CASTOR BEANS: NUTRIENT SOLUTION CULTURES AND RESPONSES TO FERTILIZER TREATMENTS UNDER GREENHOUSE AND FIELD CONDITIONS

By

Clarence Ralph Carter

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1953

Submitted to the faculty of the Graduate School of the Oklahoma Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
January 1954

CASTOR BEANS: NUTRIENT SOLUTION CULTURES AND RESPONSES TO FERTILIZER TREATMENTS UNDER GREENHOUSE AND FIELD CONDITIONS

Thesis Approved:

Robert M. Reed

Thesis Advisor

[signature]

[signature]

Dean of the Graduate School

PREFACE

This investigation was carried on under the direction of Dr. Charles L. Sarthou and Dr. Robert M. Reed of the Agronomy Department and Dr. Donald Van Horn and Dr. Wade Parkey of the United States Department of Agriculture; Bureau of Plant Industry, Soils and Agricultural Engineering. When Dr. Sarthou joined the Staff of the Imperial Ethiopian College of Agricultural and Mechanical Arts and Dr. Van Horn became associated with the Baker Castor Oil Company, the writer continued his work under Dr. Robert M. Reed and Dr. Wade Parkey.

The author wishes to express his appreciation to Dr. Van Horn and Dr. Parkey for supplying the funds which made this investigation possible. The writer also wishes to thank Dr. Sarthou and Dr. Reed for their advice, assistance and criticisms throughout this research and in the preparation of this paper.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

I INTRODUCTION

Castor beans or the castor plant which produces the castor bean have been grown since biblical times for their oil content. The early Egyptians used castor oil for lamps. (8) In fact, this crop is one of the oldest crops known to man.

Today castor oil is used for the lubrication of jet engines, formulation of all-purpose greases, hydraulic and recoil fluids, and is the basic constituent of plastic coatings for electrical equipment (14). It is also used as a plasticiser in the manufacture of fabrics and explosives, artificial leather, soap, printing ink and special low temperature lubricants (14).

It therefore became necessary for the United States to initiate a program of castor bean production which would insure and adequate supply of the oil for war and industrial purposes. During World War II the tremendous demand for castor oil by the government defense program exceeded the imports from Brazil, Manchuria, Africa and India (8). When castor bean production ceased at the end of World War II,the United States Department of Agriculture realized that castor oil would probably be a critical item in any future national emergency and retained its plant breeding projects in order to maintain sufficient seed stock of adapted castor bean varieties. In 1947, a commercial castor oil company, which need ed a stable supply of raw materials set up its own agronomic division to study the improvement of castor bean production on a sound peace time basis.

The purpose of the following investigation was to determine the effect of various plant food nutrients on the growth, development and yield of castor beans. The research plan was divided into three phases. The first was the use of nutrient solution cultures to observe the growth and development of the plants as well as any deficiency symptoms which might occur. The second was a series of soil pot studies to ascertain the effect of differentially fertilized soil types on the growth and development of castor beans. Lastly, field plot trials, receiving various kinds and varying amounts of fertilizers, were conducted to determine their effect on growth and development, and yield of castor beans. It was hoped that these phases would supplement each other.

II REVIEW OF LITERATURE

The first fertilizer trials with castor beans were recorded in 1941. In that year, Domingo and Crooks (3) of the United States Department of Agriculture, Bureau of Plant Industry, Soils and Agricultural Engineering, Beltsville, Md., conducted a field fertility experiment using varying amounts of nitrogen, phosphorus and potassium fertilizers which were applied in bands at planting time. As a result of these studies, they concluded that castor beans produced no significant yield responses to any of the fertilizers used in their experiment. In 1943, the same investigators carried on trials using 250 pounds of a 4-12-8 fertilizer per acre and they also applied at the same rate, various combinations of three plant food nutrients; nitrogen, phosphorus and potassium. Phosphorus alone produced an 8.5% increase in bean yields on the plots at Princeton, Kentucky; whereas nitrogen and potassium alone or in combination had no effect on increasing the yields of beans grown on these same plots.

Quimby (10) conducted a factorial fertilizer experiment on Miles sandy loam at Chillicothe, Texas in 1951 and found a significant difference in yield due to nitrogen alone. He stated that " The addition of 30 pounds of nitrogen at planting time resulted in an increase of 386 pounds of clean beans per acre, and the addition of 60 pounds of nitrogen per acre resulted in an increase of 542 pounds of beans".

In 1951, Van Horn (15) found at Stillwater, Oklahoma that the use of 50 pounds per acre of ammonium nitrate at planting time gave a 16% increase in bean yields whilt the application of 100 pounds of ammonium nitrate per acre increased the yields 33%. He (16) also carried on other fertilizer experiments at Stillwater as well as fertilizer test under irrigated conditions at Altus and Blair, Oklahoma, in which quite different results were obtained. Fifty, one hundred, and one hundred-fifty pounds of ammonium nitrate; 100 pounds of "ammo-phos" (16-20-0); and 300 pounds of 5-10-5 fertilizer per acre were used at each of these locations. Van Horn obtained no significant increases in bean yields from the fertilizer used at these locations.

In 1952, Tucker (13) carried on factorial fertilizer trials at Stillwater, Perkins and Mc Alester, Oklahoma. The rates of application ranged up to 25-50-25 pounds per acre of plant food nutrients (nitrogen, phosphorus and potassium) at Perkins and Mc Alester. At Stillwater, the rate of nitrogen was increased to 200 pounds per acre. At Mc Alester the application of 500 pounds of 5-10-5 fertilizer gave a yield which was 17.2% greater than that obtained on the check plot and the use of 250 pounds of 20% superphosphate resulted in a 14.7% increase in the yield of beans. All these increases were significant at the 5% level. At Perkins there was a significant increase of 26.7% over the check plots from the application of 150 pounds of ammonium nitrate plus 250 pounds of 20% superphosphate. On the Stillwater plots the increase in yields on the fertilized plots were not significant, although they produced higher yields than the fertilized plots at the other two locations.

III METHODS OF EXPERIMENTATION

Nutrient Solution Cultures

The first phase of this experiment was to grow plants in nutrient solution cultures in an attempt to obtain different deficiency symptoms.

The castor bean seeds (Cimmaron variety) were planted in silica sand which had been washed with 3 N hydrochloric acid and with distilled water until no chlorides were present in the wash water. Four days after the seedlings emerged, those with two good cotyledon leaves were transplanted to one gallon battery jars, the stems were wrapped with cotton and suspended through one-quarter inch hardware cloth. For a period of 4 hours, the plants were allowed to feed from a solution containing 15 ppm. of iron as ferric citrate. Next they were transferred to a complete nutrient solution for one week and then placed in the various solutions shown in Table 1.

