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THE MINERAL COMPOSITION OF TULIPA GESNERIANA AS RELATED
TO GROWTH AND NUTRITION

By

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AN ABSTRACT

Submitted to the College of Agriculture, Michigan State University
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Mineral contents of the plant parts of Tulipa gesneriana cv. 'Blizzard' were determined periodically during the growth cycle to ascertain the extent to which stored nutrients may be utilized in growth, then redistributed to new storage tissue. The effect of applied N, P, and K, two growth media and a combined application of Ca, Mg, and B on plant nutrient content and bulb yield was investigated. Effects of varying defoliation practices on bulb production were also examined.

Bulbs were planted in pots in either a 3:1 mixture of Plainfield sand and arcillite, or in a 3:1:1 mixture of loam, sand, and manure and grown in a 60°F. minimum temperature greenhouse after having received the cold treatment necessary to break flower dormancy.

Plants grown in the sand-arcillite mixture without added nutrients were evaluated at two week intervals for their dry weight and 13 mineral elements. Dry weight, N, P, and K contents continually decreased in the original bulb tissue, increased in the green parts to the time of full bloom and then decreased, and continually increased in the new bulb tissue. Of the minor elements varying quantities of Mg, Zn, Cu, B, and Mn were redistributed to the new storage tissue from

senescent foliage, while the major portion of Ca, Na, Fe, Mo, and Al was retained in the foliage.

The bulb weight yield of plants receiving no nutrients, low or high levels of all three major nutrients, applications of Ca, Mg, and B, or none, and harvested after full bloom or at maturity was examined. Differences in harvest dates were responsible for 91% of the variation observed. Nutrient applications in this study had no significant effect on yield.

When nine N, P, and K combinations were applied to plants grown in the sand-arcillite medium, harvest date again was responsible for most of the observed variation in bulb production, but an effect of nutrients and an interaction between nutrient level, Ca-Mg-B application, and harvest date on main bulb production was found. Plants receiving the high level of N, P, and K, or the high level of any one in combination with the low level of the other two, produced weights of main bulbs above the average for all treatments. Plants receiving treatments which lacked one or all of these elements produced weights of main bulbs which were below the average. In the early harvest main bulb yields were increased by the application of Ca-Mg-B. This beneficial effect was not evident when the plants were harvested at maturity. Compared with the effect on main bulb yield, the effect on offset bulb weight yield was reversed, with the Ca-Mg-B application increasing their weight in the harvest at maturity, but not in the earlier harvest.

Applied nutrients had the following effects on bulb production:

Main bulb percentage weight increases: High N vs. no N--13%, high P vs. no P--6%, high K vs. no K--2%; Offset bulb production: High N vs. no N--19% decrease, high P vs. no P--3% decrease, and high K vs. no K--31% increase.

The contents of 12 essential elements in foliage and new bulbs were determined on the tulips grown in the two media, and which received no, high, or low applications of all three major nutrients. Nutrient level affected N, P, and K contents of the foliage and new bulbs, and the Cu content of the new bulbs. The growth medium significantly affected the residual foliar contents of N, P, K, Ca, Mg, Na, Mn, Cu, B, Zn, and Mo, but only the K, Ca, Cu, B, and Zn contents of the bulbs. The plant Fe contents were not affected by either nutrient level or growth medium.

At various nutrient levels growth medium had a differential effect on the residual foliar P contents and new bulb N, P, and Ca contents. In general the plant contents of N, P, and K increased as the level of fertilization with these elements was increased. Most striking differences were in the residual P contents of the foliage. There was only a slight change between the low N-P-K application and no nutrient application, but with the high N-P-K application the foliar P residuum increased five- and six-fold. At the same time the P contents of new bulbs increased by 57% and 19% from the nil treatment to the low N-P-K treatment, and by 18% and 29% from the low to the high level

of nutrient application in the sand-arcillite and soil respectively.

The percentage of applied nutrient that was recovered in the new bulbs was always greater in the plants grown in the sand-arcillite mixture, and at the low level of nutrient application.

Plants grown in the soil medium which contained large amounts of Ca and Mg, contained larger quantities of Ca and Mg than did plants grown in sand-arcillite.

The Na remaining in the foliage of plants grown in both media, and the bulb Na contents of plants grown in the sand-arcillite increased with increased N-P-K application. Plants grown in both media contained approximately the same amount of Na, but sand-arcillite-grown bulbs contained a higher percentage than did those grown in soil. Plants grown in the sand-arcillite medium, containing 20 p. p. m. of Mn, had a residual foliar Mn content 7.4 times that of soil-grown plants, while bulb Mn contents were essentially the same for plants grown in both media.

The Cu contents of sand-arcillite-grown plants showed no apparent relationship to the level of N-P-K fertilization. The Cu contents of soil-grown plants increased as the rate of N-P-K application was increased. Rate of N-P-K application did not affect the B contents of plants grown in either medium. Plants grown in the soil did, however, contain less B than those which were grown in the sand-arcillite mixture.

More Zn was found in the bulbs of plants grown in sand-arcillite than in those of plants grown in soil. Residual foliar Zn was at the same level for plants grown in either medium. Residual foliar Mo was greater for soil-grown plants, but the average Mo concentration was identical in bulbs from plants grown in either medium.

When nine nutrient combinations were applied to plants grown in sand-arcillite, plant N contents were related to the quantity of N applied. The bulb content of N was a more sensitive indicator of the quantity of N applied to the soil than was the residual leaf content. Plant N contents were enhanced when P and K were at the low rather than the high levels. The quantity of N in the bulbs was reduced when K was at the high level.

Bulb P was remarkably increased by P application, residual foliar P by the high P application and also by the high N application. Bulb P contents were slightly increased when N was high rather than absent.

Residual foliar K was increased by high soil N, but new bulb K levels were unaffected. When N was high, or P absent, the low K application did not increase bulb K over the nil treatment. However, when N was low, or absent, or when P was high, the low K application increased bulb K contents by 10% to 14%.

The residual foliar Na, relative to non-fertilized plants, was reduced when one of the three major elements was not supplied, or when P was at the high level. All other treatments greatly increased

residual foliar Na. Conversely, when one of the three major elements was not supplied, residual foliar Cu was increased. Foliar Cu was also increased by high P or low N-P-K applications, while it was reduced by the high N-P-K application.

Total bulb production by plants completely defoliated immediately after petal fall was significantly lower than from plants that were defoliated three weeks later, or which had only their flowers and peduncles removed.

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"Man takes interest in an object just in so far as he fashions an idea for it. It has therefore to pass into his mode of apprehension. . . In living nature nothing happens except what stands in relation to the whole, and if phenomena appear to us as if isolated, and we have to look on our investigations as isolated facts, this does not mean that they are isolated; it only raises the question how are we to ascertain the connection of these phenomena and these circumstances."

Goethe*

*Quoted by Viscount Haldane (29)

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	
Early Cultural Recommendations for the tulip	2
Fertilizer Recommendations for Commercial Bulb Production	3
Mineral Nutrient Experimentation with Bulb Crops	4
The Effects of Defoliation and Flower Removal	13
GENERAL MATERIALS AND METHODS	17
CHANGES IN COMPOSITION OF TULIP PLANTS DURING A GROWING SEASON	21
Dry Matter Content	21
Nutrient Distribution Pattern	27
THE EFFECT OF DEFOLIATION ON TULIP BULB PRODUCTION	35
THE EFFECT OF VARYING LEVELS OF N, P, AND K ON NUTRIENT REDISTRIBUTION AND BULB PRODUCTION IN THE TULIP	39
The Effect of Nutrient Level and Ratio and Time of Harvest on Bulb Yield	41
The Effect of Nutrient Level and Ratio on the Mineral Composition of the Tulip	45
Major Element Composition	46
Minor Element Composition	53
GENERAL DISCUSSION	62
SUMMARY	67
LITERATURE CITED	69

INTRODUCTION

From the time of its introduction into Europe in the middle of the XVI Century the tulip has delighted gardeners and fanciers with its variety of color, shape, size, and time of bloom. With modern production techniques and transportation facilities even the dilettante can have success in producing their much-desired spring display.

Yet the tulip retains somewhat of an air of mystery appropos of its origin in the Levant and Asia. First, optimum "dormant" period temperatures required to produce blossoms varies with the growth stages of the floral primordia. After the flower parts have been differentiated there are yet other temperature requirements to be met before blossoming can occur. These requirements have been elucidated by Dutch workers after many years of research.

Mineral nutrition requirements remain to be clearly defined. There has been no dearth of fertilization experimentation with this plant over the years. But many experiments have produced conflicting information. The investigations reported in this work concerning the movement of mineral nutrients within the plant itself may aid in the resolution of such disagreements.

REVIEW OF LITERATURE

Early Cultural Recommendations for the Tulip.

The tulip was first described in 1560 by Conrad Gesner (d'Ardene, 8) who had seen it blooming in a garden in Augsburg (Doorenbos, 21). Most tulips originated around the Mediterranean and through Asia to Japan (Gould, 25, Post, 51). The tulip became an extremely popular garden flower, especially in the Netherlands, partly due to the efforts of Carolus Clusius who spent the years 1593-1609 in Leiden actively propagandizing for the plant (Doorenbos, 21).

Early cultural recommendations for the tulip are somewhat vague. Morin (46) in 1682 stated that "tulips do not want much sun nor a very dense soil." Valnay (68) in 1696 recommended fertilizing in June and working the soil five or six times before planting the bulbs. In 1754 d'Ardene (7) cautioned that the gardener risked losing a large part of his stock by not lifting the bulbs annually.

Except for Morin's inference that tulips grow better when shaded, these recommendations persist. Barr (10), Griffiths (27), and Crossley (20) agree that annual lifting is to avoid overcrowding because of rapid proliferation of the bulbs. Nisbet (48) feels, and Crossley (20) concurs that this is a prophylactic measure for the control of "fire" disease. They indicate the desirability of a time lapse between plantings in the same location of from four to eight years.

Habershon (28), Synge (62), and Crossley (20) following Morin stress thorough preparation of the soil to achieve good drainage and fine tilth.

To recommend the use of fresh manure in home gardens is anathema (Habershon, 28, Synge, 62, Belin, 11, and Everett, 24), although organic fertilizers such as well-rotted cow manure, bone meal and dried blood are recommended by Belin and Synge. Everett (24) calls for the use of slow acting fertilizer, and, if chemical fertilizer is to be used, one of a 5-10-5 analysis. Crossley (20) states that fall applied N should be in a slowly available form, but that rapidly available N can be applied as a side dressing in spring. Belin (11) suggests the use of 25-30 grams of superphosphate per square meter when cow manure is used.

Fertilizer Recommendations for Commercial Bulb Production.

General fertilizer recommendations for commercial tulip bulb production are somewhat more specific. In Washington and Oregon the fertilizer recommendations on an acre basis are: 30-50 pounds of N, 100-200 pounds of P_2O_5 , 60-80 pounds of K_2O (preferably as the sulfate), and 30 pounds of MgO as the sulfate. This in addition to 40-80 pounds of N per acre to be worked in with a preceding cover crop, (Crossley, 20). Suggested fertilization for British Columbia by Crossley is 1000 pounds of a 6-8-6 analysis fertilizer per acre in the fall with 120 pounds of NH_4NO_3 per acre as a spring side dressing.

Nisbet (48), writing on bulb growing in the islands off the western coast of Britain, notes that fertilizers with up to 600 pounds of K_2SO_4 and 200 pounds of hoof and horn meal to supply N are normally applied per acre after planting, but may be delayed to November on light soils. Little phosphate is used although a light dressing may be applied if the soil phosphate level is low.

Griffiths (27) has stated, "That tulips are an exacting crop, as commonly supposed, must be most emphatically denied." Certainly, the wide divergence of recommendations here would seem to indicate that the soils are extremely different, and that the tulip itself can grow and multiply satisfactorily under a wide variety of conditions.

Mineral Nutrient Experimentation with Bulb Crops.

Investigations of the nutrient requirement of bulbous crops have been conducted over the years to ascertain the effect of quantity, ratio, and time of application of mineral nutrients on subsequent bulb and flower production. Algera (1) analyzed tulip bulbs seven times at intervals of five to nine weeks during the plants' growth cycle, and concluded that in the Netherlands the tulip begins to take up mineral nutrients in March. The Polish worker Woycicki (71) concurs with this observation saying that in autumn when tulips are planted they absorb only small amounts of mineral nutrients, and that in spring there is an initial intensive absorption of N. He compares the tulip with the onion in suggesting fertilization practices. Both crops absorb

similar quantities of the three major nutrients--the tulip somewhat more N and K, and the onion somewhat more P. Since the onion has a growing period of about twice the length of the tulip, he recommends giving the tulip abundant mineral elements in an easily assimilated form.

Mulder (47) was concerned with N fertilization in the Netherlands. Although he found the cultivar 'Krelage's Triumph' to grow most rapidly between the beginning of March and mid-May, he found that NO_3 applications were most satisfactory when applied both in November or December, and in February or March. He also found that bulbs which had received ample N while growing forced better than those which had been produced with insufficient N.

Swanborn (61) was concerned mainly with the problem of K leaching from dune sands in the bulb district of the Netherlands. Plants that received high or late applications of K showed a slight increase in K content, otherwise analyses of plants at intervals during the season showed only a slight influence from amount or time of K application. His results show that tulips have a high requirement for N and K, but a small requirement for P.

