SOME INFLUENCES OF MINERAL NUTRITION ON THE GROWTH AND CHEMICAL COMPOSITION OF *ASPARAGUS OFFICINALIS*

Thesis for the Degree of Ph. D.

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Lindsay Dietrich Brown

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ASPARAGUS OFFICINALIS

By

Lindsay Dietrich Brown

AN ABSTRACT

Submitted to Michigan State University
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Thirty commercial asparagus growers were contacted and data obtained on spear yield, fern growth, and management practices used. Spear and fern samples were taken periodically and analyzed for composition in terms of N, P, K, Ca, Mg, Mn, Fe, Cu, B, Zn, Mo, and Al.

Field experiments were also conducted with five-year old Viking and eleven-year old Mary Washington asparagus varieties, in which yield, fern growth, and chemical composition were evaluated. Radioactive phosphorus was employed to trace utilization of fertilizer applied to the soil. In addition, sand culture experiments were performed to study the effects of mineral nutrition on growth and composition of one-year old asparagus plants and to measure the influence of continuous removal of top growth on crown composition.

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The following results were obtained:

1. Based on an average yield of 2,300 pounds per acre of snapped asparagus, annual removal of N, P, and K amounted to 10, 2, and 7 pounds, respectively. These figures represented less than 10 per cent of the average quantities applied by the cooperating growers. No correlation was found between fertilizer applied and yields obtained.
2. Neither five-year old Viking nor eleven-year old Mary Washington asparagus showed any significant yield variation attributable to varying rates of fertilizer application.
3. Field grown asparagus utilized a maximum of 0.06 per cent of the phosphorus applied in producing the harvested crop and this amounted to only 3.0 per cent of the total P content of the spears.
4. Two- and three-year old asparagus plants grown in sand culture responded in growth to increased phosphorus application in the first year and to increased nitrogen application in both years of the study.
5. Removal of all aerial growth as it appeared and continued leaching with distilled water of four-year old asparagus grown in sand culture failed to change the composition of variably fertilized crowns during one season.

6. In field grown asparagus spear and fern composition on a dry weight basis were found to vary between the following limits:

Spears: N, 7.2 to 5.1; P, .99 to .79; K, 4.9 to 3.8; Ca, .38 to .21; and Mg, .24 to .13 per cent of dry weight. Mn, 71 to 16; Fe, 500 to 78; Cu, 35 to 10; B, 36 to 20; Zn, 112 to 61; Mo, 2 to 1; and Al, 94 to 15 parts per million.

Fern: N, 3.3 to 1.7; P, .32 to .13; K, 3.5 to 1.1; Ca, 1.4 to 0.4; and Mg, .55 to .12 per cent of dry weight. Mn, 145 to 15; Fe 289 to 60; Cu, 27 to 4; B, 91 to 21; Zn, 38 to 16; Mo, 4 to 2; and Al, 361 to 101 parts per million.

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INTRODUCTION

Asparagus grown for processing in the United States increased from 30,000 to 90,000 acres between 1925 and 1950 and in the last decade acreage has expanded another 15 to 20 per cent. Michigan had over 11,000 acres in 1960, with an annual production valued at over three million dollars.

Increasing labor costs and declining prices have expedited the development and acceptance of improved cultural practices. Harvesting by snapping versus cutting is almost universal in Michigan (18) 1958, as is the use of herbicides for controlling weeds (47) 1954. Purchase and application of chemical fertilizers, however, remain among the major fixed costs in asparagus production, and thus justify continued nutritional research.

The present study was initiated to determine the current nutritional status of the crop in terms of its mineral composition and thus its requirements for and utilization of applied fertilizers. In addition, it was designed to ascertain if variable fertilization can significantly alter the composition of the plant and the marketable yields obtained.

In this dissertation procedures used and results obtained are presented in four major sections preceded by a brief description of materials and methods.

REVIEW OF LITERATURE

According to Sturtevant (61) 1919, the native home of asparagus is Europe--the Caucasus regions and Crimea, while Henderson says in his *Handbook of Plants* that,

> The garden asparagus, *A. officinalis* is a native of Great Britain, Russia and Poland. The asparagus is one of the oldest as well as one of the most delicious of our garden vegetables. It was cultivated in the time of Cato the Elder, 200 B. C.; and Pliny mentions a sort that grew in his time near Ravenna, of which three heads would weigh a pound. (26) 1890.

Jones and Rosa (30) 1928, report more prosaically that,

> The genus *Asparagus* comprises about 150 species spread throughout the temperate and tropical regions of the Old World. All species of *Asparagus* are perennial, have fleshy or tuberous roots, and possess cladophylls, which function as leaves. *A. officinalis* is the only one cultivated as a food plant. . . . The underground portion of the asparagus plant consists of rhizomes, fleshy roots and fibrous roots. The fleshy roots may spread laterally a distance of 10 to 12 feet as they grow outward and downward. They will grow to a depth of at least eight feet and may go deeper unless a permanent water table is encountered at a higher level. The fleshy roots, being covered with root hairs function both as storage and absorptive organs. New fleshy roots arise each year just back of the terminal buds of the rhizomes; from these, fibrous roots arise which function as absorptive organs only. The fibrous roots die in late fall at the close of the growing season, and new ones develop the following spring. It is chiefly within the fleshy roots that the food supply is stored for the production of the commercial crop the following year.

Remy (49) 1938, postulates this same mechanism for

perennial grasses in general. Asparagus is a monocotyledonous plant (of the Liliaceae family) as are all grasses. Tiedjens (64) 1926, suggests that for a single year's growth asparagus needs only water and oxygen from the soil.

Jones and Rosa say,

> The asparagus plant has underground stems (rhizomes) and aerial stems arising from them. At the base of each aerial shoot, there are one or more lateral buds separated by very short internodes. The branches of the underground stem grow outward and upward; the more deeply the plant is set, the more nearly vertical is the growth of the rhizome toward the surface.

Young (68) 1939, reported an experiment in which asparagus crowns were initially planted at 2, 4, 6, and 8 inches depth. At the end of 11 years those set 2 inches deep at planting were found at a mean depth of 3.68 $\pm$ 0.26 inches and those at 8 averaged 4.35 $\pm$ 0.34 inches deep. Yields were higher from the shallow planting.

> The branches of the rhizome grow 1 to 2 inches each year. A 15-year old plant may have a rhizome spread of 2 feet or more. After the cutting season, during the summer and fall, most of the buds are formed which produce the edible spears the following spring. (30) 1928.

The standard practice in Michigan is to allow the spears that emerge after the normal harvest season to mature into the "fern" on which the flowers and fruit are borne. Asparagus is normally dioecious and the flowers occur in the axils of the scale leaves. In the primordial stages of development either the male or female sex organs are aborted and all the flowers on a given plant then become either functionally male or female (30) 1928.

In his Manual of Gardening, published four years after this previous work, Bailey (5) 1925, states,

> . . . a top dressing of nitrate of soda, at the rate of 200 pounds per acre, is often beneficial as a spring stimulant, particularly in the case of an old bed. Good results will also follow an application of bone meal or superphosphate at the rate of 300 to 500 pounds per acre.

Brooks and Morse (11) 1919, conducted an asparagus nutrition experiment over a period of seven years, in which N, P_2O_5, and K_2O were applied in various combinations. The lowest yield, 1,681 pounds, was obtained where nitrogen was omitted and the highest, 2,406 pounds, where the three nutrients were all applied at a medium rate, i.e., 467-133-260 pounds per acre. It is doubtful if the differences were truly significant since two other plots receiving this latter treatment yielded 250 to 300 pounds less than the highest.

Wessels and Thompson (65) 1937, reported that in an experiment conducted with carefully selected Mary Washington asparagus,

> Nitrogen produced greater increases in yield than any other element. Plots with no nitrogen produced the lowest yields of any in the experiment even though they received the maximum application of phosphate and potash. . . . Nitrogen applied at 50 pounds per acre produced over nine years practically the same as nitrogen at 100 pounds per acre. In the first four years the larger nitrogen application produced higher yields than the smaller, but the last five years the smaller nitrogen application produced no less asparagus than the larger application.

In addition, they found that plots receiving 128 pounds per acre of P_2O produced more asparagus each year than plots

Tiedjens (63) 1924, Haber (24) 1932, and Jones and Rosa (30) 1928, all indicate that pistillate plants produce larger spears and stalks than staminate plants, but that the latter produce more spears per plant. Young (67) 1937, found that there was a positive correlation in number and size of fern stalks and spear production the following spring and Tiedjens (63) 1924, states,

> There is a positive correlation between the number of mature fall stalks and the number of buds produced the following season . . .

but also that,

> The data reveal plants having eight mature fall stalks and only producing one spear the following year. Also plants with only one mature fall stalk produced 20 spears the following year. There are examples of all possible gradations between these.

The fertility requirement of asparagus has occupied many workers over the years and while there have been divergent opinions on the requirements for various nutrients, most researchers have recommended continued applications of complete fertilizers. Liberty Hyde Bailey (3) 1921, says,

> A deep, rich, fertile, moist, cool soil, warm exposure, thorough preparation of the land, heavy manuring, thorough tillage in late fall and early spring, are general requisites of asparagus culture.

He then says,

> After the plantation is established, a commonplace practice among market gardeners is to apply 20 to 40 tons of manure to the acre broadcast over the bed during the autumn or winter. In addition, . . . a good complete fertilizer at the rate of 1,000 to 1,500 pounds to the acre at the close of the cutting season (is recommended).

receiving no phosphate or phosphate at 64 pounds per acre.

Potash (K_2O) at 160 pounds per acre produced considerably larger yields for the first five years than it did at 80 pounds per acre, but for the next two seasons the yields did not differ and for the last two years the lower rate of application resulted in the larger yields.

White and Boswell (66) 1929, reported on field and sand culture experiments in which a chemical fertilizer (7-3-5), applied at 1,250 pounds per acre, gave significant increases over 10 tons of animal manure. Both increased yields significantly over the untreated check plots.

Seaton (55) 1932, found that with selected Mary Washington asparagus planted in 1926 and fertilized from 1929 through 1932, the maximum yield increase over the untreated check was obtained with 1,200 pounds per acre of 4-8-6 applied in a split application, half before and half after harvest.

Rahn (47) 1939, reported an experiment similar to that of White and Boswell in which chemical fertilizers were compared with animal manures. Average yields over a four-year period ranged from 3,538 pounds for plots receiving 1,500 pounds per acre of 4-20-6 (the largest phosphate application) to 3,860 pounds from plots receiving 1,500 pounds per acre of 4-10-6 plus 10 tons of manure. This suggests the possibility of too much phosphorus being a detrimental factor, as reported by Hester (27) 1947, for several truck crops and Reuther et al. (50) 1949, for citrus. However, Rahn's results actually varied only over a narrow range and the differences reported may lack statistical significance.

Clore (16) 1944, says,

> Annual applications of 200 pounds of available nitrogen in the form of ammonium sulphate increased the average asparagus yields 0.65 tons per acre over no treatment during the years 1940 to 1943, inclusive. . . . Thus far these experiments have shown no significant differences in total yield of asparagus as a result of the time of application of nitrogen.

In this connection, the work of Graber (23) 1931, on blue grass, red top, fescue, and timothy is pertinent, in which he said,

> Frequent and close removal of the succulent top growth of grasses having abundant reserves make for a heavy draft on the supplies of available nitrogen in the soil so that the first important factor of growth limitation may be nitrogen deficiency.

Clore and Stanberry (17) 1947, commenced fertilizing a previously untreated seven-year old asparagus planting with nitrogen alone and nitrogen and phosphate together in 1944 and continued this through 1946. At the end of the first year of treatment, the N-P plots averaged about 200 pounds more asparagus per acre than the N only plots which, in turn, outyielded the check plots by about 300 pounds per acre. At the end of the experiment the above differences in yield appeared to have increased by about 20 per cent.

Brasher (8) 1954, reported that while all fertilizer treatments were superior to the untreated checks in yield of cut asparagus, the 800 pounds per acre rate of application of 5-10-10 was significantly better than either the 1,600 or

2,400 pound rate in an experiment begun on three-year old plants in 1948 and terminated in 1954. On the same plots, in one more year the 800 and 1,600 pound rates no longer differed significantly and when the method of culture and weed control was altered, all yield differences between treated plots, based on three year averages, disappeared (9) 1960. Roorda van Eysinga (53) 1960, also found that established asparagus needed limited fertilization.

Rudolphs (54) 1921, reported an increase in average spear weight with applications of 300 and 500 pounds per acre of rock salt, and Bailey (5) 1925, said,

> The practice of sowing salt on an asparagus bed is almost universal; yet beds which have never received a pound of salt are found to be as productive as those having received an annual dressing. Neverthe-less, a salt dressing is recommended.