The solutions used in this work were made according to the directions given by Hoagland (7) and Ginsburg (5). They were prepared from the following stock solutions for the major plant food nutrients: 1 Molar solutions of calcium nitrate $Ca(NO_3)_2.4H_2O$, magnesium nitrate $Mg(NO_3)_2.6H_2O$, potassium nitrate, magnesium sulfate $MgSO_4.7H_2O$, potassium dihydrogen phosphate, calcium acetate $Ca(C_2H_3O_2)_2.H_2O$, magnesium

Table 1. Chemical Composition of nutrient solution cultures

nutrient solution concentrations in parts per million

Treatment	N	P	K	Ca	Mg	Fe	B	S	Mn
Complete	210	31	234	200	48	15	0.5	64	0.5
No N	0	15.5	390	100	12	15	0.5	240	0.5
No P	210	0	390	300	48	15	0.5	96	0.5
No K	210	15.5	0	320	48	15	0.5	64	0.5
No Ca	210	31	624	0	48	15	0.5	64	0.5
No Mg	210	31	429	200	0	15	0.5	80	0.5
No Fe	210	31	234	200	48	0	0.5	64	0.5
No B	210	31	234	200	48	15	0	64	0.5
No S	266	31	234	200	48	15	0.5	0	0.5
High Mn	210	31	234	200	48	15	0.5	64	3.0
High Ca	210	31	624	2000	48	15	0.5	64	0.5
High P	210	310	195	200	48	15	0.5	64	0.5
High K	210	31	1989	300	48	15	0.5	64	0.5
High Mg	210	31	234	200	480	15	0.5	0.1	0.5

acetate $Mg(C_2H_3O_2)_2.4H_2O$, potassium acetate and phosphoric acid; 0.5 Molar solution of patassium sulfate; and 0.01 Molar solutions of calcium sulfate and mono-calcium phosphate $Ca(H_2PO_4)_2.H_2O$.

The minor element stock solutions contained 0.05 ppm of zinc, 0.02 ppm of copper, and 0.01 ppm of molybdenum. In minor element stock solution number one, the zinc and copper were supplied in the sulfate form and in minor element stock solution number two, cholrides were the source of zinc and copper. The stock solution of boron had 0.5 ppm of boron as boric acid. Manganese was obtained from a stock solution of manganese chloride which contained 0.5 ppm of manganese. The first source of iron was a 0.5% ferric citrate solution. Later in the experiment, the iron supply was changed to a 1.15% solution of NaFe sequestrene (monosodium ferric ethylene-diamine tetraacetic acid) which contained 13% iron. When ferric citrate was used as the source of iron, it was applied once a week at the rate of 15 ppm. This solution was added in the absence of all other nutrients to prevent the fixation of iron and the precipitation of the phosphates. The NaFe Sequestrene was used at the same rate as ferric citrate, but it was combined with the nutrient solutions.

All solutions were changed at weekly intervals in order to keep a better ionic balance among the nutrients. The pH was checked and corrected daily to a value of 6.2 to 6.8.

There was a continual shifting of the pH in most of the nutrient solutions, some becoming acid in a period of 24 hours while some would move into the basic pH range. Very few solutions remained in the neutral range.

The nutrient solutions were aerated by the use of a small air compressor, which bubbled air through a series of rubber tubing and glass fittings. The motor which powered the air compressor was connected to an electric time clock which was set for 80 minute intervals. Thus, a steady stream of air was supplied for 80 minutes followed by an 80 minute rest period. White sodium vapor fluorescent lights were used to give the plants a constant fourteen-hour day. They were also connected to an electric time clock. During cloudy and inclement weather the lights were operated manually. Figure 1 depicts the equipment used in this nutrient solution culture experiment.

Daily observations were made and photographs were taken periodically to record any deficiency symptoms which might occur. The plants were grown in these different nutrient solutions for a period of three months.

During the latter part of May, the plants began to wilt at mid-day even though the jars contained a sufficient supply of solution and were covered with cotton to prevent contamination and evaporation. It was decided on May 26th that the plants would be harvested due to the extreme heat in the greenhouse.

Fig. 1. Nutrient solution cultures and soil pots of castor beans growing in the greenhouse.

Chemical analyses of the plant tissue were made according to the following methods. Nitrogen was determined by the Kjeldahl method (4). Phosphorus was measured colorimetrically using ammonium molybdate and stannous chloride to produce the color (6). Sodium, calcium and potassium were determined by means of a Perkin-Elmer flame photometer (12). Magnesium was run gravimetrically, with 8-hydroxy-quinoline as the precipitating agent after iron and aluminum had been removed as the phosphates and calcium as the oxalate (6). A colorimetric analysis of iron was made using 1-10 orthophenanthroline to develop the color (12). Manganese was also determined colorimetrically using potassium periodate to produce the color (12). Sulfur was precipitated as barium sulfate and weighed (12). Boron was determined by Naftel's procedure (9) using tumeric in the formation of the color.

Soil Pot Studies in the Greenhouse

The three soils chosen for this study were collected from areas where castor beans were planted extensively in 1952. The selected soils were Parsons fine sandy loam from Pittsburg county near McAlester, Oklahoma; Stidham fine sandy loam near Paradise, Oklahoma; and Stidham loamy fine sand near Perkins, Oklahoma. Both Stidham soils were located in Payne county.

These soils were all low in native fertility. The Stidham fine sandy loam contained 1.25% organic matter, 16 pounds of available phosphorus, 168 pounds of available potassium peracre and tested moderately acid with the Beckman pH meter. The total calcium content of this soil was 0.50% and the total magnesium percentage was 0.81. The Stidham loamy fine sand had 1.96% organic mat.er, 162 pounds of available potassium per acre and also tested moderately acid. The total calcium percentage of this soil 0.39 and the total phosphorus content was 0.14%. The Parsons fine sandy loam contained 1.96% organic matter,98 pounds of available potassium per acre, and was likewise moderately acid. This soil contained 0.14% total phosphorus. The Parsons soil was poorly drained because of a dense claypan beginning at a dept of approximately 13 inches.

The soils were screened through a 4-mesh sieve and 20 pounds of each soil were placed in 2½-gallon pots. Prior to the preparation of the soils a one inch layer of acid washed sand had been placed in the bottom of each pot and a glass tube was inserted through the soil into the sand. This tube would permit the siphoning off of excess amounts of water if necessary. The fertilizer treatments for the pots given in table 2 were applied in bands about four inches deep. In June of 1952 castor bean seeds (Cimmaron variety) were planted directly above the fertilizer band. Each treatment was made in triplicate except the Parsons series and it was replicated four times.