The Japanese workers Amaki and Hagiya (3) compared applications of varying amounts of N, P, and K using ammonium sulfate, calcium superphosphate and potassium sulfate and found bulb weight and number was influenced most by N and least by P. It was also their observation that the water content of bulbs tended to increase with

increasing N or K, and to decrease with increasing P.

In a subsequent report (4), on forcing of the bulbs produced, these investigators observed that as each of the three elements had been increased for the previous generation, the plants bloomed earlier, and the occurrence of "blind" plants was reduced. As N and K supply to the previous generation decreased, the production of bulbs the succeeding year was remarkably decreased. These same effects were noted in field trials. The effect of K applied in the preceding generation was less than that of N. The amount of P fertilizer seemed to be of little effect. The dry matter content of second generation bulbs increased with increased fertilization of the first generation.

In sand, Bould (13), in 1934-1936 investigated the effect of nutritional deficiencies on growth, flowering, bulb weight increase, and composition of tulip bulbs. Fertilizer treatments that did not contain N, K, or all three major nutrients, resulted in significantly lower weight increases as compared with full nutrient treatments, while the absence of P from the fertilizer had no effect on bulb weight increase. In the second year all treatments resulted in lower bulb weight increase as compared with the treatments that received the complete fertilizer. The absence of P in the second year considerably reduced bulb weight increase while production in the -K treatment equalled that of the full N-P-K treatment.

Regarding field trials in England, Shepherd (55) has stated that the only way to obtain results is over a long period of time, since bulbs

grown on agricultural land of average fertility show no measureable response to manures of any kind the first year, and little response the second. Accordingly, his reports on the use of bulky manures and mulches applied to King Alfred narcissus and Golden Harvest tulips cover a seven year period. Manure and seaweed applied eight to ten months before planting resulted in small increases in growth for both bulbs, with a slight further increase in the growth of tulips with additional N. In a factorial experiment using 27 combinations of no, moderate, or high applications of ammonium sulfate, superphosphate and potassium sulfate the narcissi responded startlingly to K with the high rate producing more and larger bulbs than the moderate rate. Neither N nor P had any great effect on the narcissi. Tulips behaved similarly, but also showed some slight response to N and P.

In yet another experiment Shepherd (55) applied K_2SO_4 in five increments from none to 600 pounds per acre with generous applications of N and P. The differences between the nil treatment and 100 pounds of K_2SO_4 were striking, but increases were recorded for both tulips and narcissi to 400 pounds per acre. In an eight year trial with narcissi no effect of N could be seen or recorded.

Similarly Horton (35) reports that over a five year period tulip, narcissus and iris bulbs gave a considerably higher response to K applications than to N or P. Contrarily, Struijs (60), in trials involving gradually increasing amounts of N, P, and K to tulips, narcissi, and gladioli showed that N and P had a favorable effect on yield.

In an experiment using the small-bulbed Dutch iris (cv. *Imperator*), to minimize the effect of nutrients available in the bulb, Stoughton (59) showed that N played the dominant role in the growth of the plant's aerial parts, while P played a dominant role in bulb development. Phosphorus application was associated with an increase in the number of large bulbs and a decrease in the number of small bulbs. Potassium had a small effect in itself, but interacted significantly with P. There was also a significant interaction between P and N.

Hewitt and Miles (33) designed an experiment to measure the cumulative effect of nutrient deficiencies on tulips and narcissi over a three year period. A treatment of an excessively high Mn level was included in their study. They found that tulips were first most drastically affected by N, Mg and Ca deficiencies. The effects of P and K deficiencies were comparable to the first year effect of these three elements only after three years. The second year yields were reduced most by N deficiency, then by deficiencies of P, Mg, and K in that order. The effects on narcissi were much less pronounced over the entire period of the experiment. Excess Mn was not detrimental to either the tulips or narcissi. Treatments that were deficient in Ca produced bulbs that did not survive the second year.

Cheal and Hewitt (17) in a detailed nutrient experiment were not successful in correlating nutrient deficiency effects on foliage growth or development with the effect on tulip bulb production. They

observed that N and Mg increased bulb yields while the effects of P and K were less marked.

Tulips used in the experiment by Cheal and Hewitt were from two different sources, and each source had a definite effect on the plants' response in the experiment. These workers feel, therefore, that, "the determination of mineral content of the bulbs before planting as well as after lifting them, as suggested by Bould (13) is evidently necessary to help in elucidating the reasons for the different reactions to the treatments."

Mineral Analyses of Bulbs.

Mineral analysis of tulips and narcissi were made by Bould (13) before and after the bulbs had been grown in sand in the absence of either N, P, or K, or all three elements. The analyses were for N, P, and K contents. None of the bulbs grown in these treatments contained the quantity of nutrients that had been found in the bulbs before planting. Potash contents of the new bulbs most closely approached those of the original bulbs when K had been present in the nutrient solution. Nitrogen and P contents, when N and P had been supplied, were about two-thirds those of the original bulbs. In all cases when N, P, or K had been omitted from the nutrient solution the bulb contents of N, P, and K respectively were approximately one-half those of the original bulbs.

Ito, Kato, and Toyoda (36) in studying the N and carbohydrate metabolism of the tulip found that the N content of the bulb increases with increase in fresh weight of the bulb although the final N content is attained later than that of fresh weight. Another of their findings was that the percentage of N in the fresh weight also increases with growth. Bulbs grown in a sandy soil had a higher N content and concentration on a fresh weight basis than bulbs grown in a paddy field.

Size and morphological site of development of tulip bulbs as factors influencing their chemical composition were investigated by Hargrave, Thompson and Wood (30). Smaller sized bulbs--those which had developed from other than the main axillary bud--were consistently significantly lower in percent dry matter and in percent N, P, K and Ca in the dry matter than the larger bulbs which developed from the central axillary bud. One striking feature was that "maiden" bulbs (bulbs which had produced but one leaf, and no flowers in the growing season) had twice the Ca content of the non-maiden bulbs. The authors felt that in this case the high Ca content was due to less being used to produce leaves and therefore, was available to the new bulb that formed.

Analyses of Bulbs Other Than Tulip.

Several bulbous crops other than tulips have been the subject of mineral nutrient experiments. Zink (72) studied field grown garlic in three California counties in part to determine the crop's nutritional

requirements by determining the mineral content of the bulbs. He found that on an acre basis garlic would absorb approximately 180 pounds of N, 165 pounds of K, 130 pounds of Ca, 37 pounds of P, 18 pounds of Mn and 7 pounds of Na.

Couto (19) studied the effect of nutrient solutions on garlic grown in quartz sand. The plants were grown from a uniform clonal line. One-half of the plants were grown from whole garlic cloves and one-half from buds dissected from the storage leaf of the clove. Although bulb weights are not reported in this paper, deficiencies of N, P, K, Ca, Mg and B all resulted in highly significant reductions in the number of cloves produced per plant. All Ca deficient plants produced bulbs with only one clove. One-cloved bulbs also resulted when plants grown from buds dissected from the storage leaf were grown in solutions containing no K or no Mg.

Again in sand cultures Woodman (70) found that onion yields were significantly reduced by the deletion of N, P, K, Ca, or Mg from the nutrient solution.

Growing Ebenezer and Yellow Globe onions in Plainfield sand or a 1:1 sandy loam-muck mixture, Downes and Carolus (22) reported that nutrient applications high in N or all three major nutrients increased the Mn concentration of the leaves three and four times, respectively over normal treatments. Significant, but much lower increases in the Mn content of the bulbs were also found with these treatments.

Boodley (12) grew Croft lilies under three fertilizer regimes and followed the nutrient content pattern of the plants by taking weekly leaf samples. The plants were grown in unfertilized sand, sand with a complete nutrient solution, or a soil mixture with a standard greenhouse fertilizer procedure. The N content of the leaves declined from juvenility to maturity and the quantity recovered was in proportion to that applied. Very small, but about equal, amounts of P were recovered in all treatments. Potassium recovery from the leaves was similar to that of N except for increases during the last three weeks in those plants receiving the complete nutrient solution. The quantities of Ca recovered showed the most striking differences. In the sand culture without added nutrients very little was recovered throughout the plants' life, but the amount recovered in the other two treatments increased steadily with maturity. Magnesium showed the same pattern as Ca, but was of smaller magnitude. Most flower buds were formed on the plants grown in the soil mixture with the standard greenhouse fertilization practices.

In field experiments with the gladiolus cultivar 'Lorelei' grown in soil of high fertility, van Diest and Flannery (69), showed that only a minor portion of nutrients in the plants at flowering time and at the end of the season were supplied by the original corm. Percentages of nutrients still present in old deteriorated corms ranged from 13% for K to 44% for P.

Contrasting with this, Brown, Lawton, and Carolus (14) report that the yield and total P content of asparagus spears from five-year-old plants were not affected by P fertilization, indicating that a major portion of the P required to produce an asparagus crop is supplied from reserves in the root system. Carolus (16) followed the nutrient content of senescent asparagus vegetation and found that 47-74% of the N, 68-76% of the P and 39-89% of the K present in the August foliage was leached from the plant, or redistributed to more permanent plant structures by the time the foliage had matured. Depletion of N, P, and K from onion and rhubarb leaves was also reported by this author.

The Effects of Defoliation and Flower Removal.

The removal of leaves from any growing plant reduces productivity since the leaves synthesize the substances stored by the plant. The extent of such diminution would be dependent upon both the time in the plant's life cycle when the defoliation occurred, and the severity of the treatment. Compton (18) clipped 'Beacon' and 'Picardy' gladioli in varying degrees periodically, or at spike emergence, and found that corm weights were reduced in proportion to the severity of the leaf clipping. Significant reductions in corm weights were obtained only after about 11% of the total leaf area per plant had been removed.

Baker and Wilcox (9) defoliated onion plants 30, 60, and 90%. When the plants were most sensitive to defoliation yield reductions were of the order of 25, 45, and 60% respectively. The most critical

stage of growth in terms of the effect of defoliation on yield was after the plant had attained its maximum vegetative development and when the bulb was enlarging.

The marketing of narcissus blossoms from fields of plants grown for bulb production prompted Kalin (37) to compare the effects of flower head removal only with flower and peduncle removal as for commercial cut flowers. Several discoveries were made when bulb production and subsequent forcing quality of the bulbs were examined. First, the peduncle was found to be an efficient synthesizing organ--leaving it on the plant without the flower head consistently increased bulb production. Second, the peduncle's effectiveness varied with the type of growing season. Complete peduncle removal reduced production 6% in a normal year, 10% in a poor year, and only 4% in a good year. Finally, there was a definite cumulative effect. Where only the flower heads were removed over a three year period, bulb size improved progressively while those that had undergone continuous flower cutting continually declined in quality. Horton (34) reported the same effect on tulip bulbs produced for forcing where "headed" plants produced bulbs which flowered earlier and had flowers of better color and greater weight.

Grainger (26) suggested removal of narcissus flower buds and peduncles while they were still in a very early stage to divert to the bulbs the carbohydrates that would have been used by these parts. This proposal was examined in another experiment by Kalin (38). Removing the buds early did result in a slight increase of total bulb weight

produced, but had no beneficial effect on the production of double-nosed bulbs and higher quality forced flowers as did the "heading" technique.

The Japanese workers Toyoda and Nishii in a series of experiments (63, 64, 65, 66) achieved similar effects with tulips. Using the information formulated by Blaauw and his co-workers (thoroughly reviewed by Hartsema, 32) on the use of cold temperatures to promote flowering, they found that treating bulbs with heat prior to planting resulted in flower stalks without flowers. Bulb production from these plants was 20% to 26% greater than for the control plants.

Removing the tulip blossoms serves a double purpose. As noted above it increases the bulb production. No less vital to bulb production is its role in the control of disease. Gould (25) identifies the tulip flower as an infection court for *Botrytis* blight (tulip "fire") (*Botrytis tulipae* (Lib.) Lind). One of the control measures he enumerates is the removal and destruction of all flowers.

Effects of Temperature on Bulb Growth.

The growth pattern of tulip bulbs has been examined by several investigators. Pryor (52) made periodic examinations of growing tulips and concluded that the bulb passes through two exhaustion periods--first when the tops and flower stems begin to elongate, the old bulb begins to disintegrate, and the new bulbs begin to develop. The second when the tops are rapidly elongating and during maturation of the flowers. He also stated that the major portion of bulb growth appears to take place after blooming.

Kraaijenga (40, 41, 42) followed tulip bulb development in relation to temperature and humidity during the growth period. Weekly increases in weight of the new bulbs and secondary bulblets were positively correlated with temperature until May, and then negatively correlated. Most rapid bulb growth was found to occur from late April or early May until early or mid-June. To check the finding that very little bulb thickening occurred in dry weather a growth meter was developed. Use of this device showed that growth was interrupted when transpiration was high.

These findings would tend to corroborate the statement by Sass (54) that high temperatures early in the growing season might have a bearing on the senescence of tulip plantings. Post (51) also states that if the spring is long and cool the plant continues to grow and store food in the bulb after flowering, and that if the temperature goes from cold to hot in a short time, bulb growth is very slight because the plant matures early.