Hester (28) 1949, analyzed asparagus spears and reported fertilizer utilization in terms of pounds of nutrients removed by two tons of cut asparagus, e.g., 16 of nitrogen, 4 of phosphate, 10 of potash, and 1 of calcium. Brooks and Morse (11) 1919, published a similar study on asparagus with comparable results.

Comparatively, these are small quantities, as a review by Romaine (52) 1957, reported 200-80-400 pounds, respectively, of nitrogen, phosphate, and potash in a 20 ton yield of tomatoes or 160-130-470 for 700 crates of celery. More comparable figures were obtained for grapes (five tons per acre) containing 35-15-45 pounds of N-P_2O_5-K_2O and 500 bushels of apples containing 45-15-55 of these three nutrient materials.

Kramer and Kozlowski (32) 1960, have summarized data for total uptake by conifers and hardwoods of P, K and Ca as well as the quantities of these elements returned annually in leaf fall: Conifers: 66, 306, and 581 pounds per acre total uptake and 2, 6, and 26 pounds per acre returned in annual leaf fall. Hardwoods: 64, 277, and 1,019 pounds per acre total uptake and 3, 13, and 66 pounds per acre returned in annual leaf fall. Thus, it appears that the nutrients returned to the soil over a period of years more than compensate for amounts utilized in the permanent growth of the tree. A similar computation, reported by Gardner et al. (22) 1952, for phosphorus utilization by 100-year old apple trees reveals 47 pounds of elemental P in the 27 trees on an acre with an annual return of four pounds in the leaf fall.

Also with tree fruits, Lilleland (35) 1935, and Lilleland and Brown (36) 1939, obtained positive growth responses to phosphate application on one-year old apple, peach, and prune trees, but not when the same treatments were applied to three-year old trees. Phosphorus content of the leaves was positively influenced by these treatments in the younger trees but not in the older ones. Lilleland et al. (37) 1942, reported,

> Eighteen different annual crops were tested and failed to make satisfactory growth unless phosphate was added. Established fruit trees, however, showed no response to phosphate in the same soil and their growth, yield and quality of fruit were comparable to those obtained on the more fertile soils of California.

Proebsting and Kinman (46) 1933, and Potter (45) 1934,

conducted orchard trials with phosphate on apricots and mature Baldwin apples, respectively, and both found that the responses to the application of phosphate did not justify the cost.

In the past 20 years the availability of the radioactive isotope P^{32} has made more precise studies of plant utilization of applied phosphorus possible. Lawton (33) 1958, using 30 pounds per acre of tagged P_2O_5 on field grown corn, found that after 45 days of growth plant phosphorus from applied fertilizer amount to 30 per cent of the total. Nelson et al. (43) 1947, in an extensive study of phosphorus utilization, found that the percentage of the phosphorus in the plant that was derived from the applied fertilizer attained maxima of 45 for cotton, 63 for potatoes and corn, and 65 for tobacco. These values were recorded 30 days after planting for corn, cotton, and tobacco, and after 38 days for potatoes. In young field grown wheat, Spinks and Barber (59) 1947, found that up to 21 per cent of the total phosphorus in the plant was from the current application.

In a greenhouse study Lawton, Erickson, and Lemon (34) 1952, found that at final harvest, after 60 days of growth, the tomato plant had obtained up to 70 per cent of its total phosphorus from the fertilizer treatment.

Eggert, Kardos, and Smith (21) 1952, however, applied P^{32} labelled fertilizer to six 25-year old apple trees and found that determination of the total phosphorus content of fruit cores, terminal and spur leaves showed no P^{32} in four

trees, and less than 3 and approximately 6 per cent in the other two trees, respectively.

In conclusion, there appears to be some disagreement among investigators as to the fertilizer requirement of asparagus, but the evidence indicates a reduced response to applied fertilizer as the plants grow older (10, 53, 65). Several studies (11, 65) suggest that nitrogen is the most critical of the nutrients commonly applied and that phosphorus elicits little response from perennial plants after the first few years of growth (35, 37). Hester (28) 1949, and Brooks and Morse (11) 1919, computed nutrient utilization by asparagus, and Brasher (8) 1954, discusses it briefly, but no attempt has been made to establish fertilizer recommendations on the basis of this information.

MATERIALS AND METHODS -- GENERAL

Sampling Procedures

For spear analysis, the edible portion of 20 spears was used except in the P^{32} tracer study.

Mature fern samples, consisting of two male and two female stems of green fern of a size considered average for the particular planting, were cut into approximately three-inch sections and alternate sections dreied in large paper bags. Side branches and fruit were included with the main stem in the cutting process.

Chemical Analyses

All samples taken for analysis were dried at approximately 70°C. for several days, ground to pass a 20-mesh screen, and an aliquot stored for analysis.

Nitrogen was determined using the Kjeldahl-Gunning-Arnold method (1) and potassium using a flame photometric technique on water extracts of dried plant tissue (2).

Phosphorus in the samples collected from the P^{32} experiment was determined colorimetrically by Lindner's (38) method, modified to use an ammonium vanadate reductant instead of stannous chloride.

The remainder of the analyses were accomplished on

emission spectrographic equipment in the Departments of Agricultural Chemistry in 1958, and Horticulture in 1959 and 1960. Samples were prepared for analysis by ashing one-half gram aliquots at 550°C. in a muffle furnace for 12 to 15 hours. The ashed material was then taken up in an HCl solution containing cobalt as an internal standard. Concentrations of phosphorus, calcium, magnesium, manganese, iron, copper, boron, zinc, molybdenum, and aluminum were determined by excitation of aliquots of the HCl-ash solution using an A.C. spark (31).

Phosphorus in soil samples were determined using Bray's P-1 method while active K and Mg were determined with the Spurway method (60), using an extractant. The pH values were obtained from a soil:water suspension using the glass electrode technique (58).

Statistical Procedures

With the exception of the data obtained in the nutritional survey and some of that from the P^{32} experiment, differences between treatment means were tested using the analysis of variance technique appropriate to the experimental design employed (44, 57). Where significant "F" values were obtained, the means were separated using Duncan's Multiple Range Test (20).

A NUTRITIONAL SURVEY OF THE COMMERCIAL ASPARAGUS CROP

To study the current nutritional status of established asparagus plants growing in the most representative geographic area, which in Michigan is the southwestern part of the state where over three-fourths of the commercial crop is grown, were sampled.

Materials and Methods

Asparagus growers in Berrien and Van Buren Counties were interviewed to obtain information on management practices, age of plantings, and yield. Thirty farms were selected and a row of asparagus was chosen in a field from each location for use in a survey of the nutritional status of the crop.

In early August, 1958, mature green fern samples and soil samples were taken from a 50-foot long section of row previously staked out. In October, 1958, all the fern growing on 50 feet of the selected row from each farm was cut off at ground level, weighed, and its dry matter determined.

Edible spear samples were collected on May 8 and 29, and on June 15, 1959, from each farm plot. Mature fern samples were again collected in September and information on management and yields for the season obtained. The weight

of mature fern from a 50-foot section of row was again determined.

Samples of edible spears were collected on May 6 and June 6, 1960, from these farms. At the end of the summer, information on cultural practices and yield was again obtained from most of the cooperators. Thus, at the end of this survey, data had been collected on fern growth in 1958 and 1959 and spear production in 1959 and 1960.

The plant samples were analyzed chemically using the procedures previously described and spear samples were composited from all sampling dates.

Complete survey information was used to compute product moment correlations between the variables measured. The computations were performed with the use of a digital computer and as the program available for this type of calculation was limited to 38 variables, it was necessary to separate the data into two problems.

The first problem included as variables the data taken in 1958, age of planting, fertilizer applied, soil test results, fern growth and composition as well as yield of edible spears, spear composition values, and fern growth data from 1959; a total of 29 factors. The second problem consisted of edible spear yield, fertilizer application and fern growth and composition from 1959 and the yield and composition values for edible spears in 1960 (25 factors) as variables.

Results and Discussion

In Table 1 are summarized the measurements taken over a three-year period, grouped into three classes: highest observed value, lowest observed value, and average value obtained from 30 observations.

Age of the plantings surveyed varied from four to fifteen years and averaged around nine years. This is a reflection of the post-World War II boom in asparagus demand which resulted in greatly expanded commercial acreage.

Fertilizer practices varied widely among cooperating growers, evidenced by the extremely large coefficients of variation shown in Table 1.

Soil test values were quite variable also with coefficients of variation of 50 per cent for soil P and 40 per cent for soil K. Growth of fern and yield of spears differed widely between farms, but in both fern and particularly spears, the major nutrient composition was remarkably uniform, reflecting slightly, if at all, the differences noted in application of fertilizer, soil composition, and growth (Table 1).

A survey of climatological data is also presented in Table 1, which represents an average of values recorded at weather stations in the two counties where samples of asparagus were collected. The year 1959 was the warmest from May to September with temperatures averaging about four or five degrees higher than 1958 and 1960. More precipitation

TABLE 1 High, low, and average values for fertilizer application, soil test results and spear and fern yield and composition from 30 asparagus fields.

Variable Measured	High Value 1958	High Value 1959	Low Value 1958	Low Value 1959	Av.[1] Value 1958	Av.[1] Value 1959	C. V. % 1958	C. V. % 1959
Age of planting (years)	15	--	4	--	8.6	--	33	--
N applied (lbs./A.)	425	300	none	none	132	152	57	41
P_2O_5 applied (lbs./A.)	225	250	none	none	86	82	80	90
K_2O applied (lbs./A.)	350	415	none	none	153	144	65	79
Dry wt. of 50' fern (lbs.)	24	38	3	5	13.5	15	39	48
Dry wt. of fern (lbs./A.)	4175	6612	522	870	2350	2610	--	--
Fern composition								
N (% dry wt.)	3.30	2.39	2.32	1.68	2.76	2.07	8	10
P (% dry wt.)	0.32	0.24	0.20	0.13	0.25	0.18	14	15
K (% dry wt.)	3.46	3.35	1.52	1.06	2.74	2.48	15	19
Ca (% dry wt.)	0.93	1.35	0.50	0.45	0.65	0.72	19	24
Mg (% dry wt.)	0.40	0.55	0.12	0.12	0.22	0.22	25	49
Mn (parts per million)	120	145	15	18	44	51	45	51
Fe (parts per million)	235	289	86	60	140	128	29	35
Cu (parts per million)	27	20	9	4	14	7	24	41
B (parts per million)	58	91	21	21	36	47	27	33
Soil pH	6.7	--	4.5	--	5.3	--	9	--
Soil P (lbs./A.)	108	--	8	--	37	--	52	--
Soil K (lbs./A.)	295	--	69	--	146	--	41	--
Soil Mg (lbs./A.)	48	--	8	--	30	--	47	--

[1] Based on 30 observations; individual pH values converted to hydrogen ion concentration for computation of mean.

TABLE 1 (continued)

Variable Measured	High Value 1959	High Value 1960	Low Value 1959	Low Value 1960	Av.1/ Value 1959	Av.1/ Value 1960	C. V. % 1959	C. V. % 1960
Edible yield (lbs./A.)	4500	3700	1000	1000	2380	2282	38	32
Edible yield (dry wt.)	315	259	70	70	167	170		
Spear composition								
N (% dry wt.)	7.21	6.88	6.11	5.10	6.62	5.98	4	6
P (% dry wt.)	0.99	0.95	0.81	0.79	0.91	0.87	5	5
K (% dry wt.)	4.93	4.32	3.90	3.82	4.35	4.00	6	3
Ca (% dry wt.)	0.38	0.32	0.22	0.21	0.30	0.27	13	12
Mg (% dry wt.)	0.24	0.22	0.13	0.17	0.21	0.20	12	8
Mn (parts per million)	71	50	19	16	35	31	33	30
Fe (parts per million)	211	500	85	78	129	164	22	48
Cu (parts per million)	35	30	15	10	27	22	19	18
B (parts per million)	36	33	20	21	28	26	13	11

Climatological Data2/

Month	Temperature - °F. 1958	Temperature - °F. 1959	Temperature - °F. 1960	Precipitation - Inches 1958	Precipitation - Inches 1959	Precipitation - Inches 1960
April	49.1	47.2	51.4	2.62	3.40	3.06
May	58.5	63.6	56.6	2.18	2.75	4.22
June	62.7	70.4	65.7	3.90	2.33	4.63
July	70.8	72.1	70.1	3.33	5.85	2.83
August	70.7	75.9	71.4	2.64	2.14	2.65
September	63.2	67.1	67.8	2.86	3.16	1.31
Total				17.53	19.63	18.70
Average	62.5	66.0	63.8			

1/Based on 30 observations.