After emergence, the plants were thinned to four plants

Table 2. Fertilizer treatments (pounds per acre) in soil pots

Treatment No.	N	P_2O_5	K_2O
1	0	50	0
2	0	50	25
3	25	50	25
4	25	0	25
5	25	50	0
6	0	0	25
7	25	0	0
8	0	0	0

Sources of fertilizers

ammonium nitrate (33%N)
superphosphate (20%P_2O_5)
muriate of potash (60%K_2O)

per pot. Enough water to saturate the soil was applied every secon or third day. Each week the pots were rotated around the greenhouse in order that each pot would receive the same amount of light. To produce more favorable air and water relationships, "Aerotil" soil conditioner was applied to each pot during the third month of the experiment.

The plants were harvested by Tucker (13) on December 5, 1952 by clipping them above the first node. Castor beans are perennials in the warmer climates. Thus in the greenhouse, where the temperature exceeded 100 degrees F., the plants reacted in a like manner and began to put out new growth. On March 18, 1953, each pot received another dosage of fertilizers. The plants were harvested again on June 10, 1953, chemical analyses were made and dry weights were recorded. The procedures for chemical analyses were the same as the ones used for the plants grown in nutrient solution cultures.

Field Plots at Two Locations in Oklahoma

Two soils were selected for field plot trials; a Paradise fine sandy loam near Paradise, Oklahoma, (Payne County) and a Bates sandy loam near Miami, Oklahoma (Ottawa county).

The soil tests from the Miami Plots indicated a low fertility status; phosphorus ranged from 0 to 6 pounds of available phosphorus per acre, available potassium averaged 75 pounds per acre and the nitrogen content was 0.08%. The pH of this soil was approximately 5.3. The soil tests from Paradise showed a higher fertility level; available phosphorus was 15 pounds per acre, there were 350 pounds of available potassium per acre, and nitrogen percentage was 0.06. The pH of this soil was about 5.8.

The Miami plots were prepared by flat breaking to a depth of 7 or 8 inches, double disc-harrowed in the early spring and allowed to lay fallow until May. The plots were disc-harrowed, marked off, and the fertilizer was placed at a depth of 6 inches just before the beans were planted. The fertilizer treatments for these plots shown in Table 3 were applied from a two-row belt distributor, mounted on an Allis Chalmers garder tractor. The castor bean seeds (Western oil-seed hybrid 4 variety) were planted on May 22 with an inclined plate planter. The seeds were placed at a depth of 3 inches directly above the fertilizer.

The plots at Paradise were prepared in the early spring by listing, re-listing, disking and fallowing until May. The plots were disc-harrowed and planted on May 27 with the 367 variety of castor beans. On June 5, the fertilizer applications given in table 3 were added as a side dressing about 3 inches to the side and 3 inches below the seed. All plots were hoed once and cultivated throughout the season to keep down weeds.

The plots were observed at least once a month during the growing season and plant material was selected for field and laboratory tissue testing. The beans were harvested on October 8, 1953 at Paradise, Oklahoma, and on November 12, 1953 at Miami, Oklahoma.

Table 3. Fertilizer treatments (pounds per acre) on field plots

	Paradise			Miami		
Treatment No.	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1	0	0	0	0	0	0
2	0	0	25	0	0	25
3	0	50	25	0	50	25
4	25	50	25	25	50	25
5	25	50	0	25	50	0
6	25	0	0	25	0	0
7	25	0	25	25	0	25
8	0	50	0	0	50	0
9	50	50	25			
10	50	50	0			
11	50	0	0			
12	50	0	25			
13	12	48	0			
14	100	0	0			
15	100	50	0			

Sources of fertilizers

ammonium nitrate (33%N)
superphosphate (20%P_2O_5)
muriate of potash (60%K_2O)

IV RESULTS AND DISCUSSION

Nutrient Solution Cultures

Plant Symptoms

Only one replication was used in the culture solutions which received the following treatments; no nitrogen, no phosphorus, no potassium, no calcium, no magnesium and no iron. The original study of these treatments had been carried on extensively the previous year. The experiment was repeated in an attempt to verify the plant symptoms which had been previously produced. Three replications were used for the study of the cultures containing no boron and no sulfur as well as the solutions having large amounts of calcium, phosphorus, potassium, magnesium, and manganese. The complete solutions were also run in triplicate. All plants were allowed to feed on a complete nutrient solution for one week after they had been transplanted from the silica sand. Then the actively growing plants of uniform size were transferred to the various solutions which were listed in Table 1.

Nitrogen Deficiency. Nine days after the plants had been changed to the solution receiving no nitrogen, their lower leaves began to droop and the petioles seemed to be weakened. (Fig. 2) The older leaves began to lose color around their margins. Then the entire leaf including the midrib and veins lost its color. As the symptoms progressed up

Fig. 2 Comparison of castor bean plants growing in a complete nutrient solution and in a solution containing no nitrogen.

Fig. 3. Comparison of castor bean plants growing in a complete nutrient solution and in a solution containing no phosphorus.

the plant, the older leaves became chlorotic and finally sloughed at the abscission layer between the stem and the petiole. The new leaves had a good green color which indicated a translocation of the nitrogen from the lower leaves. Later these upper leaves became chlorotic and were sloughed. The leaves of nitrogen deficient plants seemed to be longer and narrower than those of the plants growing in a complete solution. The leaves also were sharper at the apex. The most striking symptom of the plants receiving no nitrogen was the shortening of the internodes. The plants growing in a no nitrogen solution had the same number of nodes as the plants growing in a complete solution, but the nodes would be approximately one-fourth of the normal length.

Phosphorus Deficiency. Phosphorus deficiency symptoms were not displayed until the plants were 12 weeks old. (Fig.3) The deficient plants appeared to be darker in color than the plants growing in a complete solution. Their internodes were longer than those of the plants growing in a complete solution. The first signs obtained were a slight chlorosis in the lower leaves. Next, the internodes increased in length, while the upper leaves remained a dark green color. Thus a translocation of phosphorus to upper leaves probably occurred. Then, reddish to purplish spots would develop on the lower leaves, disappear, and produce an area of necrotic tissue. After this sequence of the symptoms, the leaves dried up and abscissed.

Potassium Deficiency. The signs of potassium deficiency did not occur until the plants were 6 weeks ole. When potassium was excluded from the solution, the plants were less vigorous than those growing in a complete colution, but there was no definite symptoms of potassium hunger for several weeks. These symptoms appeared initially in the lower leaves when the tips and margins became chlorotic. The tissue finally died and the outer magrins became involute. As the temperature increased, small brown and white splotches appeared throughout the lower leaves. Some leaves contained only a few of these specks while others were completely covered. Soon after the leaves became speckled, they would begin to droop and drop off.