GENERAL MATERIALS AND METHODS

One thousand bulbs of Tulipa gesneriana 'Blizzard', produced by one grower under uniform conditions, were obtained from the Netherlands on October 30, 1962 and stored at 45°F. for six weeks. Bulbs were then weighed into uniform 128 ± 1 gram lots of four bulbs each and planted in six-inch sterilized clay pots. Growing media were steam sterilized mixtures of either one part manure, one sand, and three loam, or three parts Plainfield sand and one of arcillite*. The Plainfield sand had a pH of 5.6 and contained 4 p.p.m. of P, 80 p.p.m. of K, 74 p.p.m. of Ca, 2 p.p.m. of Mg, 20 p.p.m. of Mn, and traces of Fe and Cl. The manure, sand and loam mixture had a pH of 7.1 and contained 48 p.p.m. of P, 480 p.p.m. of K, 1128 p.p.m. of Ca, and 119 p.p.m. of Mg. Phosphorus in soil samples was determined using Bray's P-1 method while active K and Mg were determined with the Spurway method (58), using an extractant. The pH values were obtained from a soil:water suspension using the glass electrode technique (57).

The planted pots were initially well watered with tap water and returned to 45°F. storage for six additional weeks, after which all plants were removed to a 60°F. minimum temperature greenhouse. After the initial watering additional moisture was provided by distilled water only.

*Arcillite--an inert calcined montmorillonitic clay product, trade name Turface.

Representative bulbs were analyzed at planting time to determine their mineral nutrient composition. The bulb scales and incipient scapes of leaves, stems and flowers (Figure 1) were separated and analyzed to provide a basis with which to compare later analyses of the developing plants. As the plants developed the parts analyzed were: Roots, original bulb scales, new bulbs and bulblets, stems with leaves, and flowers with peduncles. The latter two categories were separated just above the uppermost leaf on the plant (Figure 2).

All plant parts were weighed as harvested, dried at 160°F., weighed again, ground to pass a 20-mesh-to-the-inch screen, and analyzed for their mineral nutrient contents. Nitrogen was determined by the Kjeldahl-Gunning-Arnold method (Anonymous, 5). Potassium was determined by flame photometry (Anonymous, 6) using a Beckman Model B spectrophotometer. Phosphorus, Ca, Mg, Fe, Mn, Cu, B, Zn, Mo, and Al were analyzed with a direct-reading photoelectric spectrometer* (Kenworthy, 39).

*"Quantograph" manufactured by Applied Research Laboratories, Glendale, Calif.

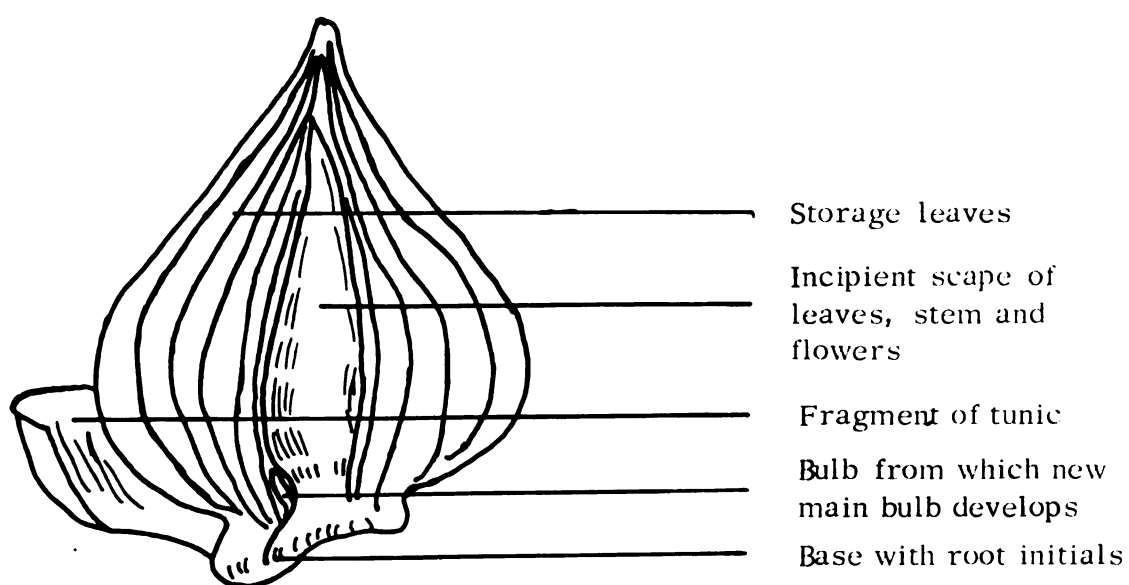


Figure 1. Diagrammatic cross-section of tulip bulb at planting time. (After Hall, 31)



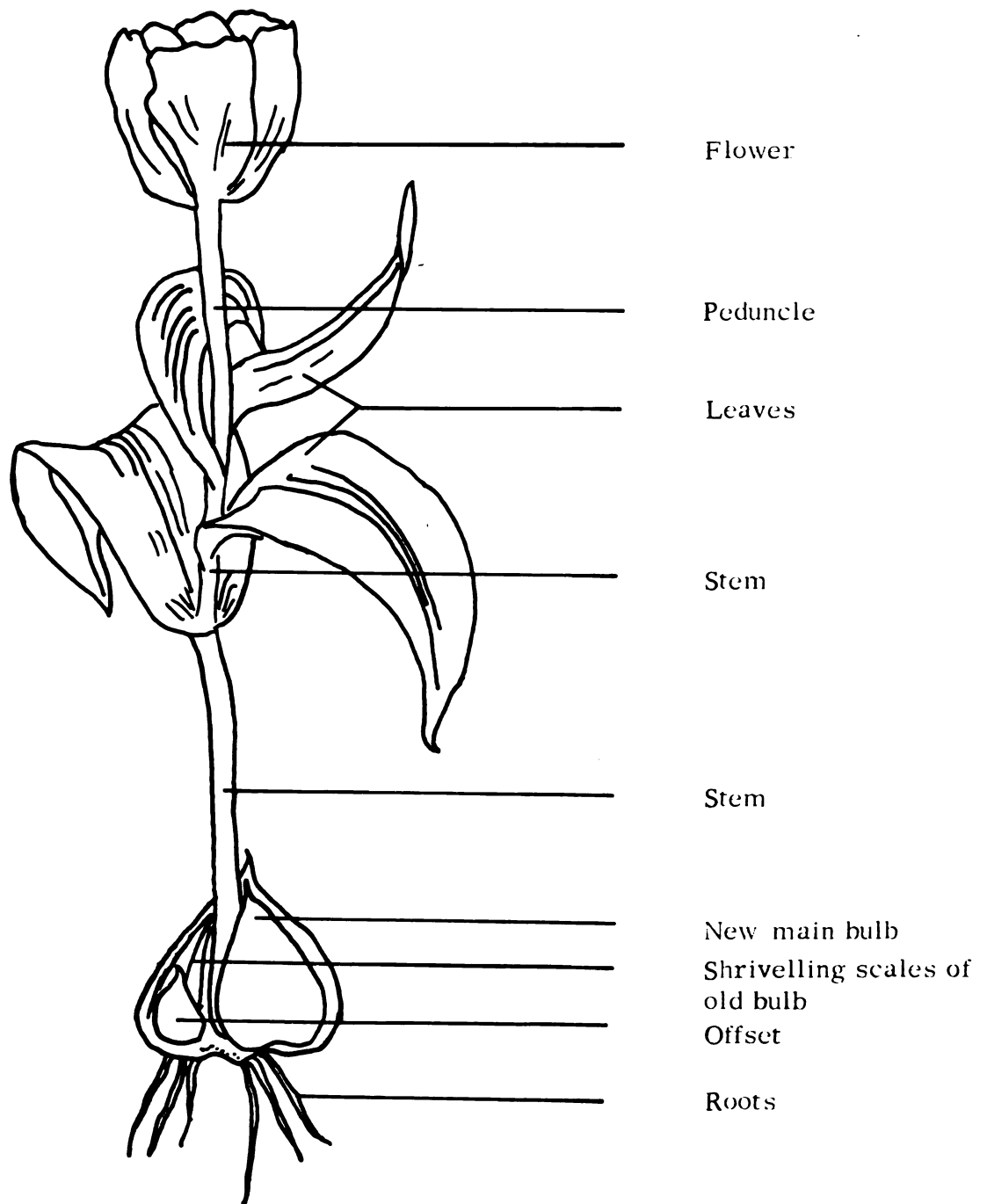


Figure 2. Diagrammatic representation of tulip at flowering time. (After Hall, 31)

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CHANGES IN COMPOSITION OF TULIP PLANTS DURING A GROWING SEASON

On December 9, 1962, forty-eight 4-bulb lots were planted in the Plainfield sand-arcillite mixture. No nutrients were added to the growth medium. Two 4-bulb lots were harvested weekly for 19 weeks beginning December 17 to observe the plants' development. Mineral analyses were determined on lots harvested on alternate weeks.

Results and Discussion

A. Dry Matter Content.

The fresh weight and dry matter content of the various plant parts are presented in Table I. The changes in the dry matter in the original bulbs, the new bulbs and the combined green organs of stems, leaves and flowers during the 19 week forcing period are graphically shown in Figure 3.

Average dry weight per old bulb decreased steadily from 16.3 grams to 0.6 gram. The dry weight of the stem, foliar and floral parts, beginning with the scape within the old bulb, increased from 0.4 g. to 5.3 g. at flowering and then decreased to 2.2 g. at maturity. The new bulb presented sufficient material for analysis beginning February 18. Its dry weight increased markedly in the six-week period from two weeks before until four weeks after flowering. The final average dry weight of approximately 10 g. was about two-thirds the weight of the original bulb.

Table I. Changes in growth, dry matter and mineral composition of various tissues of unfertilized tulip plants during a 19 week growth and development period. (Values averaged from 8 plants.)

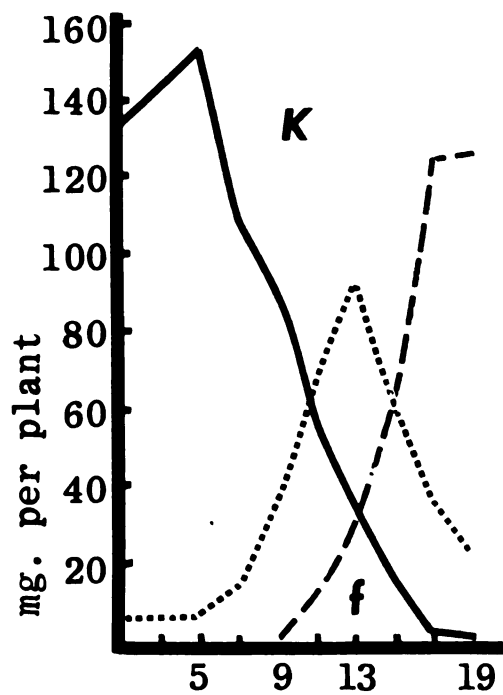
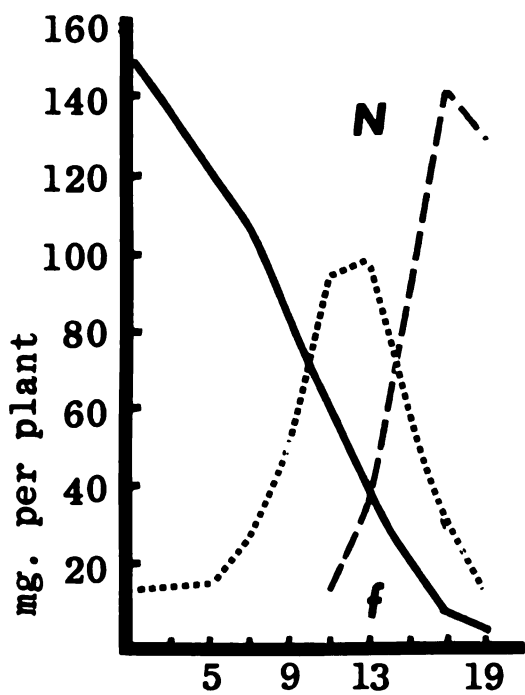
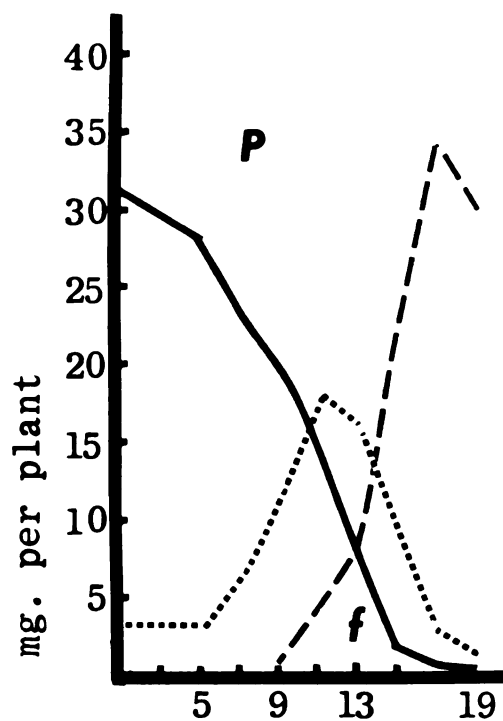
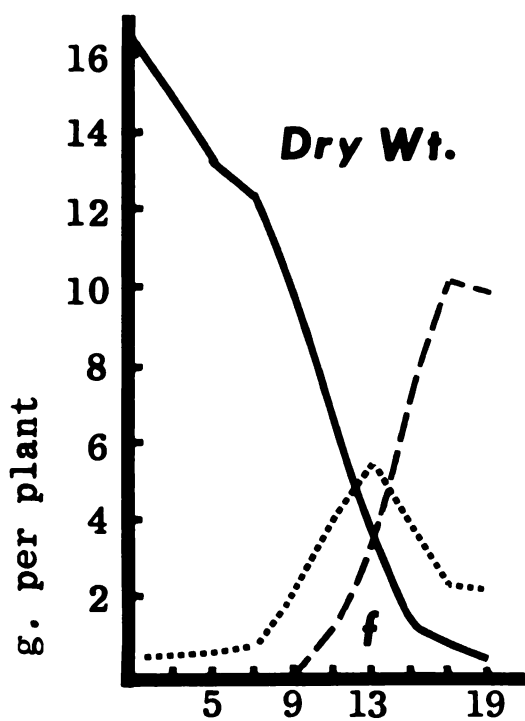
Plant Part	Week of Growth	Fresh Wt.	Dry Wt.	%D.W.	% of Dry Weight				p.p.m. of Dry Weight									
					N	P	K	Ca	Mg	Na	Mn	Fe	Cu	B	Zn	Mo	Al	
Original bulb	0	32.0	16.3	50.9	.92	.19	.82	.05	.09	.24	8	18	3.0	5.6	--	0.7	12	
	5	31.6	13.2	41.8	.91	.21	1.16	.10	.10	30	14	29	3.0	7.2	--	1.0	19	
	7	31.0	12.4	40.0	.89	.19	.87	.10	.09	30	16	28	2.5	6.6	--	1.1	15	
	9	28.2	9.8	34.8	.84	.20	.93	.09	.09	21	22	32	3.3	6.6	10	0.7	13	
	11	21.9	6.7	30.6	.96	.21	.83	.12	.10	36	34	37	3.7	7.8	9	0.8	27	
	13	15.0	3.8	25.3	1.00	.18	.91	.21	.11	293	70	43	4.7	7.5	5	0.9	40	
New Bulbs	15	9.3	1.6	17.2	1.50	.13	1.00	.38	.26	512	198	156	6.0	16.8	7	1.4	213	
	17	4.7	.9	19.1	1.06	.07	.36	.67	.38	464	484	235	23.2	26.0	19	2.8	307	
	19	--	.6	--	.70	.08	.16	.80	.34	310	370	556	21.3	33.0	34	4.0	1325	
	9	.73	.12	16.4	--	.68	1.56	.24	.17	11	54	41	11.0	14.8	34	1.2	12	
	11	4.3	1.07	24.9	1.21	.38	1.10	.18	.10	7	30	19	4.3	8.7	19	1.0	10	
	13	11.8	3.14	26.6	1.08	.26	.90	.15	.07	24	34	20	4.7	3.7	11	0.7	8	
	15	20.7	6.80	32.9	1.24	.32	.88	.13	.07	60	38	22	4.3	3.3	13	0.5	12	
	17	29.0	11.0	37.9	1.44	.31	1.28	.19	.09	74	34	25	5.0	5.6	13	0.7	12	
	19	24.1	9.99	41.5	1.26	.30	1.26	.13	.08	160	12	44	1.0	6.6	7	0.7	26	