2/Data are averages for two representative areas covered in the survey.

was also recorded in 1959, but considerably more rain fell during the harvest months of May and June in 1960 than in either of the other two years. These climatological factors probably exerted some influences on the composition and yield of asparagus sampled. Doubtless the warmer season in 1959 accounted for the higher yields obtained since asparagus growth is temperature sensitive (6). Higher concentrations of the major plant nutrients in the fern in 1959 might be due to more advanced physiological age at the time of sampling brought on by the warmer air temperatures. N, P, K, and Ca were more concentrated in spears taken in 1959 also, but this is most likely due to the greater rainfall during harvest in 1960 which could result in an increased water uptake and consequent dilution of mineral constituents.

All significant correlations from the 680 calculated are shown in Table 2; however, discussion will generally be limited to those found to occur for more than one season since these are probably the most valid, and are summarized in Table 3. Age of planting was highly and positively correlated with soil phosphate content, due to the buildup of this material in long fertilized fields. Age was negatively correlated with Ca concentration in spears during both years of the survey, possibly due to leaching of this element from the relatively acid soils of the asparagus fields sampled.

Phosphate and potash applications were positively and

TABLE 2. Significant linear correlations between measurements in asparagus survey - 1958.

*Variable Measured	Correlated with:			
Age	++ soil P r=.56	- fern Mg r=.40	+ applied N r=.42	-- '59 spear ca r=.47
N appl.	+ age r=.42	++ soil P r=.58		
P_2O_5 appl.	+ applied K r=.39	+ '59 yield r=.43	+ '59 spear Mn r=.41	
K_2O appl.	- fern Fe r=.39	+ applied P =.39	+ '59 spear K r=.41	
Soil pH	-- soil K r=.54	++ soil Mg r=.49	+ fern Mg. r=45	- fern Mn r=.39
	+ '59 spear Mg. r=.40			
P_2O_5	+ fern K r=.44	- fern Mg r=.36	++ applied N r=.58	++ age r=.56
	- '59 spear P r=.38	- '59 spear K r=.42		
K_2O	+ fern K r=.36	- fern Mg r-.39	-- soil pH r=.54	
Mg	++ soil pH r=.49			
Fern growth	++ '59 fern growth r=.48			
N	+ fern P r=.36	++ fern Cu r=.46	+ fern B r=.41	- '59 spear P r=.45
	+ '59 spear Ca r=.43	++ '59 spear cu r=.46	-- '59 spear B r=.51	
P	-- fern Ca r=.64	++ fern Mg r=.48	++ fern B r=.62	+ fern N r=.36
K	-- fern Mg r=.73	+ soil P r=.44	+ soil K r= .36	-- '59 spear Cu r=.46
Ca	-- fern P r=.64			
Mg	+ fern B r=.36	- age r=.40	+ soil pH r=.45	- soil P r=.36
	- soil K r=.39	++ fern P r=.48	-- fern K r=.73	+ '59 spear P r=.39
	+ '59 spear Cu r=.38	+ '59 spear B r=.43		
Mn	- soil pH r=.39	-- '59 spear N r=.59	++ '59 spear Mn r=.75	
Fe	- applied K r=.39	+ '59 spear N r=.43	+ '59 spear Ca r=.39	- '59 spear Mn r=.38
Cu	++ fern N r=.46	++ fern B r=.63	+ '59 spear Cu r=.43	
B	+ fern N r=.41	++ fern P r=.62	+ fern Mg r=.36	++ fern Cu r=.63
	++ '59 spear cu r=.49			

*Correlation coefficients significant (23 d.f.), (+) positive at P = 0.05; (-) negative at P = 0.05; (++) positive at P = 0.01; (--) negative at P = 0.01. r values required for significance:
28 d.f.--r = 0.36 for P = 0.05; r = 0.46 for P = 0.01.
23 d.f.--r = 0.38 for P = 0.05; r = 0.49 for P = 0.01.

TABLE 2 (con't) Significant linear correlations between measurements in asparagus study - 1959

*Variable Measured	Correlated with:			
Age	- '60 spear Ca r=.40			
N appl.	- '60 spear B r=.48			
P_2O_5 appl.	++ appl. K r=.56	+ fern K r-.42	- fern Mg r=.40	
K_2O appl.	++ appl. P r=.56	- '60 spear Mg r=.49	- '60 spear Cu r=.48	
Spear yield	+ '58 appl. P =.43	++ '60 yield r=.66		
N	+ spear P r=.39	-- spear Mn r=.47	-- fern Mn r-.59	+ fern Fe r=.43
P	+ spear N r=.39	++ spear B r=.75	- '58 soil P r=.38	- '58 fern N r=.45
	+ fern Mg r=.39			
K	+ spear Cu r=.39	+ '58 appl. K r=.41	- '58 soil P r=.42	
Cu	+ spear Fe r=.37	+ spear Cu r=.40	-- age r=.46	+ '58 fern N r=.43
	+ '58 fern Fe r=.39			
Mg	+ '58 soil pH r=.40			
Mn	-- spear N r=.47	+ '58 appl. P r=.41	++ '58 fern Mn r=.75	- '58 fern Fe r=.38
Fe	+ spear Ca r=.37			
Cu	+ spear K r=.39	+ spear Ca r=.40	++ '58 fern N r=.46	-- '58 fern K r=.46
	+ '58 fern Mg r=.38	+ '58 fern Cu r=.43	++ '58 fern B r=.49	
B	++ spear P r=.75	-- '58 fern N r=.51	+ '58 fern Mg r=.43	
Fern growth	+ fern K r=.40	++ '58 fern growth r= .48		
N	++ fern P r=.56	++ fern B r=.52		
P	++ fern N r=.56	- fern Cu r=.39	++ fern B r=.53	
K	+ applied P r=.42	+ fern growth r=.40	-- fern Mg r=.49	+ '60 yield r=.39
Ca	+ '60 spear Ca r=.46			
Mg	- applied P r=.40	-- fern K r=.49	+ fern B r=.40	
Mn	++ '60 spear Mn r=.62	- '60 spear Cu r=.42	+ '60 spear B r=.40	
Fe	+ '60 spear P r=.40			
Cu	- fern P r=.39			
B	++ fern N r=.52	++ fern P r=.53	+ fern Mg r=.40	+ '60 spear Cu r=.47

*Correlation coefficients significant (28 or 23 d.f., see page 16 of text), (+) positive at P = 0.05; (-) negative at P = 0.05; (++) positive at P = 0.01; (--) negative at P = 0.01. r values required for significance: 28 d.f.--r = 0.36 for P = 0.05; r = 0.46 for P = 0.01.
23 d.f.--r = 0.38 for P = 0.05; r = 0.49 for P = 0.01.

TABLE 2 (con't) Significant correlations obtained between measurements in asparagus survey - 1960.

*Variable Measured	Correlated with:			
Spear yield	++ '59 yield r=.66	+ '59 fern K r=.39		
Spear N	++ spear K r=.59			
P	++ spear Mg r=.53	+ '59 fern Fe r=.40		
K	++ spear N r=.59	- '59 fern growth r=.40		
Cu	- age r=.40	+ '59 fern Ca r=.46		
Mg	++ spear P r=.53	- '59 fern growth r=.46	-'59 appl. K r=.49	
Mn	++ '59 fern Mn r=.62			
Fe	+ spear Cu r=.41			
Cu	+ spear Fe r=.41	- '59 fern Mn r=.42	+ '59 fern B r=.47	- '59 appl. K r=.48
B	- '59 appl. N r=.48	+ '59 fern Mn r=.40		

*Correlation coefficients significant (23 d.f.), (+) positive at P = 0.05; (-) negative at P = 0.05; (++) positive at P = 0.01; (--) negative at P = 0.01. r values required for significance:

28 d.f.--r = 0.36 for P = 0.05; r = 0.46 for P = 0.01

23 d.f.--r = 0.38 for P = 0.05; r = 0.49 for P = 0.01

consistently correlated with each other, a fact which is not surprising since most of the growers questioned used a mixed fertilizer frequently supplemented with nitrogen. As was implied in Table 1, no consistent yield response to fertilizer was observed.

Spear and fern growth during the first year were positively correlated with themselves in the second year, but not with each other. Yield varied from a low of around one-half ton to over two tons per acre, the former being considerably below the requirement for economic production. Fern production, which has been reported to be directly related to spear production (59, 64), varied even more widely, from around 1,500 to over 17,000 pounds on a fresh weight basis, or from 522 to 6,612 pounds dry matter per acre. It is to be remembered that the data on spear production was taken from receiving station receipts and growers estimates of planted area and fern growth was extrapolated from measurements taken on a 50-foot row. Both of these are somewhat subjective measurements.

Soil tests (Table 3), of samples collected only in the first year of this study, showed some highly significant correlations. Phosphorus soil values were correlated with nitrogen application, possibly because the farmers using the heavier fertilizer rates in general also put on the most nitrogen in the years of this study.

Potash in the soils sampled varied inversely with the pH value. Magnesium concentration varied directly with soil

TABLE 3. Summary of significant linear correlations found for two consecutive seasons in the asparagus nutritional survey.

Factor Determined[1]	Positively correlated with:*	Negatively correlated with:*
Age of planting		Spear calcium content --, -
Phosphate applied	Potash applied +, ++	
Potash applied	Phosphate applied +, ++	
Fern growth (weight)	Succeeding fern growth ++	
Fern nitrogen content	Fern phosphorus content +, ++	
	Fern boron content +, ++	
Fern phosphorus content	Fern nitrogen content +, ++	
	Fern boron content ++, ++	
Fern potassium content		Fern magnesium content --, --
Fern magnesium content	Fern boron content +, +	Fern potassium content --, --
Fern manganese content	Spear manganese content ++, ++	
Fern boron content	Fern nitrogen content +, ++	
	Fern phosphorus content ++, ++	
	Fern magnesium content +, +	
	Spear copper content ++, +	
Spear yield (weight)	Succeeding spear yield ++	
Spear calcium content		Age of plant --, -
Spear manganese content	Fern manganese content ++, ++	
Spear copper content	Fern boron content ++, +	Fern manganese content -, -

[1] Calculations based on 30 observations for each factor.

* Degree of statistical significance for the two years shown in order following each entry, one character for P = 0.05 and two for P = 0.01.

pH. In Michigan lime is usually applied as Dolomitic limestone and the woils having the highest pH values were undoubtedly those which had been limed.

The nitrogen, phosphorus, and boron concentration in the fern were positively correlated with each other, while potassium and magnesium were negatively correlated (Table 3). This influence of K on Mg is a common occurrence. Boynton (7) cites a number of instances in apple, Awad (3) found it in leaves of Jonathan apples, and Carolus (13) in green beans. Magnesium concentration was positively correlated with boron concentration in the fern which, in turn, varied directly as the copper concentration of the edible spears.

The summary information in Table 1 was used in calculating the values found in Table 4. It should be noted that fern normally remains on the field and is disked into the soil in the spring, thus the nutrients found in this tissue do not constitute removal. Two previous investigations of asparagus composition included a similar calculation of nutrient removal and are compared below:

	N	P	K
	(lbs./A. removed)		
Brown, 2,300 lbs./A.--snapped asparagus	10.3	1.5	6.9
Brooks and Morse (11), 4,500 lbs./A.--cut	15.0	2.1	12.4
Hester and Shelton (28), 4,000 lbs./A.--cut	16.0	1.8	8.3

Carolus (14) has reported that cut asparagus is about 53.5 per cent edible and since the snapped asparagus in this

TABLE 4. Nutrient utilization by mature asparagus in terms of calculated removal (in pounds per acre).

Element	High Value 1958	1959	Low Value 1958	1959	Average Value 1958	1959	Per cent of Appl. (Av.) 1958	1959
				Fern Data[1]				
Nitrogen	137.8	158.0	12.1	14.6	64.9	54.0	48.2	35.5
Phosphorus	13.4	15.9	1.0	1.1	5.9	4.7	6.9	5.7
Potassium	144.4	221.5	7.9	9.2	64.4	64.7	42.1	44.9
Calcium	38.8	89.3	2.6	3.9	15.3	18.8	--	--
Magnesium	16.7	36.4	0.62	1.0	5.2	5.7	--	--
Manganese	0.50	0.96	0.01	0.01	0.10	0.13	--	--
Iron	0.98	1.91	0.04	0.05	0.33	0.33	--	--
Copper	0.11	0.13	0.005	0.005	0.03	0.02	--	--
Boron	0.24	0.60	0.01	0.02	0.08	0.12	--	--
				Spear Data[2]				
	1959	1960	1959	1960	1959	1960	1959	1960
Nitrogen	22.7	17.8	4.3	3.6	11.1	9.6	8.4	6.3
Phosphorus	3.1	2.5	0.6	0.6	1.5	1.4	1.7	1.7
Potassium	15.5	11.2	2.7	2.7	7.3	6.4	4.8	4.4
Calcium	1.2	0.8	0.2	0.1	0.5	0.4	--	--
Magnesium	0.8	0.6	0.1	0.1	0.4	0.3	--	--
Manganese	0.02	0.01	0.001	0.002	0.01	0.005	--	--
Iron	0.07	0.13	0.01	0.01	0.02	0.03	--	--
Copper	0.01	0.01	0.001	0.002	0.004	0.004	--	--
Boron	0.01	0.01	0.001	0.002	0.005	0.004	--	--

1/ Based on average dry weight of 31%.

