrogen in the soil (211.83 kilograms per hectare in 1969 and 61.64 kilograms per hectare in 1970) along with applied nitrogen (0, 56.04, 112.08 and 168.12 kilograms per hectare). Thus total available nitrogen in 1969 was 211.83, 267.87, 323.91 and 379.95 kilograms per hectare, whereas in 1970 the levels were 61.64, 117.68, 173.72 and 229.76 kilograms per hectare.

Nitrogen had no significant effect on the average total above-ground plant weight in 1969, although there was a trend for an increase in plant weight with increases in nitrogen (Table III). In 1970, however, nitrogen highly significantly increased total above-ground plant weight (Table III).

There was a trend in 1969 for an increase in the total marketable head weight with increasing levels of nitrogen (Table III and Figure 1), but this increase was not significant. In 1970, however, highly significant differences were obtained between treatments. The highest level of 229.76 kilograms of available nitrogen per hectare (Table III and Figure 1) gave a highly significant increase in marketable head weight over the check treatment (61.64 kilograms) and the second level of nitrogen (117.68 kilograms per hectare). In addition, the second level of nitrogen gave a significantly higher yield than the check treatment. These increases in

Table III: The Effect of Nitrogen on the Total Above-Ground Weight, Total Marketable Weight and the Ratio of Polar to Equatorial Diameter of Cabbage, 1969 and 1970.

| Year | Total available nitrogen in kilograms per hectare | Average above-ground weight in kilograms per 17.1 meters | Total marketable weight in kilograms per 17.1 meters | Polar to Equatorial Diameter |
|---|---|---|---|---|
| 1969 | 211.83 | 131.8 | 59.89 | 1.025 |
| | 267.87 | 137.2 | 61.20 | 1.025 |
| | 323.91 | 139.6 | 62.79 | 1.038 |
| | 379.95 | 143.6 | 64.32 | 1.034 |
| 1970 | 61.64 | 92.9 | 46.19 | 0.996 |
| | 117.68 | 101.2 | 49.69 | 0.988 |
| | 173.72 | 108.0 | 52.44 | 1.014 |
| | 229.76 | 113.7 | 55.00 | 1.021 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (Solid line at one per cent and broken line at five per cent level)

Data for each level of nitrogen includes all levels of phosphorus.

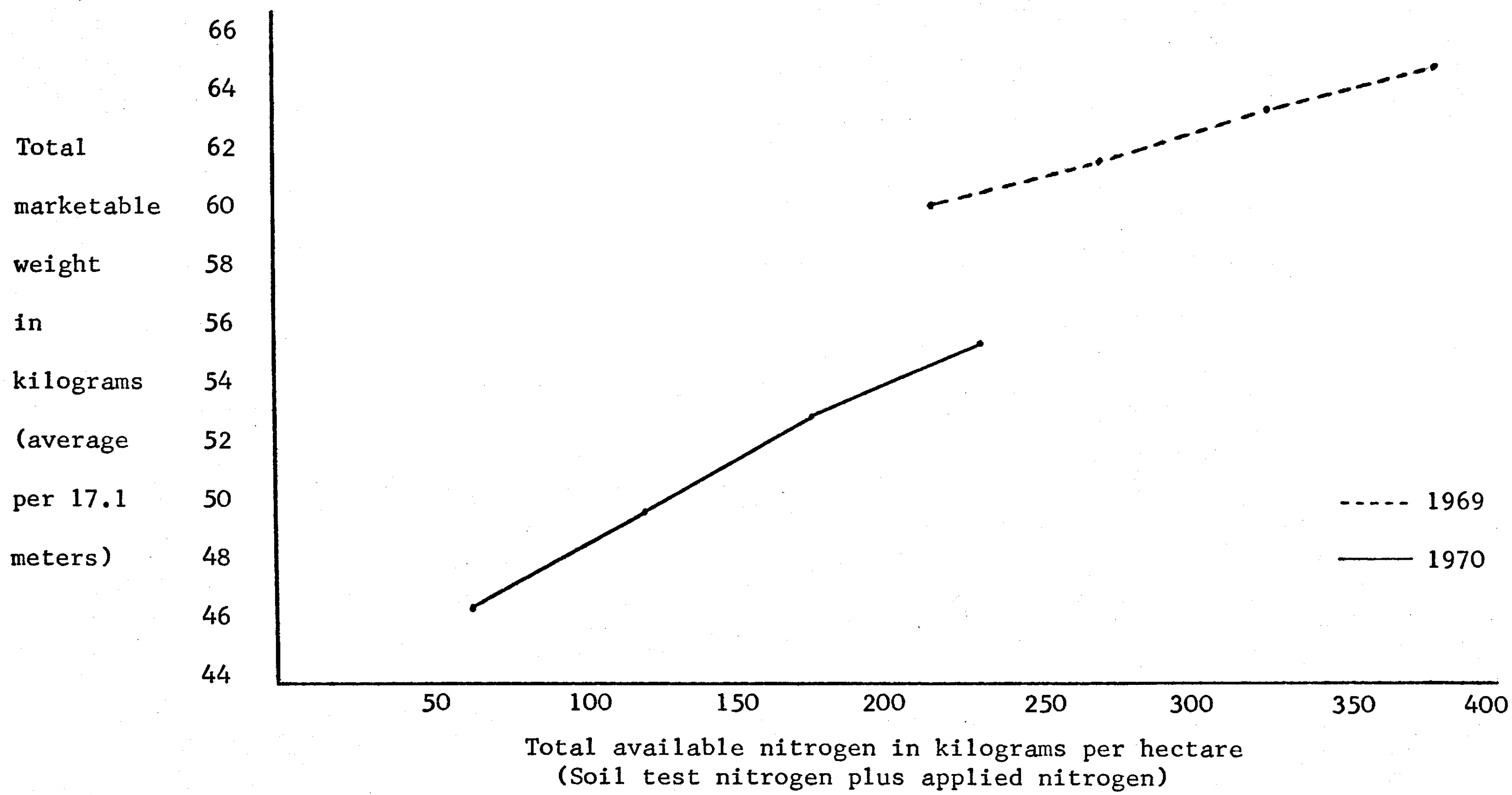


Figure 1: The effect of nitrogen on the average marketable weight of cabbage, 1969 and 1970.

yield are in accordance with the results reported by Burleson et al (17), Haworth (37) and Heilman et al (40), but contrast with the results reported by Ziegler and Böttcher (109).

No significant effect of nitrogen on the ratio of polar diameter to equatorial diameter of marketable cabbage heads was found in 1969. The effect of nitrogen, however, was found to be highly significant in 1970. In that year, the two highest levels of available nitrogen (229.76 and 173.72 kilograms per hectare) gave heads which were highly significantly more elongated polarly than did the first and second levels of nitrogen (Table III and Figure 2). Over the two years there appeared to be a trend for an increase in the polar to equatorial ratio with increases in available nitrogen.

Nitrogen had a highly significant effect on the total content of nitrogen in cabbage leaves at the end of the growing season in both years. In 1969 a level of 323.91 kilograms per hectare gave a highly significant increase in the average nitrogen content of leaves over the check treatment (Table IV), and in 1970 a level of 229.76 kilograms of nitrogen gave the same effect. Figure 3 illustrates a trend, but diminishing at higher levels, for an increase in nitrogen content of the leaves as the available nitrogen increased (Figure 3). This supports the work done by Heintze (41). In addition, there was a correlation of +0.813 between the average nitrogen content in the leaves and marketable head weight for 1969. This compares with a correlation of +0.627 for 1970. These correlation coefficients were significant at the one per cent level.

Nitrogen did not have any significant effect on the levels of phosphorus or potassium present in cabbage leaves (Table IV).

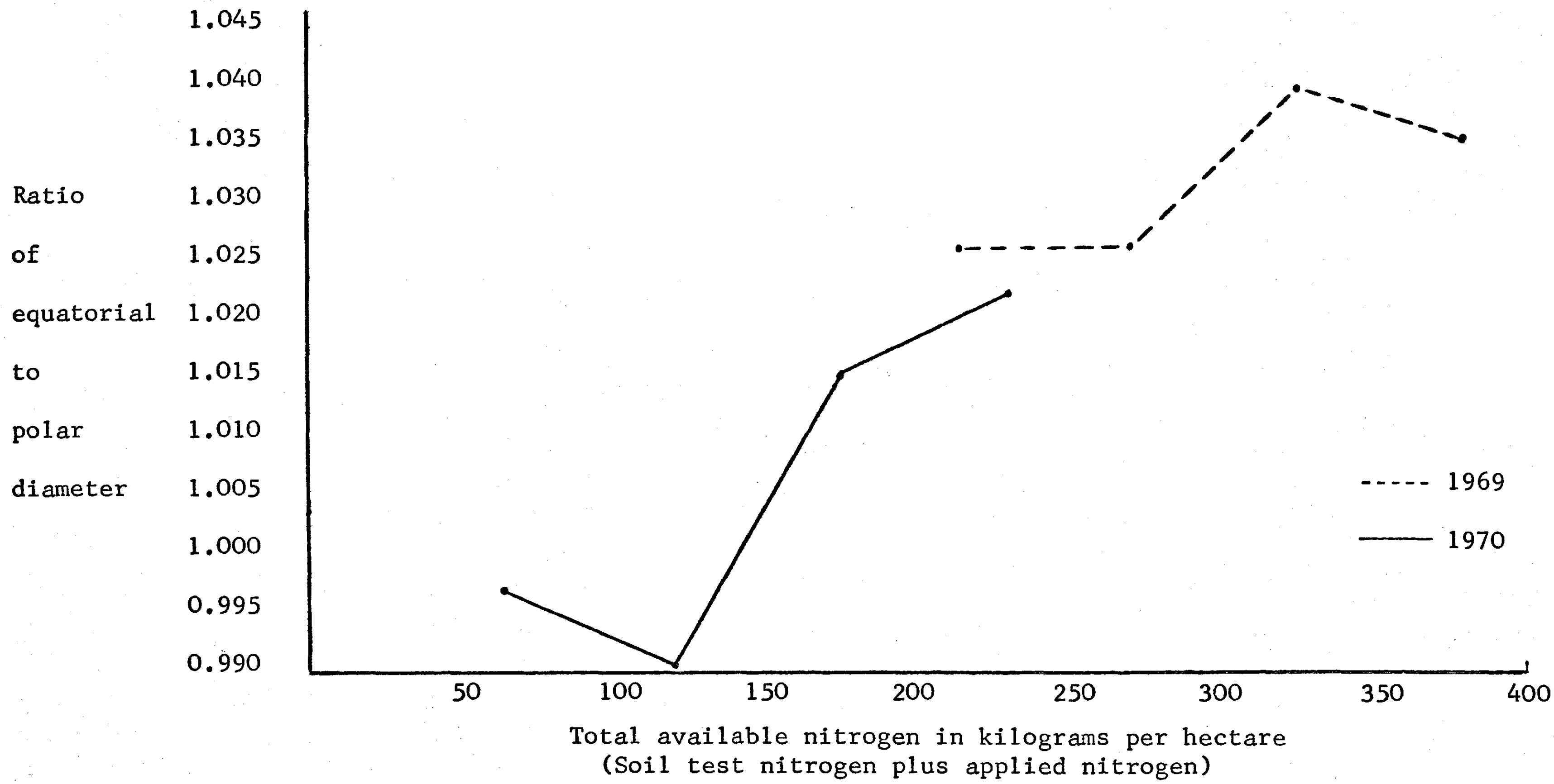


Figure 2: The effect of nitrogen on the ratio of equatorial diameter to polar diameter of cabbage, 1969 and 1970.

Table IV: The Effect of Nitrogen on the Average Nitrogen, Phosphorus and Potassium Content in Cabbage Leaves, 1969 and 1970.

| Year | Total available nitrogen in kilograms per hectare | Average N content in ppm | Average P content in ppm | Average K content in ppm |
|---|---|---|---|---|
| 1969 | 211.83 | 28,000 | 3940 | 22,900 |
| | 267.87 | 28,200 | 4070 | 23,750 |
| | 323.91 | 30,400 | 4140 | 23,900 |
| | 379.95 | 29,700 | 4090 | 24,400 |
| 1970 | 61.64 | 25,100 | 2905 | 25,200 |
| | 117.68 | 26,300 | 2930 | 24,950 |
| | 173.72 | 28,300 | 2725 | 25,200 |
| | 229.76 | 29,400 | 2680 | 24,550 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (Solid line at one per cent level and broken line at five per cent level).

Data for each level of nitrogen includes all levels of phosphorus.

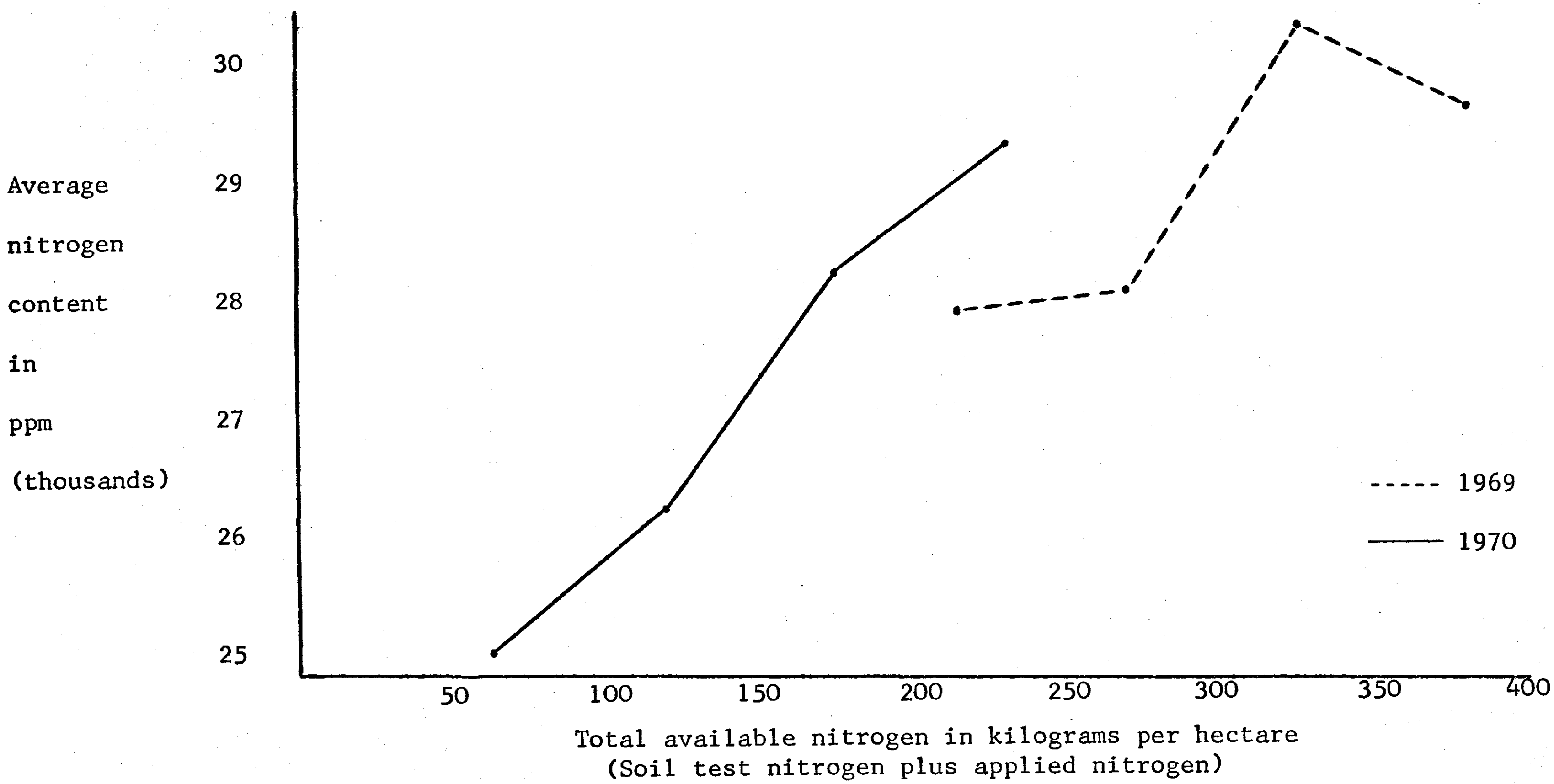


Figure 3: The effect of nitrogen on average nitrogen content in cabbage leaves, 1969 and 1970.