Calcium Deficiency. After four weeks of growth on a solution containing no calcium, the plants portrayed signs of extreme calcium starvation. Calcium deficiency symptoms began with small brown and white spots in the leaves similar to those of a potassium deficiency. However, these symptoms occurred in the upper rather than the lower leaves of the plant. There was some curling of the leaf margins, but not as pronounced as in the potassium study. The terminal growth turned black and finally disintegrated. The roots also became dark in color. Later they died and disintegrated along with the terminal bud. (Figs. 4 and 5)

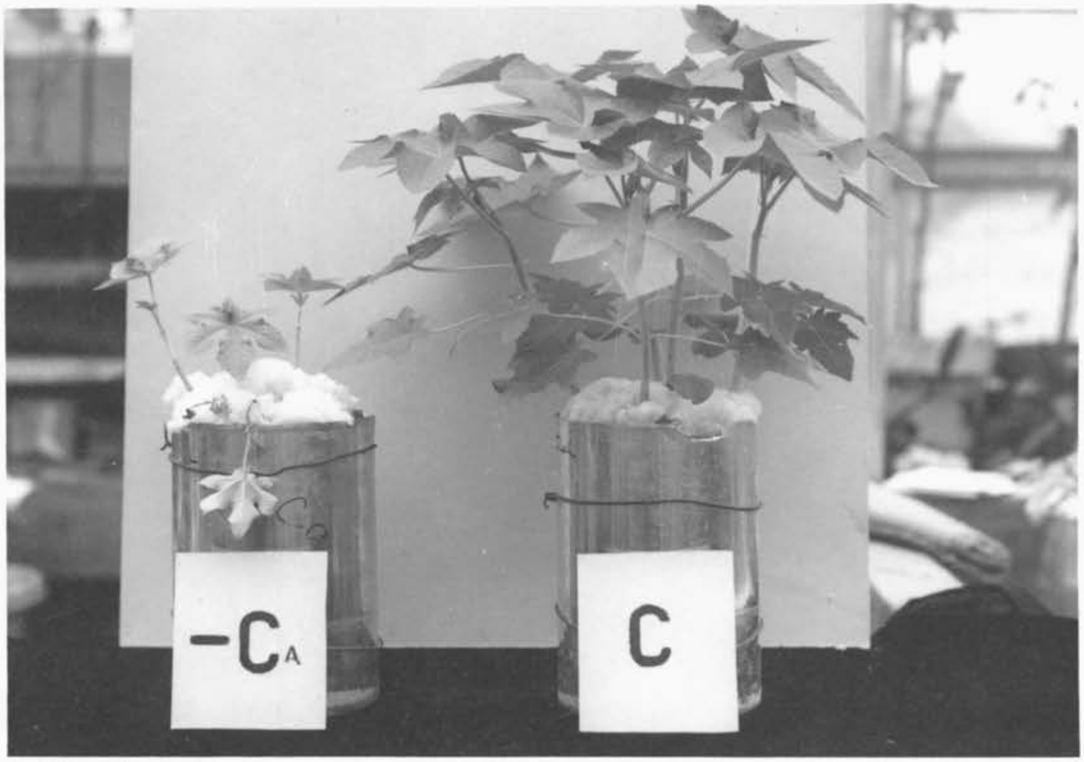

Fig. 4. Comparison of young castor bean plants growing in a complete nutrient solution and in a solution having no calcium.

Fig. 5. Comparison of maturing castor bean plants growing in a complete nutrient solution and in a solution having no calcium.

Magnesium Deficiency. Symptoms due to a lack of magnesium appeared at approcimately the same time as those developed by calcium deficient plants (Figs. 6 and 9). Plants receiving no magnesium exhibited a streaked chlorosis of the terminal leaves. The streaks in the upper leaves would be a combination of colors ranging from a dark green to a yellow and finally a white in the inter-veinal area. The veins and midrib of the leaves would always remain green. In the acute stages, brown and white lesions sometimes appeared in the older leaves just before they sloughed. The roots of the magnesium deficient plants seemed to be very much lighter in color than the roots of the plants growing in a complete solution.

Iron Deficiency. The first visible signs of a deficiency in this study were those of iron (Fig. 7). Within one week after iron had been withheld from the nutrient solution, a general chlorotic condition was observed in the newly emerging leaves. These leaves were very light in color and later turned yellow between the veins while the veins retained their green color. As the new leaves formed, they too were lighter in color than the preceding ones, until they were almost white. The newer would become necrotic while the older ones would exhibit large necrotic areas along the margins which gave them a very ragged appearance. The leaves of the plants growing in the solution receiving no iron were constantly smaller than the leaves of the plants growing in the

Fig. 6. A comparison of castor bean plants growing in a co plete nutrient solution and in a solution containing no magnesium .

Fig. 7. A Comparison of castor bean plants growing in a nutrient solution receiving no iron with plants in a complete nutrient solution.

complete solution. The lower leaves which developed before the initial symptoms appeared seemed to keep their color, except for a slight yellowing along the margins, as the plants matured.

Boron Deficiency. Two weeks after boron had been excluded from the nutrient solution, a slight chlorosis occurred in the older leaves. During the next week, the new leaves took on a reddish cast and rolled up along the margins, beginning at the tip and working progressively back toward the petioles. This was followed by extreme yellowing of the interveinal area of the older leavers and the appearance of brown spots in the terminal growth. As the symptoms progressed, the lower leaves exhibited large necrotic spots and the petioles became weak allowing the leaves to droop. The roots of the boron deficient plants were short and stubby. They posessed rough spots and large crevises. The base of the stem was greatly thickened as were the older portions of the root system.