2/ Based on average dry weight of 7%.

present study was essentially all edible material, the yields from Brooks and Morse (11) and Hester and Shelton (27) are approximately equivalent, respectively, to 2,407 and 2,140 pounds per acre of snapped asparagus. Considering this factor, the values reported are in quite close agreement even though they were widely separated in space and time, i.e., Massachusetts, New Jersey, and Michigan, and 1919, 1949, and 1959, respectively.

Assuming that the nutrient removal figures in Table 4 do present a realistic picture, it becomes apparent that the annual fertilizer requirement of asparagus is quite small when compared to the amounts normally applied (Table 1).

RESPONSE TO MATURE ASPARAGUS TO VARIABLE FERTILIZER APPLICATION

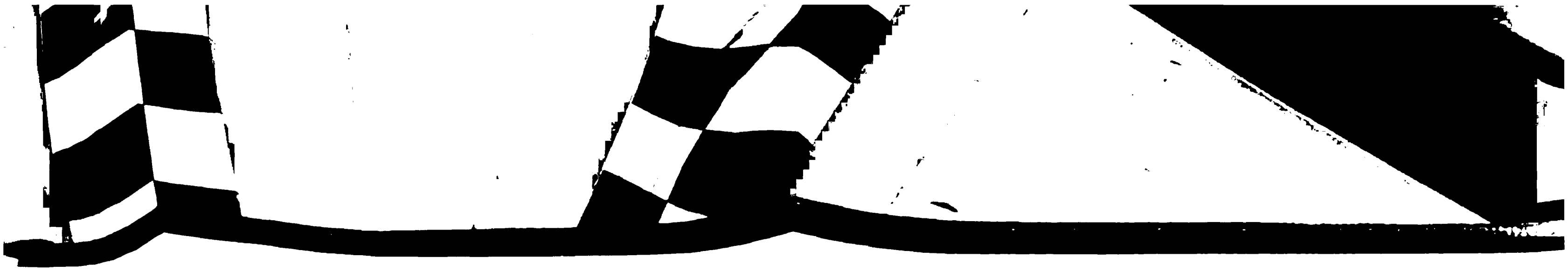
In order to obtain more objective data than was possible with the survey reported in the previous section, a field experiment with mature asparagus was instituted at East Lansing and selected plots chosen for sampling from a fertilizer study already in progress at Sodus, Michigan.

Materials and Methods

A. Studies with an 11-Year Old Planting

A field of Mary Washington asparagus, located on the Horticulture Farm at East Lansing, was utilized in evaluation of the effects of fertilizer application on yield and composition of the crop. Prior to the commencement of this study, the entire field had received a complete fertilizer annually. Twelve treatments were applied in a randomized, complete block design, in which a block consisted of a single, 30-foot long section of row. Single guard rows alternated with treated rows and a five-foot section of row was left untreated between plots. Each treatment occurred in two replications.

The materials, applied in July, 1958, and again in April, 1959, and May, 1960, are listed in Table 5.



Samples of mature green fern were collected from each plot on September 2, 1958. In both 1959 and 1960 yield records were taken from each plot and samples of both edible spears and mature fern were saved for chemical analysis.

B. Fertilizer of 5-Year Old Asparagus

Selected plots from a fertilizer experiment on a field of five-year old asparagus of the Viking variety were also sampled. Planted in 1955, the treatments listed in Table 9 were first applied in April 1956 and continued unchanged to the present. Yields reported are on the basis of four replicates while composition data are derived from two. Each plot consisted of a 33-foot long section of a single row, with guard rows on either side. The data were analyzed as a randomized complete block design. Mature fern for chemical analysis was collected in September, 1958 and again in 1959 and 1960. Edible spears were sampled in 1959 and 1960.

Results and Discussion

Marketable yields from the older planting averaged 4,998 pounds of snapped asparagus per acre in the first harvest year reported and 4,226 in the second year when temperatures averaged five to six degrees lower (Table 5). For the same two years the five-year old asparagus averaged 1,310 and 1,579 pounds of snapped asparagus per acre (Table 6). This disparity is not attributable to variety as Honma

TABLE 5. Yield of asparagus in response to variable fertilizer application on an 11-year old planting (pounds per acre).

Treatment Applied	1959 Spear Yield*	1960 Spear Yield*	Average Yield 1959-60
N-P_2O_5- K_2O			
0-0-0	4050	3432	3741
0-0-120	3784	3641	3737
0-120-0	5496	4537	5016
120-0-0	6822	5367	6094
120-120-120 (STD.)	3451	3557	3509
120-120-240	5901	5144	5522
120-240-120	5653	4731	5192
240-120-120	4169	2970	3569
Manure 10 T/A.	5402	4521	4961
STD. + Na_2O (120 lbs./A.)	5682	4598	5140
STD. + MgO (120 lbs./A.)	4561	3981	4271
STD. + CaO (120 lbs./A.)	5002	4237	4619
General Mean	4998.6	4226.4	4612
C. V. %	29	24	37

*Data for single years are averages from two replications. No significant differences in yield were observed in either year of this study or when data were combined from both years. All asparagus harvested by snapping.

TABLE 6. Yield of asparagus in response to variable fertilizer application on a 5-year old planting (pounds per acre).

Treatment Applied	Spear Yield* 1958	Spear Yield* 1959	Spear Yield* 1960	Average Yield 1958-59-60*
$N-P_2O_5-K_2O$				
60-40-40	837	1202	1563	1201
60-80-80	788	1227	1486	1167
120-40-80	948	1428	1801	1392
120-80-40	800	1206	1572	1193
120-80-80	1071	1514	1916	1500
120-80-160	866	1404	1596	1288
120-160-80	825	1350	1416	1197
120-160-160	825	1153	1284	1089
General Mean	870	1310	1579	1253
C.V. %	23	27	25	45

*Data for single years are averages for four replications. No significant differences in yield were observed in any one year of this study or when data from the three years were combined. All asparagus harvested by snapping.

TABLE 7. Average mineral composition of asparagus spears and fern from a variably fertilized 11-year old planting.

Element	1958 % D.W.	1958 C.V. %	1959 % D.W.	1959 C.V. %	1960 % D.W.	1960 C.V. %
			Spear Data			
Nitrogen	--	--	5.65	6	5.96	5
Phosphorus	--	--	0.76	8	0.71	10
Potassium	--	--	3.63	3	3.52	8
Calcium	--	--	0.23	18	0.28	13
Magnesium	--	--	0.17	6	0.20	6
	p.p.m.		p.p.m.		p.p.m.	
Manganese	--	--	31.2	19	46.0	18
Iron	--	--	80.4	12	73.2	10
Copper	--	--	24.2	16	22.8	11
Boron	--	--	21.1	14	17.7	16
Zinc	--	--	76.7	13	78.4	13
Molybdenum	--	--	1.3	28	1.3*	16
Aluminum	--	--	27.7	37	18.4	27
			Fern Data			
	% D.W.	C.V. %	% D.W.	C.V. %	% D.W.	C.V. %
Nitrogen	2.40	8	2.27	8	1.80	9
Phosphorus	0.22	14	0.21	17	0.19	20
Potassium	2.23	10	2.22	9	2.28	11
Calcium	0.91	15	0.87*	9	0.56	13
Magnesium	0.25	17	0.20	13	0.15	14
	p.p.m.		p.p.m.		p.p.m.	
Manganese	49.8	13	100.8*	36	80.1	53
Iron	131.7	14	112.9	18	105.1	13
Copper	14.3	25	10.6	28	11.4	24
Boron	48.2	33	64.5	20	37.6	18
Zinc	--	--	20.7	14	24.3	12
Molybdenum	--	--	2.9	26	2.5	20
Aluminum	--	--	199.8	19	149.2	48

*Data presented are general means, those starred showed significant differences between treatment means.

TABLE 8. Average mineral composition of asparagus spears and fern from a variably fertilized 5-year old planting.

Element	1958 % D.W.	C.V. %	1959 % D.W.	C.V. %	1960 % D.W.	C.V. %
			Spear Data			
Nitrogen	--	--	6.46	7	6.25	4
Phosphorus	--	--	0.87	6	0.90	6
Potassium	--	--	3.89	5	4.16	4
Calcium	--	--	0.34	12	0.28	8
Magnesium	--	--	0.20	5	0.20	2
	p.p.m.		p.p.m.		p.p.m.	
Manganese	--	--	77.1*	13	75.2	21
Iron	--	--	158.9	18	114.7	33
Copper	--	--	28.2*	5	24.0	28
Boron	--	--	27.9	8	24.3	6
Zinc	--	--	104.1	6	92.6	8
Molybdenum	--	--	1.5	33	0.8	32
Aluminum	--	--	79.0	17	61.0*	15
			Fern Data			
	% D.W.	C.V. %	% D.W.	C.V. %	% D.W.	C.V. %
Nitrogen	2.11	7	1.78	5	2.05	12
Phosphorus	0.24	17	0.17	8	0.20	12
Potassium	2.21	13	2.08	7	2.09	12
Calcium	1.08	32	0.68	9	0.82	18
Magnesium	0.26	23	0.20*	11	0.20	17
	p.p.m.		p.p.m.		p.p.m.	
Manganese	91.4	35	118.7	39	88.1	27
Iron	106.1	17	135.9	9	125.7	13
Copper	14.5	25	10.4	38	12.5	54
Boron	44.8	19	37.2	16	46.4	18
Zinc	--	--	24.0	12	30.6	21
Molybdenum	--	--	2.6	29	2.6	32
Aluminum	--	--	226.3	23	191.1	25

*Data presented are general means, those starred showed significant differences between treatment means.

(29) found no significant yield differences between the Viking and Mary Washington varieties after six years of harvest, but rather due to differences in age and soil edaphic conditions. The 11-year old Mary Washington was grown in a sandy loam soil and the 5-year old Viking on a sand from which nutrients, particularly nitrogen, could be more readily leached.

Statistical analyses indicated that there was no significant yield response to any fertilizer treatment at either location. This is contrary to the results reported by Brasher (8), Seaton (55), Brooks and Morse (11), Rahn (47), White and Boswell (66), all of whom reported yield increases to certain fertilizer practices. Wide differences between replicates in yield produced relatively large experimental erros and large coefficients of variation, making statistical significance difficult to obtain.

The composition data obtained from these experiments, in terms of the average value for each element in each tissue as well as the calculated coefficients of variation are summarized in Tables 7 and 8. The spears from the younger plants contained somewhat higher concentrations of N, P, and K than the older ones and much higher concentrations of Mn, Fe, Zn, and Al, possibly attributable to age, variety, soil type, or some combination of these. These consistent differences were not obtained in the fern except for aluminum which was about 50 per cent higher in the younger plants. Significant differences between treatment means were observed

for Ca and Mn in fern and Mo in spears from 11-year old plants (Tables 9 and 10), and from Mn, Cu, and Al in spears and Mg in the fern from the younger plants (Tables 11 and 12).

The situation with calcium (found only in 1959) in the 11-year old plants (Table 9) is comparable to that found by Reuther and Smith (51) in Valencia oranges and by Carolus (13) with the bean; as the level of potassium increased in the medium, the utilization of Ca by the plant decreased. Lundegardh's (40) work in solution cultures reflects the same finding. The manganese concentration in the plants reflects the findings of Downes (18) in the onion and again of Reuther and Smith with oranges, where the Mn content of the tissue increases as the nitrogen application is increased (Table 9).

Magnesium was most concentrated in 5-year old fern which had received the lowest rate of fertilizer application but did not differ significantly between any other of the treatments (Table 11). This suggests the potash-magnesium antagonism reported by Boynton (7) on apples, Carolus (13) with bean, and Smith et al. (56) with citrus. Asparagus plants receiving the highest levels of potassium contained the lowest concentrations of magnesium in two years out of three. Manganese (Table 11) was consistently higher in spears which received the higher nitrogen application, bearing out the work cited above. Reuther and Smith (51) found that copper content of apple leaf tissue varied inversely with nitrogen application and a suggestion of this was found here, for copper [illegible]

plants [illegible]

and Mn [illegible]

the [illegible]

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(13) [illegible]

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antagonism re[illegible] on apples, [illegible]

with bean, [illegible] with citrus. [illegible]

plants receiving the highest levels of potassium [illegible]

the lowest concentrations of magnesium in two years out of

three. Manganese (Table 11) was consistently higher in

[illegible] which received the higher nitrogen application, [illegible]

ing out the work cited above. Reuther and Smith (54) found

that copper content of [illegible] leaf tissue varied inversely

nitrogen application [illegible] of this was found [illegible]

TABLE 9. Calcium and manganese concentration in fern of 11-year old asparagus as influenced by treatment.