For 1969 the per cent weight loss before and after trimming of cabbage heads held in cold storage was recorded in January, March and April. Significant differences at the five per cent level were found only between the check treatment and the three applied nitrogen levels (Table V), but there was no significant difference between the applied levels. There was a trend for a slight increase in weight loss with increases in nitrogen levels applied and this is in keeping with the results reported by several workers (1,3,83,109). Cabbage from the 1970 crop year was not placed in cold storage because freezing temperatures (-12.7 degrees C) a few days before harvest injured the heads. Examination of the heads showed that the core and apical buds were the most severely affected and this supported the observations of Saburov et al (78).

According to the results obtained in 1970, there appeared to be a requirement of between 173.72 and 229.76 kilograms per hectare of total available nitrogen for maximum yields of marketable heads. Although there was no significant difference in yield between any consecutive pair of treatments (Table VI), it would appear that the increased returns for the investment, although diminishing, were still of considerable magnitude.

The effects of phosphorus

Although for the purpose of this experiment the treatment levels designated are only for the applied levels of fertilizer phosphorus ($P_2O_5$) and not added to the levels of phosphorus in the soil as was

Table V: The Effect of Nitrogen on the Average Per Cent Weight Loss of Cabbage Held in Cold Storage, 1969.

| Total available nitrogen in kilograms per hectare | Per cent weight loss |
|---|---|
| 211.83 | 13.26 |
| 267.87 | 26.92 |
| 323.91 | 27.36 |
| 379.95 | 27.40 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of nitrogen includes all levels of phosphorus.

Table VI: Fertilizer Cost and Marketable Yield Values for the Various Nitrogen Levels on Cabbage, 1970.

| Total available nitrogen in kilograms per hectare | Fertilizer rate kilograms/hectare | Fertilizer cost per hectare | Marketable yield in kilograms | | Returns per hectare | |
|---|---|---|---|---|---|---|
| | | | Per 17.1 meters | Per hectare | Total | Increase less cost |
| 61.64 | 0.00 | $ 0.00 | 46.19 | 29,591 | $2935.72 | $ |
| 117.68 | 56.04 | 12.35 | 46.69 | 31,834 | 3158.18 | 210.11 |
| 173.72 | 112.08 | 24.71 | 52.44 | 33,596 | 3329.58 | 146.69 |
| 229.76 | 168.12 | 37.00 | 55.00 | 35,116 | 3495.67 | 129.09 |

Figures not significantly different according to Duncan's Multiple Range test are joined by vertical lines. (Solid line at one per cent and broken line at five per cent level).

Data for each level of nitrogen includes all levels of phosphorus.

Based on a 1970 cost of 22¢ per kilogram of nitrogen and 9.9¢ per kilogram of cabbage.

done with nitrogen, it is obvious that the soil phosphorus played an important role.

No significant effect of phosphorus on the average above-ground plant weight of cabbage was found in 1969 (Table VII). In contrast, highly significant differences between the first and second levels of phosphorus (0 and 84.06 kilograms of $P_2O_5$ per hectare) were obtained in 1970.

In 1969 there was no significant effect of phosphorus on the average marketable head weight of cabbage, and results were similar in 1970 (Table VIII). Generally, the treatments receiving phosphorus fertilizer gave higher marketable yields than the check treatment, but these differences were not found to be significant. Khupse and Kalke (50), as well as Odland and Cox (68), however, found that phosphorus significantly increased yields.

The ratio of polar diameter to equatorial diameter of marketable cabbage heads was not found to be significant in either 1969 or 1970 with regard to the effect of phosphorus (Table IX).

No significant difference in phosphorus content of the leaves was found in 1969 (Table X). In 1970, however, the phosphorus content of the check treatment was found to be highly significantly lower than that for the two highest applications of phosphorus (252.18 and 168.12 kilograms per hectare), but no significant differences were found between the plants receiving various rates of phosphorus fertilizer (Figure 4). In addition, there was a significant correlation of +0.673 between the average phosphorus content and the marketable yield of cabbage in 1970.

Table VII: The Effect of Phosphorus on the Average Above-Ground Plant Weight of Cabbage, 1969 and 1970.

| Applied $P_2O_5$ in kilograms per hectare | Average above-ground weight in kilograms per 17.1 meters | |
|---|---|---|
| | 1969 | 1970 |
| 0.00 | 136.6 | 99.1 |
| 84.06 | 136.4 | 107.4 |
| 168.12 | 135.3 | 103.9 |
| 252.18 | 144.0 | 106.5 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at one per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 32 kilograms per hectare in 1969 and 21 kilograms in 1970.

Table VIII: The Effect of Phosphorus on the Average Marketable Head Weight of Cabbage, 1969 and 1970.

| Applied $P_2O_5$ in kilograms per hectare | Average marketable weight in kilograms per 17.1 meters | |
|---|---|---|
| | 1969 | 1970 |
| 0.00 | 61.9 | 49.3 |
| 84.06 | 61.9 | 51.4 |
| 168.12 | 61.4 | 50.8 |
| 252.18 | 63.0 | 51.8 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 32 kilograms per hectare in 1969 and 21 kilograms per hectare in 1970.

Table IX: The Effect of Phosphorus on the Ratio of Polar Diameter to Equatorial Diameter of Marketable Cabbage Heads, 1969 and 1970.

| Applied $P_2O_5$ in kilograms per hectare | Ratio of polar diameter to equatorial diameter | |
|---|---|---|
| | 1969 | 1970 |
| 0.00 | 1.029 | 1.002 |
| 84.06 | 1.032 | 1.006 |
| 168.12 | 1.038 | 1.004 |
| 252.18 | 1.023 | 0.998 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 32 kilograms per hectare in 1969 and 21 kilograms per hectare in 1970.

Table X: The Effect of Phosphorus on the Average Nitrogen, Phosphorus and Potassium Content in Cabbage Leaves, 1969 and 1970.

| Applied $P_2O_5$ in kilograms per hectare | Average N content in ppm | | Average P content in ppm | | Average K content in ppm | |
|---|---|---|---|---|---|---|
| | 1969 | 1970 | 1969 | 1970 | 1969 | 1970 |
| 0.00 | 28,800 | 27,300 | 3795 | 2520 | 23,250 | 25,050 |
| 84.06 | 28,700 | 26,800 | 4010 | 2860 | 23,400 | 24,800 |
| 168.12 | 29,600 | 27,200 | 4265 | 3000 | 24,400 | 25,100 |
| 252.18 | 29,300 | 27,800 | 4185 | 3060 | 23,900 | 24,900 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line (solid line at one per cent and broken line at five per cent level).

Data for each level of phosphorus included all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 32 kilograms per hectare in 1969 and 21 kilograms in 1970.

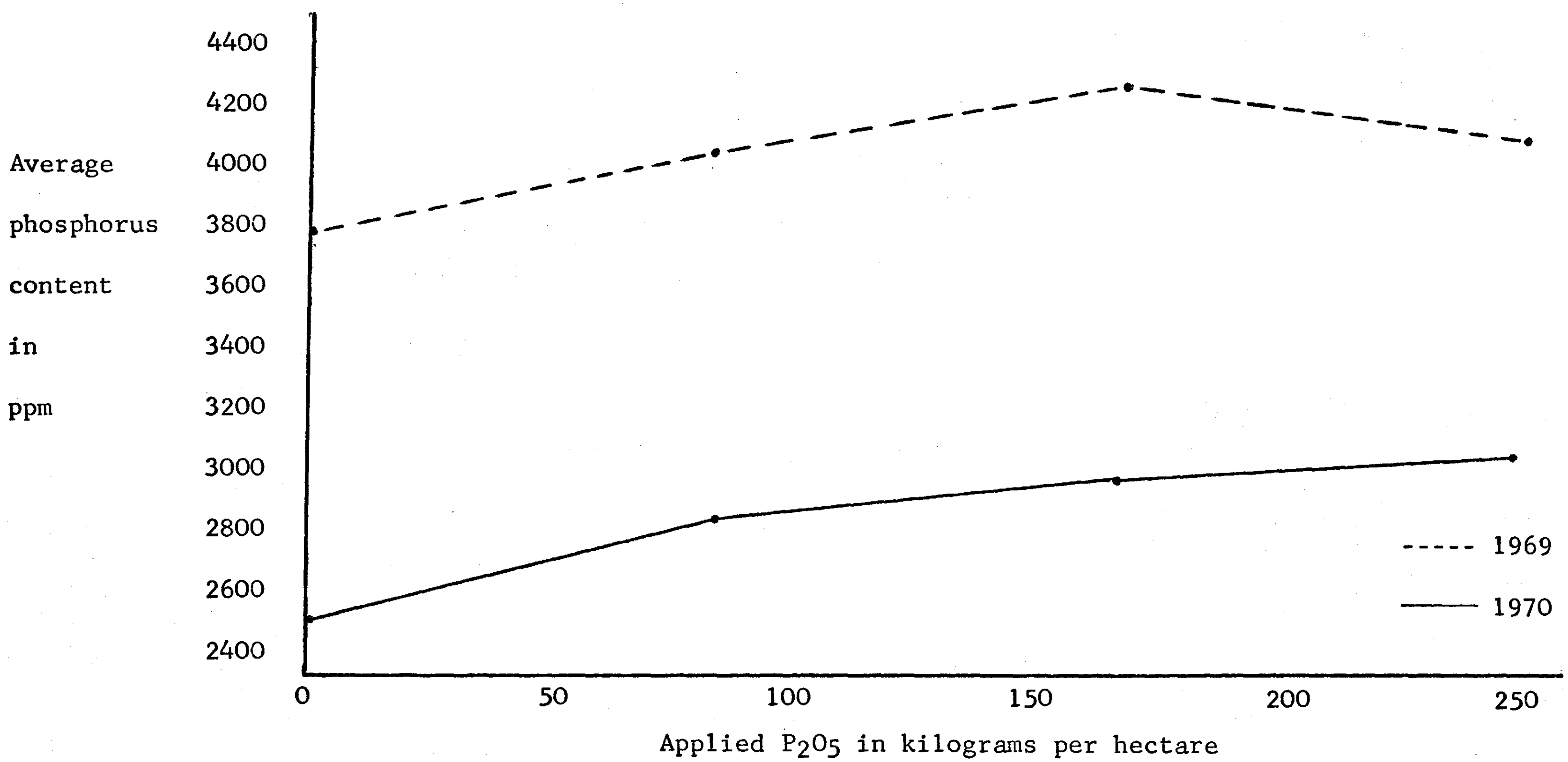


Figure 4: The effect of phosphorus on the average phosphorus content in cabbage leaves, 1969 and 1970.

The differences in phosphorus levels between the two years are probably the result of the difference in initial phosphorus levels in the soil.

No significant effect of phosphorus on the potassium or nitrogen content of cabbage leaves in 1969 or 1970 (Table X) was found.

Statistical analysis did not indicate any significant effect of phosphorus on the keeping quality of cabbage in cold storage (Table XI).

In general, phosphorus increased total plant yields and gave some increases in marketable yield as well. While there was a considerable increase in the value of the marketable yield for the first level of phosphorus (84.06 kilograms per hectare) compared to the check level (Table XII), the increases in marketable yield were not significant. Thus, it appears that the initial level of phosphorus in the soil (21 kilograms per hectare) in the top 15 centimeters may have been adequate for optimum marketable yields of cabbage. Generally, however, additional phosphorus is usually added for most crops in Saskatchewan.

## Carrots

### The effects of nitrogen

As with cabbage, the levels of nitrogen reported refer to the total available nitrogen which includes soil test nitrogen and applied nitrogen. In 1969 the total available nitrogen levels were 187.00, 274.42, 361.84 and 536.69 kilograms of nitrogen per hectare, whereas in 1970 the nitrogen levels included 18.00, 102.06, 186.12 and 354.24 kilograms per hectare.

In 1969 nitrogen appeared to give a reduction in total plant yields of carrots compared to the check treatment (Figure 5). The two highest levels of nitrogen (536.69 and 361.84 kilograms per hectare) gave lower

Table XI: The Effect of Phosphorus on the Per Cent Weight Loss of Cabbage Held in Cold Storage, 1969.

| Applied $P_2O_5$ in kilograms per hectare | Per cent weight loss |
|---|---|
| 0.00 | 28.59 |
| 84.06 | 26.48 |
| 168.12 | 26.91 |
| 252.18 | 32.95 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 32 kilograms per hectare in 1969.

Table XII: Fertilizer Costs and Marketable Yield Values for the Various Phosphorus Levels on Cabbage, 1970.

| Fertilizer rate kilograms/hectare | Fertilizer cost per hectare | Marketable yield in kilograms | | Returns per hectare | |
|---|---|---|---|---|---|
| | | Per 17.1 meters | Per hectare | Total | Increase less cost |
| 0.00 | $ 0.00 | 49.31 | 31,591 | $3134.02 | $ |
| 84.06 | 15.20 | 51.37 | 32,910 | 3264.95 | 115.73 |
| 168.12 | 30.09 | 50.81 | 32,552 | 3229.36 | - 86.40 |
| 252.18 | 44.58 | 51.81 | 33,192 | 3292.92 | 20.98 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Based on a 1970 cost of 18¢ per kilogram of phosphorus and 9.9¢ per kilogram of cabbage.

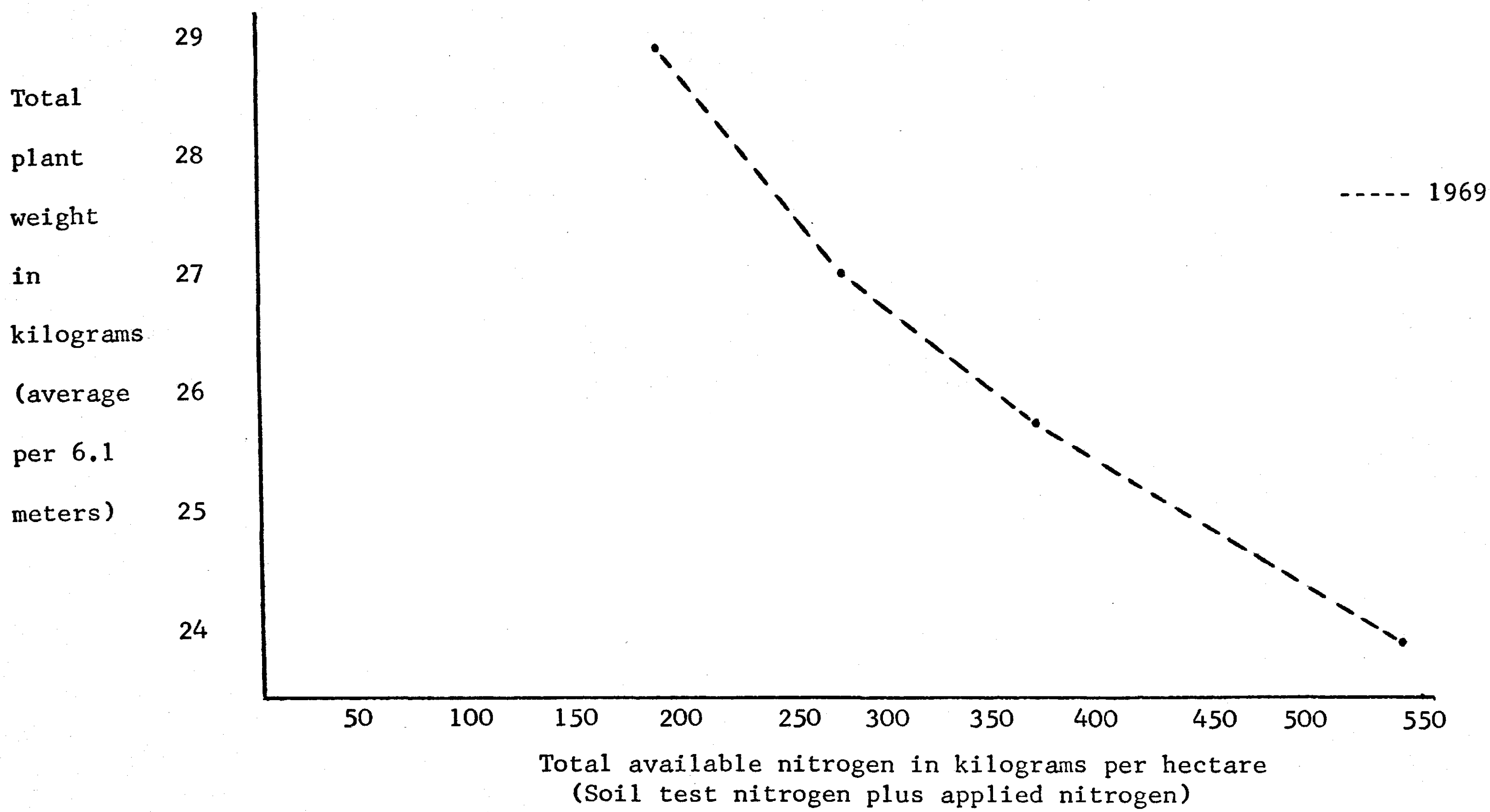


Figure 5: The effect of nitrogen on total plant weight for carrots, 1969.

total plant yields than the check treatment of 187 kilograms (Table XIII) and the differences were significant at the five per cent level. No record was made of total plant yield in 1970.