Sulfur Deficiency. The starvation signs of the plants growing in a solution containing no sulfur were not as prominent and distinct as those exhibited in the other culture solutions. (Figs. 8 and 9). The symptoms were distinguishable but at times the appearances were dull. Sulfur deficiency symptoms developed very slowly. They began with a general chlorotic condition in the lower leaves of the plants similar to nitrogen deficiencies. About 4 weeks after sulfur had

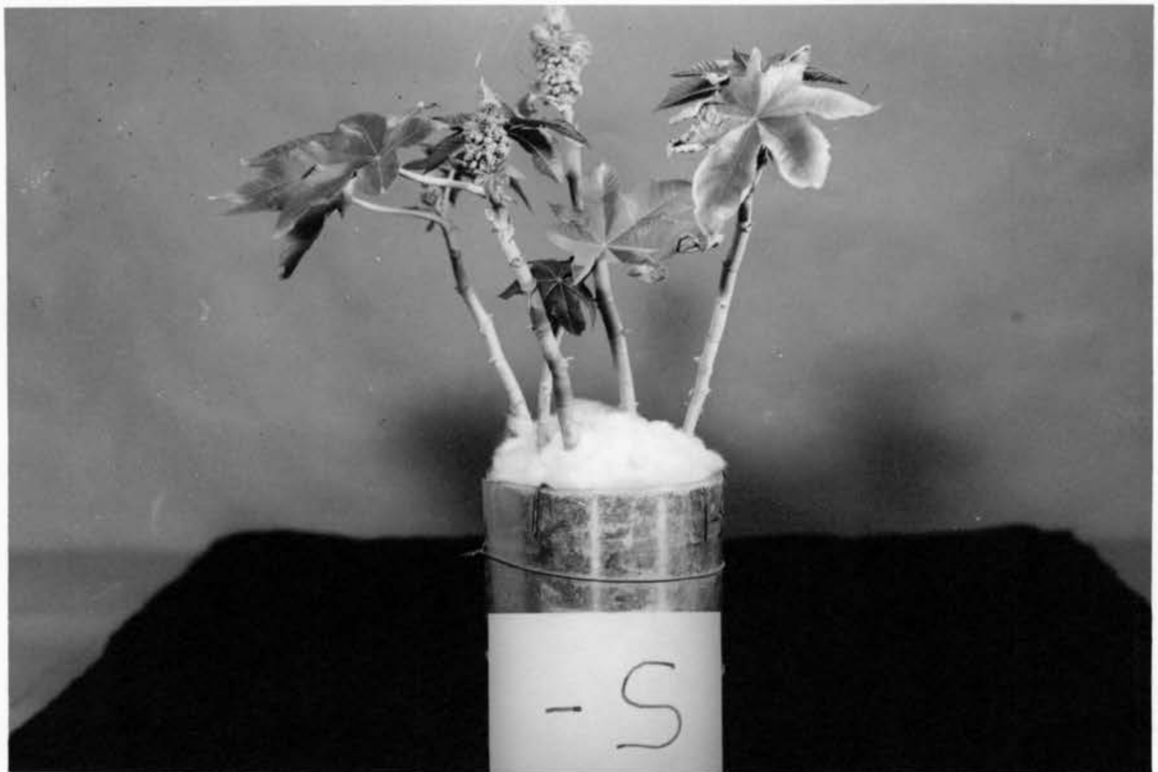

Fig. 8. Castor bean plants growing in a nutrient solution which lacked sulfur.

Fig. 9. Castor bean plants growing in nutrient solutions; containing no magnesium, receiving no sulfur, and having all nutrients present.

been eliminated from the nutrient solution, large areas in the leaves displayed various colors went from a red to a purple to a brown. These areas later became necrotic and in some cases left holes in the leaves. In addition to the necrotic areas, the leaves also started to curl along the margins in much the same manner as the leaves of potassium deficient plants. Some of the leaves on the plants growing in a solution which lacked sulfur seemed to be somewhat longer and more pointed at the apex than the leaves of the plants growing in a complete solution. This was particularly true of the new emerging leaflets. These leaves were very slow in attaining the size and shape of regular leaves.

Unbalanced Nutrient Symptoms. When excessive amounts of different nutrients were included in the solution cultures, startling results were obtained in a very short period of time. Calcium, magnesium, potassium, and phosphorus were increased 10 times and manganese was raised sixfold. The plants growing in the solution containing large amounts of manganese were the only ones that lived throughout the experiment.

Within 5 days, the lower leaves of the plants growing in the high calcium nutrient solution were dying and sloughing. The remaining leaves in the terminal growth turned a brown or purplish color similar to the phosphorus deficient plants. These plants were changed to a complete nutrient solution immediately, but did not recover within 21 days and had to be discarded.

A nutrient solution containing large amounts of magnesium did not produce any ill effects during the first week, but during the second week, the leaves took on a mottled appearance sonsisting of small white and later brown spots. The plants were then changed to a complete solution to await recovery. It was noted during the next 2 weeks that instead of recovering the plants still showed the ill effects of the excessive magnesium. The terminal growth curled inward along the margins, was purplish in color, and slowly became necrotic. The plants were kept on a complete nutrient solution for 3 weeks, but were not able to recover and grow normally. These plants were also discarded.

The nutrient solution containing an excessive amount of phosphorus brought about a rather quick change in the appearance of the plants. Within 3 days, the plants pocessed a very light green color in the terminal growth which indicated either the absemce of iron or if iron were present that it was fixed within the lower leaves of the plants. After 9 days, the upper leaves became necrotic, exhibited brown and white lesions and were abscissing. The stemd became soft and black before disintegrating. The plants were then placed in a complete solution, but they failed to recover.

An excessive supply of potassium in the nutrient solution was a little slower in changing the appearances of the plants. After 2 weeks, the plants became chlorotic with a general mottling of the leaves. The leaves contained large purple areas and began to roll inward along the margins. The plants were then transfered to a complete solution, but did not develop normal growth.

In the case of excessive calcium, potassium and magnesium it seems that all the translocation vessels of the plants were plugged or filled with a gelatinous substance which prevented any moverment up and down the plant. This might have been caused by the chemicals which supplied the large concentrations of nutrients for these solution cultures.

The symptoms of an over supply of manganese seemed to be a combination of iron and magnesium deficiencies. After a period of 9 days, the plants growing in a solution containing large amounts of manganese exhibited a light colored terminal growth. The newly emerging leaves were green and white stripped between the veins. Three days later, small brown spots appeared in the new leaves. A few days later the leaves began an inward rolling, extending from the tip to the petiole. Finally they died and dropped off.

Chemical Analysis of the Plants

The results of the chemical analyses of the plants grown in nutrient solution cultures are given in Table 4. The percentages listed in this table are the average of duplicates and triplicates wherever possible. Some analyses were omitted because of a insufficient amount of plant material.