Treatment Applied	1958[1/]	Stat. Sig.*	1959	Stat. Sig.*	1960	Stat. Sig.*
$N-P_2O_5-K_2O$ lbs./A.	Calcium concentration - % dry weight					
0-0-0	0.86	a	0.86	abcd	0.52	a
0-0-120	0.84	a	0.72	cd	0.50	a
0-120-0	0.84	a	0.84	abcd	0.58	a
120-0-0	0.92	a	1.00	ab	0.55	a
STD.	0.96	a	0.97	ab	0.60	a
120-120-240	0.88	a	0.70	d	0.58	a
120-240-120	0.88	a	0.80	bcd	0.58	a
240-120-120	0.98	a	1.02	a	0.56	a
Manure	0.96	a	0.90	abc	0.58	a
STD. + Na_2O	0.90	a	0.82	abcd	0.67	a
STD. + MgO	0.94	a	0.89	abcd	0.47	a
STD. + CaO	0.94	a	0.96	ab	0.53	a
General Mean	0.91		0.87		0.56	
C. V. %	15		9		13	
	Manganese concentration - parts per million					
0-0-0	44.0	a	51.0	cd	38.0	a
0-0-120	41.0	a	56.5	cd	38.0	a
0-120-0	45.5	a	47.0	d	40.0	a
120-0-0	53.0	a	92.0	bcd	51.5	a
STD.	52.5	a	86.0	bcd	74.0	a
120-120-240	47.0	a	98.0	bcd	87.5	a
120-240-120	52.5	a	91.0	bcd	95.0	a
240-120-120	57.0	a	216.0	a	145.5	a
Manure	55.5	a	55.0	cd	41.0	a
STD. + Na_2O	48.0	a	135.0	abc	173.5	a
STD. + MgO	47.5	a	136.5	abc	79.5	a
STD. + CaO	54.5	a	145.5	ab	98.0	a
General Mean	49.8		100.8		80.1	
C. V. %	13		36		53	

[1/] All data presented as treatment means.

* Treatment means designated with the same letter do not differ significantly at P = 0.05.

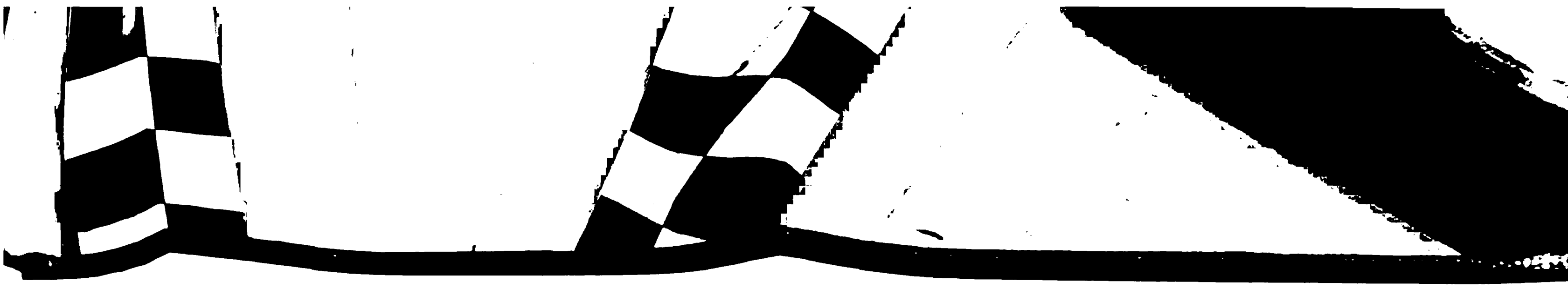

TABLE 10. Molybdenum concentration in asparagus spears from 11-year old plants as influenced by treatment.

Treatment Applied	1959 [1/]	Stat. Sig.*	1960	Stat. Sig.*
	parts per million			
0-0-0	1.15	a	1.00	ef
0-0-120	1.50	a	1.75	a
0-120-0	1.65	a	1.55	abcd
120-0-0	1.65	a	1.65	ab
STD.	0.65	a	1.50	abcde
120-120-240	1.25	a	1.60	abc
120-240-120	1.15	a	0.90	f
240-120-120	1.55	a	1.35	abcdef
Manure	1.05	a	1.05	def
STD. + Na_2O	1.45	a	1.65	ab
STD. + MgO	0.95	a	1.20	bcdef
STD. + CaO	1.60	a	1.10	cdef
General Mean	1.30		1.36	
C. V. %	28		16	

1/ All data presented as treatment means.

* Treatment means designated with the same letter do not differ significantly at P = 0.05.

TABLE 11. Magnesium concentration in fern and manganese concentration in spears of 5-year old asparagus as influenced by treatment.

Treatment Applied	1958[1/]	Stat. Sig.*	1959	Stat. Sig.*	1960	Stat. Sig.*
$N-P_2O_5-K_2O$ lbs./A.			Magnesium in fern - % dry weight			
60-40-40	0.25	a	0.28	a	0.24	a
60-80-80	0.25	a	0.20	b	0.19	a
120-40-80	0.24	a	0.18	b	0.18	a
120-80-40	0.26	a	0.20	b	0.23	a
120-80-80	0.27	a	0.21	b	0.19	a
120-80-160	0.27	a	0.17	b	0.17	a
120-160-80	0.27	a	0.18	b	0.20	a
120-160-160	0.26	a	0.18	b	0.17	a
General Mean	0.26		0.20		0.20	
C. V. %	23		11		17	
			Manganese in Spear - parts per million			
60-40-40	--	--	51.5	c	49.5	a
60-80-80			69.0	bc	65.5	a
120-40-80			91.0	ab	78.5	a
120-80-40			76.0	ab	83.5	a
120-80-80			95.5	a	77.5	a
120-80-160			84.0	ab	84.0	a
120-160-80			72.0	abc	69.5	a
120-160-160			78.0	ab	93.5	a
General Means			77.1		75.2	
C. V. %			13		21	

[1/] All data presented as treatment means.

* Treatment means designated with the same letter do not differ significantly at P = 0.05.

TABLE 12. Copper and aluminum concentration in spears of 5-year old asparagus as influenced by treatment.

Treatment Applied	1959[1/]	Stat. Sig.*	1960	Stat. Sig.*
$N-P_2O_5-K_2O$ lbs./A.	Copper concentration - parts per million			
60-40-40	33.2	a	20.8	a
60-80-80	27.6	bc	22.2	a
120-40-80	27.4	bc	23.4	a
120-80-40	29.6	b	24.4	a
120-80-80	26.6	bc	24.2	a
120-80-160	29.2	b	33.8	a
120-160-80	24.2	c	20.6	a
120-160-160	28.0	b	22.8	a
General Mean	28.2		24.0	
C. V. %	5		28	
	Aluminum concentration - parts per million			
60-40-40	64.0	a	45.0	c
60-80-80	80.5	a	71.0	ab
120-40-80	81.5	a	65.0	bc
120-80-40	94.0	a	90.0	a
120-80-80	89.0	a	49.0	bc
120-80-160	83.0	a	60.0	bc
120-160-80	72.0	a	52.0	bc
120-160-160	68.0	a	56.0	bc
General Mean	79.0		61.0	
C. V. %	17		15	

1/ All data presented as treatment means.

* Treatment means designated with the same letter do not differ significantly at P = 0.05.

but the data are not conclusive on this point (Table 12). Copper was most concentrated in plants receiving the minimum level of the three nutrients applied in 1959.

Climatological factors undoubtedly influenced the concentration in plant tissue of the various elements determined. A summary of weather information for the two locations at which the experiments were conducted is shown below:

	11-Year Planting			5-Year Planting		
	1958	1959	1960	1958	1959	1960
	Mean Air Temperatures - °F.					
April	48	48	50	50	48	52
May	58	63	57	59	64	57
June	62	69	65	63	71	66
July	70	71	69	72	73	71
August	69	75	70	71	76	72
September	62	66	66	64	68	68
Average	62	67	63	63	67	64
	Total Precipitation - Inches					
April	1.5	4.2	2.7	2.8	3.7	3.0
May	0.4	2.7	3.5	2.4	2.8	4.1
June	3.5	2.2	3.5	4.3	1.3	4.5
July	4.6	5.6	2.0	2.7	4.9	2.0
August	3.5	4.5	3.8	2.6	1.6	3.4
September	2.8	2.8	1.3	2.3	2.9	1.4
Total	16.3	22.0	16.8	17.1	17.2	18.4

In spears from the older plants, five of the ten elements determined were most concentrated in the 1959 samples and five in the 1960 samples. Spears of the five-year old plants contained the greatest concentrations of all elements, except P and K, in 1959. Almost four more inches of rain during spear harvest reduced the dry matter content and so

the concentration of most of the mineral constituents in the spears in 1960.

N, P, Ca, and Mg were most concentrated in fern collected from both locations in 1958 conceivably resulting from the lesser rainfall for the season, and consequent advance in physiological age at the time of sampling. Concentration of the remainder of the elements varied between samples from the three years and the two ages of plants.

UTILIZATION OF APPLIED PHOSPHORUS AND DEPLETION
OF MINERAL RESERVES IN GROWTH OF
FIVE-YEAR OLD ASPARAGUS

The extensive mass of asparagus roots containing large carbohydrate and mineral reserves makes it difficult to evaluate response to or utilization of applied nutrients. Study of phosphorus utilization was made possible by the use of the radioisotope P^{32} which could be determined easily in the tissue. The effect of seasonal demands on storage reserves could most easily be observed in a sand culture situation.

A. Utilization of Applied Phosphorus

Materials and Methods

Five-year old asparagus plants which had not been fertilized for three years were used in this study. The planting consisted of a double row of asparagus with plants spaced at two foot intervals in rows spaced four feet apart. Six treatments were assigned in duplicate at random to four plant plots.

Phosphorus was applied on April 25 at three rates: 0, 30, and 90 pounds per acre, and at three depths: 4 inches, 8 inches, and a half each at 4 and 8 inches. All the phosphorus was applied as monammonium phosphate in water.

solution, with the P^{32} added as high specific activity H_3PO_4. The field received a uniform application of 100 pounds per acre of N and K_2O as a soil drench.

The treatments were applied, with a stainless steel probe attached to a graduated medical syringe, as ten 10-milliliter injections of stock solution per plant at the appropriate depth, with injections evenly spaced in the shape of a two by four foot rectangle with the plant at the center. The treatments are indicated in Table 13.

The edible portions of the spears, harvested by "snapping" from May 5 to June 11 to approximate commercial practice, were dried and ground for analysis. The ground material from the various harvests for each treatment was grouped into composite samples, as indicated in Table 13.

The total phosphorus content was determined colorimetrically using the method of Lindner (38), and the quantity of phosphorus supplied by the applied fertilizer was estimated using a briquet method similar to that described by MacKenzie and Dean (41).

Results and Discussion

A statistical evaluation indicated that neither the quantity nor placement of applied phosphorus had a significant influence on the yields obtained (Table 13).

Total phosphorus content of the dried spears varied from 0.58 to 0.80 per cent for individual samples and from 0.66 to 0.68 per cent for treatment means, which also were

TABLE 13. The utilization of applied phosphorus by asparagus spears.

	Treatment		P^{32}	Yield	Phosphorus	P^{32}	Fertilizer P
	P-lbs./A	Depth in.	mc/plant	Gms. dry wt.	% dry wt.	% of total	% Utilization
A	none	-	-	115[1]	0.66[2]	none[2]	none[2]
B	30	4	1	119	0.68	1.54ab	0.06
C	30	8	1	78	0.68	1.18a	0.03
D	90	4	3	82	0.67	2.46c	0.03
E	90	8	3	99	0.68	1.99bc	0.02
F	90	4 & 8	3	122	0.66	2.35bc	0.03
Sampling Dates							
	May 5 & 9			161	0.67[3]	0.45[3]	0.002[4]
	May 16 & 19			91	0.66	0.98	0.005
	May 23 & 26			142	0.71	1.41	0.012
	May 31 & June 5			172	0.67	2.31	0.025
	June 8 & 11			58	0.67	2.91	0.030

[1] eight plant total.
[2] seasonal average.
[3] average of all treatments.
[4] cumulative per cent of applied.
a, b, c - figures designated by the same letter in one column do not differ statistically at $P = 0.05$.

not significantly different. This uniformity in the total phosphorus content of the asparagus throughout the season indicated that the phosphorus applied had no measurable effect on spear composition.