The effect of nitrogen on total root weight was similar to that for total plant weight in 1969. Again, the high levels of nitrogen caused a reduction in total root weight compared to the check treatment. The check treatment was found to give a significantly higher root yield than the highest fertilizer treatment (Table XIII). In 1970, nitrogen levels of 102.06, 186.12 and 354.24 kilograms per hectare each gave a highly significant increase in root weight over the check treatment, but there were no significant differences between the top three nitrogen levels. According to Dhesi _et al_ (20), as well as Goodman (31,32), only moderate amounts of nitrogen were required for maximum yields, but they did not indicate any yield reductions at the higher rate.

There was a trend in 1969 for a decrease in marketable root weight with increasing increments of nitrogen (Table XIII), but none of these differences were found to be significant. These differences likely resulted because the initial level of available nitrogen in the soil was adequate. Because of the much lower level of nitrogen initially in 1970, results of that year were the opposite, with each increment of nitrogen giving highly significant increases in marketable root yield compared to the check treatment. Additional increments of nitrogen, however, did not give significant increases over the first level of nitrogen (102.06 kilograms per hectare).

Whereas increments of nitrogen in 1969 gave a decline in the average marketable weight of carrot roots, on a percentage basis nitrogen treatments

Table XIII: The Effect of Nitrogen on Total Plant Weight, Total Root Weight and Total Marketable Root Weight of Carrots, 1969 and 1970

| Year | Total available nitrogen in kilograms per hectare | Total plant weight in kilograms per 6.1 meters | Total root weight in kilograms per 6.1 meters | Total marketable root weight in kilograms per 6.1 meters |
|---|---|---|---|---|
| 1969 | 187.00 | 28.82 | 23.96 | 17.49 |
| | 274.42 | 26.92 | 19.23 | 16.60 |
| | 361.84 | 25.67 | 18.68 | 16.11 |
| | 536.69 | 23.80 | 17.38 | 15.43 |
| 1970 | 18.00 | | 5.41 | 3.21 |
| | 102.06 | | 8.50 | 6.86 |
| | 186.12 | | 9.90 | 8.21 |
| | 354.24 | | 10.18 | 8.77 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (Solid line at one per cent and broken line at five per cent).

Data for each level of nitrogen includes all levels of phosphorus.

gave an increase in marketable root weight (Figure 6). Only the highest level of nitrogen (536.69 kilograms per hectare) gave a highly significant increase over the check level (Table XIV). The highest level of nitrogen (354.24 kilograms per hectare) in 1970 gave a highly significant increase in per cent marketable carrots over the lowest two levels, but this amount was not significant over the second highest level of nitrogen (186.12 kilograms per hectare).

The number of marketable carrots expressed as a percentage of total root number was not significantly affected by nitrogen in 1969. In contrast, the per cent marketable carrots in 1970 was found to increase with each increment of nitrogen (Table XIV and Figure 7). The three highest levels of nitrogen gave highly significantly greater per cent marketable carrots on a number basis compared to the check treatment, but there were no significant differences between these three levels.

On a weight basis, the per cent oversized carrots in 1969 declined with the addition of nitrogen fertilizer (Table XIV). The check treatment gave a significantly higher proportion of oversized roots compared to the two highest levels (536.69 and 361.84 kilograms per hectare). Thus, the very high levels of nitrogen seemed unfavorable to the formation of large carrots. Once again the 1970 results differed with those for 1969. In 1970 the effect of nitrogen on the per cent oversized carrots on a weight basis (Table XIV) was not significant.

The per cent oversized carrots expressed on a number basis in 1969 declined with the addition of nitrogen fertilizer (Table XIV). As with the per cent oversized carrots expressed on a weight basis, those carrots receiving no additional nitrogen gave a highly significantly greater per

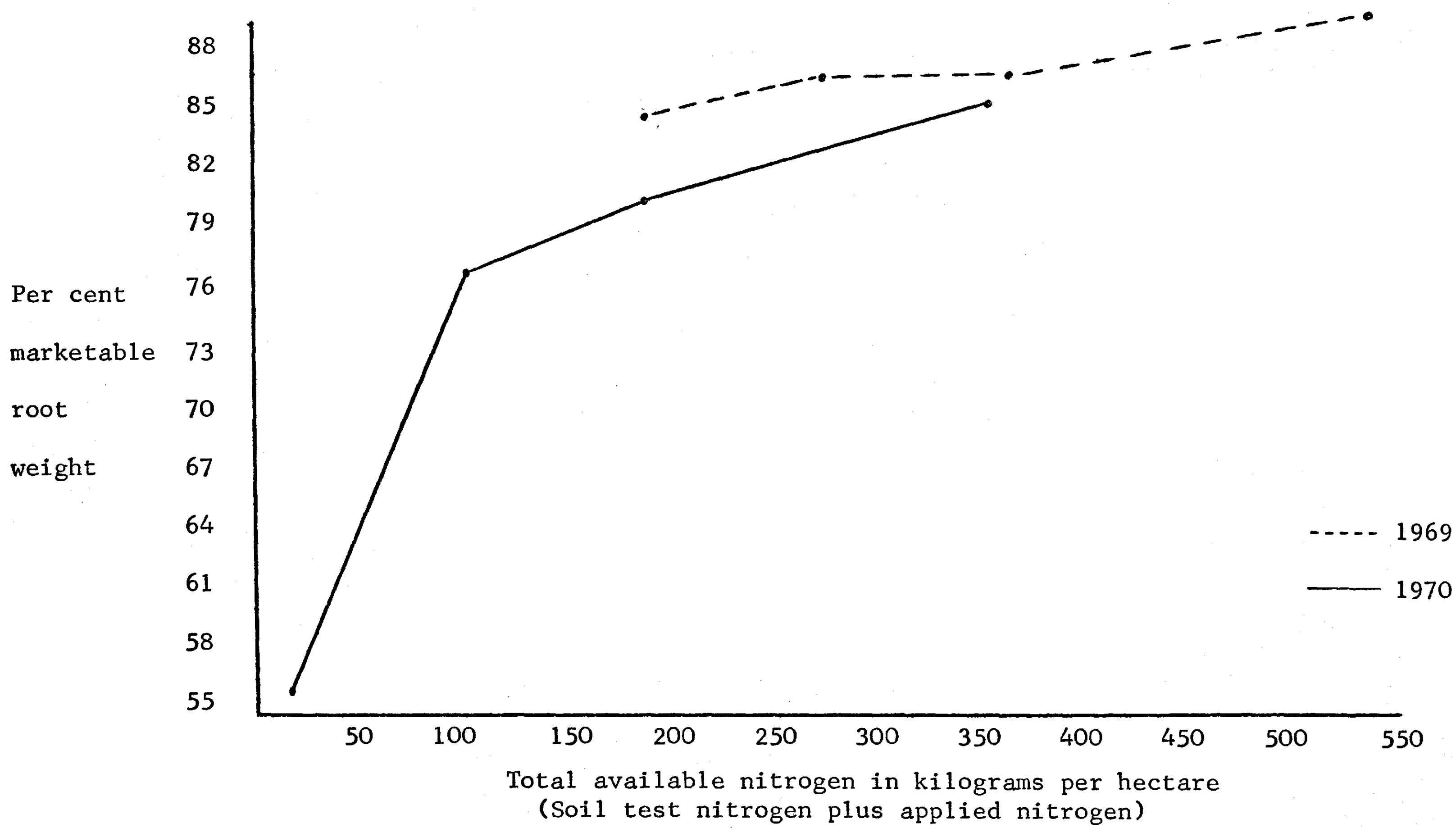


Figure 6: The effect of nitrogen on per cent marketable root weight of carrots, 1969 and 1970.

Table XIV: The Effect of Nitrogen on Per Cent Marketable Root Weight and Number, and Per Cent Oversized Root Weight and Number of Carrots, 1969 and 1970

| Year | Total available nitrogen in kilograms per hectare | Per cent marketable roots | | Per cent oversized roots | |
|---|---|---|---|---|---|
| | | By weight | By number | By weight | By number |
| 1969 | 187.00 | 84.47 | 85.94 | 11.27 | 4.79 |
| | 274.42 | 86.07 | 85.38 | 9.79 | 3.90 |
| | 361.84 | 86.03 | 84.92 | 7.96 | 3.25 |
| | 536.69 | 88.82 | 87.18 | 6.30 | 2.36 |
| 1970 | 18.00 | 55.32 | 29.75 | 0.43 | 1.43 |
| | 102.06 | 77.18 | 50.06 | 0.00 | 0.00 |
| | 186.12 | 80.37 | 59.74 | 0.48 | 3.81 |
| | 354.24 | 85.27 | 61.65 | 0.59 | 2.32 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (Solid line at one per cent and broken line at five per cent level).

Data for each level of nitrogen includes all levels of phosphorus.

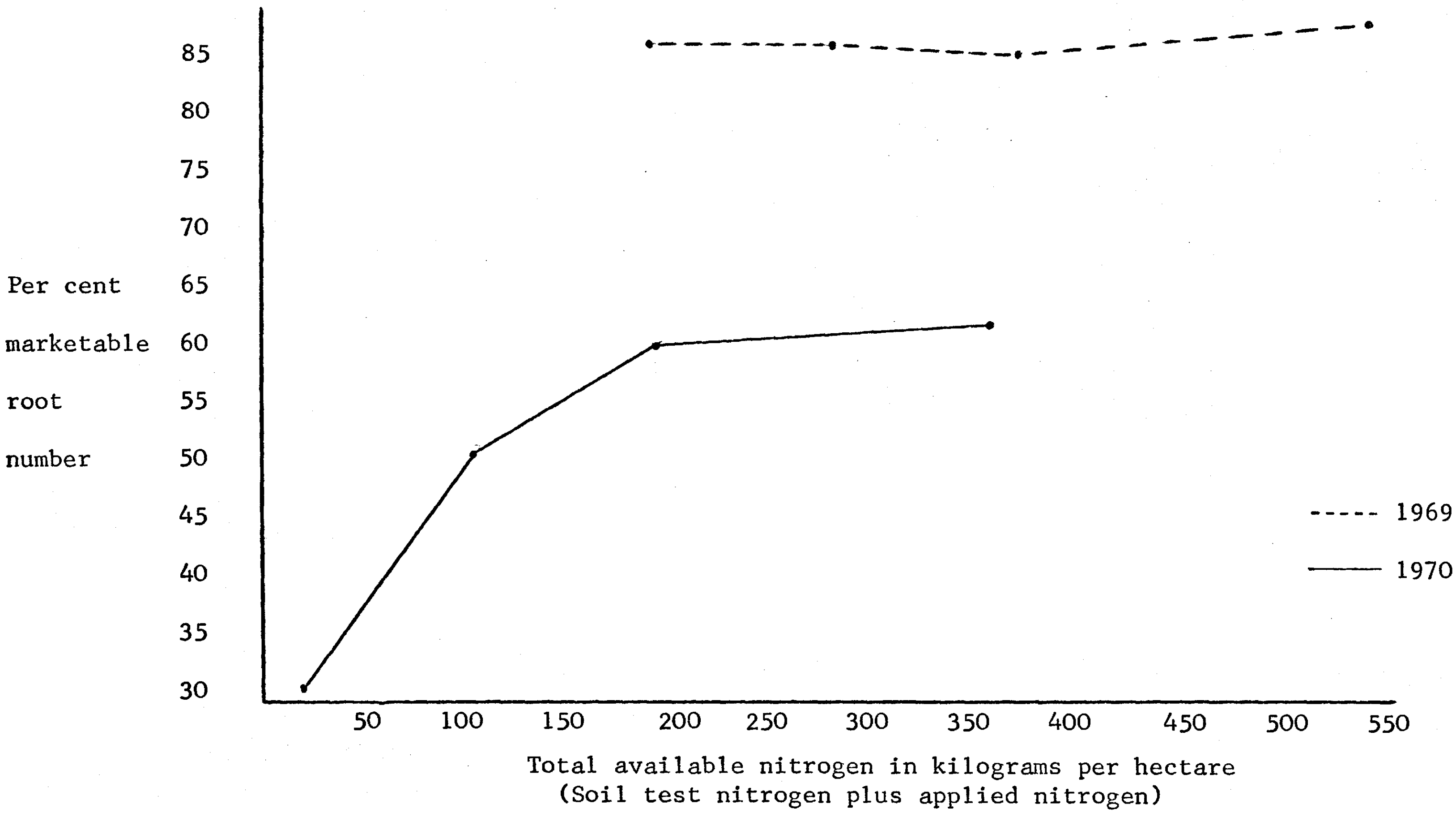


Figure 7: The effect of nitrogen on per cent marketable number of carrots, 1969 and 1970.

cent oversized roots on a number basis than those receiving the highest level of nitrogen. In 1970, no significant effect of nitrogen was found on the per cent oversized carrots based on root number (Table XIV), and this agrees with the results based on root weight as well.

The high nitrogen levels in 1969 also seemed to have an effect on the per cent undersized carrots on a weight basis (Table XV). The two highest levels of nitrogen (536.69 and 361.84 kilograms per hectare) gave a significantly greater percentage of undersized roots compared to the check treatment (Table XV and Figure 8), although the low figure for the check in 1969 seems to be out of line with the apparent trend. In 1970, the check treatment (18 kilograms) gave a highly significantly greater percentage of undersized roots on a weight basis compared to all other levels of nitrogen. Over the two years, there appeared to be a trend for a decline in the per cent undersized carrots with increases in available nitrogen. The results confirm the report of Southards and Miller (90), who noted that the smallest roots were obtained from plants receiving the smallest amount of nitrogen.

When the per cent undersized carrots was expressed on a number basis in 1969, no significant effect of nitrogen was obtained (Table XV). In 1970, however, nitrogen was found to have a highly significant effect, with the check treatment giving a highly significantly larger proportion of undersized roots compared to all other nitrogen levels (Table XV). This agrees with the results for 1970 when expressed on a weight basis.