Table I. Continued. Composition of unfertilized tulip plants.

Plant Part	Week of Growth	Fresh		Dry Wt.	%D.W.	% of Dry Weight					p.p.m. of Dry Weight										
		Wt.				N	P	K	Ca	Mg	Na	Mn	Fe	Cu	B	Zn	Mo	Al			
Leaves with stems	0	--	.44	--		3.18	.73	1.56	.13	.20	39	16	28	8.4	16.8	19	0.9	15			
	5	1.9	.51	26.8		3.08	.68	1.66	.13	.18	35	26	28	9.3	14.6	19	1.0	15			
	7	4.2	.82	19.5		3.34	.73	1.80	.19	.20	49	42	41	6.8	17.9	15	1.3	23			
	9	11.4	1.5	12.7		2.87	.67	2.04	.27	.19	22	67	58	6.8	29.5	30	1.3	42			
	11	28.9	3.1	10.6		2.24	.42	1.84	.38	.21	48	111	46	7.2	31.9	25	1.7	27			
	13	30.4	3.4	11.3		1.73	.29	1.89	.45	.17	102	155	27	5.9	21.3	17	2.0	26			
	15	27.9	3.1	10.9		1.66	.25	1.80	.41	.16	203	--	31	3.0	31.9	9	1.8	26			
	17	13.3	2.0	15.3		1.26	.11	1.50	.77	.23	608	231	50	8.4	36.8	11	3.2	54			
	19	--	1.4	--		1.00	.03	1.00	1.26	.34	1312	343	102	16.6	95.8	44	5.6	200			
Flowers with peduncles	9	1.9	.30	15.8		3.24	.77	1.76	.22	.16	19	46	50	8.4	16.8	38	1.2	12			
	11	7.7	.99	12.9		2.50	.54	1.41	.19	.14	13	51	35	5.5	18.4	27	1.0	8			
	13	14.2	1.8	12.4		2.19	.36	1.53	.23	.15	50	86	30	6.0	19.6	24	1.1	14			
	15	4.8	.72	15.0		1.64	.18	1.12	.35	.15	64	119	25	4.3	16.8	9	1.4	19			
	17	1.3	.50	38.5		1.10	.12	1.38	.52	.28	141	134	37	9.3	28.3	28	1.9	35			
	19	--	.75	--		1.30	.16	1.30	.46	.23	320	76	59	9.3	40.4	24	2.2	62			

Table I, Concluded. Composition of unfertilized tulip plants.

TABLE 2. COMPOSITION OF DRY MATTER OF ROOTS OF PARSNIPS.																	
Plant Part	Week of Growth	Fresh		%D.W.	% of Dry Weight					p.p.m. of Dry Weight							
		Wt.	Dry Wt.		N	P	K	Ca	Mg	Na	Mn	Fe	Cu	B	Zn	Mo	Al
Roots	5	3.5	.36	10.3	2.76	.59	2.44	.19	.20	--	--	--	7.6	20.2	19	1.2	--
	7	5.5	.38	6.9	3.18	.77	2.74	.22	.23	--	--	--	8.4	26.0	19	1.4	--
	9	10.2	.55	5.4	2.94	1.16	3.32	.46	.26	--	--	--	17.6	42.8	--	3.0	--
	11	5.0	.63	12.6	1.90	.87	2.32	.32	.15	--	--	--	12.9	39.2	47	1.6	--
	13	8.2	.59	7.2	1.36	.57	1.44	.31	.17	--	--	--	10.6	33.7	32	1.4	--
	15	4.8	.35	7.3	--	.56	1.46	.41	.17	--	--	--	12.0	58.0	36	1.8	--
	17	3.4	.24	7.1	--	.37	.68	.38	.17	--	--	--	17.6	45.5	41	1.4	--
	19	--	.32	--	0.80	.46	1.80	.58	.15	--	--	--	46.7	79.8	79	1.0	--



Growth Period (Weeks)

Growth Period (Weeks)

Figure 3. Composition of unfertilized tulip plants sampled at bi-weekly intervals. Average of 8 plants. Analyses for dry weight, N, P, K.

Orig. Bulbs —
 New Bulbs - - -
 Green Parts
 Full Bloom f

The decline in the dry weight of the original bulb scales would be attributed to natural translocation of carbohydrate and mineral matter to the new vegetative and reproductive parts, and to provide respiratory energy for plant development. The new plants' leaves would also have provided newly synthesized carbohydrate material for these purposes. Visually there appeared to be little, if any, decomposition of the original bulb scales until the very end of the growth cycle.

After flowering, rapid new bulb growth continued for an additional four weeks. The abrupt end of bulb dry weight increase and the fact that there was a large net loss of bulb dry matter contents from the beginning to the end of the season is partly the result of high greenhouse temperatures. Kraaijenga (42) has noted that increases in bulb weight in the latter part of the growing season are negatively correlated with temperature. By mid-April daytime temperatures frequently rose above 80°F. and temperatures of 75°F. were common. Low growth values for the new bulbs are probably not due to nutrient deficiencies since concentrations of the elements in the new bulbs equalled or exceeded those of the original bulbs (Table I).

The decrease in dry matter content of the leaves and stems indicates that most of the carbohydrate material was either translocated to the new bulbs, or lost through respiration. Since none of the plants set seed it is futile to speculate on the effect fruiting would have had on carbohydrate use and translocation.

As shown in Table I the original bulbs contained 50.9% dry matter while the new bulbs contained only 41.8%. These bulbs were analyzed at different times--the new bulbs immediately after harvest, the original bulbs approximately six months after harvest. The differences in dry matter content may partly be the result of normal water loss from the original bulbs during post-harvest storage.

B. Nutrient Distribution Pattern.

The major nutrient content variations of the three tissues closely resemble those of the dry weight. Nitrogen (Figure 3) steadily declined in the original bulbs from 150 mg. to 4 mg. In the green parts it increased from 16 mg. at planting to 99 mg. at full bloom, and then declined to 15 mg. at maturity. Sufficient new bulb tissue to provide material for nitrogen analysis was not available until nine weeks after planting. Thirteen milligrams were present at that time. Nitrogen content of the new bulb then increased sharply to 142 mg. on April 15 and declined to 130 mg. at maturity. The new bulbs contained 1.26% N, the original bulbs (excluding the incipient scape) contained only 0.92% N (Table I).

Phosphorus in the dry scales of the mother bulbs measured 0.4 mg. (Figure 3) at maturity compared with 31 mg. at planting. The peak in leaf-stem-flower P content was measured two weeks before full bloom. Only 1.5 mg. remained in these parts at maturity. The final P content of the new bulbs averaged 30 mg., or one milligram less than that

of the larger original bulb. The P content of the new bulbs, indicated in Table I, averaged .30% as compared with .19% for the original bulbs.

There appears to have been an initial absorption of K (Figure 3) from the sand-arcillite medium while the bulbs were receiving the flower dormancy-breaking treatment. Original bulb K rose to 153 mg. from 133 mg., but then declined to maturity when only one milligram was found in the dry tissues. In the leaves and flowers the weight of K increased from an initial low of 7 mg. to a peak at flowering of 93 mg., then fell to a level of 24 mg. at maturity. Potassium in the new bulbs increased sharply over a ten week period to 126 mg. at maturity. The new bulbs contained 1.26% K as compared with 0.8% K in the original bulbs analyzed at planting (Table I).

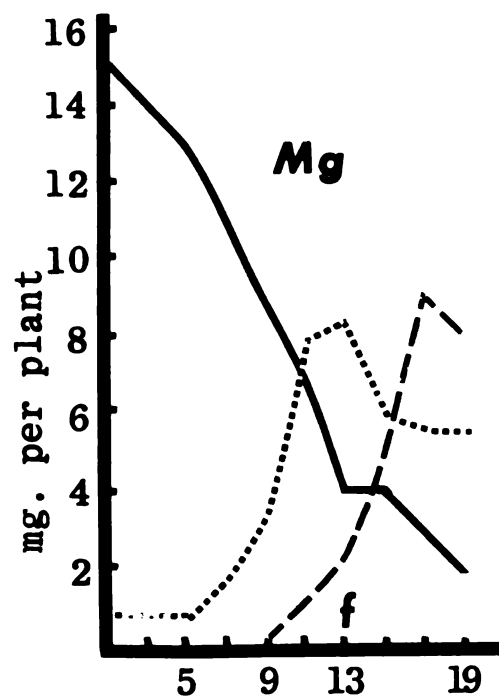
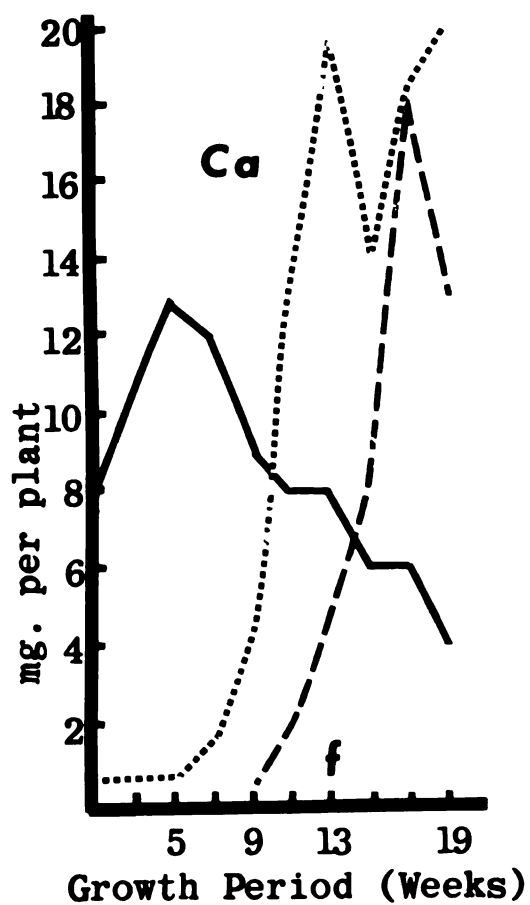
Since the new bulbs were smaller than the original bulbs, and since their N, P, and K contents were not reduced to the same extent, the percentages of N, P, and K in the new bulbs all exceeded the percentages in the original bulbs. This contrasts sharply with results reported by Bould (13) wherein the bulbs not only decreased in size, but also decreased in N, P, and K content as percent of dry weight. Bould's experiments were conducted out-of-doors thereby exposing the plants and growing medium to leaching by rain. Since foliar leaching is acknowledged to be of considerable extent in many crops (Tukey and Tukey, 67), lack of leaching may in part explain the high values observed in this study.