The percentages of plant phosphorus obtained from radioactive fertilizer were significantly different when subjected to an analysis of variance (57) (Table 13). The maximum utilization of the P^{32} tagged fertilizer was 0.06 per cent in treatment B, and equivalent of 0.02 pounds per acre. Treatments D and F used the equivalent of 0.03 pounds each, the maximum actual removal of fertilizer by the harvested crop. Linear regression lines, shown in Figure 1, were calculated for each treatment using the formula $y = a + bx$, where a and b are constants, y the concentration of P^{32} in the sample, and x the sampling date. The reduction in sum of squares, due to fitting the linear term x, was significant in every case, indicating that the straight lines shown adequately represent the results obtained. Inspection of the observed points in Figure 1 suggested the possibility of a curvilinear response to treatments C, E, and F, but when this was tested, the improvement in fit of the regression lines obtained was not significant (44). The salient feature of these data is that in every case the concentration of P^{32} in the spears continued to increase throughout the harvest season.

Eggert et al. (21) state that in apple trees utilizing P^{32}, small quantities were measureable in the tissue in July

and significant amounts in September, suggesting a utilization pattern similar to that found in asparagus.

The increase in the utilization of P^{32} may be due to an increase in root development and function as the soil becomes warmer. For the 30-pound rate, utilization was slower than for the 90-pound rate of application. Spears, particularly in early harvests, utilized more P^{32} from that placed at the four than from the eight-inch depth. This may be related to the earlier development of an active root system in the warmer and better aerated surface soil. At both rates, the regression lines for single depths of P^{32} placement are converging, indicating an equalization of placement effect in time. This was not verifiable because of reduced P^{32} activity by the end of the season. The line in Figure 1, denoting the most rapid rate of utilization, is for the variable depth application, which suggested that this placement may expose more roots to the volume of treated soil.

B. Depletion of Mineral Reserves

Materials and Methods

Twenty five-year old asparagus plants of the Mary Washington variety were dug in April and replanted in washed sand in shortened 55-gallon drums. The plants were quite variable in size as reflected in individual weights varying from 3.1 to 12.8 pounds each. In order to minimize differences, they were grouped into five "treatment groups" of four by rate and depth

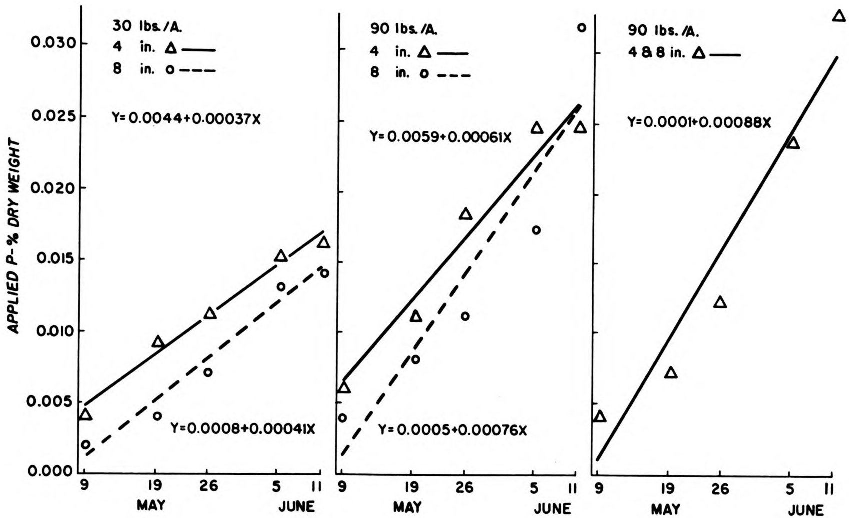

Figure 1: The effect of sampling date on the concentration of P^{32} labelled phosphorus in asparagus spears as influenced by rate and depth of placement.

single plants which varied in total weight from 31.4 to 35.7 pounds. The average weight per plant was 8.4 pounds. The statistical design used was a randomized complete block of five treatments each occurring in four replicates. The treatments were applied once on April 22, the N as ammonium nitrate, P as treble superphosphate, K as a mixture of muriate, and sulfate of potash, and N-P-K as 12-12-12 fertilizer.

Aerial growth was harvested at a height of eight inches until October 23 when the crowns were removed from the drums. The crowns were then washed and dried for analysis.

Results and Discussion

All aerial growth, both spears and fern, was considered in calculating the yield (Table 14). All growth was harvested until the plants were dug out of the drums in order to exert the greatest possible drain on the mineral supplies of the crowns. No significant differences in growth were observed (Table 14).

The nutrients applied had no significant influence on the concentration of any of the nutrients determined on the final dry weight basis (Table 14). Coefficients of variation varied from 13 for magnesium to 75 for zinc; the latter due primarily to two samples, one from a check plant and one from a plant receiving N only.

Results obtained in this experiment taken in

TABLE 14. Aerial growth and crown composition of four-year old asparagus grown in sand culture.

Treatment $N-P_2O_5-K_2O$ (lbs./A.)	Top Growth (g./ plant)	N (% dry wt.)	P (% dry wt.)
100-0-0	908[1/]	1.38	0.35
0-100-0	886	1.37	0.35
0-0-100	944	1.20	0.33
100-100-100	879	1.35	0.31
0-0-0	846	1.16	0.27
General Mean	893	1.29	0.32
C. V. %	31	21	20

Treatment	K (% dry wt.)	Ca (% dry wt.)	Mg (% dry wt.)
100-0-0	1.49	0.94	0.22
0-100-0	1.61	0.82	0.21
0-0-100	1.27	0.80	0.20
100-100-100	1.37	0.81	0.20
0-0-0	1.54	0.72	0.19
General Mean	1.46	0.82	0.20
C. V. %	21	17	13

Treatment	Mn p.p.m.	Cu p.p.m.	B p.p.m.
100-0-0	146	17.8	40.4
0-100-0	176	19.4	43.2
0-0-100	149	20.1	44.9
100-100-100	171	21.5	43.9
0-0-0	133	20.4	41.8
General Mean	155	19.8	42.8
C. V. %	19	16	14

Treatment	Zn p.p.m.	Mo p.p.m.
100-0-0	44.0	4.3
0-100-0	35.5	3.2
0-0-100	42.2	4.2
100-100-100	43.5	4.7
0-0-0	67.0	3.6
General Mean	46.4	4.0
C. V. %	75	33

[1/] All data presented as treatment means. There were no significant differences observed between treatment means for growth or for concentration of any element.

conjunction with those reported in previous sections of this dissertation lend credence to the theory that composition of mature asparagus crowns is not readily affected by fertilizer application.

INFLUENCES OF NUTRITION ON THE DEVELOPMENT AND MINERAL COMPOSITION DURING EARLY GROWTH OF ASPARAGUS

Introduction

All of the work previously outlined has been concerned with asparagus which was considered commercially productive. In order to obtain information on the response of newly planted asparagus to applied nutrients, a sand culture experiment was established in which the mineral resources of the plants could be closely controlled.

Materials and Methods

Forty-eight 55-gallon drums with the top third removed were embedded in soil and provided with suitable drainage. Forty-five were filled with bank sand of neutral pH and three with a manured soil. All drums exposed a surface area of three square feet. Twenty grams of elemental sulfur added to each sand drum changed the pH to about 6.0.

Three one-year old Mary Washington asparagus crowns, weighing 30 to 40 grams each, were planted in each drum on April 10. The fertilizer chemicals were applied three weeks later, and again in May of the following year, in a randomized block design consisting of three replications of 16

treatments each. Treatments consisted of six nutrients applied in various concentration combinations as listed in Table 15. Treatment (1), the X level of all elements, is the check treatment and also the medium or X level of each nutrient variable.

The drums were exposed to seasonal rainfall which amounted to 22 inches in 1959 and 16 inches in 1960 for the months April through September. They received an additional one inch of deionized water per week during dry periods.

On October 10 and again on September 26 of the following year, the largest plant in each drum was removed and separated at the soil line into top and roots. Fresh weights were recorded and the dried, ground material analyzed chemically for N, P, K, Ca, Mg, Mn, Cu, B, Zn, Mo, Fe, and Al.

Results and Discussion

Plants grown in soil with the medium level of all nutrients made the greatest top and root growth in both years of the study. In the first year top growth from these plants exceeded any other by a hundred per cent, but in the second the differences had diminished to about 20 per cent. Root growth remained about twice as large for the soil grown plants as for any other for both years.

This suggests that the sand treatments did not furnish sufficient nutrients to the plants, probably due to leaching of those applied. Of the single elements varied, only nitrogen resulted in growth increases with increased

TABLE 15

Outline of Nutrient Treatments

Medium (X) Level of Nutrients in Pounds per Acre

Element	Rate	Chemical Sources
N	100	NH_4NO_3, KNO_3, $(NH_4)_2HPO_4$, $Ca(NO_3)_2 \cdot 2H_2O$
P	100	$(NH_4)_2HPO_4$, KH_2PO_4
K	100	KNO_3, KH_2PO_4, K_2SO_4, KCl
Ca	100	$Ca(NO_3)_2 \cdot 2H_2O$, $CaCl_2 \cdot 6H_2O$
Na	100	NaCl
Mg	50	$MgSO_4 \cdot 7H_2O$

Description*

X all

¼X all

4X all

¼X N	¼X MgO
4X N	4X Mgo
¼X P_2O_5	¼X Na_2O
4X P_2O_5	4X Na_2O
¼X K_2O	¼X CaO
4X K_2O	4X CaO

X level of all nutrients in manured soil.

*With the exception of the first three treatments, all nutrients other than the one listed were maintained at the medium or X level.

application, thus the larger growth of the soil grown plants may be due to the continued availability of nitrogen in the manured soil and not in the sand. Conversely, the restricted fern growth of the plants receiving the $\frac{1}{4}$X All and the $\frac{1}{4}$X N treatments is probably due to the limited nitrogen supply. Variation between individual plants was much greater in terms of top growth in the first year than in the second, resulting in a coefficient of variation of over 50 per cent (Table 16). The smallest root growth was obtained with the heaviest application of potassium in the first year and with the heaviest sodium application in the second year. Also, in the second year there was much more variation between plants in root growth than in the first, the reverse of the situation found in the fern. Generally there was less intrasample variation between roots than tops, suggesting that the underground portions of asparagus become stabilized in size before top growth does.

Dry matter content of the samples collected was essentially constant, at 44.6 and 44.9 per cent, respectively, for the fern of the two- and three-year old plants and 40.6 and 40.9 per cent for the roots taken the same years.

At the end of the first season, nitrogen was from two to four times as concentrated in the tops and three to six times in the roots of soil as in sand grown plants, again indicating the influence of organic matter on maintaining nitrogen available for developing asparagus (Table 17). Much more nitrogen was taken up in the 4X All and 4X N

TABLE 16. Top and Root growth of two- and three-year old asparagus plants as influenced by treatment.

Treatments	Grams Dry Weight: Fern 2-Year	Fern Stat. Sig.*	Fern 3-Year	Fern Stat. Sig.*	Roots 2-Year	Roots Stat. Sig.*	Roots 3-Year	Roots Stat. Sig.*
X all - sand	15[1]	d	36	cd	62	cdef	155	bc
1/4 X all - sand	6	d	22	d	29	g	114	bc
4 X all - sand	41	bc	55	b	110	b	183	b
1/4 N - sand	10	d	24	d	42	fg	126	bc
4 N - sand	54	b	47	bc	127	b	182	b
1/4 P_2O_5 - sand	13	d	36	cd	66	cde	129	bc
4 P_2O_5 - sand	26	cd	31	cd	83	c	134	bc
1/4 K_2O - sand	9	d	31	cd	72	cd	160	bc
4 K_2O - sand	8	d	27	d	44	fg	110	bc
1/4 MgO - sand	16	d	34	cd	60	def	102	bc
4 MgO - sand	12	d	34	cd	50	efg	97	c
1/4 Na_2O - sand	15	d	33	cd	60	def	121	bc
4 Na_2O - sand	10	d	35	cd	55	def	79	c
1/4 CaO - sand	17	d	31	d	56	def	109	bc
4 CaO - sand	15	d	36	cd	69	cde	150	bc
All in soil	110	a	97	a	160	a	322	a
General Mean	24		38		72		142	
C. V. %	51		21		16		29	

[1] All data expressed as average for three plants.

* Statistical significance: Means designated by the same letter do not differ significantly at P = 0.05.

TABLE 17. Nitrogen concentration in two and three-year old asparagus plants as influenced by various nutrients.