Nitrogen alone had no significant effect on the per cent split and forked carrots expressed either on a weight or number basis for 1969 or 1970 (Table XV). Several workers have indicated, however, that high

Table XV: The Effect of Nitrogen on the Per Cent Undersized, as well as the Per Cent Split and Forked Carrots, 1969 and 1970.

| Year | Total available nitrogen in kilograms per hectare | Per cent undersized | | Per cent split and forked | |
|---|---|---|---|---|---|
| | | By weight | By number | By weight | By number |
| 1969 | 187.00 | 9.16 | 6.76 | 3.33 | 2.58 |
| | 274.42 | 12.27 | 8.13 | 3.27 | 2.68 |
| | 361.84 | 12.82 | 8.00 | 3.69 | 3.55 |
| | 536.69 | 12.95 | 7.20 | 3.67 | 3.27 |
| 1970 | 18.00 | 39.27 | 73.79 | 1.22 | 0.53 |
| | 102.06 | 20.32 | 48.50 | 2.03 | 1.26 |
| | 186.12 | 13.26 | 38.54 | 2.58 | 1.64 |
| | 354.24 | 11.73 | 36.79 | 2.11 | 1.43 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (Solid line at one per cent and broken line at five per cent level).

Data for each level of nitrogen includes all levels of phosphorus.

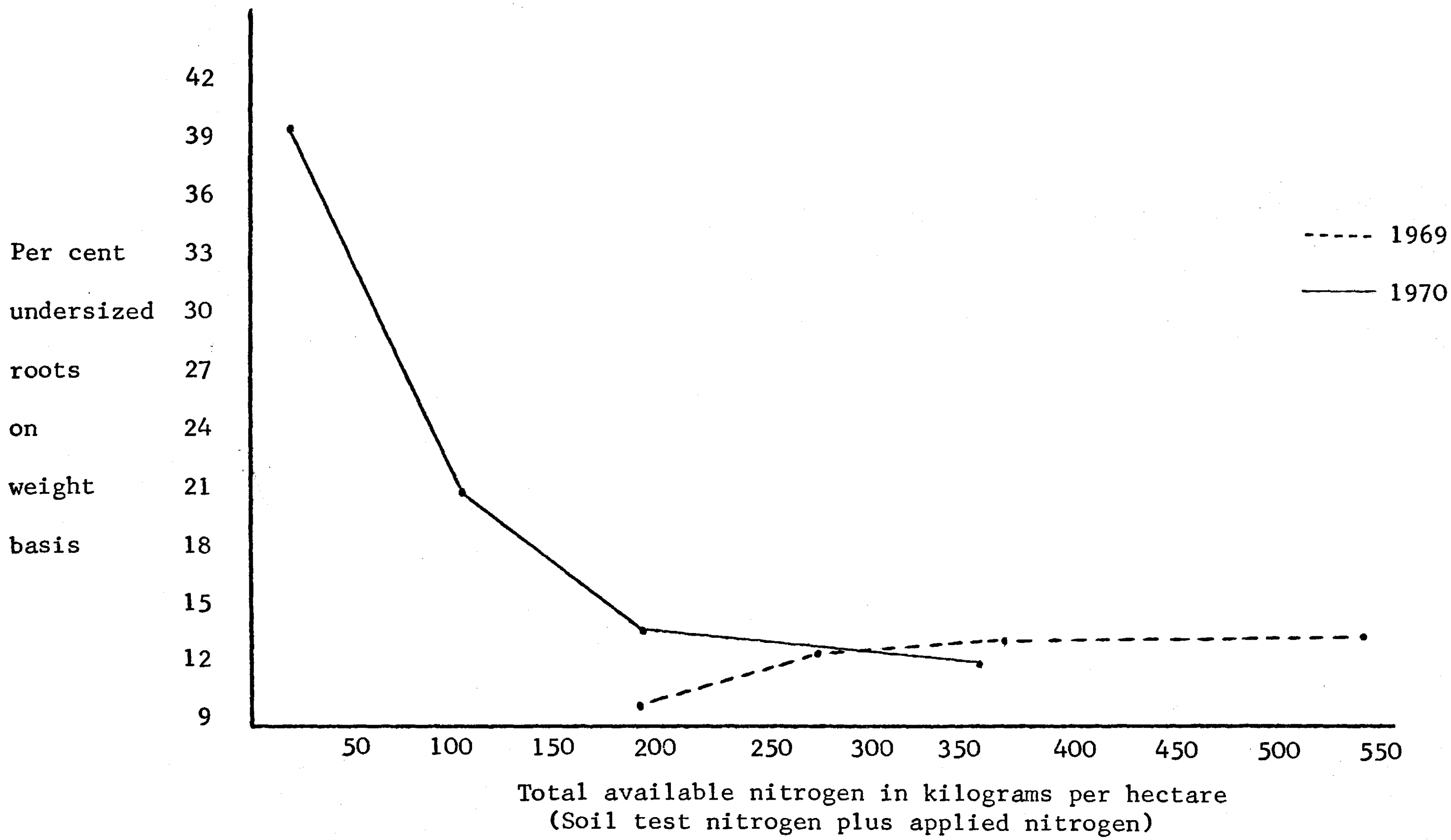


Figure 8: The effect of nitrogen on per cent undersized roots by weight for 1969 and 1970

nitrogen applications increased splitting and forking (31,32,69,100).

In both experimental years, the levels of available nitrogen in the soil had a marked influence on the total nitrogen content in the carrot leaves. In 1969 the two highest levels of nitrogen (536.69 and 361.84 kilograms per hectare) gave leaves which had a highly significantly greater total nitrogen content compared to the check treatment (Table XVI and Figure 9). In addition, the highest level of nitrogen gave leaves which had a highly significantly greater content of nitrogen than did all other levels of nitrogen. As nitrogen had a depressing effect on yields in 1969, the correlation between marketable yield of roots and nitrogen content in the leaves was -0.584. In contrast, the correlation in 1970 was +0.649, indicating there was a positive correlation between marketable root yields and foliar levels of nitrogen. These figures were significant at the one per cent level. In 1970 the two highest levels of nitrogen gave highly significantly greater nitrogen levels in the leaves than did the lowest two levels (Table XVI and Figure 9). The differences in the actual levels of nitrogen for the two years may have resulted because of the different sampling times used (October, 1969 and July, 1970). The increases in nitrogen content of carrot leaves agree with the findings of Heintze (41).

Significant effects of nitrogen levels on nitrogen content in carrot roots were also obtained in both years. In 1969, the highest level of nitrogen (536.69 kilograms per hectare) gave a highly significantly greater nitrogen content in the roots than the check treatment (Table XVI and Figure 10), but this rate was not significantly different from any of the other treatments. There was, however, a significant negative correlation

Table XVI: The Effect of Nitrogen on the Average Nitrogen, Phosphorus and Potassium Content in Carrot Leaves and Roots, 1969 and 1970.

| Year | Total available nitrogen in kilograms per hectare | Nitrogen content in ppm | | Phosphorus content in ppm | | Potassium content in ppm | |
|---|---|---|---|---|---|---|---|
| | | Leaves | Roots | Leaves | Roots | Leaves | Roots |
| 1969 | 187.00 | 22,400 | 13,800 | 2,350 | 3,470 | 23,350 | 29,650 |
| | 274.42 | 23,600 | 14,900 | 2,700 | 3,420 | 25,650 | 23,100 |
| | 361.84 | 23,900 | 14,600 | 2,550 | 2,950 | 25,850 | 28,650 |
| | 536.69 | 25,600 | 15,000 | 2,500 | 2,915 | 26,350 | 28,950 |
| 1970 | 18.00 | 31,100 | 7,200 | 4,963 | 2,100 | 38,850 | 21,900 |
| | 102.06 | 30,800 | 7,700 | 4,167 | 2,100 | 36,350 | 21,800 |
| | 186.12 | 34,300 | 9,100 | 3,642 | 1,950 | 38,850 | 22,900 |
| | 354.24 | 35,300 | 10,600 | 3,808 | 1,900 | 40,500 | 23,250 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (Solid line at one per cent and broken line at five per cent).

Data for each level of nitrogen includes all levels of phosphorus.

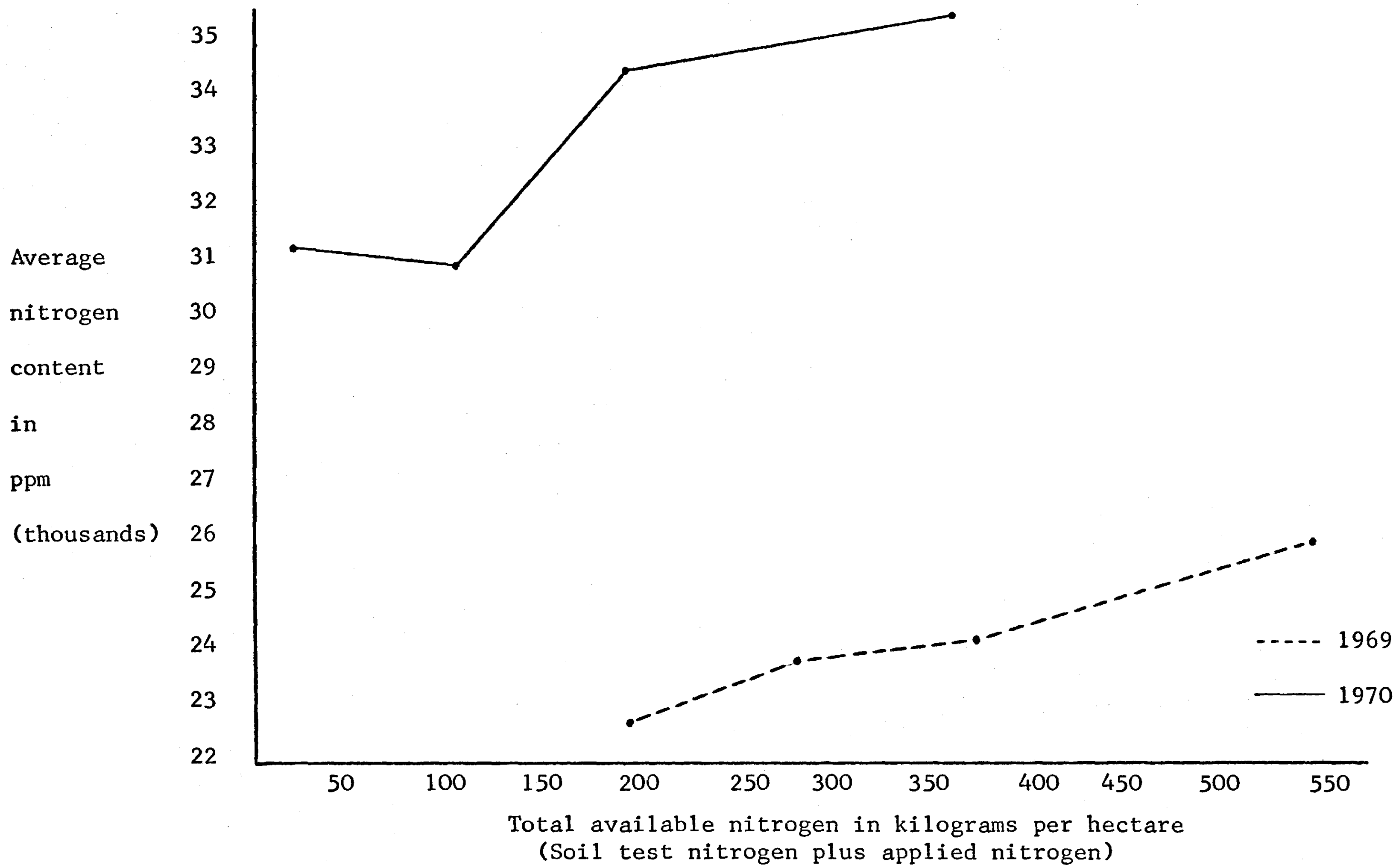


Figure 9: The effect of nitrogen on the nitrogen content in carrot leaves, 1969 and 1970.

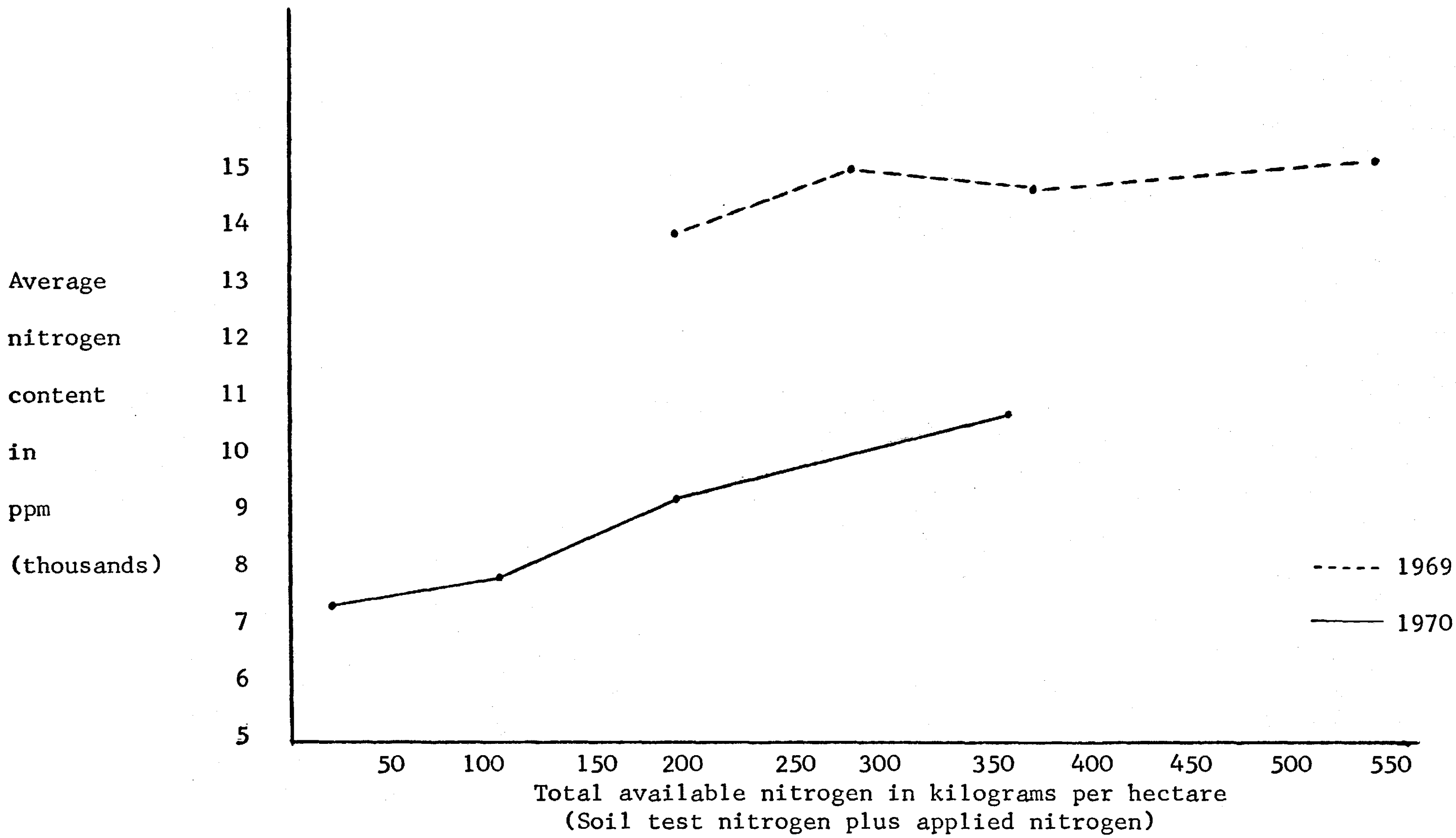


Figure 10: The effect of nitrogen on the average nitrogen content of carrot roots, 1969 and 1970.

of -0.744 with marketable yields in 1969. In 1970, when available nitrogen in the soil was at a much lower level, the highest level of nitrogen (354.24 kilograms per hectare) gave roots which were significantly higher in nitrogen content than those for the lowest two levels (Table XVI and Figure 10). The correlation between marketable root yield and nitrogen levels in carrot roots was +0.804 in 1970 and was significant at the one per cent level.