Table 4. Percentage chemical composition of castor bean plants grown in nutrient solution cultures

Treatment		N	P	K	Na	Ca	Mg	Fe	B	S	Mn
Complete		2.95	0.11	3.10	0.30	1.11	0.50	0.08	*	1.14	0.007
No	N	2.36	0.10	3.35	0.20	0.81	0.41	0.07	.0010	1.65	0.009
No	P	2.88	0.06	3.25	0.35	1.29	0.36	0.07	.0011	1.74	0.008
No	K	4.12	0.11	2.65	0.25	1.86	0.31	0.05	*	1.73	0.008
No	Ca	4.31	0.12	2.40	0.20	0.24	0.18	0.06	*	*	*
No	Mg	3.66	0.10	4.35	0.25	1.83	0.14	0.06	*	2.12	0.013
No	Fe	3.47	0.15	3.70	0.15	1.98	0.49	0.05	*	0.38	0.015
No	S	3.02	0.10	2.80	0.25	1.11	0.30	0.18	.0010	0.73	0.006
No	B	2.90	0.11	2.80	0.55	1.17	0.42	0.14	.0009	0.43	0.006
High	Mn	3.40	0.10	2.40	0.50	0.99	0.32	0.08	*	0.29	0.005

* Insufficient sample

In most instances, the nutrient which was eliminated from the solution was found in the lowest concentration with in the plants growing in that particular solution. It is interesting to note that the absence of one plant food nutrient may cause a greater uptake of other nutrients. The plants growing in a solution receiving no potassium had a nitrogen percentage which far exceeded that found in the plants growing in a complete solution. Similarly, the plants growing in a minus calcium solution had an extremely high concentration of nitrogen. This phenomenon was referred to as luxury consumption by Thomas (11). Ginsburg (5) found that soybean plants growing in incomplete nutrient culture solutions absorbed greater quantities of calcium and smaller amounts of nitrogen and magnesium than did the plants which were grown in a complete solution.

Soil Pot Studies in the Greenhouse

Yields of the vegetative portions of the plants

The castor bean plants growing in the soil pots recovered slowly from the clipping operation on December 5, 1952. However, they were very responsive to the second dosage of fertilizers which were applied on March 18, 1953.

Several deficiency symptoms developed but the most notable one was reduced growth. Nitrogen deficiency signs were exhibited in the pots receiving no nitrogen . Besides the chlorotic condition of the leaves which has been previously described, the stems were very red at the base. Symptoms of potassium starvation appeared primarily in the Parsons soil pots which did not receive any potassium fertilizers. This soil in its natural state was low in available potassium and had poor physical condition due to a dense claypan at a depth of 13 inches. Phosphorus hunger signs were observed on the plants growing in all three soils where nitrogen alone or nitrogen and potassium fertilizer had been applied.

The yields of the vegetative portions of the plants grown in the three different soils are shown in Table 5. Treatment 3 (25-50-25) produced the greatest total amount of dry matter on the Stidham fine sandy loam soil, but treatment 7 (25-0-0) gave the greatest increase for any single nutrient. Similar results were obtained on the Stidham loamy fine sand soil. Treatment 4 (25-0-25) gave the best total dry matter yields on the parsons fine sandy loam soil.

Chemical analyses of the plants

The chemical analyses of the plants grown in the three different soils are presented in Table 6. These plants were harvested according to their component parts: spikes, leaves and stems. Treatments 2 (0-50-25) and 6 (0-0-25) produced no spikes, while treatment 4 (25-0-25) yielded the most spikes. Total nitrogen was run on all samples. Phosphorus and potassium determinations were made on the leaf and stem tissues. The analyses were quite variable, but in general the element

Table 5. Dry matter yields (grams per pot) and percentages of leaves and stems of castor bean plants grown in soil pots.

Treatment	Stidham Fine sandy loam series			Stidham loamy fine sand series			Parsons fine sandy loam series		
	Total	%leaves	%stems	Total	%leaves	%stems	Total	%leaves	%stems
1. (0-50-0)	25.8	11	89	11.1	41	59	19.5	28	72
2. (0-50-25)	22.4	13	87	9.8	31	69	16.9	21	79
3. (25-50-25)	40.6	15	85	27.3	21	79	27.8	15	85
4. (25-0-25)	33.5	9	91	24.7	25	75	28.7	18	82
5. (25-50-0)	34.2	19	81	26.5	21	79	22.8	13	87
6. (0-0-25)	22.9	11	89	15.8	26	74	25.9	15	85
7. (25-0-0)	36.6	19	81	26.8	37	63	25.2	22	78
8. (0-0-0)	22.4	15	85	15.6	27	73	20.1	19	81

average of two replications

Table 6. Percentage Chemical composition of castor bean plants grown in soil pots

Treatment	Plant Part	Stidham fine sandy loam series			Stidham loamy fine sand series			Parsons fine sandy loam series		
		N	P	K	N	P	K	N	P	K
1 (0-50-0)	leaves	2.17	0.07	1.45	1.73	0.07	1.25	1.86	0.06	1.60
	stems	0.34	0.05	1.10	0.34	0.17	1.00	0.43	0.09	1.00
2 (0-50-25)	leaves	1.94	0.07	1.00	1.95	0.09	1.80	1.83	0.06	2.20
	stems	0.32	0.09	1.25	0.28	0.18	1.35	0.40	0.09	1.10
3 (25-50-25)	leaves	2.04	0.06	1.80	2.09	0.06	1.35	2.13	0.06	1.45
	stems	0.43	0.05	0.95	0.58	0.06	0.95	0.48	0.04	0.60
4 (25- 0-25)	leaves	3.51	0.06	1.10	1.90	0.05	1.60	2.38	0.04	1.35
	stems	0.72	0.02	0.80	0.63	0.04	1.00	0.57	0.02	0.90
5 (25-50- 0)	leaves	2.31	0.07	1.60	2.17	0.08	1.20	2.43	0.05	0.45
	stems	0.52	0.06	0.80	0.52	0.16	0.50	0.50	0.05	0.40
6 (0- 0-25)	leaves	2.45	0.10	1.25	1.70	0.07	1.45	2.38	0.04	2.10
	stems	0.34	0.07	1.90	0.41	0.08	1.25	0.47	0.02	0.90
7 (25- 0- 0)	leaves	2.37	0.03	1.60	2.79	0.06	1.10	2.38	0.05	1.25
	stems	0.69	0.02	0.80	1.03	0.03	0.45	0.76	0.02	0.60
8 (0- 0- 0)	leaves	1.88	0.05	1.95	1.77	0.06	1.70	1.94	0.05	1.80
	stems	0.32	0.06	1.00	0.28	0.07	0.85	0.42	0.03	0.65

which was excluded in the fertilizer treatment was the lowest percentagewise within the plant.

In the Stidham fine sandy loam series, the nitrogen concentrations of the leaves and stems were the highest in treatment 4 (25-0-25). Phosphorus percentage was the greatest in the leaf tissue when the plants received an application of 25 pounds of available potash, but higher in the stem tissue obtained from treatment 2 (0-50-25). Potassium was the greatest in the leaves of the plants growing on the unfertilized pots, but higher in stem tissue produced in treatment 6 (0-0-25).