	Per Cent Dry Weight							
	Fern				Roots			
Treatments	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*
X all - sand	0.74[1/]	bc	0.90	a	0.44	b	0.32	cd
¼ X all - sand	0.72	bc	0.96	a	0.52	b	0.25	d
4 X all - sand	1.01	b	0.99	a	0.49	b	1.05	b
¼ N - sand	0.76	bc	1.06	a	0.47	b	0.34	cd
4 N - sand	0.83	bc	0.87	a	0.48	b	1.08	b
¼ P_2O_5 - sand	0.62	c	0.89	a	0.54	b	0.48	cd
4 P_2O_5 - sand	0.76	bc	0.99	a	0.43	b	0.48	cd
¼ K_2O - sand	0.63	bc	1.21	a	0.41	b	0.36	cd
4 K_2O - sand	0.54	c	0.86	a	0.41	b	0.31	cd
¼ MgO - sand	0.74	bc	0.99	a	0.40	b	0.48	cd
4 MgO - sand	0.80	bc	0.93	a	0.44	b	0.60	c
¼ Na_2O - sand	0.65	bc	0.97	a	0.33	b	0.49	cd
4 Na_2O - sand	0.67	bc	0.92	a	0.41	b	0.38	cd
¼ CaO - sand	0.73	bc	1.03	a	0.39	b	0.59	c
4 CaO - sand	0.90	bc	1.01	a	0.36	b	0.55	cd
All in soil	2.02	a	0.91	a	2.10	a	1.46	a
General Mean	0.82		0.97		0.54		0.58	
C.V. %	24		22		24		29	

[1/] All data expressed as average for three plants.

* Statistical significance: Means, in a column, designated by the same letter do not differ significantly at P = 0.05.

treatments than in any others (Tables 16 and 17) of the sand treatments. Concentration of N in fern of the three-year old plants became stabilized to the point where no significant differences were found, but the concentration in roots varied more in the older than the younger plants.

Although nitrogen concentration had been influenced by the soil, there was no difference in phosphorus concentration between the soil-grown plants and the sand-grown plants. The average P concentration in both fern and roots dropped markedly from the first to the second year of the study; possibly indicating that the P in the two-year old plants came from that stored in the roots and that in the three-year old plants was influenced by treatment (Table 18). In the older fern the P concentration in the plants receiving 4X P was almost double that in those receiving $\frac{1}{4}$X P. There was an indication of a growth response in the younger plants but no concentration change (Table 16). This is comparable to Lilleland's (35) work with apple, peach, and prune in which one-year old trees exhibited a growth response to applied P, but three-year old trees did not and also in which the P concentration in leaves was lower in the older than in the younger trees.

Soil grown plants consistently contained more potassium than any others, in both top and root tissue. As Table 16 indicates, there was no positive response to high potash application and, in fact, a depression of root growth. This is interesting in view of the fact that in each case

TABLE 18. Phosphorus concentration in two and three-year old asparagus plants as influenced by various nutrients.

	Per Cent Dry Weight							
	Fern				Roots			
Treatments	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*
X all - sand	0.22[1]	a	0.18	abc	0.32	cd	0.21	bc
¼ X all - sand	0.31	a	0.15	bc	0.46	a	0.22	bc
4 X all - sand	0.22	a	0.14	bc	0.30	cd	0.27	ab
¼ N - sand	0.26	a	0.22	ab	0.34	bcd	0.21	bc
4 N - sand	0.21	a	0.12	c	0.25	d	0.25	ab
¼ P_2O_5 - sand	0.27	a	0.14	bc	0.29	cd	0.17	c
4 P_2O_5 - sand	0.26	a	0.24	a	0.31	cd	0.22	bc
¼ K_2O - sand	0.27	a	0.17	abc	0.31	cd	0.21	bc
4 K_2O - sand	0.27	a	0.13	c	0.43	ab	0.20	bc
¼ MgO - sand	0.26	a	0.17	abc	0.38	abc	0.18	bc
4 MgO - sand	0.24	a	0.13	c	0.28	cd	0.20	bc
¼ Na_2O - sand	0.28	a	0.13	c	0.30	cd	0.20	bc
4 Na_2O - sand	0.25	a	0.13	c	0.37	abc	0.22	bc
¼ CaO - sand	0.26	a	0.16	bc	0.34	bcd	0.23	b
4 CaO - sand	0.23	a	0.14	bc	0.27	cd	0.21	bc
All in soil	0.23	a	0.11	c	0.43	ab	0.29	a
General Mean	0.25		0.15		0.34		0.22	
C.V. %	18		25		18		12	

[1] All data expressed as average for three plants.

* Statistical significance: Means, in a column, designated by the same letter do not differ significantly at P = 0.05.

the plants receiving the 4X application contain more than those receiving the $\frac{1}{4}$X application (Table 19). This suggests a luxury consumption situation substantiated by the data presented in Tables 16 and 19 which show that plants receiving the largest nitrogen application and showing more growth consistently contained potassium in lesser concentration than those receiving the least nitrogen and showing least growth. Thus, the higher tissue concentration of potassium failed to benefit the plants.

The calcium concentration in the roots of soil-grown plants was greater in both years of this study and the remainder of the samples was essentially homogeneous statistically for this element, indicating little effect of Ca concentration in sand culture on root tissue concentration (Table 20).

Concentration in the top growth did not vary significantly in two-year old tissue even though the samples receiving the 400 pound rate of CaO contained the most calcium, doubtless due to the random variation evidenced in a coefficient of variation of 29 per cent. Statistical differences were observed in three-year old tissue and the highest Ca concentration was found in plants receiving the $\frac{1}{4}$X All treatment. This may be due to the poor growth resulting from the low rate of fertilization and too high Ca in the soil.

Generally speaking, the concentration of calcium in the top growth is two or three times that in root tissue,

TABLE 19. Potassium concentration in two and three-year old asparagus plants as influenced by various nutrients.

	Per Cent Dry Weight							
	Fern				Roots			
Treatments	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*
X all - sand	1.33[1]	b	1.48	bcd	1.35	cde	0.90	cd
¼ X all - sand	0.95	bcd	0.92	def	1.46	bc	0.72	d
4 X all - sand	1.37	b	1.29	bcde	1.30	cdef	1.20	b
¼ N - sand	1.39	b	1.61	bc	1.44	bcd	0.97	c
4 N - sand	0.53	d	0.36	f	0.73	g	0.82	cd
¼ P_2O_5 - sand	1.17	bc	1.04	cde	1.35	cde	0.97	c
4 P_2O_5 - sand	0.93	bcd	0.82	ef	1.09	f	0.87	cd
¼ K_2O - sand	0.69	cd	0.41	f	1.16	ef	0.63	d
4 K_2O - sand	1.19	bc	1.74	ab	1.64	b	1.05	bc
¼ MgO - sand	1.37	b	1.25	bcde	1.34	cde	0.86	cd
4 MgO - sand	1.10	bcd	0.92	def	1.45	bc	0.95	cd
¼ Na_2O - sand	1.19	bc	0.96	def	1.25	cdef	0.96	c
4 Na_2O - sand	0.85	bcd	1.09	cde	1.40	bcde	0.95	cd
¼ CaO - sand	1.19	bc	0.77	ef	1.19	def	0.93	cd
4 CaO - sand	1.46	b	0.86	ef	1.35	cde	0.95	cd
All in soil	2.53	a	2.17	a	2.34	a	1.56	a
General Mean	1.20		1.11		1.36		0.96	
C.V. %	26		28		10		13	

[1] All data expressed as average for three plants.

* Statistical significance: Means, in a column, designated by the same letter do not differ significantly at P = 0.05.

TABLE 20. Calcium concentration in two and three-year old asparagus plants as influenced by various nutrients.

	Per Cent Dry Weight							
	Fern				Roots			
Treatments	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*
X all - sand	0.79[1]	a	0.81	c	0.32	b	0.29	bc
¼ X all - sand	0.69	a	1.45	a	0.37	b	0.27	bc
4 X all - sand	0.85	a	0.88	bc	0.27	b	0.29	bc
¼ N - sand	0.86	a	1.11	bc	0.35	b	0.32	bc
4 N - sand	0.89	a	0.72	c	0.29	b	0.29	bc
¼ P_2O_5 - sand	0.66	a	0.70	c	0.32	b	0.26	bc
4 P_2O_5 - sand	0.75	a	1.16	b	0.27	b	0.26	bc
¼ K_2O - sand	0.86	a	1.02	bc	0.30	b	0.31	bc
4 K_2O - sand	0.69	a	0.68	c	0.36	b	0.25	bc
¼ MgO - sand	0.89	a	0.76	c	0.31	b	0.24	bc
4 MgO - sand	0.95	a	0.70	c	0.30	b	0.22	c
¼ Na_2O - sand	0.70	a	0.81	c	0.32	b	0.29	bc
4 Na_2O - sand	0.88	a	0.86	bc	0.32	b	0.27	bc
¼ CaO - sand	0.90	a	0.96	bc	0.31	b	0.28	bc
4 CaO - sand	1.27	a	0.90	bc	0.30	b	0.22	c
All in soil	0.82	a	0.75	c	0.63	a	0.69	a
General Mean	0.84		0.89		0.33		0.30	
C.V. %	29		19		23		16	

[1]/All data expressed as average for three plants.

* Statistical significance: Means, in a column, designated by the same letter do not differ significantly at P = 0.05.

thus Ca in the roots did not reflect Ca in the fern, due to the immobility of this element in plant tissue (12).

Magnesium evidenced the same phenomenon as calcium: the roots of soil-grown plants contained more Mg than the remainder, which fell into one class statistically. Another similarity was the higher average concentration of the element in top growth than in roots (Table 21).

Concentration varied significantly between top growth samples, and an inverse relationship with potash application (similar to that noted in the nutritional survey) confirmed work of Boynton (7), Carolus (13), and Reuther et al. (50). Mg additions apparently exerted no influence on plant growth (Table 16) in either fern or roots.

Sodium determinations were made only on plants receiving X All, ¼ Na, and 4 Na, and the average values presented in Table 24. No fern growth response was obtained with Na, but in the older plants the 4X application depressed root growth (Table 16). Na concentrations averaged 133,229 and 374 parts per million in the younger fern samples receiving the ¼X, X, and 4X applications and 216, 370, and 813 parts per million in the older fern samples. Sodium concentration increased with increased application in the root samples also; 148, 343, and 367 parts per million in two-year old roots; and 194, 277, and 558 in three-year old roots for the ¼X, X, and 4X rates of application. Concentration increased in a more nearly linear fashion with application rate in the older plants, perhaps

TABLE 21. Magnesium concentration in two and three-year old asparagus plants as influenced by various nutrients.

	Per Cent Dry Weight							
	Fern				Roots			
Treatments	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*
X all - sand	0.24[1]	bc	0.22	bc	0.14	b	0.13	b
¼ X all - sand	0.28	abc	0.35	ab	0.15	b	0.14	b
4 X all - sand	0.25	bc	0.35	ab	0.11	b	0.15	b
¼ N - sand	0.24	bc	0.26	b	0.14	b	0.14	b
4 N - sand	0.28	abc	0.29	ab	0.15	b	0.14	b
¼ P_2O_5 - sand	0.21	c	0.21	bc	0.13	b	0.13	b
4 P_2O_5 - sand	0.24	bc	0.33	ab	0.14	b	0.14	b
¼ K_2O - sand	0.35	a	0.36	a	0.14	b	0.15	b
4 K_2O - sand	0.20	c	0.16	c	0.15	b	0.13	b
¼ MgO - sand	0.24	bc	0.21	bc	0.16	b	0.14	b
4 MgO - sand	0.33	ab	0.31	ab	0.14	b	0.15	b
¼ Na_2O - sand	0.21	c	0.26	b	0.15	b	0.14	b
4 Na_2O - sand	0.21	c	0.24	bc	0.15	b	0.13	b
¼ CaO - sand	0.28	abc	0.34	ab	0.15	b	0.14	b
4 CaO - sand	0.28	abc	0.29	ab	0.15	b	0.13	b
All in soil	0.25	bc	0.21	bc	0.26	a	0.24	a
General Mean	0.25		0.27		0.15		0.14	
C.V. %	19		19		19		11	

[1] All data expressed as average for three plants.

* Statistical significance: Means, in a column, designated by the same letter do not differ significantly at P = 0.05.

due to increased absorptive root surface.

Manganese (Table 22) was least concentrated in fern of soil-grown plants suggesting an inverse relationship with nitrogen concentration (Table 17). There is a suggestion of this in two-year old roots but not in fern, a situation different from that found by Downes (18) or in field experiments previously described. Treatments exerted no significant effect on Mn concentration in roots of either age.