In both 1969 and 1970, nitrogen seemed to have an effect on the uptake of phosphorus in carrot leaves. In 1969 the second level of nitrogen (274.42 kilograms per hectare) gave leaves with a highly significantly greater phosphorus content compared to the check treatment (Table XVI and Figure 11), although there was no apparent reason for this low value. In 1970 the check treatment gave leaves with a significantly higher phosphorus content compared to all other levels of nitrogen (Table XVI). The results from both years suggest there may be a trend for a decrease in phosphorus content with increasing nitrogen levels. Again, different sampling times might explain the difference in actual phosphorus levels between the two years.

Nitrogen also seemed to have an effect on the uptake of phosphorus in roots during 1969 (Table XVI). In that year, the highest level of nitrogen (536.69 kilograms per hectare) gave roots with a highly significantly lower phosphorus content than did the lowest two levels of nitrogen (Figure 12). No effect of nitrogen on phosphorus content in carrot roots was found in 1970.

Nitrogen did not have any effect on the uptake of potassium in carrot leaves during 1969, but it did have an effect in 1970 (Table XVI).

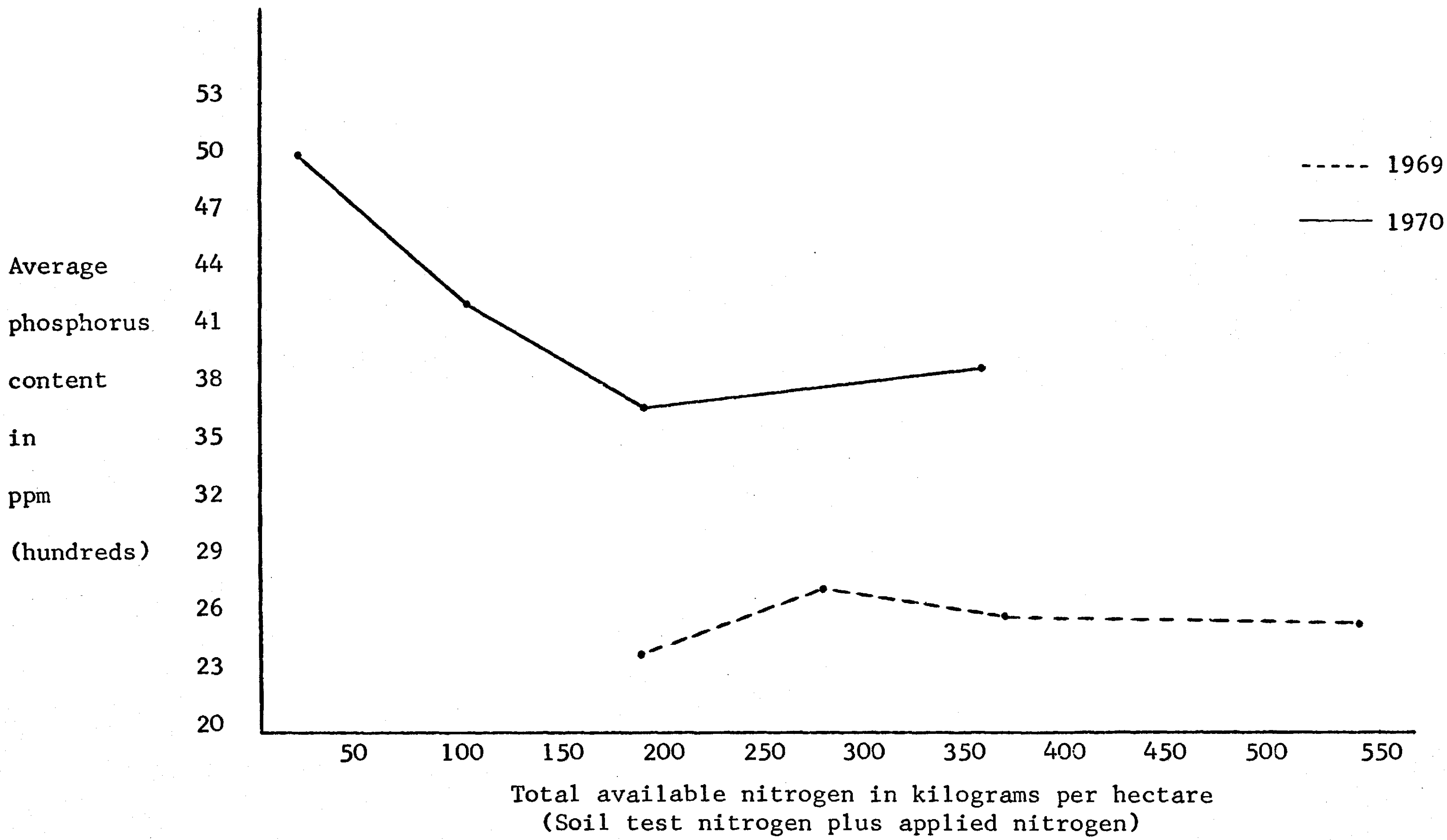


Figure 11: The effect of nitrogen on phosphorus content in carrot leaves, 1969 and 1970.

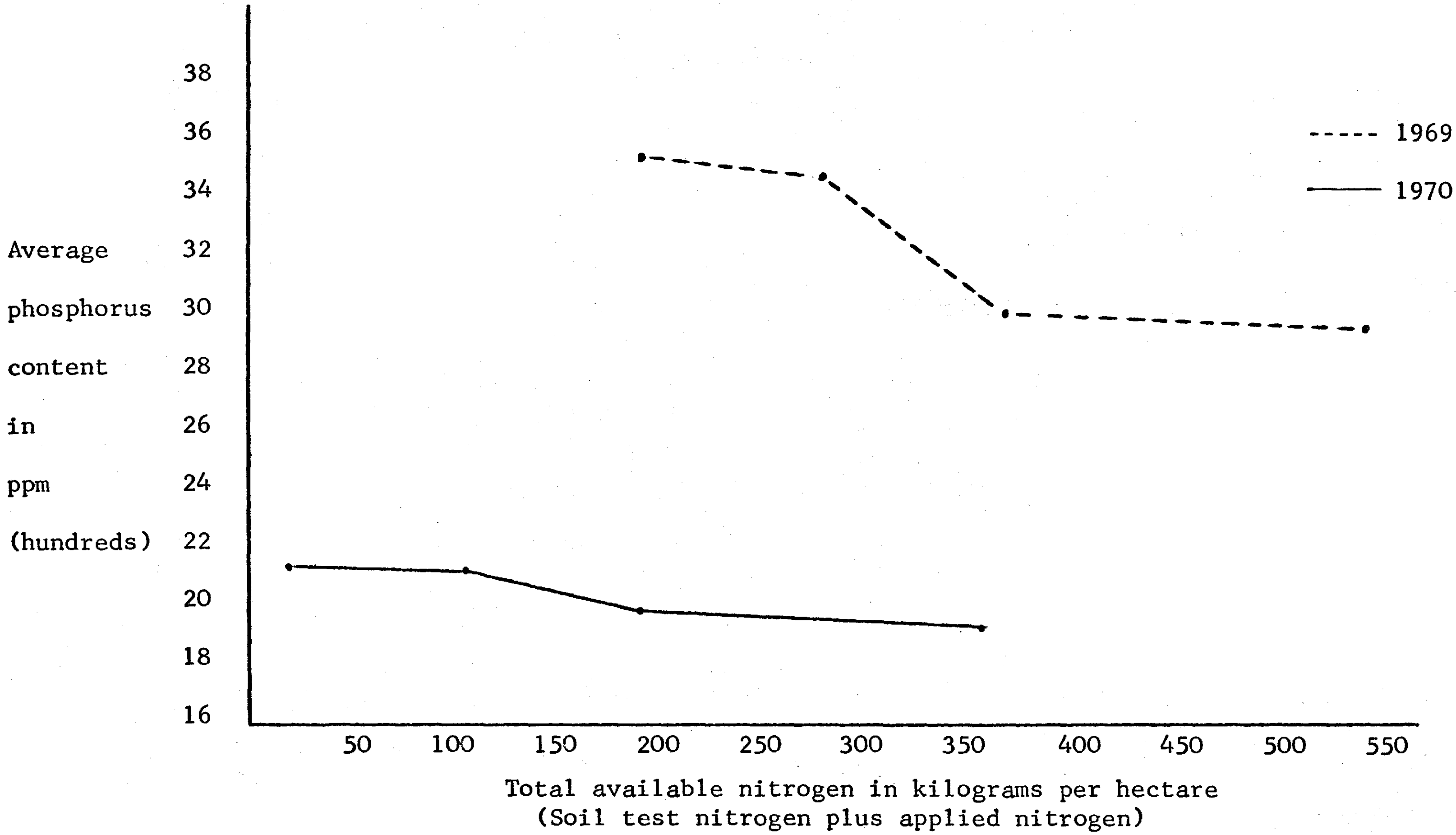


Figure 12: The effect of nitrogen on the average phosphorus content of carrot roots, 1969 and 1970.

In that year, the lowest levels of potassium in carrot leaves were found in those plants receiving the second level of nitrogen (102.06 kilograms per hectare), and these amounts were significantly lower than those for all other levels of nitrogen (Table XVI and Figure 13).

The uptake of potassium in carrot roots during 1969 was found to be affected considerably by nitrogen. The second level of nitrogen (274.42 kilograms per hectare) gave roots with the lowest potassium content compared to all other levels of nitrogen (Table XVI and Figure 14), and the differences were significant at the one per cent level (Figure 14). In contrast, no differences were found in 1970. Possibly the significant differences obtained in 1969 and 1970 for carrot leaves and roots were the result of error because they are so far out of line.

The levels of nitrogen used during 1969 did not seem to have any effect on the keeping quality of carrots held in cold storage for seven months (Table XVII). With the exception of a slight weight loss and some growth of root hairs, very little change in carrot appearance took place and rotting was found to be minimal.

Based on the value of the marketable yields in 1970, it would appear economical to have up to 186.12 kilograms per hectare of total available nitrogen in the soil (Table XVIII). As this level did not give a significant increase in yield over the second level, however, it would be difficult to recommend the addition of the extra fertilizer.

## The effects of phosphorus

As discussed with cabbage, the levels of phosphorus reported in this discussion refer only to the actual levels of phosphorus applied as

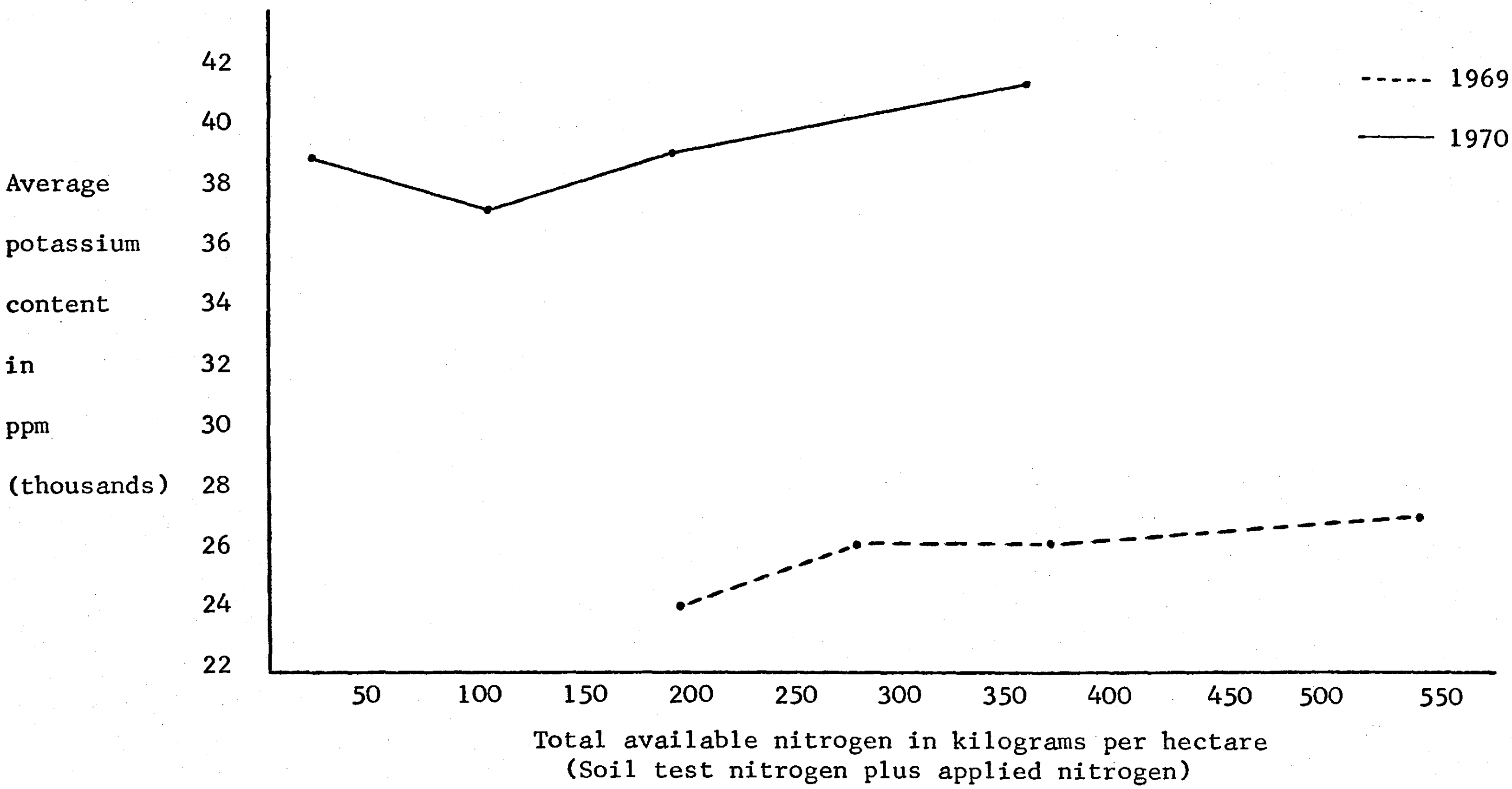


Figure 13: The effect of nitrogen on the average potassium content of carrot leaves, 1969 and 1970.