An aspect of Bould's work which tends to agree with this experiment is the K analysis of the new bulbs. None of the bulbs grown by Bould contained as high a percentage of N, P, or K as the original stock. But where K was supplied the K content of the new bulbs closely approached the original content. In the present experiment, new bulb N and P content increased by about one-third, while the K content increased by about one-half (Table I). The increase in K over the N and P would partly be due to absorption of K from the medium. It also reflects the ease with which it is redistributed in the plant which could, under Bould's conditions, possibly have prevented it from being leached.

The major element content of the plants in this experiment remained remarkably consistent. If the amounts present in each plant part are added at any time, the total approximates the original amount (Figure 3). Removal of major nutrients from the above ground parts and old bulb scales to the new bulb was very great in the case of N and K and virtually complete in the case of P.

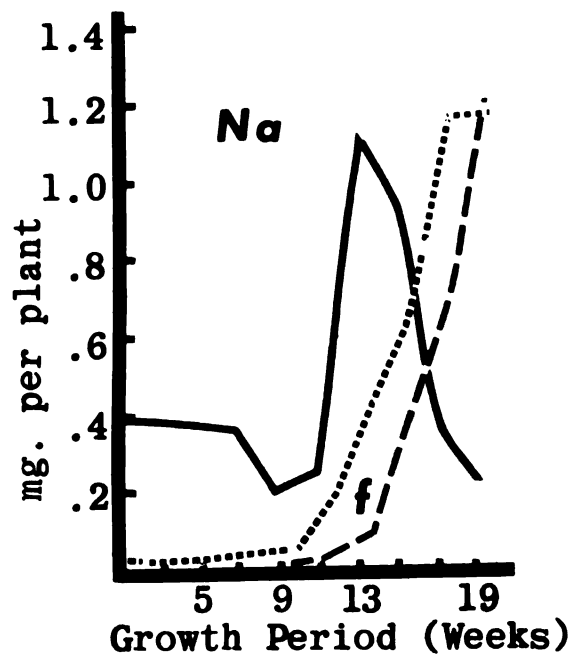
In Figures 4, 5, and 6 the periodic analyses of the original bulb indicate a diminution of the ten other elements to varying degrees during the period of active growth. Exceptions to this generalization are apparent increases in the Al and Mn contents.

The decrease of the other elements from the original bulbs tends to be indicative partly of their relative availability in the medium, and their essentiality. Calcium, which was present in the growth medium,



Orig. Bulbs ———
 New Bulbs - - - - -
 Green Parts
 Full Bloom *f* - . - . -

Figure 4. Composition of unfertilized tulip plants sampled at bi-weekly intervals. Average of 8 plants. Analyses for Ca, Mg, Na.



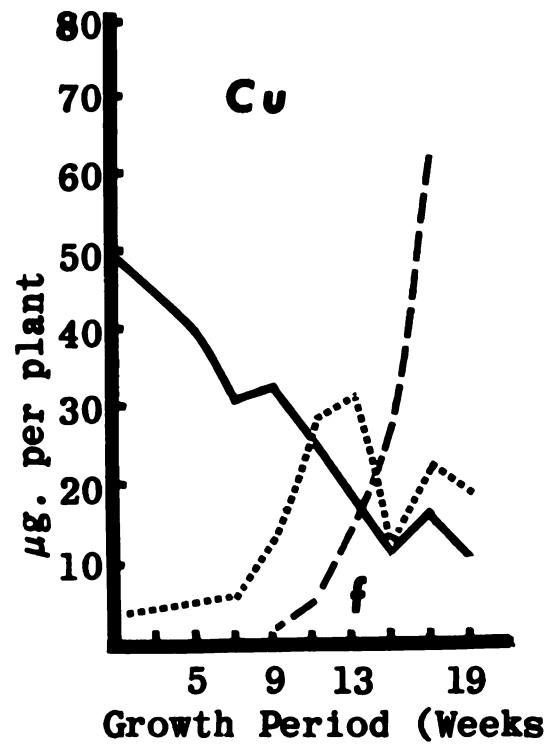
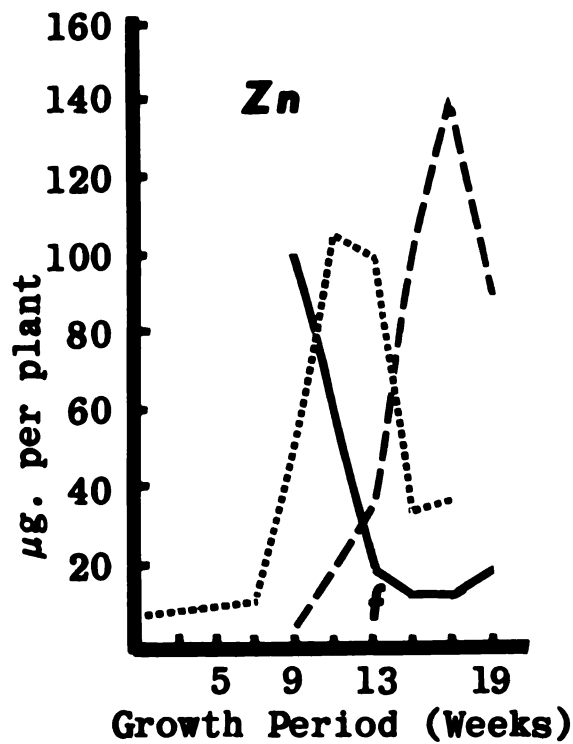
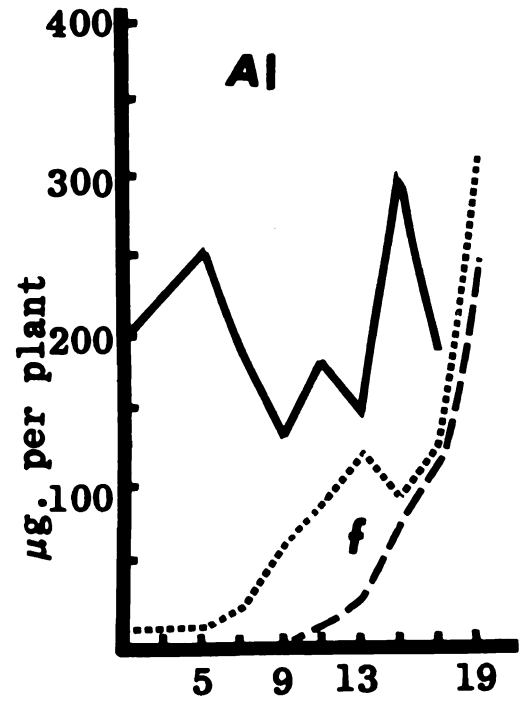
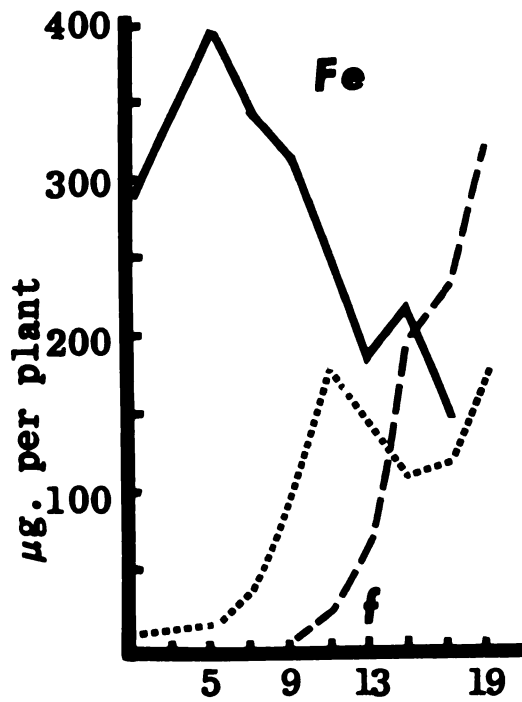


Figure 5. Composition of unfertilized tulip plants sampled at bi-weekly intervals. Average of 8 plants. Analyses for Fe, Al, Zn, Cu.

Orig. Bulbs —
 New Bulbs ---
 Green Parts
 Full Bloom f

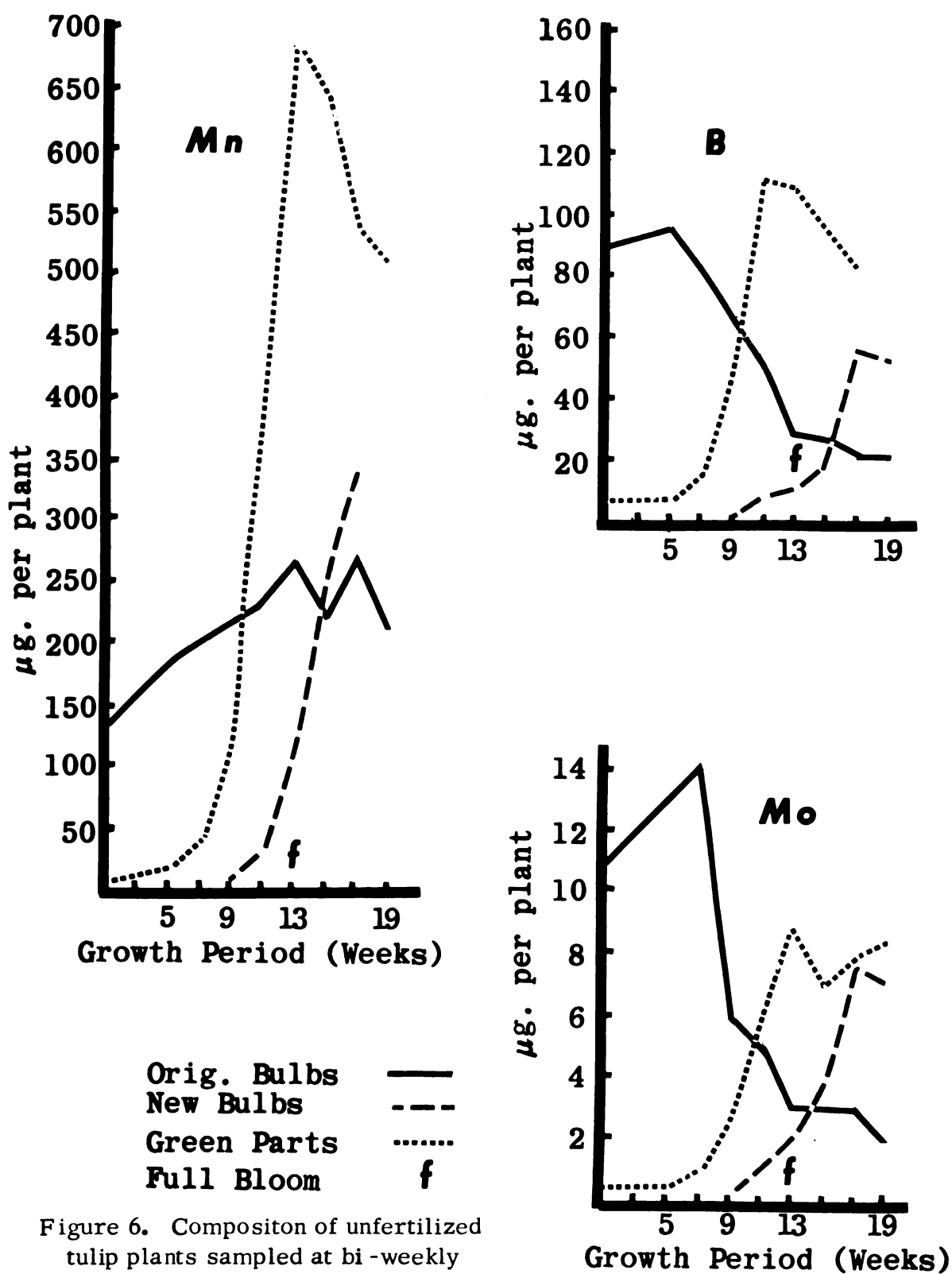


Figure 6. Composition of unfertilized tulip plants sampled at bi-weekly intervals. Average of 8 plants. Analyses for Mn, B, Mo.

was reduced to one-third of the bulb's maximum content, while Mg, which was very low in the substrate, was reduced to one-seventh. Manganese, which was abundantly available, apparently increased in the original bulbs. This high value for Mn resulted partly from the increasing difficulty of removing soil particles from the shrivelling scales. Aluminum showed a slight decrease, and then an apparent increase. This increase was again probably the result of contamination.

The role of contamination overall was small and can be attributed to two sources. Soil particles adhering to the underground portions would distort Fe, Mn and Al values. Another source of contamination would be dust from flaking aluminum paint of the greenhouse. The opening and closing of ventilators did result in such dust being scattered over the growing plants. Inability to remove this dust completely may have resulted in high Al values for the foliar organs. In all cases the new bulbs, which were very smooth, and which were protected within the original bulb scales, were freest of contamination.

The leaf content of a minor element tended to reflect the mobility of the element, and its availability from the substrate. Calcium, which is not mobilized from leaves, continually increased in the leaf tissue. Calcium was also available from the sand. Foliar Mn content increased greatly, and although there was a slight drop-off near maturity, it reflected the availability of Mn to the plant. Although no soil analysis was made for Na and B these elements were evidently available in the soil as indicated by their high content in the plant.