In the Stidham loamy fine sand and the Parsons fine sandy loam series, the nitrogen concentrations of the leaves and stems were the largest in the plants which were given a dosage of 25 pounds of available nitrogen. Phosphorus and potassium percentages were the highest under treatment 2 (0-50-25).

Field Plots

Tissue Tests

Field and laboratory tissue tests were conducted at monthly intervals on the field plots. The leaves and petioles were tested for nitrates, phosphates, and potassium. It was very difficult to test the leaves of the castor bean plant because the extracting agent removed the color pigment, which masked the colors developed in the various tissue tests. Field tests were made on the petiole using Bray's reagent No. 5 (2) and diphenylamine prepared according to the directions

Table 7. Results of the tissue tests on castor bean plants grown on field plots at Miami. (July 13, 1953)

Treatment	Replication	Lower Petioles NO_3	Lower Petioles PO_4	Lower Petioles K	Lower Leaves NO_3	Lower Leaves PO_4	Lower Leaves K
1. (0-0-0)	2	L	L	L	L	M	H
	3	H	L	L	L	M	H
2. (0-0-25)	2	L	L	M	L	L	H
	3	L	L	H	L	M	H
3. (0-50-25)	2	L	H	H	L	L	H
	3	L	L	H	L	H	H
4. (25-50-25)	2	M	M	M	L	H	L
	3	M	L	H	L	M	M
5. (25-50-0)	2	M	H	L	L	H	M
	3	M	M	L	L	H	H
6. (25-0-0)	2	L	L	H	L	H	M
	3	H	M	M	L	H	H
7. (25-0-25)	2	H	L	H	L	M	M
	3	H	L	H	L	L	H
8. (0-50-0)	2	M	H	M	L	L	M
	3	L	L	L	L	H	H

Legend

Nitrates

L(Low) Deficient
M(Medium) Adequate Supply
H(High) Abundant Supply

Phosphates

L(Low) Deficient
M(Medium) Moderate Supply
H(High) Abundant Supply

Potassium

L(Low) Deficient
M(Medium) Doubtful Supply
H(High) Sufficient to Abundant

Table 8. Results of the tissue tests on castor bean plants grown on field plots at Paradise. (July 26, 1953)

Treatment	Lower petioles*			Lower leaves*		
	NO_3	PO_4	K	NO_3	PO_4	K
1. (0-0-0)	L	L	L	L	L	L
2. (0-0-25)	H	L	L	L	L	L
3. (0-50-25)	M	L	L	L	L	L
4. (25-50-25)	H	L	L	L	L	L
5. (25-50-0)	H	L	L	H	L	L
6. (25-0-0)	M	L	L	L	H	H
7. (25-0-25)	H	L	L	M	M	L
8. (0-50-0)	L	L	L	L	H	L
9. (50-50-25)	M	M	L	L	H	M
10. (50-50-0)	H	L	L	M	H	L
11. (50-0-0)	H	L	L	M	L	M
12. (50-0-25)	L	L	L	L	L	L
13. (12-48-0)	M	L	L	L	M	L
14. (100-0-0)	H	L	L	L	L	M
15. (100-50-0)	H	M	L	H	H	L

* The levels (L, M, H) of nitrates, phosphates and potassium are explained in the legend found in table 7.

given by Krantz, et al. (1). Laboratory determinations of both the leaves and petioles were made using reagents listed in the book "Diagnostic Techniques" (1). Results of tissue testing are given in Tables 7 and 8.

Castor Bean Yields

The 1953 season was not a particularly favorable one for castor bean production. At Miami, Oklahoma the rainfall was 30% below normal for that area. There was a severe wind at Paradise, Oklahoma during the latter part of the growing season which resulted in the loss of beans at harvest time.

Table 9 gives the yields of beans from the Miami plots. The analysis of variance for the randomized block treatment from the Miami plots showed no significance. However, when these results were analyzed factorially for interactions among the different fertilizer treatments, nitrogen applied at the rate of 25 pounds per acre was significant at the 5% level and phosphorus added at the rate of 50 pounds of P_2O_5 per acre was significant at the 10% level (table 10).

The yields of beans from the Paradise plots are found in Table 11. An analysis of variance of the randomized plot treatment from the Paradise field gave no significance from any of the fertilizer treatments. However, substantial increases in yields were obtained from the application of 50 pounds of P_2O_5 per acre and a combination of nitrogen and phosphorus fertilizers.

Table 9. Effect of fertilizer treatments on the castor bean yields (pounds per acre) from the Miami field plots

	Replication Number			
Treatment	1	2	3	4
1. (0-0-0)	751	768	853	815
2. (0-0-25)	681	828	692	870
3. (0-50-25)	901	947	694	810
4. (25-50-25)	791	1072	765	967
5. (25-50-0)	867	969	823	956
6. (25-0-0)	810	951	696	867
7. (25-0-25)	734	694	823	933
8. (0-50-0)	924	849	768	875

Analysis of Variance

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square
Total	31	296,464	----
Replications	3	86,747	----
Treatments	7	86,091	9,441
Error	21	142,636	6,792

F value not significant F= 1.39

Table 10. Factorial analysis for the interaction among fertilizer treatments on the Miami field plots.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Total	31	296,534	----	
Replication	3	86,090	----	
N	1	45,687	45,687	6.69*
P	1	14,781	14,781	2.16**
K	1	3,709	3,709	1
NP	1	1,097	1,097	1
NK	1	4	4	1
PK	1	865	865	1
NPK	1	118	118	1
Error	21	143,363	6,827	

* F value significant at the 5% level
**F value significant at the 10% level

Table 11. Effect of fertilizer treatments on the castor bean yields (pounds per acre) from the Paradise field plots.

Treatment	Replication Number 1	2	3	4
1. (0-0-0)	866	992	1006	874
2. (0-0-25)	970	1070	902	866
3. (0-50-25)	880	1006	1004	1092
4. (25-50-25)	954	1086	1032	966
5. (25-50-0)	1118	1098	1170	882
6. (25-0-0)	956	866	826	1038
7. (25-0-25)	984	900	1070	1020
8. (0-50-0)	1084	1094	998	958
9. (50-50-25)	896	1088	1198	1074
10.(50-50-0)	1092	1056	930	966
11.(50-0-0)	962	846	1032	954
12.(50-0-25)	986	1026	846	1060
13.(12-48-0)	844	1096	1016	1214
14.(100-0-0)	1036	1016	934	728
15.(100-50-0)	1004	980	902	992

Analysis of Variance

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square
Total	59	554,084	-----
Treatment	14	128,675	9,191
Error	45	425,409	9,454

F value not significant F- less than 1

V SUMMARY AND CONCLUSIONS

Castor bean plants (Cimmaron variety) were grown in nutrient solution cultures of no nitrogen, no phosphorus, no potassium, no calcium, no magnesium, no iron, no boron, no sulfur, high calcium, high phosphorus, high potassium, high magnesium and high manganese. Plant symptoms were observed and chemical analyses of the plants were made.