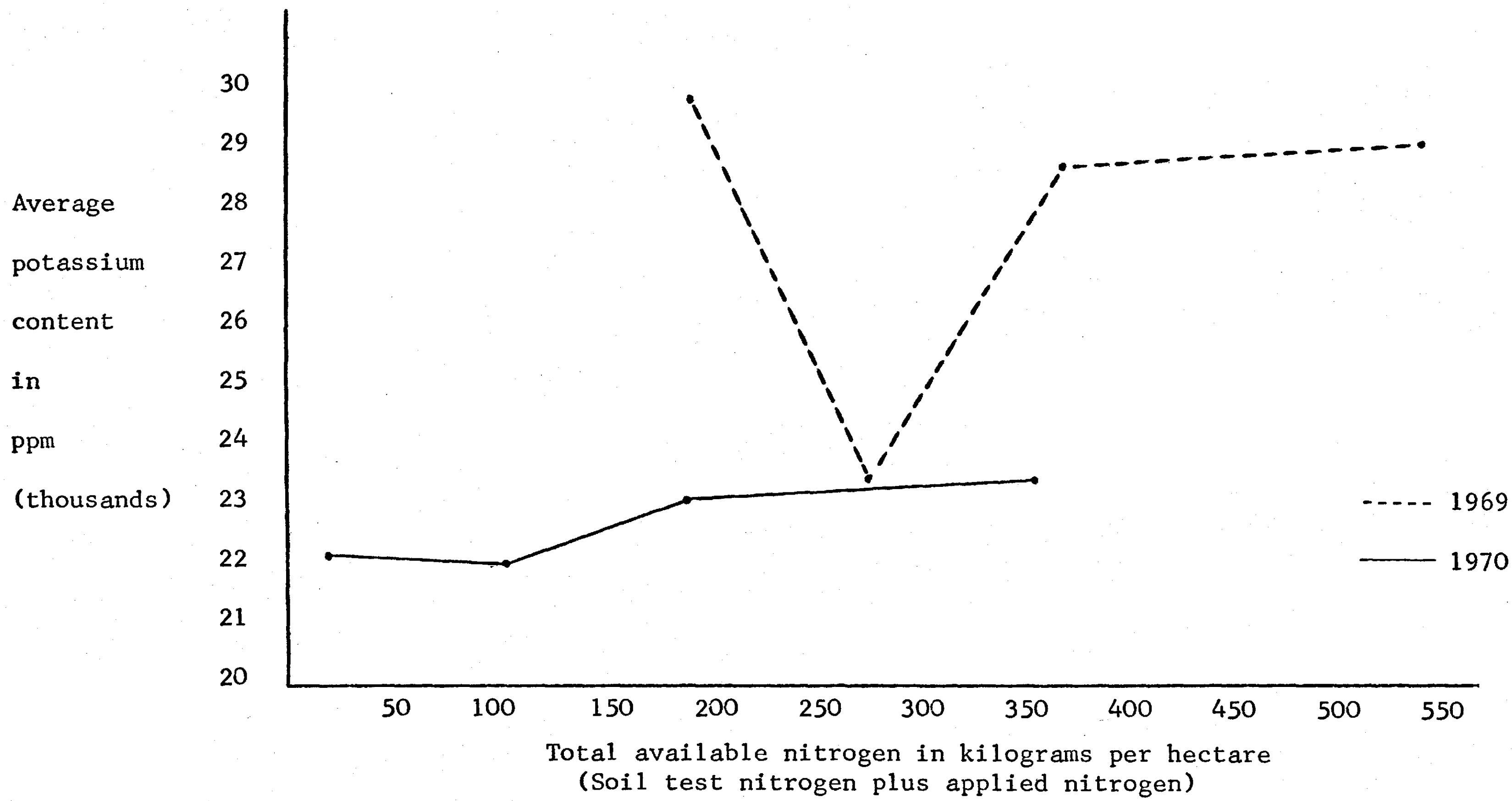


Figure 14: The effect of nitrogen on the average potassium content in carrot roots, 1969 and 1970.

Table XVII: The Effect of Nitrogen on the Average Per Cent Weight Loss of Carrots Held in Cold Storage, 1969.

| Total available nitrogen in kilograms per hectare | Per cent weight loss |
|---|---|
| 187.00 | 3.35 |
| 274.42 | 3.31 |
| 361.84 | 1.06 |
| 536.69 | 1.28 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of nitrogen includes all levels of phosphorus.

Table XVIII: Fertilizer Cost and Marketable Yield Values for the Various Nitrogen Levels on Carrots, 1970.

| Total available nitrogen in kilograms per hectare | Fertilizer rate kilograms/hectare | Fertilizer cost per hectare | Marketable yield in kilograms | | Returns per hectare | |
|---|---|---|---|---|---|---|
| | | | Per 6.1 meters | Per hectare | Total | Increase less cost |
| 18.00 | 0.00 | $ 0.00 | 3.213 | 13,001 | $ 429.94 | $ |
| 102.06 | 84.06 | 18.53 | 6.856 | 27,742 | 917.42 | 468.95 |
| 186.12 | 168.12 | 37.06 | 8.208 | 33,213 | 1098.30 | 143.82 |
| 354.24 | 336.24 | 74.13 | 8.766 | 35,471 | 1173.00 | 0.57 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at one per cent level).

Data for each level of nitrogen includes all levels of phosphorus.

Based on a 1970 cost of 22¢ per kilogram of nitrogen and 33¢ per kilogram of carrots.

fertilizer and do not include phosphorus levels occurring in the soil.

Phosphorus had a significant effect on the total plant yield of carrots in 1969. In that year, the highest level of phosphorus (174.84 kilograms per hectare) gave significantly greater total plant yields than the check treatment (Table XIX). The highest level of phosphorus, however, did not give significantly greater yields over the intermediate level (87.42 kilograms per hectare). No record was made of total plant weight in 1970.

Phosphorus did not have any significant effect on total root weight in either 1969 or 1970. In 1969, however, there was a trend for an increase in total root weight with an increase in phosphorus applied (Table XIX). As phosphorus in that year had a significant effect on the total plant yield, the effect of phosphorus must have been greater on leaf production than it was on root production. Southards and Miller (90), in fact, noted that leaf production was markedly affected by phosphorus.

No significant effect of phosphorus was found on marketable weight of roots or per cent marketable roots expressed on either a weight or number basis for 1969 or 1970 (Table XX). Thus, initial levels of phosphorus in the soil seemed to give satisfactory yields of marketable carrots.

Generally, phosphorus had little effect on the incidence of oversized carrots in either year (Table XXI). The only effect noted was a significant interaction between nitrogen and phosphorus on the per cent oversized carrots expressed on a weight basis for 1969 (Table I,

Table XIX: The Efect of Phosphorus on the Average Total Root Weight of Carrots, 1969 and 1970.

| Year | Applied $P_2O_5$ in kilograms per hectare | Average total plant weight in kilograms* | Average total root weight in kilograms* |
|---|---|---|---|
| 1969 | 0.00 | 24.48 | 17.89 |
| | 87.42 | 26.62 | 19.27 |
| | 174.84 | 27.38 | 19.78 |
| 1970 | 0.00 | | 8.28 |
| | 84.06 | | 8.81 |
| | 168.12 | | 8.40 |

* based on 6.1 meters of row harvested

Figures not significantly different are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 38 kilograms per hectare in 1969 and 17 kilograms per hectare in 1970.

Table XX: The Effect of Phosphorus on the Average Marketable Weight, Average Per Cent Marketable Weight and Average Per Cent Marketable Number of Carrots, 1969 and 1970.

| Year | Applied $P_2O_5$ in kilograms per hectare | Marketable weight in kilograms* | Per cent marketable | |
|---|---|---|---|---|
| | | | Weight | Number |
| 1969 | 0.00 | 15.44 | 86.07 | 85.65 |
| | 87.42 | 16.68 | 86.51 | 86.45 |
| | 174.84 | 17.10 | 86.46 | 85.60 |
| 1970 | 0.00 | 6.37 | 72.85 | 47.92 |
| | 84.06 | 7.32 | 76.45 | 55.40 |
| | 168.12 | 6.59 | 74.30 | 47.59 |

* based on 6.1 meters of row harvested

Figures not significantly different are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 38 kilograms per hectare in 1969 and 17 kilograms per hectare in 1970.

Table XXI: The Effect of Phosphorus on the Average Per Cent Oversized Carrot Roots, 1969 and 1970.

| Year | Applied $P_2O_5$ in kilograms per hectare | Per cent oversized roots | |
|---|---|---|---|
| | | By weight | By number |
| 1969 | 0.00 | 9.27 | 3.96 |
| | 87.42 | 8.48 | 3.45 |
| | 174.84 | 8.75 | 3.31 |
| 1970 | 0.00 | 1.56 | 0.42 |
| | 84.06 | 1.06 | 0.67 |
| | 168.12 | 1.88 | 0.32 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 38 kilograms per hectare in 1969 and 17 kilograms per hectare in 1970.

Appendix). On a root number basis for that year, no interaction was obtained, and no significant effect of phosphorus alone was found in 1970.

Phosphorus did not have any effect on the per cent undersized carrots in either year (Table XXII).

Very little effect of phosphorus on the incidence of split and forked carrots was found (Table XXIII). When expressed on a weight basis, the per cent split and forked roots did not significantly vary with differences in phosphorus levels. When expressed on a basis of root number, the per cent split and forked roots was found to have a significant interaction between nitrogen and phosphorus (Table II, Appendix), but only in 1969.

In neither year did phosphorus alone have any significant effect on the nitrogen content in carrot leaves or roots (Table XXIV). Some effect of phosphorus on nitrogen content in carrot roots was found in 1970 as there was a highly significant interaction between phosphorus and nitrogen (Table III, Appendix).

The rates of phosphorus used in the two years had considerable bearing on the levels of phosphorus found in leaf tissue. In 1969, the highest level of phosphorus (174.84 kilograms per hectare) gave a highly significantly greater phosphorus content in the leaves than did the check treatment (Table XXIV). In addition, there was an interaction at the one per cent level between nitrogen and phosphorus in that year (Table IV, Appendix). In 1970, both levels of applied phosphorus gave a significantly greater phosphorus content in the leaves than did the check treatment. No significant correlation (+0.070)

Table XXII: The Effect of Phosphorus on the Average Per Cent Undersized Carrots, 1969 and 1970.

| Year | Applied $P_2O_5$ in kilograms per hectare | Per cent undersized roots | |
|---|---|---|---|
| | | By weight | By number |
| 1969 | 0.00 | 12.55 | 7.55 |
| | 87.42 | 10.98 | 7.34 |
| | 174.84 | 11.90 | 7.69 |
| 1970 | 0.00 | 22.53 | 50.83 |
| | 84.06 | 18.06 | 46.42 |
| | 168.12 | 22.84 | 50.96 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 38 kilograms per hectare in 1969 and 17 kilograms per hectare in 1970.

Table XXIII: The Effect of Phosphorus on the Average Per Cent Split and Forked Carrot Roots, 1969 and 1970.

| Year | Applied $P_2O_5$ in kilograms per hectare | Per cent split and forked roots | |
|---|---|---|---|
| | | By weight | By number |
| 1969 | 0.00 | 3.46 | 3.09 |
| | 87.42 | 3.56 | 2.94 |
| | 174.84 | 3.67 | 3.03 |
| 1970 | 0.00 | 2.50 | 1.25 |
| | 84.06 | 1.77 | 1.31 |
| | 168.12 | 1.68 | 1.06 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 38 kilograms per hectare in 1969 and 17 kilograms per hectare in 1970.

Table XXIV: The Effect of Phosphorus on the Average Nitrogen, Phosphorus and Potassium Content in Carrot Leaves and Roots, 1969 and 1970.

| Year | Applied $P_2O_5$ in kilograms per hectare | Average N content in ppm | | Average P content in ppm | | Average K content in ppm | |
|---|---|---|---|---|---|---|---|
| | | Leaves | Roots | Leaves | Roots | Leaves | Roots |
| 1969 | 0.00 | 24,100 | 14,600 | 2,330 | 3,100 | 26,600 | 30,400 |
| | 87.42 | 23,600 | 14,600 | 2,520 | 3,100 | 24,250 | 28,750 |
| | 174.84 | 23,900 | 14,500 | 2,770 | 3,250 | 26,750 | 29,400 |
| 1970 | 0.00 | 33,700 | 9,020 | 3,872 | 1,890 | 37,200 | 22,950 |
| | 84.06 | 33,300 | 9,080 | 4,303 | 2,135 | 39,000 | 22,550 |
| | 168.12 | 31,700 | 7,810 | 4,259 | 2,005 | 39,700 | 21,850 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (Solid line at one per cent and broken line at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 38 kilograms per hectare in 1969 and 17 kilograms per hectare in 1970.

between phosphorus content in the leaves and the marketable root yield was obtained in 1969, but in 1970 there was a correlation of +0.395 which was significant at the one per cent level.

No effect of phosphorus on the phosphorus content in carrot roots for 1969 was obtained, but an effect was found in 1970. In that year, the lowest level of phosphorus applied (84.06 kilograms per hectare) gave the highest phosphorus content in carrot roots (Table XXIV), and this content was significantly greater than the phosphorus content in roots receiving no additional $P_2O_5$. Furthermore, there was a significant correlation of +0.715 in 1969 and +0.996 in 1970 between phosphorus content in the roots and marketable weight.

No significant effect of phosphorus on the potassium content in carrot leaves was found in 1969 (Table XXIV). In 1970, however, the potassium content was found to be smaller in leaves receiving no additional phosphorus than in those receiving the highest level of phosphorus fertilizer, and the difference between the highest and lowest level was significant at the five per cent level (Table XXIV).

The potassium content of carrot roots was found to be highest in those receiving no additional phosphorus during 1969 (Table XXIV) and the content was significantly higher than that for the lowest level of applied phosphorus (87.42 kilograms per hectare). No significant effect on potassium content was found in 1970.

Phosphorus did not have any significant effect on the keeping quality of carrots held in cold storage in 1969 (Table XXV). As indicated under the effects of nitrogen, the carrots remained in very good condition during storage.

Table XXV: The Effect of Phosphorus on the Per Cent Weight Loss of Carrots Held in Cold Storage, 1969.

| Applied $P_2O_5$ in kilograms per hectare | Per cent weight loss |
|---|---|
| 0.00 | 3.08 |
| 87.42 | 1.87 |
| 174.84 | 2.42 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Soil phosphorus in the top 15 centimeters was 38 kilograms per hectare.

In general, phosphorus did not greatly increase total root yields or marketable root yields. The addition of phosphorus fertilizer did not give a significant increase in marketable yield of carrots, although it appeared that it might be economical to apply up to 84.06 kilograms of $P_2O_5$ per hectare for optimum yields of marketable carrots (Table XXVI) when there is a soil level of 17 kilograms of phosphorus per hectare.

Table XXVI: Fertilizer Costs and Marketable Yield Values for the Various Phosphorus Levels on Carrots, 1970.

| Fertilizer rate kilograms/hectare | Fertilizer cost per hectare | Marketable yield in kilograms | | Returns per hectare | |
|---|---|---|---|---|---|
| | | Per 6.1 meters | Per hectare | Total | Increase less cost |
| 0.00 | $ 0.00 | 6.371 | 25,780 | $852.52 | $ |
| 84.06 | 15.20 | 7.317 | 29,608 | 979.10 | 111.38 |
| 168.12 | 30.09 | 6.595 | 26,686 | 882.48 | -126.71 |

Figures not significantly different according to Duncan's Multiple Range test are joined by a vertical line. (at five per cent level).

Data for each level of phosphorus includes all levels of nitrogen.

Based on 1970 cost of 18¢ per kilogram of phosphorus and 33¢ per kilogram of carrots.

# SUMMARY AND CONCLUSIONS

During the summers of 1969 and 1970 fertility studies were conducted on irrigated Houston Evergreen cabbage and Gold Pak Improved carrots. In each year four levels of nitrogen combined with four levels of phosphorus were used for cabbage and four levels of nitrogen combined with three levels of phosphorus were used for carrots. As the initial fertility levels differed considerably for each year, the total available nutrients also varied considerably.

In 1969 it was obvious that the initial nitrogen level of 212 kilograms per hectare and the phosphorus level of 32 kilograms per hectare was too high for cabbage. No significant yield differences occurred with cabbage and the addition of nitrogen fertilizer was unfavorable to stored cabbage. Similarly, a nitrogen level of 187 kilograms per hectare and a phosphorus level of 38 kilograms per hectare was too high for carrots in 1969. Additional nitrogen tended to decrease the production of carrots and although phosphorus increased the top growth, no significant difference in root growth occurred.

The following year, however, when the nitrogen level in the soil for cabbage was 61 kilograms per hectare and the phosphorus level was 21 kilograms per hectare, significant differences in yields were obtained from fertilizer treatments. The total yield was significantly greater at 229.76 and 173.72 kilograms of nitrogen per hectare than at 117.68 and 61.64 kilograms per hectare, but there was no significant difference between the top two levels. These levels of nitrogen also produced the greatest amount of marketable yield, but again there was no significant difference between them. Both levels were deemed to be economical. Nitrogen also increased the ratio of polar diameter to equatorial diameter of cabbage heads at the two highest rates of 229.76 and 173.72 kilograms per hectare. In addition, nitrogen at 229.76 kilograms per hectare increased the total nitrogen content in cabbage leaves and this content gave a correlation of +0.627 with the marketable yield. No significant effect of nitrogen on phosphorus content or potassium content was obtained.