In the new bulbs the quantity of the minor elements with the exception of Mg, Mo, and B exceeded those of the original bulbs. Since the concentrations of these three elements in the new bulbs equalled those of the original bulbs (Table I) it is conceivable that the concentrations observed represent adequate levels, and that an additional accumulation might not readily be accomplished by the plant. At any rate, about 20% of these nutrients remained in the original bulbs, and, supposedly, still should have been available to the new bulb.

The analyses of tulips, grown in a medium of very low nutrient content illustrate the tendency for nutrients to be utilized in foliar growth and then to be redistributed and conserved in new bulb growth. However, this experiment did not facilitate bulb weight increase comparable to that which would normally be expected in outdoor culture. Low production was also apparently related to abnormally high greenhouse temperature conditions, and not to deficiencies of the elements analyzed since their percentages in the new bulbs exceeded those in the original planting stock.

THE EFFECT OF DEFOLIATION ON TULIP BULB PRODUCTION

Materials and Methods

Forty 4-bulb lots of tulips providing eight replications of five randomized treatments were planted in the loam-sand-manure mixture on December 9, 1962. These plantings were allowed to develop normally until just before flowers were in full bloom, and then were subjected to five defoliation treatments which fall into three main categories--(1) complete removal of all above-ground parts, (2) removal of flowers and peduncles only, and (3) no foliage removal. Complete defoliations were made at petal fall, or three weeks after petal fall. Flower and peduncle removals were made as the flowers came into full bloom, or at petal fall. Foliage that remained on the plants and intact plants dried down naturally six weeks after full bloom at which time the bulbs were harvested.

Results and Discussion

The average fresh weights of bulbs produced by four plants are indicated in Table II. Plants that were completely defoliated at petal fall produced lower weights of main bulbs* and total bulbs than any of the other treatments. No other treatment influenced main bulb growth. No treatment affected offset production.

*main bulb--the bulb produced from the central axillary bud of the original bulb.

1

TABLE II
The Effect of Defoliation on Tulip Bulb Production

	<u>Complete Defoliation</u>		<u>Flowers and Peduncles</u>		No
	at	at	removed at		Defoli-
	Petal Fall	Petal Fall	Petal Fall	Opening	ation
		+3 Weeks			
Main Bulbs	52.8** ¹	70.0	74.1	80.1	77.0
Offsets	13.6	22.4	21.1	19.0	22.0
Total Production	66.4**	92.4	95.2	99.1	99.0
Total per-centage of Orig. Weight	52	72	74	77	77
% of maximum Main Bulbs Produced	65.9	87.4	92.5	100	96.1
% of maximum Total Production	67.0	93.2	96.0	100	99.9

1. Fresh weight in grams per 4 plants.

** Significantly lower at .01 level.

Plants in this experiment produced approximately two-thirds of their main and total bulb growth by the time the petals had fallen from the flowers (Table II). By three weeks after full bloom this had increased to approximately 90% of the maximum fresh weight. This is in agreement with observations of the dry weight increase pattern shown in Figure 3.

The largest fresh weight of main bulbs was produced by the plants from which the flowers with peduncles were removed as the flowers reached full bloom. However, this treatment did not result in yields that were significantly different from the other treatments except where complete defoliation at petal fall was practiced (Table II). The pronounced reduction of bulb production by plants defoliated at full bloom is to be expected since they were in a vigorous vegetative state when defoliated. Plants which were defoliated three weeks later also appeared to be growing vigorously, but their production of main bulbs did not differ significantly from that of plants that were allowed to mature naturally. Therefore, the plants defoliated three weeks after full bloom were defoliated only shortly before growth ceased. This is in agreement with the results shown in Figure 3 in which dry weight increase ceased four weeks after full bloom.

Some support for Grainer's (26) contention that early removal of peduncles and flowers will increase bulb production has been indicated. In this experiment the bulb weights from plants which had had their

flowers removed earliest were slightly, but not significantly, above those of the other plants.

Simons (56) maintains that if flowers are cut for sale or for indoor use, leaving two leaves to remain is desirable if the bulbs are to be kept for growing again. Allen (2) found that leaving only one leaf per plant reduced bulb production by one-half. Horton (35) states that stock may be maintained by leaving one leaf on each plant but that two leaves per plant results in a better increase in bulb weight. It would appear from the data presented that gathering tulip flowers without leaves for home use is probably not a factor in reducing bulb vitality.

THE EFFECT OF VARYING LEVELS OF N, P, AND K ON NUTRIENT REDISTRIBUTION AND BULB WEIGHT IN THE TULIP

One-hundred forty-four 4-bulb lots were planted-- $\frac{3}{4}$ in the sand-arcillite mixture and $\frac{1}{4}$ in soil--on December 8, 1962. Twelve replications of nine nutrient combinations as indicated in Table III were used in the pots containing the sand-arcillite mixture; the O, 1X and 3X N-P-K levels were repeated in the soil medium. In the nutrient combinations the "X" level was equivalent to .25 g. of N, .50 g. of P and .25 g. of K. The nutrients were supplied by appropriate combinations of reagent grade NH_4NO_3 , KNO_3 , H_3PO_4 , $\text{NH}_4\text{H}_2\text{PO}_4$, and KH_2PO_4 . After cold treatment, the planted, treated pots were randomized in complete blocks in the greenhouse.

The nutrients were applied in solution $\frac{1}{2}$ one month, $\frac{1}{4}$ two months, and $\frac{1}{4}$ three months after planting. One-half of the plants were additionally fertilized with Ca, Mg, and B two months after planting using gypsum, Epsom salts, and "Safety-Bor" to provide .25 g. of Ca, 0.83 g. of Mg, and .02 g. of B per pot. Bulbs from one-half of the plants were harvested following full bloom, the remainder after they had matured normally.

TABLE III. Influence of Time of Harvest and Nutrient Level on Tulip Bulb Weight.

NPK Ratio	0-0-0	1-1-1	3-3-3	0-1-1	1-0-1	1-1-0	3-1-1	1-3-1	1-1-3	Harvest Avg.
<u>Main Bulbs</u>										
Harvest 1										
+ Minor Elements	46.3 ¹	50.7	58.0	53.7	47.0	53.0	56.0	51.0	46.3	51.3
- Minor Elements	55.3	54.3	48.3	45.0	46.3	48.0	54.3	51.3	56.0	51.0
Average	51.0	52.5	53.2	49.4	46.7	50.5	55.2	51.2	51.2	51.2
Harvest 2										
+ Minor Elements	77.0	75.3	85.7	66.7	78.7	84.3	82.0	82.7	83.7	79.6
- Minor Elements	79.3	83.7	82.7	83.0	82.7	81.0	88.7	85.3	85.3	83.5
Average	78.2	79.5	84.2	74.9	80.7	82.7	85.4	84.0	84.5	81.6
Main Bulb Average	64.6	66.0	68.7	62.0	63.7	66.6	70.3	67.6	67.9	66.4
<u>Offsets</u>										
Harvest 1										
+ Minor Elements	21.7	10.3	10.0	11.3	13.7	13.3	10.7	16.3	20.3	14.5
- Minor Elements	12.3	14.0	18.3	16.3	17.0	15.7	13.0	12.7	15.3	15.0
Average	17.0	12.1	14.1	13.8	15.3	12.8	11.8	15.8	17.8	14.7
Harvest 2										
+ Minor Elements	26.3	25.0	26.3	29.3	26.3	19.0	25.0	23.7	25.7	25.3
- Minor Elements	21.0	21.3	22.3	20.3	21.0	19.6	16.0	20.0	23.0	20.5
Average	23.6	23.1	24.3	24.8	23.6	19.5	20.5	21.8	24.3	22.9
Offset Average	20.3	17.6	19.2	19.3	19.5	16.1	16.2	18.8	21.1	18.8
Total Bulb Average	84.9	83.6	87.9	81.1	83.3	83.7	86.4	86.8	88.3	85.1

1. Bulb yield in grams per pot of four plants. Average of 3 replications.

Results and Discussion

The Effect of Nutrient Level and Ratio and Time of Harvest on Bulb Yield.

A statistical evaluation of the effect of 0-0-0, X-X-X, and 3X-3X-3X treatments in the sand-arcillite and the soil media were made. Harvest date proved to be the only significant factor affecting bulb production in this comparison, and was responsible for 91% of the variance observed. The average total bulb weight per pot of four plants was 65.9 g. for the first harvest and 104.6 g. for the harvest at maturity.

The analyses of variance for bulb yield of the nine nutrient treatments on the sand-arcillite mixture are summarized in Table IV. Harvest dates significantly influenced both main bulb and offset bulb production. Nutrient treatments had a significant influence on main bulb weight and there was an apparent interactive influence of nutrient level, minor elements and harvest date on both main bulb and offset bulb production. However, there was no statistical influence attributable to minor element addition per se or to the various first order interactions involving minor elements and either harvest date or nutrient level, with the exception of a slightly significant influence of nutrient level with minor elements on main bulb yield.

Plants that received the high level of N, P, or K or all three, on the average of both harvests, produced higher main bulb yields than the average (Table III). Plants that were fertilized with solutions lacking N, P, or K or all three nutrients in general produced main bulb weights that were below the average. These observations indicate

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TABLE IV. Analyses of Variance Summaries for the Effects of Nutrient Level, Minor Elements and Harvest Date on Tulip Bulb Yield.

Source of Variation	Degrees of Freedom	Main Bulbs			Offsets		
		Sum of Squares	F	Sum of Squares	F	Sum of Squares	F
Total	107	30769		6062		43605	
Replication	2	546	14.8	113	2.6	238	1.6
Harvest Date	1	24904	1353**	1784	81.8*	40136	553**
Minor Elements	1	89	0.7	118	1.0	1	0.0
Nutrient Level	8	640	2.8*	244	0.9	539	3.7**
ME X HD	1	125	0.9	179	1.5	2	0.0
NL X HD	8	228	1.0	123	0.5	152	1.0
NL X ME	8	462	2.0 ^a	231	0.9	240	1.6
NL X ME X HD	8	1364	5.9**	595	2.2*	615	4.2*

** Significant at .01 level

* Significant at .05 level

a Significant at .10 level

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that N, P, and K separately or combined were beneficial to main bulb production.

Main bulb yields--when the high level of any or all of the three major nutrients were applied--were generally benefitted more by the addition of minor elements in harvest 1 than in harvest 2 as indicated by the relative values calculated in Table V. In harvest 1 where no minor elements were added nutrient additions were apparently of little benefit to yield, but if N or P were omitted the yield was reduced by 19 and 16% respectively (Tables III, V).

In the first harvest, high N, and the high level of N-P-K when in combination with minor elements greatly enhanced main bulb production as indicated by relative yield values of 125 and 121. The high N-P-K level with minor elements also increased main bulb production as related to the control treatment in the second harvest, while the high N treatment increased production both with and without minor elements (Table V).

In general, the increases in main bulb production resulting from minor element additions in combination with nutrient application were eliminated when the bulbs were harvested at maturity. This is evidenced in the treatments deficient in any one of the major elements. In harvest 1 the plants were benefitted by the minor elements in these treatments, while in harvest 2 there was no benefit from Ca-Mg-B (Table III). The reverse, however, is true in the case of offset production. In harvest 1, in general, plants without the Ca-Mg-B application produced more weight of offsets than plants receiving the minor elements, but in harvest 2 minor elements consistently increased production of offset weight.

TABLE V. Bulb Yield of Fertilized Plants Relative to Non-fertilized Plants.

N-P-K Ratio	0-0-0	1-1-1	3-3-3	0-1-1	1-0-1	1-1-0	3-1-1	1-3-1	1-1-3
	<u>Main Bulbs</u>								
Harvest 1									
+ Minor Elements	100	110	125	116	102	114	121	110	100
- Minor Elements	100	98	87	81	84	87	98	93	101
Harvest 2									
+ Minor Elements	100	98	111	87	102	109	106	107	109
- Minor Elements	100	106	104	105	104	102	112	108	108
Main Bulb Average	100	102	106	96	99	103	109	105	105
	<u>Offsets</u>								
Harvest 1									
+ Minor Elements	100	47	46	52	63	61	49	75	94
- Minor Elements	100	114	149	133	138	128	106	103	124
Harvest 2									
+ Minor Elements	100	95	100	111	100	72	95	90	98
- Minor Elements	100	101	106	97	100	93	76	95	110
Offset Average	100	87	95	95	96	79	80	93	104
Total Yield Average	100	98	104	96	98	99	102	102	104

The importance of N to main bulb production is indicated by the treatment averages in Table III--62.0 g. for no N vs. 70.3 g. for high N, an increase of about 13%. The yield increase between the -P and high P treatments was 6%, and the increase from the -K to the high K treatment was only 2%. This trend is also reversed in the case of off-set production. High N and high P resulted in offset yield decreases of 19% and 3% from the -N and -P treatments while high K treated plant offset production increased 31% over the -K treatment.

From these observed differences in growth of main bulbs and off-sets as a result of nutrient treatment, it appears that when conditions are favorable for main bulb weight increases, growth is made at the expense of offset weight increases. It also appears that when minor elements are present, and bulbs are harvested at maturity, offset growth adversely influenced main bulb growth.

The Effects of Nutrient Level and Ratio on the Mineral Composition of the Tulip.

The stems with leaves, and the combined main bulbs and offsets of the plants in the three replications of twelve treatments that were grown to maturity and which received no minor element applications were analyzed for N, P, K and ten other elements.