Boron was more concentrated in both fern and roots of the younger than in the older plants (Table 23). Soil-grown fern contained generally lower concentrations of B than sand-grown fern, but the values were comparable to those from plants receiving the 4X All and 4X N treatments. This suggests an inverse relationship with N applied similar to Downes' (18) results with onion bulbs. No significant differences were observed in B concentration between root samples in either year of this study or in fern samples from the first year of sampling.

The extremely high concentration of iron and aluminum in the plant tissue made it impossible to obtain reliable data with the spectrographic method used (Table 24).

The average concentration of Cu, Zn, and Mo are presented for reference in Table 24. In general, no significant differences between treatment means were found.

Table 25 contains data on relative growth response to and utilization of six applied elements by young sand grown asparagus. The values obtained from three-year old

TABLE 22. Manganese concentration in two and three-year old asparagus plants as influenced by various nutrients.

	Parts Per Million							
	Fern				Roots			
Treatments	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*
X all - sand	101.3[1/]	a	54.6	a	62.0	a	73.3	a
¼ X all - sand	92.0	a	58.6	a	114.0	a	74.6	a
4 X all - sand	88.0	ab	61.3	a	81.3	a	76.0	a
¼ N - sand	85.3	ab	64.0	a	106.6	a	81.0	a
4 N - sand	86.6	ab	46.0	b	72.0	a	70.6	a
¼ P_2O_5 - sand	105.3	a	54.6	a	102.0	a	70.0	a
4 P_2O_5 - sand	56.6	b	76.0	a	78.6	a	80.0	a
¼ K_2O - sand	97.3	a	72.0	a	95.3	a	94.6	a
4 K_2O - sand	98.6	a	56.0	a	77.3	a	69.3	a
¼ MgO - sand	91.3	a	60.0	a	67.0	a	76.0	a
4 MgO - sand	82.6	ab	49.3	a	85.3	a	58.6	a
¼ Na_2O - sand	96.0	ab	41.3	b	100.0	a	65.3	a
4 Na_2O - sand	97.3	a	57.3	a	122.0	a	66.6	a
¼ CaO - sand	94.6	a	70.3	a	81.3	a	66.6	a
4 CaO - sand	118.0	a	60.0	a	78.6	a	68.0	a
All in soil	24.0	c	22.6	b	69.3	a	70.6	a
General Mean	88.4		56.5		87.1		72.6	
C.V. %	21		24		28		17	

[1/] All data expressed as average for three plants.

* Statistical significance: Means, in a column, designated by the same letter do not differ significantly at P = 0.05.

TABLE 23. Boron concentration in two and three-year old asparagus plants as influenced by various nutrients.

	Parts Per Million							
	Fern				Roots			
Treatments	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*	2-Year	Stat. Sig.*	3-Year	Stat. Sig.*
X all - sand	82.3[1/]	a	49.6	bc	50.6	a	36.6	a
¼ X all - sand	71.3	a	89.6	a	60.3	a	43.4	a
4 X all - sand	52.3	a	24.0	c	52.0	a	37.8	a
¼ N - sand	68.0	a	80.6	a	51.0	a	44.6	a
4 N - sand	57.3	a	22.0	c	47.3	a	37.6	a
¼ P_2O_5 - sand	74.3	a	29.6	c	59.6	a	35.8	a
4 P_2O_5 - sand	73.3	a	62.0	b	51.0	a	40.0	a
¼ K_2O - sand	87.0	a	39.6	c	59.0	a	47.2	a
4 K_2O - sand	71.3	a	34.0	c	70.0	a	40.8	a
¼ MgO - sand	82.3	a	44.3	bc	55.0	a	37.7	a
4 MgO - sand	80.3	a	29.3	c	49.3	a	32.1	a
¼ Na_2O - sand	91.6	a	31.3	c	52.3	a	36.9	a
4 Na_2O - sand	68.0	a	44.3	bc	67.6	a	36.6	a
¼ CaO - sand	82.6	a	39.0	c	57.0	a	38.5	a
4 CaO - sand	71.0	a	49.3	bc	43.0	a	36.5	a
All in soil	45.6	a	26.0	c	47.3	a	41.3	a
General Mean	72.4		43.4		54.5		38.9	
C.V. %	30		23		24		19	

[1/] All data expressed as average for three treatments.

* Statistical significance: Means, in a column, designated by the same letter do not differ significantly at P = 0.05.

TABLE 24. Average concentration of Fe, Zn, Mo, Al, and Na in two and three-year old asparagus.

Nutrient Determined	Parts Per Million							
	Fern				Roots			
	2 yr.	C.V. %	3 yr.	C.V. %	2 yr.	C.V. %	3 yr.	C.V. %
Fe	>750 1/	--	--	--	>750	--	>750	--
Cu	11	44	8*	37	13	78	13	26
Zn	34	42	32	66	35	44	40	57
Mo	3.4	29	3.5	28	2.1	36	3.2	31
Al	> 1600 1/	--	295	27	> 1600	--	>1600	--
Na	246 2/	--	467	--	286	--	343	--

1/ Fe and Al were generally too concentrated to be determined with the technique used.

2/ Na values are averages of determinations from plants receiving ¼ Na, 4 Na, and X all only. Thus no C.V. % value was calculated.

* Cu concentration in asparagus receiving the X All treatment was significantly higher than any other in this set of samples.

TABLE 25. Relative change in growth and nutrient content of three- versus two-year old asparagus as influenced by treatment level.

Nutrient Varied	Tissue	½X (25 lbs./A.) Growth	½X (25 lbs./A.) Nutrient Content	X (100 lbs./A.) Growth	X (100 lbs./A.) Nutrient Content	4X (400 lbs./A.) Growth	4X (400 lbs./A.) Nutrient Content
N	Top-sand	243	353	240	289	87	91
	Top-soil	--	--	88	40	--	--
	Root-sand	300	215	250	183	143	321
	Root-soil	--	--	204	140	--	--
P	Top-sand	273	146	240	194	119	110
	Top-soil	--	--	88	42	--	--
	Root-sand	195	114	250	165	161	114
	Root-soil	--	--	204	135	--	--
K	Top-sand	344	200	240	264	338	439
	Top-soil	--	--	88	76	--	--
	Root-sand	222	120	250	168	250	161
	Root-soil	--	--	204	134	--	--
Mg	Top-sand	212[1/]	189	240	216	284	260
	Top-soil	--	--	88	74	--	--
	Root-sand	170	151	250	235	194	209
	Root-soil	--	--	204	185	--	--
Ca	Top-sand	182	192	240	243	240	166
	Top-soil	--	--	88	81	--	--
	Root-sand	195	174	250	228	218	159
	Root-soil	--	--	204	220	--	--
Na	Top-sand	220	355	240	391	350	770
	Top-soil	--	--	88	134	--	--
	Root-sand	200	264	250	201	144	218
	Root-soil	--	--	204	113	--	--

1/ Mg applied at ½ indicated amounts.

plants are expressed as percentages of those from two-year old plants.

Only in fern of sand grown plants receiving the 4X N treatment were the growth and composition values lower for the older plants, suggesting that the optimum nitrogen application for the conditions of the experiment had been passed. Phosphorus content and fern growth were essentially unchanged for plants receiving the 400-pound per acre application of this element, indicating that this application was adequate for the experiment.

Both growth and nutrient contact of K, Ca, Mg, and Na treated plants increased in the second year compared to the first.

GENERAL DISCUSSION

It has been reported in the literature that storage reserves in the fleshy roots of asparagus furnish the necessary materials for production of the edible spears (30, 64), but investigators (3, 8, 55, 65, 66) have taken little cognizance of this in conducting nutritional experiments with the crop. As early as 1916, Morse (42) published a careful study of the composition of the various portions of the asparagus plant and Hester (28), in 1949, published figures on the removal of ten elements in two tons of cut spears, but neither of these studies appear to have been seriously considered in fertilizer trials with asparagus or in formulating recommendations for the crop.

Several workers have suggested that nitrogen is the single most important element needed for spear production (11, 65) and that response to complete fertilization is reduced as the plants mature (10, 53, 65).

Workers with other perennials have long recognized the minimal response of mature plants to fertilizer, particularly phosphate application (35, 36, 45, 46). Kramer and Kozlowski (32) found that in deciduous forest trees 50-years old, P, K, and Ca in annual leaf fall amounted to about 5 per cent each of the total amounts in the trees, and Gardner et al. (22) reported a similar condition with apple

trees (exclusive of fruit), both suggesting a self-sustaining system.

This study showed that a 2,300-pound crop of snapped asparagus removed about 10, 2, and 7 pounds, respectively, of N, P, and K, but that about 60, 5, and 50 pounds, respectively, are returned to the soil by the fern each autumn. Nitrogen, phosphorus, and potassium in asparagus roots from one acre amounted to about 150, 40, and 200 pounds (based on an average root weight of nine pounds for a four-year old plant). Thus annual removal is less than 10 per cent of the amounts stored in the roots and is more than compensated for by annual return.

Fertilizer phosphorus in spears of five-year old asparagus amounted to 2½ per cent of the total, an explanation for the lack of yield response to this element and possibly to others also. Presumably the remainder of the spear P came from storage reserves in the roots or from sources in the soil. This is comparable to Eggert's (21) work with apple trees where a maximum of 6 per cent of the P in the leaf and none in the fruit was from current fertilization.

Applied N elicited positive growth responses from two- and three-year old asparagus grown in sand culture, but significant responses were not observed in field experiments. Phosphorus proved beneficial only in the year of planting in the sand culture experiment. None of the fertilizer treatments applied to either five- or eleven-year old field grown

asparagus resulted in significant yield responses. Data from a survey of 30 commercial asparagus fields also failed to show correlations between rate of fertilizer application and yield.

Composition changes in asparagus attributable to variable fertilizer application were noted. In field grown asparagus Mn was most concentrated in fern of plants receiving the largest nitrogen applications, confirming investigations with onions and citrus (18, 51), but no such phenomenon was seen in sand culture experiments. This was probably due to the rapid leaching of applied N and limited Mn in the medium.

Ca concentration in 11-year old plants decreased with larger potash applications, reflecting similar findings with the bean (13) and citrus (51) as well as work with solution cultures (40). Asparagus is also subject to the luxury consumption of potassium common in many plant species.

Mg concentration in asparagus fern from plants grown in sand culture and, to a lesser extent, from those grown in the field, varied inversely with potash application. Boynton (7), Carolus (13), and Smith et al. (56) reported comparable results with the apple, bean, and citrus, respectively.

Sodium, which has been recommended as beneficial (5, 54), had no effect on top growth, but depressed root growth in sand culture experiments. Na concentration in both fern and roots increased with increased applications comparable

to Lingle's (39) results with celery and Harmer and Benne's (25) with asparagus.

Root and crown composition were not significantly affected by the removal of all aerial growth as it was produced, even though differential nutrient treatments were applied to the plants. This study was performed in sand culture, but demonstrated a remarkable stability of concentration of the elements determined over the course of a growing season. Taken in conjunction with the results obtained using the P^{32} tracer, the indication is that composition of an asparagus plant, four-years old or older, is not readily affected by a single season's fertilizer application.

Asparagus has a limited requirement for mineral nutrients, but can tolerate wide ranges of fertilizer application. Nitrogen is apparently of greatest importance in producing satisfactory top growth and either potassium or sodium may be harmful in excessive quantities. With the exception of the first year after planting, phosphorus did not benefit growth directly. Neither calcium nor magnesium elicit significant growth responses.

In order to confirm the findings reported here, it will be desirable to establish new field plantings on soils of low fertility to establish nutrient requirements from time of planting until the maximum yields are obtained. Fertilizer treatments varying from very low to very high should be applied at planting and continued annually, some

increasing, some decreasing, and others maintained at a constant level, thus measuring response over the widest practicable range. Asparagus crowns should be carefully selected in order to eliminate plant size as a variable factor.

In conclusion, it is suggested that once an asparagus plantation is properly established, a complete fertilizer every third year with annual nitrogen applications should constitute an adequate nutrient supply.

SUMMARY AND CONCLUSIONS

A three-year study of the mineral nutrition of asparagus included a survey of cultural practices, yields, and plant composition from 30 farms; controlled field experiments with five- and eleven-year old plantings; an isotopic tracer study; and sand culture experiments.

The results of these studies can be summarized as follows:

1. On the basis of crop nutrient removal, a marked reduction in application of N, P, and K appears warranted.
2. Spear yield of commercially productive asparagus (i.e., four years and older) was not readily affected by fertilizer application.
3. Current fertilizer applications have little effect on crown composition and, in terms of phosphorus concentration, spear composition.
4. In sand culture and possibly under field conditions, nitrogen was the single most beneficial element commonly applied. Phosphorus also benefitted asparagus in the planting year but less thereafter.
5. Potassium and sodium were harmful to root growth if applied in large amounts (400 pounds per acre in this study).

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