An application of 84.06 kilograms of phosphorus per hectare significantly increased the total plant weight of cabbage, but marketable yield was not increased significantly by phosphorus applications. Phosphorus levels of 84.06 and 168.12 kilograms per hectare gave a significant increase in the phosphorus content of cabbage leaves in 1970 and there was a correlation of +0.673 with marketable yields. No significant effect of phosphorus on nitrogen or potassium uptake was found.

Additional fertilizer to the lower nitrogen level of 18 kilograms per hectare and the phosphorus level of 17 kilograms per hectare in 1970 also gave significant differences in yields with carrots. Although significant increases in total root weight and marketable root weight of carrots were only obtained up to a total available nitrogen level of at least 102.06 kilograms per hectare, apparent economical returns were obtained when a total available nitrogen level in the soil of 186.12 kilograms per hectare was present. A nitrogen level of 186.12 kilograms per hectare increased the per cent marketable carrots by weight and a level of 102.06 kilograms per hectare increased the per cent marketable root number. The lowest level of nitrogen (18 kilograms per hectare) gave the greatest per cent undersized carrots. The nitrogen content of leaves was highly significantly greater with the two highest levels of nitrogen (354.24 and 186.12 kilograms per hectare) and a correlation of +0.649 with marketable yield was obtained. A level of 354.24 kilograms of nitrogen per hectare gave higher nitrogen levels in the roots than the lowest two levels. A good correlation of +0.804 with marketable yields was obtained. The phosphorus content in carrot leaves was highest in the check carrots in 1970 (18 kilograms of nitrogen per hectare). Increasing the nitrogen level appeared to decrease the phosphorus content. A level of 102.06 kilograms per hectare of nitrogen in 1970 gave leaves which were significantly lower in potassium content. No significant effect of nitrogen on per cent oversized or forked and split carrots, as well as phosphorus and potassium uptake in carrot roots, was found.

Phosphorus at levels of 168.12 and 84.06 kilograms per hectare significantly increased the phosphorus uptake in carrot leaves and there was a correlation of +0.395 between leaf phosphorus and marketable yields. A phosphorus level of 84.06 kilograms per hectare gave the highest phosphorus content in roots. A correlation of +0.996 between carrot root phosphorus uptake and marketable yields was obtained. Potassium content in carrot leaves was smaller in the check carrots than those receiving phosphorus. Phosphorus did not have any significant effect on marketable root yields, nitrogen uptake in carrot leaves or potassium uptake in carrot roots, but there was a highly significant interaction between nitrogen and phosphorus on the nitrogen content in carrot roots for 1970.

# LITERATURE CITED


1. Arnon, D.I. 1966. Quality criteria of agricultural produce and the influence of mineral fertilizers on quality. Potassium and the quality of agricultural products. Proc. 8th Congress Int. Potash Inst., Brussels. 339-400.

2. Austin, R.B. 1963. A study on the growth and yield of carrots in a long term manurial experiment. J. Hort. Sci. 38: 264-276.

3. Åvall, H. 1963. Storage trials with brassicas. Medd. Tradgardsfors. Alnarp. 149: 41. (Hort. Abst. 34: 2692. 1964.)

4. Banga, O. 1958. Effect of some environmental factors on the carotene content of carrots. Meded. Inst. Vered. Tuinbouwgew 122. (Hort. Abst. 28: 2624. 1958.)

5. Barnes, W.C. 1936. Effects of some environmental factors on growth and color of carrots. Mem. Cornell Agric. Exp. Sta. 186.

6. Bazier, R.A., Guérillot-Vinet and J. Guérillot. 1966. The influence of some fertilizers on the amino acids of wheat grains and carrot roots. Ann. Agron. 17: 673-686. (Hort. Abst. 37: 5066. 1967.)

7. Betzema, J. and J.C. Commandeur. 1968. Plant spacing and nitrogen manuring for Danish white cabbage. Groent. en Fruit 23: 2033. (Hort. Abst. 38: 7611. 1968.)

8. Bielka, R. 1966. The time of planting out as a critical factor to the production of late cabbage yields. Internat. Z. Landwirt. 1: 2-4. (Hort. Abst. 38: 7610. 1968.)

9. Bienz, D.R. 1965. Carrot splitting and second growth in Central Washington as influenced by spacing, time of side-dressing and other cultural practices. Proc. Amer. Soc. Hort. Sci. 86: 406-410.

10. Bleasdale, J.K.A. et al. 1961. Studies on carrots. J. Roy. Hort. Soc. 86:222-225. (Hort. Abst. 32: 1035. 1962)

11. Boschart, K. 1944 Potassium fertilizer trials in vegetable growing. Prakt. Bl. Pflanzenb. 20: 25-42. (Hort. Abst. 14: 647. 1944.)

12. Bradley, G.A. and R.L. Dyck. 1968. Carrot color and carotenoids as affected by growing conditions. Proc. Amer. Soc. Hort. Sci. 93: 402-407.

13. Bradley, G.A. and D. Smittle. 1965. Carrot quality as affected by variety, planting and harvest dates. Proc. Amer. Soc. Hort. Sci. 86: 297-405.

14. Bradley, G.A., D.A. Smittle, A.A. Kattan and W.A. Sistrunk. 1967. Planting date, irrigation, harvest sequence and varietal effects on carrot yields and quality. Proc. Amer. Soc. Hort. Sci. 90: 223-234.

15. Bradley, G.A. *et al*. 1965. Carrot yields and color in Arkansas. Arkans. Farm Res. 14(3): 8. (Hort. Abst. 36: 1109. 1966.)

16. Brown, G.B. 1947. The effect of maturity and storage on the carotene content of carrot varieties. Proc. Amer. Soc. Hort. Sci. 50: 347-352.

17. Burleson, C.A., W.R. Cowley and G. Otey. 1958. The yield, head weight and head size of cabbage as affected by different fertilizer treatments. J. Rio Grande Valley Hort. Soc. 12: 114-118. (Hort. Abst. 28: 3651. 1958.)

18. Chipman, E.W. 1959. The influence of length of growing season on root type of carrot varieties. Proc. Amer. Soc. Hort. Sci. 74: 583-586.

19. Dennison, R.A. and B.E. Janes. 1948-1949. Quality of vegetables as related to fertilizer materials with emphasis on potash salts. Ann. Rev. Fla. Agric. Exp. Sta. 97-99. (Hort. Abst. 21: 543. 1951.)

20. Dhesi, N.S., D.A. Padda and B.S. Malik. 1965. Effect of different doses of nitrogen at two levels of potash on the development and yield of carrot. Punjab Agric. Univ. Ludhiana, J. Res. 1: 50-55. (Hort. Abst. 35: 5821. 1965.)

21. Drew, D.H. 1966. Irrigation studies on summer cabbage. J. Hort. Sci. 41: 103-114.

22. Džebrailov, M.G. 1962. The efficiency of fertilizers applied to carrots. Vestn. Sel'sk. Nauki. 7: 37-38. (Hort. Abst. 33: 5214. 1963.)

23. Florescu, M. and S. Cernea. 1961. A study on the variation in the contents of carotenoids and sugars in carrots as a function of the microelements magnesium, boron, copper, zinc and molybdenum applied to differently fertilized plots. Lucr. Sti. Inst. Agron. Cluj. 17: 75-83. (Hort. Abst. 34: 6885. 1964.)

24. Forbes, R.B. Nitrogen sources for carrots. 1966. Proc. Soil Sci. Soc. Fla. 26: 120-124. (Hort. Abst. 38: 5790. 1968.)

25. Freeman, G.G. Studies on potassium nutrition of plants. 1967. II. Some effects of potassium deficiency on the organic acids of leaves. J. Sci. Fd. Agric. 18: 569-76. (Hort. Abst. 38: 3125. 1968.)

26. Freeman, J.A. and G. H. Harris. 1951. The effect of nitrogen, phosphorus, potassium and chlorine on the carotene content of the carrot. Sci. Agric. 31: 207-211. (Hort. Abst. 21: 3618. 1951.)

27. Gallagher, P.A. 1966. The effect of potassium on yield and quality of carrots. Potassium and the quality of agricultural products. Proc. 8th Congress Int. Potash Inst. Brussels. 257-263.

28. Garner, H.V. 1967. Results of fertilizer experiments on carrots in 1941 and 1942. J. Agric. Sci., Camb. 69: 209-215. (Hort. Abst. 38: 1151. 1968.)

29. Giardini, L. and F. Pimpini. 1966. Experiments on the manuring of carrots in Venetia. Agric. Venezie 20: 183-210. (Hort. Abst. 36: 6761. 1966.)

30. Goodall, D.W. and F.G. Gregory. 1947. Chemical composition of plants as an index of their nutritional status. Technical Communication No. 17. Imp. Bur. Hort. Plant. Crops. 167p.

31. Goodman, O. 1952-1953. A preliminary investigation of some factors affecting quality and yield in carrot crops. J. Dept. Agric. Dublin 49: 99-105. (Hort. Abst. 24: 3890. 1954).

32. Goodman, O. 1953-1954. Further investigations of some of the factors affecting quality and yield in carrot crops. J. Dept. Agric. Dublin 50: 104-128. (Hort. Abst. 26: 1782. 1956.)

33. Hahn, P. 1953. The effect of sowing and transplanting dates on yields of late cabbage. Arch. Gartenb. 1: 223-228. (Hort. Abst. 24: 1529. 1954.)

34. Halliday, D.J. 1948. A guide to the uptake of plant nutrients by farm crops. Bull. No. 7. Jealott's Hill Research Station. Imperial Chemical Industries Ltd., Bracknell, Berks. Eng. 34p.

35. Hansen, E. 1945. Variations in the carotene content of carrots. Proc. Amer. Soc. Hort. Sci. 46: 355-358.

36. Haworth, F. 1959. Fertilisers beat soil cultivations in cabbage trial results. Comm. Grower No. 3290. 165. (Hort. Abst. 29: 1406. 1959.)

37. Haworth, F. 1962. The effects of different rates of application of nitrogenous fertilizer on the yield and mineral composition of spring cabbage. J. Hort. Sci. 37: 35-43. (Hort. Abst. 32: 4787. 1962.)

38. Haworth, F. and T.J. Cleaver. 1964. The effects of the uptake of different amounts of potassium on the rate of growth of carrot seedlings. J. Hort. Sci. 38: 40-45.

39. Haworth, F., T.J. Cleaver and J. M. Bray. 1967. The effects of different manurial treatments on the yield and mineral composition of spring cabbage. J. Hort Sci. 42: 13-21.

40. Heilman, M.D., J.R. Thomas and C.A. Burleson. 1961. Nitrogen requirements of cabbage. J. Rio Grande Valley Hort. Soc. 15: 106-111. (Hort. Abst. 32: 2882. 1962.)

41: Heintze, K. 1955. Studies on the effect of high N applications on the formation of individual N fractions in several vegetables. Landw. Forsch. 7: 216-231. (Hort. Abst. 25: 3915. 1955.)

42. Hensel, D.R. 1967. Fertilizer placement on cabbage. Proc. Soil Sci. Soc. Fla. 27: 227-234. (Hort. Abst. 39: 6678. 1969.)

43. Hester, J.B., F.A. Shelton and R.L. Isaacs, Jr. 1950. The rate and amount of plant nutrients absorbed by various vegetables. Proc. Amer. Soc. Hort. Sci. 57: 249-251.

44. Iwata, M. and A. Utada. 1968. Effects of nitrogen at various growth stages on the growth and yield of several vegetable crops. J. Jap. Soc. Hort. Sci. 37: 57-66. (Hort. Abst. 39: 654. 1969.)

45. Jadhav, V.M. and L. Sreenivas. 1968. Influence of spacing-cum-irrigation on growth, yield and quality of cabbage. Poona Agric. Coll. Mag. 58: 18-25. (Hort. Abst. 39: 4670. 1969.)

46. Jamison, F.S. 1955. Irrigation of vegetables in Florida. Proc. Soil Sci. Soc. Fla. 15: 173-175. (Hort. Abst. 27: 1429. 1957.)

47. Janes, B.E. 1950. The effect of irrigation, nitrogen level and season on the composition of cabbage. Plant Physiol. 25: 441-452. (Hort. Abst. 20: 2775. 1950.)

48. Janes, B.E. and W. O. Drinkwater. 1959. Irrigation studies on vegetables in Connecticut. Bull. Conn. Agric. Exp. Sta. 338. 82p. (Hort. Abst. 30: 604. 1960.)

49. Jankovskaja, N.M. 1967. The effect of fertilizers on the chemical composition of cabbages and carrots. Himija sel'. Hoz. 5: 11-13. (Hort. Abst. 38: 5483. 1968.)

50. Khupse, V.S. and S.D. Kalke. 1968. Growth and yield of cabbage as influenced by the application of nitrophosphate and ammonium sulphate and superphosphate combined. Poona Agric. Coll. Mag. 58: 26-32. (Hort. Abst. 39: 4676. 1969.)

51. Kimbrough, W.D. 1936. Effect of source of nitrate-nitrogen and a mixture of minor plant nutrients on the growth of cabbage plants in pots. Proc. Amer. Soc. Hort. Sci. 34: 488-492.

52. Kudzjaveca, A.A. 1940. The effect of potassic fertilizers on vegetable yield and quality. Vestnik Ovoscevodsvo i Kartofel'. 3: 72-85. (Hort. Abst. 13: 1335. 1943.)

53. Kurdina, V.N. 1957. The effect of the dates of sowing on the yield, chemical composition and storage quality of carrots. Dokl. Mosk. s-h. Akad. im. K.A. Timiryazcva. 28: 380-385. (Hort. Abst. 29: 3654. 1959.)

54. Lantz, E.M. 1949. Carotene and ascorbic acids in carrots during growth, storage and cooking. New. Mex. Agric. Exp. Sta. Bull. 350. 1-18.

55. Laverton, S. 1964. Irrigation. Its profitable use for agriculture and horticultural crops. London Oxford Univ. Press. 166p.

56. Lemke, M. 1941. Investigations on the quality of stored vegetables. Gartenbauwiss 16: 129-135. (Hort. Abst. 12: 1532. 1942.)

57. Lentz, C.P. 1966. Moisture loss of carrots under refrigerated storage. Food Technol. 20: 553-556. (Hort. Abst. 37: 1097. 1967.)

58. Lyall, L.H. 1964. Houston Evergreen cabbage. Food Res. Notes. 12: 3. (Hort. Abst. 35: 918. 1965.)

59. Man, K.S. and B.S. Sandhu. 1956. On the nitrogen requirements, of cabbage. Indian J. Hort. 12: 188-195. (Hort. Abst. 26: 3720. 1956.)

60. Mann, L.K. and J. H. MacGillivray. 1949. Some factors affecting the size of carrot roots. Proc. Amer. Soc. Hort. Sci. 54: 311-318.

61. Mǎskovič, I.K. 1963. The influence of growing conditions on the keeping quality of cabbages. Dokl. Mosk. Sel'. -hoz. Akad. K. A. Timirjazeva 83: 306-310. (Hort. Abst. 34: 6702. 1964.)

62. Matuura, H. 1960. A study on the year round culture of vegetables containing pigments other than chlorophyll. No. 2. The influence of temperature and fertilization on the growth, coloring and sugar content of Sanzun carrots. Bull. Kanagawa Agric. Exp. Sta. Hort. Branch. 8: 41-47. (Hort. Abst. 31: 2534. 1961.)

63. McMurtrey, J.E. 1948. Visual symptoms of malnutrition in plants. Diagnostic techniques for soils and crops. American Potash Inst., Washington. 231-289.

64. Nettles, V.F., F.S. Jamison and B.E. Janes. 1952. Irrigation and other cultural studies with cabbage, sweet corn, snap beans, onions, tomatoes and cucumbers. Agric. Exp. Sta. Univ. Fla., Gainesville. Bull. 495. 26p.

65. Nicolaison, W. and R. Haar. 1964. Investigations into the effect of nitrate manuring on the total nitrogen and nitrate content of carrots. Gartenbauwiss. 29: 463-480. (Hort. Abst. 35: 5822. 1965.)