The Effect of Three N-P-K Levels on Tulips Grown in Two Media.

The chemical analyses of the parallel treatments receiving the 0, 1X and 3X levels of N-P-K on sand-arcillite or soil were statistically

compared by analysis of variance. Except for Fe the growth medium significantly affected leaf and stem nutrient contents to varying degrees. Treatment had no influence on Mg, Na, Mn, Fe, or Mo contents of the bulbs. The F values, where significant differences were found in mineral nutrient contents of stems with leaves, and of bulbs, are listed in Table VI.

Increased N-P-K fertilization of plants grown in either the soil or sand-arcillite medium in general resulted in an increase in the quantity of N in the new bulbs with concomitant increases in the residual N content of the foliage. (Table VII). The N content, however, was larger in plants grown in soil than in those grown in the sand-arcillite mixture. This is in part associated with varying bulb size as well as N concentration. Bulb dry weight from plants grown in soil averaged 11.0 g. while that of plants grown in sand-arcillite averaged 10.5 g. The N concentration of soil-grown bulbs was about equal to the N concentration of those grown in sand-arcillite except in the unfertilized plants. (Table VIII). The higher N concentration in unfertilized, soil-grown bulbs is accounted for by the natural N content of the soil. In the fertilized plants, larger bulb weight resulted in the increased quantity of N.

The N found in new bulbs from fertilized plants compared to that found in non-fertilized plants is presented in Table IX. The bulbs grown in sand-arcillite recovered 8.8% more of the N applied at the 1X

TABLE VI

Summary of Statistical Evaluations of Nutrient Contents in Foliage and Bulbs as Related to Soil and Nutrient Level Treatment

Element	Foliage			New Bulbs		
	Nutr. Level	Medium	NL X M	Nutr. Level	Medium	NL X M
N	11.7** ¹	7.0*	--	4.1 ^a	--	4.5 ^a
P	158**	4.1 ^a	2.3 ^a	151**	--	8.0**
K	27.6**	4.7 ^a	--	8.1**	11.8**	--
Ca	--	15.4**	--	--	8.7*	4.4*
Mg	--	11.1**	--	--	--	--
Na	--	4.6 ^a	--	--	--	--
Mn	--	67.4**	--	--	--	--
Fe	--	--	--	--	--	--
Cu	--	9.3*	--	3.9 ^a	7.4*	--
B	--	6.1*	--	--	10.5**	--
Zn	--	6.4*	--	--	8.2*	--
Mo	--	10.2**	--	--	--	--

1. F values from the analyses for each element.
 ** Significant at .01 level
 * Significant at .05 level
 a Significant at .10 level

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TABLE VII. The Influence of Growth Medium and Nutrient Level on N, P, K, Ca, Mg Contents of Tulips (Average of 4 plants X 3 replications)

Nutrient Level	Relative Yield	N		P		K		Ca		Mg		
		S-A	Soil	S-A	Soil	S-A	Soil	S-A	Soil	S-A	Soil	
Stems with Leaves												
0-0-0	100	100	4.0 ²	5.7	.38	.43	13.4	20.5	14.2	19.6	6.5	5.8
1-1-1	102	89	4.2	4.5	.61	.34	19.3	19.2	11.7	15.8	7.4	4.3
3-3-3	105	101	5.9	7.1	2.89	2.34	28.1	30.5	11.7	19.6	9.6	6.1
Average			4.7	5.8	1.29	1.04	20.3	23.4	12.5	18.3	7.8	5.4
New Bulbs												
0-0-0	100	100	119	132	32.3	39.3	121	132	21.7	19.9	8.7	13.3
1-1-1	103	109	153	160	50.8	46.7	137	146	15.1	22.7	10.4	11.0
3-3-3	98	108	177	190	60.2	60.2	133	150	14.3	21.1	10.3	11.6
Average			150	161	47.8	48.7	130	143	17.0	21.2	9.8	11.9

1. S-A--Plainfield Sand-arcillite medium.
 2. mg. per plant part.

TABLE VIII

Composition of Tulips Grown in Two Soil Media

N-P-K Level	Dry Wt.	%N	%P	%K	Dry Wt.	%N	%P	%K
<u>Plainfield Sand-Arcillite</u>					<u>Soil</u>			
<u>Stems With Leaves</u>								
0-0-0	1.26 ¹	.32 ²	.030	1.06	1.39	.41	.031	1.47
1-1-1	1.28	.33	.048	1.50	1.23	.36	.028	1.35
3-3-3	1.32	.45	.219	2.12	1.40	.50	.167	2.17
<u>Main Bulbs and Offsets</u>								
0-0-0	10.50	1.14	.308	1.15	10.39	1.27	.333	1.27
1-1-1	10.80	1.41	.471	1.27	11.35	1.41	.408	1.29
3-3-3	10.26	1.73	.589	1.30	11.27	1.69	.543	1.33

1. Dry weight in g. per plant. Average of 4 plants.

2. Weighted averages for 3 replications.

TABLE IX

Quantity and Percentage of Applied N, P, and K accumulated in New Bulbs of Plants Grown in Two Soil Media (Average of 3 replications).

N-P-K Level	1X	3X	1X	3X
Medium	<u>Sand-Arcillite</u>		<u>Soil</u>	
N Applied	250 ¹	750	250	750
N Recovered	133.2	232.0	111.6	232.0
% Recovery	53.2	31.4	44.4	31.4
P Applied	500	1500	500	1500
P Recovered	74.0	111.6	29.6	83.6
% Recovery	14.8	7.4	5.9	5.6
K Applied	250	750	250	750
K Recovered	63.6	50.0	55.6	73.2
% Recovery	25.4	6.6	22.2	9.8

1. Mg. per pot of 4 plants.

level than those grown in soil, but at the 3X level bulbs from each medium recovered identical quantities of the applied N.

Differences in P content of the plant parts caused by differences in P applications are very striking. Very little residual P was found in the mature leaves of plants which received no nutrients or the 1X level of N-P-K. Between the 1X and 3X levels of nutrient application the residual P content of the foliage increased five- to six-fold (Table VII). These differences appear to be an indication of P availability to the plants, and would also indicate that almost all of the P in the leaves and stems was redistributed to the new bulbs until the new bulb P content reached 50-60 mg. per plant. The P concentration at this time averaged .408 to .471% of the bulbs' dry weight (Table VIII).

Without nutrient application the amount of P in the new bulbs was the same as or slightly higher than in the original bulbs (Figure 3, Table VII). Phosphorus content of the bulbs increased in a parallel manner in sand-arcillite and in soil as the level of P fertilization increased (Table VII). But in the fertilized plants the percentage of P in the new bulbs was consistently lower for soil-grown bulbs than for those grown in sand-arcillite (Table VIII). This difference was not the result of the slightly greater dry weight of the soil-grown bulbs since sand-arcillite-grown bulbs contained a greater or equal quantity of P. This is possibly due to less P fixation in the sand-arcillite compared to soil, and its consequent increased availability to the plant.

Available P in the soil, and the fixation of applied P by the soil, reduced the recovery of applied P by the plants (Table IX). The sand-arcillite grown bulbs at the low and high levels of fertilization contained 74.0 and 111.6 mg. more P respectively than those from the non-fertilized plants. In the soil medium only 29.6 and 83.6 mg. of the low and high P applications were recovered in the bulbs.

Fertilization with N-P-K increased the K content of plants grown in both media. Soil media significantly affected the residual K content of the foliage, and highly significantly affected the K contents of the new bulbs (Table VII). Residual K contents increased in the foliage with increasing fertilization, but not as regularly for the two media as did the K contents of the new bulbs. In the new bulbs the K contents of plants grown in soil was consistently above that of plants grown in the sand-arcillite mixture. This would in part be due to the higher level of K in the soil medium.

The largest percentage of applied K was recovered by the new bulbs of plants receiving the low treatment in the sand-arcillite medium (Table IX). Bulbs from plants receiving the high level of fertilization grown in sand-arcillite recovered the lowest percentage of the applied K. Potassium contents of bulbs from this treatment were about equal to those of bulbs from unfertilized plants grown in the soil (Table VII).

Foliar and new bulb Ca was not affected by the N-P-K fertilizations, but the effect of growing media was significant (Table VI). The soil contained 15 times as much Ca as the Plainfield sand, thus accounting

for the significance of soil media on the plant Ca contents. Although Mg was also more plentiful in the soil than in the sand, more residual Mg was present in the foliage of plants grown in the sand-arcillite mixture than in those grown in soil (Table VII). There was more Mg in the bulbs of unfertilized plants grown in the soil than in those grown in the sand-arcillite. With nutrient applications, however, bulb Mg content was at the same level from both media indicating better utilization, or greater availability of Mg as a result of N-P-K applications.

In general, quantities of N, P, and K were all increased in the plants as the level of nutrient application was increased. The amount of the applied nutrient which was recovered in the bulbs was also related to the quantity applied, with a higher percentage being recovered at the lower level of application. The quantity of P in the new bulbs from the low level of application was much larger than from the control treatment. Residual foliar P, however, was only increased at the high level of its application suggesting that P is reduced to a lower level in the leaves if adequate quantities of P for bulb growth are not available.

Statistically significant differences observed in minor element contents of the tulip plants were mainly associated with soil media. (Table VI). There are, however, some noticeable trends in minor element contents of both foliar and storage organs as affected by nutrient level or growth medium.

Residual Na content increased in the leaves of plants grown in both media and in bulbs from plants grown in sand-arcillite as the nutrient level increased from zero to the high level (Table X). The combined Na contents of both foliar and storage organs grown in either medium vary by less than 5%. But in soil-grown plants, the Na content averages 36% greater for foliage and 26% less for bulbs than in plants grown in the sand-arcillite mixture. Sodium was evidently about equally available in either medium, or equally absorbed by the plants. The differences in the redistribution of this element to the bulbs may be related to a substitution of Na for Ca in the bulbs grown in the low Ca content sand-arcillite mixture.

Foliar Mn of the sand-arcillite-grown plants averaged 7.4 times greater than that of soil-grown plants, but caused no apparent toxic effects. Despite the availability of excess Mn in the sand-arcillite mixture, evidenced by soil and foliar analysis, the bulbs produced in either medium contain similar quantities of Mn, which generally followed the same trend, and were apparently satisfactory. The excess Mn that was absorbed by the sand-arcillite-grown plants was retained in the leaves, and may have reduced the possibility of toxic effects to the bulb from the high Mn levels. In both media more Mn was found in bulbs from the unfertilized plants than from fertilized plants.

The Cu contents of both foliar and storage organs of plants grown in the sand-arcillite mixture show no definite relationship to the level of N-P-K application. In plants grown in soil, however, more Cu was

TABLE X. The influence of two soil media and three N-P-K levels on minor element composition of tulips. (Average of 4 plants x 3 replications.)

Level	Na		Mn		Cu		B		Zn		Mo	
	S-A ¹	Soil	S-A	Soil	S-A	Soil	S-A	Soil	S-A	Soil	S-A	Soil
Stems with Leaves												
0-0-0	808 ²	1129	360	44	19	26	99	100	22	29	6.2	8.0
1-1-1	897	1152	401	39	27	31	110	88	26	29	5.1	6.9
3-3-3	918	1271	375	70	15	32	122	95	24	34	5.3	7.9
Average	874	1187	378	51	20	29	110	94	24	31	5.5	7.6
New Bulbs												
0-0-0	1768	1517	274	365	35	38	121	72	522	217	6.6	5.9
1-1-1	2140	1759	234	223	16	34	88	70	357	196	5.4	6.4
3-3-3	2358	1652	206	236	32	49	107	78	379	204	5.1	6.4
Average	2089	1643	238	275	26	40	105	77	419	206	5.7	6.2

1. Plainfield Sand-Arcillite.
2. µg. per plant part.

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found as the level of fertilization increased. On the average there was 45% more Cu in the foliage, and 48% more in the bulbs of soil-grown plants than of sand-arcillite-grown plants indicating increased Cu content and/or availability in the soil.

Boron contents in bulbs were not appreciably influenced by the nutrient level. Soil-grown bulbs had a lower B content than bulbs grown in the sand-arcillite medium.

The average Zn accumulation in the sand-arcillite-grown bulbs was twice that of soil-grown bulbs, while the residual foliar Zn was at the same low level for each medium. Since leaf Zn was redistributed to the bulbs it appears that high levels are not retained in the leaves or that tulip bulbs have a large Zn requirement. As with Mn, the largest quantities of Zn were found in the bulbs from non-treated plants, which may partly be the result of differential absorption when nutrients were applied.

Molybdenum contents of the bulbs were at equal levels for each medium and nutrient application level, while foliar contents of soil-grown plants exceeded those of sand-arcillite-grown plants. Original bulb Mo concentration was .7 p.p.m. of the dry weight. (Table I). Using the average dry weight of bulbs grown in sand-arcillite and in soil (10.5 and 11.0 g. respectively) the average Mo concentration of these bulbs both equal .56 p.p.m. indicating again that the leaves may retain excess minerals when adequate levels have been translocated to the storage organs.

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These minor element composition values tend mainly to reflect the influence of the growth medium on the plant parts. Sodium was the only element to be influenced to any large extent by N-P-K nutrient application.