Soil pot studies of castor beans were conducted on Stidham fine sandy loam, Stidham loamy fine sand and Parsons fine sandy loam soils collected from 3 different locations in Oklahoma. Varying rates of nitrogen, phosphorus, and potassium fertilizers were added to the pots. Dry matter yields and percantage chemical composition of the plants were recorded.

Field plots of castor beans were grown at Miami and Paradise, Oklahoma, using varying rates of nitrogen, phosphorus and potassium fertilizers. The plants were subjected to periodical tissue tests and the yields of castor beans were measured.

From the results obtained in the foregoing experiment, the following conclusions seem justifiable.

1. Deficiency symptoms were noted in the nutrient solution cultures, when the nutrient was excluded from the solution.

2. The plants growing in the solutions of high phosphor-

us, high potassium, high calcium and high magnesium did not survive. Therefore, very little information was gained from this po rtion of the study.

3. The castor bean plants growing in the soil pots responded fairly well to the various fertilizer applications and deficiency symptoms of nitrogen, phosphorus and potassium were observed in some of the plants particularly those which had not been fertilized with that nutrient.

4. No deficiency symptoms were observed in the field plots. However, when tissue tests were conducted, it was found that the nutrients were either absent or present in such small quantities within the plant that they could not be detected.

5. Yields of castor beans from each of the field plots show increases over the check plots from the various fertilizer additions.

6. Nitrogen used at the rate of 25 pounds per acre was significant at the 5% level and phosphorus applied at the rate of 50 pounds per acre was significant at the 10% level on the Miami field plots.

7. On the Paradise field, a substantial increase in castor bean yields was obtained for fertilizer treatments of phosphorus and a combination of nitrogen and phosphorus.

VI LITERATURE CITED

1. Bear, Firman E. Diagnostic Techniques for Soils and Crops. The American Potash Institute, Washington 6, D. C. 1948.

2. Bray, Roger H. Nitrate Tests for Soils and Plant Tissue. Soil Sci. 60: 219-221. 1945.

3. Domingo, W. E. and D. M. Crooks. Investigations with the Castor Bean Plant. I. Adaption and Variety Tests. II. Rate of Planting and Date of Planting Tests. III. Fertilizers, Clipping, Method of Planting, and Time of Harvest. Jour. Amer. Soc. Agron. 37: 750-812-910. 1945.

4. Fisher, H. J. et al. Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemist. Sixth Edition. Association of Official Agricultural Chemists. P. O. Box 540, Benjamin Franklin Station, Washington 4, D. C. 1945.

5. Ginsburg, J. M. Composition and Appearance of Soybean Plants Grown in Culture Solution Each Lacking a Different Essential Element. Soil Sci. 20: 1-13. 1925.

6. Harper, H. J. Tentative Methods for the Analysis of Soil and Plant Material. A Mimeographed Publication Used in the Soils Laboratory at Oklahoma A. and M. College. 1948.

7. Hoagland, O. E. and W. C. Snyder. Nutrition of the Strawberry Plant Under Controlled Conditions. Amer. Soc. Hort. Sci. Proc. 30: 228-294. 1933.

8. Miller, et al. Castor Beans in Texas. Tex. Agri. Ext. Ser. B-195. or Tex. Agri. Exp. Sta. B-744. 1952.

9. Naftel, James A. Colorimetric Determination of Boron. Ind. and Eng. Chem. Anal. Ed. 11: 407. 1939.

10. Quimby, J. R. et al. Progress Report 1455. Tex. Agri. Exp. Sta. 1952.

11. Thomas, Walter. The Reciprocal Effects of Nitrogen, Phosphorus and Potassium as Related to the Absorption of these Elements by Plants. Soil Sci. 33: 1-20. 1932.

12. Toth, S. J. et al. Rapid Quantitative Determinations of Eight Mineral Elements in Plant Tissue by a Systematic Procedure Involving the Use of a Flame Photometer. Soil Sci. 66: 459-466. 1948.

13. Tucker, Billy Bob. Castor Beans: Their Nutrient Requirements, Responses to Fertilization Treatments and Deficiency Symptoms under Controlled Conditions. Masters Thesis. Oklahoma A. and M. College. 1953.

14. Van Horn, D. L. Castor Bean Production. U. S. D. A. Farmers Bull. 2041. 1952.

15. Van Horn, D. L. DR-61 U. S. D. A. Agri. Res. Adm. B.P. I., S. and A. E. and The Okla. Agri. Exp. Sta. 1951.

16. Van Horn, D. L. DR-62 U. S. D. A. Agri. Res. Adm. B. P. I., S. and A. E. and The Okla. Agri. Exp. Sta. 1951.

VITA

Clarence Ralph Carter
candidate for the degree of
Master of Science

Thesis: CASTOR BEANS: NUTRIENT SOLUTION CULTURES AND RESPONSES TO FERTILIZER TREATMENTS UNDER GREENHOUSE AND FIELD CONDITIONS

Major: Soils

Biographical and Other Items:

Born: February 28, 1922 at Panama, Oklahoma

Undergraduate Study: Eastern Oklahoma A. and M. College Wilburton, Oklahoma, 1940 and 1946-47; Southeastern State College, Durant, Oklahoma, 1950; Oklahoma A. and M. College, Stillwater, Oklahoma, 1951-53.

Graduate Study: Oklahoma A. and M. College, 1953-54

Experiences: Farm reared; U. S. Army Air Corps, 1943-46; Veterans Agricultural Training Program Instructor, State Board of Voc. Agri., Panama, Oklahoma, 1947-1951; Laboratory Technician, Soils Lab. Oklahoma A. and M. College, Stillwater, Oklahoma, 1951-53.

Member of Agronomy Club, Masonic Club, Alpha Zeta and The Order of the Red Red Rose.

Date of Final Examination: January 1954.

THESIS TITLE: CASTOR BEANS: NUTRIENT SOLUTION CULTURES AND RESPONSES TO FERTILIZER TREATMENTS UNDER GREENHOUSE AND FIELD CONDITIONS

AUTHOR: Clarence Ralph Carter

THESIS ADVISER: Dr. Robert M. Reed

The content and form have been checked and approved by the author and thesis adviser. The Graduate School Office assumes no responsibility for errors either in form or content. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

TYPIST: Betty Sue Carter