66. Niemann, J. 1955. A contribution to the nutrition of garden carrot, with particular reference to water relations. Z. Pflernahr. Dung. 71: 19-33. (Hort. Abst. 27: 2469. 1957.)

67. Nowosad, F.S., J.D. Warren, I.D. Hoffman and R.B. Carson. 1967. An evaluation of vegetables grown in the eastern Arctic region of Canada. Canada Dept. Agric. Publ. 1336. 50p.

68. Odland, T.E. and T.R. Cox. 1942. Field experiments with phosphate fertilizers. Bull. R.I. Agric. Exp. Sta. 281. 27p. (Hort. Abst. 13: 459. 1943.)

69. Osawa, T. 1962. Studies on the sodium chloride injury of vegetable crops in relation to the form of nitrogen and sand culture. II. In some leaf vegetables and root vegetables. J. Jap. Soc. Hort. Sci. 31: 157-167. (Hort. Abst. 33: 2851. 1963.

70. Penningsfeld, F. and L. Forchthammer. 1961. The reaction of the main types of vegetables to variable nutrient ratios in manuring; a report of two years pot trials with nine vegetables. Gartenbauwiss 26: 347-372. (Hort. Abst. 33: 2848. 1963.)

71. Pew, W.D. 1957. Carrots in Arizona. Agric. Exp. Sta., Univ. Ariz., Tucson. Bull. 285. 25p.

72. Platenius, H. 1934. Physiological and chemical changes in carrots during growth and storage. Mem. Cornell Agric. Exp. Sta. Bull. 161. 18p. (Hort. Abst. 4: 594. 1934.)

73. Poapst, P.A. and W.R. Phillips. 1955-1956. Storage of carrots in polyethylene bags. Rep. Canada Committee Fruit Veg. Pres. p.4. (Hort. Abst. 27: 493. 1957.)

74. Pollard, A. 1941-1942. Note on the effect of manurial treatments on the carotene content of carrot roots. Ann. Rep. Long Ashton Hort. Res. Sta. p.32. (Hort. Abst. 12: 949. 1942.)

75. Purvis, E.R. and R.L. Carolus. 1964. Nutrient deficiencies in vegetable crops. Hunger signs in crops. David McKay Co. Third Ed. 461p.

76. Ram, K. and R.K. Sharma. 1969. Effect of nitrogen supply on growth, yield and ascorbic acid content of cabbage. Poona Agric. Coll. Mag. 59: 25-29. (Hort. Abst. 40: 6119. 1970.)

77. Roll-Hansen, J. 1966. Trials on carrot fertilization. Gartneryrket 56: 90-92. (Hort. Abst. 36: 6762. 1966.)

78. Saburov, N.V., E.P. Širokov and M. N. Rodin. 1964. Organization of long storage of cabbage. Izv. Timirjazev. Sel'sk. Akad. 4: 74-87. (Hort. Abst. 35: 3315. 1965.)

79. Saburov, N.V. and S. Sirtautajte. 1966. The storage life of carrots in relation to maturity. Izv. Timirjazev. Sel'. -hoz. Akad. 5: 121-134. (Hort. Abst.37: 5075. 1967.)

80. Salter, P.J. and J.E. Goode. 1967. Crop response to water at different stages of growth. Research Review No. 2. Comm. Bur. Hort. Plant. Crops, East Malling. 87-88.

81. Sayre, C.B. 1934. Root development of beans, cabbage and tomatoes as affected by fertilizer placement. Proc. Amer. Soc. Hort. Sci. 32: 564-571.

82. Scharrer, K. and R. Burke. 1953. The effect of nutrition on provitamin A (carotene) formation in cultivated plants. Z. Pflernahr. Dung. 62: 244-262. (Hort. Abst. 24: 3413. 1953.)

83. Shafer, J.Jr. and C.B. Sayre. 1946. Internal breakdown of cabbage as related to nitrogen fertilizer and yield. Proc. Amer. Soc. Hort. Sci. 47: 340-342.

84. Shaw, E.J. 1965. Diagnostic tests for soil and crop problems. Western fertilizer handbook. California Fertilizer Association Soil Improvement Committee. Fourth Ed. 200p.

85. Širokov, E.P. 1962. The redistribution of organic substances in cabbage heads during storage. Dokl. Mosk. Sel'. -hoz. Akad. K.A. Timirjazeva 77: 465-470. (Hort. Abst. 34: 2705. 1964.)

86. Širokov, E.P. 1966. Cooling cabbage with air at sub-zero temperatures during storage. Izv. Timirjazev. Sel'. -hoz. Akad. 6: 218-224. (Hort. Abst. 37: 4804. 1967.)

87. Sistrunk, W.A., G.A. Bradley and D. Smittle. 1967. Influence of pre-harvest factors on carbohydrates in carrots. Proc. Amer. Soc. Hort. Sci. 90: 239-251. 1949.

88. Smith, J.B. and M. Salomon. 1949. Optimum soil-nitrate levels for celery, carrots, spinach, onions and beets at different growth levels. Bull. R.I. Agric. Exp. Sta. 300. 27p. (Hort. Abst. 19: 2094. 1949.)

89. Somos, A. 1952 (issued 1954). Results of irrigation trials with winter cabbage. Agrartud. Egy. 16: 3-25. (Hort. Abst. 26: 561. 1956.)

90. Southards, C.J. and C.H. Miller. 1962. A greenhouse study on the macroelement nutrition of the carrot. Proc. Amer. Soc. Hort. Sci. 81: 335-340.

91. Thomas, J.R. and L.N. Namken. 1969. Yield and mineral composition of cabbage in relation to nitrogen and water supply. HortSci. 4(2) Section 2: 185

92. Tsai, M.J. 1969. The effects of nitrogen, phosphate and potash application on carrots, potatoes and sweet corn. M. Sc. thesis. Univ. of Sask., Saskatoon.

93. Vaidya, S.J. and A.V. Patil. 1965. Influence of date of transplanting and age of seedling on growth, yield and quality of cabbage. II. Indian J. Agron. 10: 420-422. (Hort. Abst. 37: 811. 1967.)

94. Van den Berg, L. and C.P. Lentz. 1966. Effect of temperature, relative humidity and atmospheric composition on changes in quality of carrots during storage. Food Technol. 20: 954-957. (Hort. Abst. 37: 1098. 1967.

95. Vihtenko, I.I. 1959. The effectiveness of fertilizers on cabbage plants irrigated with subterranean water in the condition of the Donbas region. Izv. Timirirjazev. seljsk. Akad. 4: 235-240. (Hort. Abst. 30: 2145. 1960.)

96. Vittum, M.T., R.B. Alderfer, B.E. Janes, C.W. Reynolds and R.A. Struchtemeyer. 1963. Soil-plant water relationship as a basis for irrigation. Crop response to irrigation in the north-east. New York State Agric. Exp. Sta., Geneva. Bull 800. 66p.

97. Vittum, M.T. and N.H. Peck. 1956. Response to irrigation, fertility level, and spacing. New York State Agric. Exp. Sta., Cornell Univ., Geneva. Bull. 777. 34p.

98. Volk, G.M., C.E. Bell and E.N. McCubbin. 1947. The significance and maintenance of nitrate-nitrogen in Bladen fine sandy loam in the production of cabbage. Bull. Fla. Agric. Exp. Sta. 430. 22p. (Hort. Abst. 19: 1234. 1949.)

99. Wagner, M. and V. Beneš. 1955. The influence of spacing on the yield of carrots. Sborn. Csl. Akad. Zemed. Ved. Rostl. Vyroba 28: 117-124. (Hort. Abst. 26:665. 1956.)

100. Wallace, T., H.E. Croxall and P.T.H. Pickford. 1941-1942. Manurial experiments on vegetable crops. 1. Effects of farmyard manure and of various fertilizer treatments on savoys and carrots. Ann. Rep. Long Ashton Agric. Hort. Res. Sta. 25-31. (Hort. Abst. 12: 959. 1942.)

101. Warne, L.G.G. 1953. Spacing experiments on vegetables. VII. The growth and yield of globe beet, parsnips and carrots grown at several spacings in two adjacent fields of different fertility. J. Hort. Sci. 28: 114-120.

102. Weaver, J.E. and W.E. Bruner. 1927. Root development of vegetable crops. McGraw Hill Book Co. 351p.

103. Wolf, E. 1955. The effect of duration of growth and increasing nutrient applications on the carotene content and vitamin C content of carrots and celeriac. Landw. Forschung 7: 139-143. (Hort. Abst. 25: 2920. 1955.)

104. Woodman, R.M. 1941. The nutrition of the spring cabbage. Ann. Appl. Biol. 28: 181-188. (Hort. Abst. 11: 1242. 1941.)

105. Woodman, R.M. 1943. The nutrition of the carrot. Ann. Appl. Biol. 30: 1-7. (Hort. Abst. 13: 909. 1943.)

106. Woodman, R.M. and D.A. Johnson. 1946. The nutrition of the carrot. III. Grown in a gravel soil. J. Agric. Sci. 36: 10-17. (Hort. Abst. 16: 2080. 1946.)

107. Woodman, R.M. and H. Paver. 1945. The nutrition of the carrot. II. Growth in a fen soil. J. Agric. Sci. 35: 30-32. (Hort. Abst. 15: 680. 1945.)

108. Ziegler, G. and H. Böttcher. 1966. The influence of potassium fertilization on the keeping quality and quality maintenance during the storage of carrots. Arch. Gartenb. 14: 493-511. (Hort. Abst. 38: 1152. 1968.)

109. Ziegler, G. and H. Böttcher. 1966. A contribution to the effects of nitrogen and potassium on the yield and keeping quality of white cabbage. Arch. Gartenb. 14: 513-535. (Hort. Abst. 38: 860. 1968.)

# APPENDIX

Table 1: Per Cent Oversize Carrots by Weight, 1969.

| Treatment | Replicate 1 | Replicate 2 | Replicate 3 | Replicate 4 | Total |
|---|---|---|---|---|---|
| $N_0P_0$ | 10.97 | 9.72 | 17.87 | 19.26 | 57.82 |
| $P_1$ | 6.81 | 6.31 | 12.46 | 9.27 | 34.85 |
| $P_2$ | 8.06 | 11.58 | 10.83 | 12.20 | 42.67 |
| $N_1P_0$ | 6.74 | 7.18 | 7.89 | 10.94 | 32.75 |
| $P_1$ | 8.63 | 11.85 | 15.29 | 8.29 | 44.06 |
| $P_2$ | 8.99 | 8.78 | 11.07 | 11.89 | 40.73 |
| $N_2P_0$ | 8.97 | 5.61 | 11.24 | 5.92 | 31.74 |
| $P_1$ | 7.58 | 6.58 | 11.81 | 6.04 | 32.01 |
| $P_2$ | 6.62 | 8.04 | 5.26 | 11.87 | 31.79 |
| $N_3P_0$ | 5.91 | 5.72 | 5.87 | 8.52 | 26.02 |
| $P_1$ | 4.50 | 7.06 | 8.72 | 4.40 | 24.68 |
| $P_2$ | 7.62 | 5.41 | 5.80 | 6.03 | 24.86 |
| Total | 91.40 | 93.84 | 124.11 | 114.63 | 423.98 |

Analysis of Variance

| Source | Sum of squares | Degrees of freedom | Mean square | Calculated F |
|---|---|---|---|---|
| Replicates | 66.6228 | 3 | 21.2076 | 3.95* |
| Treatments | 254.5242 | 11 | 23.1385 | 4.31** |
| N | 169.1677 | 3 | 56.3892 | 10.49** |
| P | 5.2169 | 2 | 2.6084 | 0.49 |
| N x P | 80.1396 | 6 | 13.3566 | 2.48* |
| Error | 177.2684 | 33 | 5.3717 | |
| Total | 495.4154 | 47 | | |

Table II: Per Cent Split and Forked Carrots by Number, 1969.

| Treatment | Replicate 1 | Replicate 2 | Replicate 3 | Replicate 4 | Total |
|---|---|---|---|---|---|
| $N_0P_0$ | 2.53 | 3.10 | 2.08 | 3.39 | 11.10 |
| $P_1$ | 1.85 | 2.64 | 1.39 | 3.18 | 9.06 |
| $P_2$ | 2.39 | 3.76 | 2.39 | 2.22 | 10.76 |
| $N_1P_0$ | 3.78 | 2.27 | 2.63 | 3.29 | 11.97 |
| $P_1$ | 1.32 | 3.57 | 3.49 | 1.58 | 9.96 |
| $P_2$ | 1.88 | 3.60 | 1.96 | 2.82 | 10.26 |
| $N_2P_0$ | 3.26 | 2.98 | 5.27 | 1.87 | 13.38 |
| $P_1$ | 2.93 | 4.30 | 5.68 | 2.59 | 15.50 |
| $P_2$ | 1.53 | 2.02 | 5.05 | 5.09 | 13.69 |
| $N_3P_0$ | 1.71 | 2.92 | 3.35 | 5.07 | 13.05 |
| $P_1$ | 2.12 | 4.34 | 1.94 | 4.05 | 12.45 |
| $P_2$ | 2.78 | 4.89 | 2.72 | 3.35 | 13.74 |
| Total | 28.08 | 40.39 | 37.95 | 38.50 | 144.92 |

Analysis of Variance

| Source | Sum of squares | Degrees of freedom | Mean square | Calculated F |
|---|---|---|---|---|
| Replicates | 7.6553 | 3 | 2.5517 | 2.05 |
| Treatments | 9.8635 | 11 | 0.8967 | 0.72 |
| N | 7.8144 | 3 | 2.6048 | 2.09 |
| P | 0.2020 | 2 | 0.1010 | 0.03 |
| N x P | 1.8471 | 6 | 3.0785 | 2.47* |
| Error | 41.1208 | 33 | 1.2460 | |
| Total | 58,6436 | 47 | | |

Table III: Nitrogen Content in Carrot Roots, 1970.

| Treatment | Replicate 1 | Replicate 2 | Replicate 3 | Replicate 4 | Total |
|---|---|---|---|---|---|
| $N_0P_0$ | 0.80 | 0.95 | 0.60 | 0.84 | 3.19 |
| $P_1$ | 0.71 | 0.71 | 0.69 | 0.77 | 2.88 |
| $P_2$ | 0.46 | 0.76 | 0.67 | 0.63 | 2.52 |
| $N_1P_0$ | 1.23 | 0.57 | 0.77 | 0.64 | 3.21 |
| $P_1$ | 0.80 | 1.16 | 0.76 | 0.70 | 3.42 |
| $P_2$ | 0.46 | 0.80 | 0.71 | 0.69 | 2.66 |
| $N_2P_0$ | 1.05 | 1.11 | 1.13 | 0.57 | 3.88 |
| $P_1$ | 0.96 | 0.84 | 1.57 | 0.70 | 4.07 |
| $P_2$ | 0.77 | 0.94 | 0.67 | 0.62 | 3.00 |
| $N_3P_0$ | 1.23 | 1.12 | 0.88 | 0.95 | 4.18 |
| $P_1$ | 1.15 | 0.76 | 0.95 | 1.30 | 4.16 |
| $P_2$ | 1.18 | 0.91 | 0.91 | 1.32 | 4.32 |
| Total | 10.80 | 10.63 | 10.31 | 9.73 | 41.47 |

Analysis of Variance

| Source | Sum of squares | Degrees of freedom | Mean square | Calculated F |
|---|---|---|---|---|
| Replicates | 0.0554 | 3 | 0.0185 | 0.38 |
| Treatments | 1.1220 | 11 | 0.1020 | 2.12* |
| N | 0.8243 | 3 | 0.2748 | 5.71** |
| P | 0.1643 | 2 | 0.0822 | 1.70 |
| N x P | 0.1334 | 6 | 0.2223 | 4.62** |
| Error | 1.5859 | 33 | 0.0481 | |
| Total | 2.7633 | 47 | | |