The Effect of Nutrient Ratio on Composition

The N, P, and K contents of stems with leaves and of the new bulbs were significantly affected by the nine nutrient treatments on the sand-arcillite mixture. Of the other elements only the Na and Cu contents of the foliage were significantly affected by the various N-P-K treatments. The significance of variations in plant part contents of these minerals were evaluated by Duncan's Multiple Range Test (23) and are presented in Table XI. Contents of minerals not significantly affected are listed in Table XII.

The residual N content of the foliage and the N content of the new bulbs is clearly related to the level of N applied. The bulb N contents appear to be a more sensitive indicator of N application than the residual N in the mature leaf. In the bulb the N contents varied with the quantity applied while in the foliage they only showed a significant increase at the high level of application. Although the plant N contents appear to be related to the quantity of N applied, at the high level of application the N contents were also enhanced when the P and K were at the low rather than high levels. High K had the effect of reducing the quantity of N present in the new bulbs (Table XI). This may be

TABLE XI. The influence of nine N, P, and K combinations on the N, P, K, Na, and Cu content of tulips

Level	0-0-0	1-1-1	3-3-3	0-1-1	1-0-1	1-1-0	3-1-1	1-3-1	1-1-3
Element	<u>Stems with Leaves</u>								
N	4.04 ^a , 1	4.23 ^a	5.91 ^b	3.74 ^a	3.60 ^a	3.36 ^a	8.73 ^c	4.28 ^a	4.27 ^a
P	.38 ^a	.61 ^a	2.89 ^c	.54 ^a	.30 ^a	.57 ^a	1.53 ^b	1.59 ^b	.65 ^a
K	13.4 ^a	19.3 ^b	28.1 ^d	12.2 ^a	14.3 ^a	13.4 ^a	25.3 ^c	13.1 ^a	18.3 ^b
Na	808 ^c	897 ^d	918 ^c	741 ^a	761 ^b	765 ^b	929 ^c	803 ^c	894 ^d
Cu	19.0 ^b	27.0 ^d	15.3 ^a	21.3 ^c	28.0 ^{de}	28.0 ^{de}	18.6 ^b	28.3 ^{de}	18.3 ^b
	<u>New Bulbs</u>								
N	119 ^a	153 ^c	177 ^d	123 ^a	140 ^b	142 ^b	188 ^c	141 ^b	134 ^b
P	32.3 ^a	50.8 ^{cd}	60.4 ^c	43.5 ^b	34.4 ^a	45.0 ^b	47.6 ^b	54.9 ^d	46.3 ^b
K	121 ^a	137 ^{bc}	133 ^{bc}	132 ^b	126 ^a	121 ^a	122 ^a	134 ^{bc}	138 ^c
Na	1768	2140	2358	1720	1452	2534	1625	1205	1837
Cu	34.6	16.0	32.3	12.3	33.6	19.3	30.3	21.6	33.0

1. N, P, and K in mg. per plant part, Na, and Cu in μ g. per plant part. Average of 4 plants $\times$ 3 replications.



TABLE XII. The Ca, Mg, Mn, Fe, B, Zn, and Mo contents of tulips fertilized with nine N, P, and K combinations. (Average of 4 plants $\times$ 3 replications)

Level	0-0-0	1-1-1	3-3-3	0-1-1	1-0-1	1-1-0	3-1-1	1-3-1	1-1-3
Element	<u>Stems with Leaves</u>								
Ca	14.2 ¹	11.7	11.7	11.0	11.9	12.6	10.5	14.1	11.4
Mg	6.5	7.4	9.6	7.3	7.7	8.5	8.1	9.5	6.4
Mn	360	401	375	370	211	403	165	543	340
B	99	110	122	115	130	109	124	132	87
Zn	22	26	24.	27	26	30	33	34	25
Fe	110	151	140	136	123	127	132	135	105
Mo	6.2	5.1	5.3	4.8	5.6	5.9	5.0	5.5	5.2
	<u>New Bulbs</u>								
Ca	21.7	15.1	14.3	15.0	17.1	13.9	18.2	16.2	22.5
Mg	8.7	10.4	10.3	9.3	9.4	9.5	10.4	10.5	10.5
Mn	274	234	206	194	199	191	215	235	251
B	29	25	25	20	41	56	65	36	38
Zn	174	119	126	117	116	122	144	155	203
Fe	337	277	277	221	303	264	312	303	359
Mo	6.6	5.4	5.1	5.4	5.8	4.9	6.8	5.4	7.3

1. Ca and Mg in mg., Mn, B, Zn, Fe, and Mo in $\mu\text{g.}$ per plant part.

related to Lambeth's (45) finding of reduced lettuce yields due to a N-K imbalance.

In addition to the increase of P in plants treated with the two levels of N-P-K, as discussed previously, the data in Table XI indicate that high N had the effect of increasing residual foliar P of the low P treated plants to equal that of those that were treated with the high level. Bulbs from the high N treatment had slightly, but not significantly, more P than bulbs from the -N treatment. These data, therefore, suggest increased P uptake with increased N application. This contrasts with the finding by Patterson, et al. (50) that applications of N significantly decreased the P content of onion bulbs from that where no N was applied.

High N also increased the residual foliar K but not new bulb K, and when compared with the two levels of N-P-K, depressed bulb K. The low K application did not increase bulb K over no K when N was high, or P was absent. However, when N was low, or omitted, or when P was high, bulb K content at the low level of K application was 10 to 14% higher than in bulbs from plants which did not receive K.

When either N, P, or K was not applied, quantities of residual foliar Na were smaller than in the non-treated plants. Foliage from other treatments, except the high P treatment contained quantities of Na considerably greater than non-treated plants. There is a trend for the N, P, and K to follow the same pattern (Table XI) indicating that

major nutrient balance may partly influence residual nutrient contents in the foliage.

When N, P, and K were applied together at the high level foliar Cu was significantly reduced. With high N and high K the Cu contents were the same as in untreated plants. High P, the low level of all three nutrients, or the absence of one of the nutrients considerably increased foliar Cu. This is partly in agreement with Labanauskas et al. (43, 44) who found the Cu concentration of avocado leaves to decrease appreciably with high applications of chemical N. However, when foliar and bulb Cu contents are added, plant Cu appeared to have been increased by the -P treatment and decreased by the -N treatment. Copper content totals for these treatments are 62 and 33 μg . respectively while those of the other treatments range from 43 to 54 μg .

Increasing the level of N-P-K, resulted in increases in plant N, P, and K content. Different nutrient ratios interacted to influence the quantity of these elements in the plant. Sodium uptake appeared to be decreased when one of the elements was missing, while reduction of foliar Cu was induced by high levels of N or K or all three major elements.

GENERAL DISCUSSION

Periodic analyses showed that the dry weight of the original bulbs decreased steadily from planting time until they were reduced to brown, shrivelled scales shortly before the plant matured. Developing bulbs began to increase rapidly in dry weight in the period two weeks prior to full bloom, and continued to develop for a total period of approximately six weeks. During these six weeks increases occurred at a slightly greater rate immediately following blossoming than during other periods. This is in agreement with observations by Kraaijenga (40) who found the most rapid bulb growth period to be the four to five days following blossom removal. Pryor (52) found that bulbs increased 85% over the planted weight within eight days following the blooming period, but that until then bulb weights had only increased slightly over the planted weights.

Four weeks after full bloom the periodic measurements indicated little or no growth continuation. Tulips that had been completely defoliated three weeks after full bloom achieved 93% of the maximum total bulb weight produced. This also is in accordance with Kraaijenga (41) who found that bulb weight increases were small in the final week before harvest.

In plants grown in a medium very low in nutrients, major nutrient contents in the new bulbs began to increase about four weeks before full

bloom. Immediately after full bloom new bulb nutrient contents increased very sharply as nutrients were translocated from the foliage. Just prior to blossoming the foliage itself had increased rapidly in nutrients derived from the old bulb.

Rogers, et al. (53) followed the seasonal trend of nutrient element contents in apple leaves and found that the dry weight, N, P, and K contents reached a peak and then decreased before abscission. They estimated that approximately one pound of N and 0.1 pound of P were returned to the tree in this manner. Calcium increased in the apple leaves up to the time of abscission, and Mg contents remained about constant from the time that the first samples were taken 20 days after full bloom. Bukovac, et al. (15) could demonstrate no basipetal movement of Mg^{28} in Phaseolus vulgaris. In the tulip foliage Ca remained immobile, but the Mg contents declined about 30%. Zinc, Cu, Mn, and B also tended to decrease considerably in the tulip leaves as they matured.

Nutrient applications to the tulip plants elicited a number of responses. Main bulb growth was benefitted by the addition of Ca, Mg, and B when plants were harvested immediately after flowering, but not when plants were allowed to grow to maturity, possibly in part the result of redistribution of Mg and B from the leaves.

Bulb weights have been reported by Amaki and Hagiya (3) to be increased most by applications of N, and least by P. Results obtained in this study agree in part, with N increasing main bulb weight, but with

P appearing to be more beneficial than K. The reverse occurred in the case of offset production where K applications resulted in the largest weight increases and N was least beneficial. This may in part be the reason for conflicting reports in the literature (3, 33, 35, 55, 70, and 61) as to which of the three major elements elicits the best tulip bulb growth response.

In this experiment main bulb and offset production tended to complement each other--one being high when the other was low, and vice versa. This had the effect of obscuring the response to added nutrients if only total bulb production was examined. Hargrave, et al. (30) found that bulbs produced from lateral buds were lower in percent dry weight and in percent of N, P, K, Ca, and Mg in the dry weight than the bulbs produced from the main axillary bud, which finding may also be related to the differences observed in bulb weight increases in this investigation.

The differential effects of N and K may be of practical interest to both those who use tulips for landscape purposes, and to those who produce them commercially. Additional investigation may disclose optimum levels of N applications necessary to maintain main bulbs in good vigor, while discovery of the proper levels of K fertilization to insure maximum offset growth would increase production for bulb growers.

Increasing the amount of a nutrient applied to the growth medium increased the quantity of that element in the plant. The percentage of applied nutrient that was recovered in the new bulbs was always

largest in bulbs from plants which were grown in the sand-arcillite mixture, and which received the lower level of applied nutrients.

The N contents of new bulbs were not only related to the quantity of N applied, but also to the quantity of K applied. Residual foliar N was not affected by increased K levels. Applied N tended to have the reciprocal effect on plant K contents, i. e. with high N applications new bulb K was reduced, and residual foliar K was increased.

Paterson et al. (50) report that applied N reduced the P contents of onion bulbs. This relationship was not found in the tulip, with bulb P contents at high and low N levels being statistically the same. High N did significantly increase residual foliar P. The great increase noted in residual foliar P contents when P was applied illustrates the extent of P redistribution which takes place. This redistribution of P in plants is probably in part the reason for lack of uptake by asparagus of applied P as described by Brown, Lawton and Carolus (14).

In general the quantity of minor elements in the plant was affected to a larger extent by the growth medium than the differential N-P-K nutrient applications. This is especially noticeable where plant Ca and Mg were highest for soil-grown plants and Mn and Zn were highest for sand-arcillite-grown plants.

Although total plant Mn contents for sand-arcillite-grown plants greatly exceeded those of soil-grown plants, bulb Mn contents were at the same level for both media. The retention of excess Mn in the foliage removed the mineral from the plant by normal foliar abscission

at the end of the season. This would in part explain the lack of injury to tulips from excessively high Mn levels as found by Hewitt and Miles (33).

SUMMARY

When the various parts of unfertilized tulip plants grown in a medium very low in nutrient contents were periodically analyzed it was found that most of the N and K, and virtually all of the P that had been utilized in foliar growth was redistributed to the new bulbs after the blossoming period. This recycling phenomenon may occur in other plants with storage organs thus reducing the amount of applied nutrients needed to maintain their growth. Redistribution of Mg, Zn, Cu, B, and Mn from the foliage to the new bulbs also occurred, while Ca, Na, Fe, Mo, and Al remained immobile.

Complete defoliation of tulip plants immediately after flowering reduced total bulb production by one-third. Complete defoliation three weeks later, or removal of peduncles and flowers at opening or at petal fall did not significantly alter bulb production from that of plants which were allowed to grow intact to maturity.

The relative importance of the major nutrients to main bulb and offset production differ. High N was most beneficial to main bulb and least beneficial to offset bulb yield. High K was least beneficial to main bulb and most beneficial to offset bulb yield. Main bulbs and offset yields were also differentially affected by harvest date and an application of Ca-Mg-B. When harvested immediately after flowering these minor elements benefitted main bulb yield and did not affect offset bulb

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yield. When harvested at maturity offset yield was benefitted and main bulb yield was not affected.

Plant contents of N, P, and K were increased by application of these nutrients to the growing medium. Large increases were noted in foliar P contents at the high level of P application. The N-P-K ratio applied also affected the N-P-K contents. More N was found in the plants when P and K were applied at low rather than at high levels, and the quantity of N in the bulbs was reduced when the K application was high.

Phosphorus in the bulbs was increased by high N applications. Bulb K contents were not affected when the application of N was high or when P was omitted, however when N was omitted or when the high level of P was applied bulb K was increased.

The amount of Mn and the concentration of Mo in bulbs grown in two media were very similar. At the same time leaves of plants grown in soil contained more Mo than those of plants grown in sand-arcillite, and leaves of sand-arcillite-grown plants contained 7.4 times more Mn than those of soil-grown plants. This illustrates a possible function of plant leaves in disposing of excess levels of nutrients at the end of the season.

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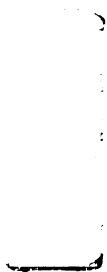
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