THE EFFECTS OF NITROGEN ON JOJOBA, *SIMMONDSIA CHINENSIS* (LINK) SCHNEIDER

by

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ABSTRACT

The growth response of jojoba, Simmondsia chinensis, to different nitrogen concentrations in the nutrient feeding solution, was tested. Two experiments were conducted, one in the summer-fall of 1974 for 124 days and one in winter-spring, 1975, for 71 days. Plants growing in silica sand were periodically fed six different treatments, ranging from 0 to 400 ppm ammonium nitrate. Growth response was determined by measuring stem lengths, fresh and dry weights, and per cent nitrogen per gram of dried leaf tissue.

Although no significant difference between treatments in height and weight was found, plants that received 100 ppm in the summer-fall experiment were 18.9% greater in height and 4.7% greater in fresh weight than the next best treatment of 50 ppm. A significant difference was found at the .01 confidence level between treatments in the measurement of per cent nitrogen per gram of dried leaf tissue.

Based on results and observations recommendations are made on methods of seed germination, water schedule, optimum germination and growth temperatures, and optimum nitrogen levels for growth of seedlings.

INTRODUCTION

Simmondsia chinensis (Link) Schneider., commonly called jojoba, goatnut, or pignut (McKinney and Jamieson, 1936; Markwood, 1942), was described by Gentry (1958) as a gray-green, long-lived, drought resistant, desert shrub of unique character. Others (Baker, 1965; Mirov, 1972; Yermanos, 1974) have characterized jojoba as a plant of numerous uses. For example, oil extracted from jojoba seeds contains up to 50% liquid wax, and possesses properties similar to sperm whale oil (McKinney and Jamieson, 1936; Markwood, 1942). It can be used in many products such as candle wax, mechanical lubricants, and cosmetics. In addition, jojoba is becoming a popular landscape plant in the southwestern United States.

During the past 30 years several attempts have been made to establish experimental plantings of jojoba. These studies were intended to produce information on growth habits and response to cultivation. Unfortunately, most of this research has met with limited success (Mirov, 1972; Yermanos, 1974). Field research, primarily on yield data, is still being pursued at the Coit Plantation in Vista, California (Yermanos et al., 1968; Yermanos and Holmes, 1973); the Boyce Thompson Arboretum in Superior, Arizona (Crosswhite, 1972); and the Negev Institute in Beersheba,

Israel (Forti, 1973). Recently, because of increasing shortages of sperm whale oil and spiraling petroleum prices, interest has again been stimulated to study the cultivation of Simmondsia chinensis. But, before it can become a cultivated, commercial crop, many questions related to its domestication, such as water and nutritional requirements, sex differentiation, propagation, harvesting, and heterogeneous characteristics will have to be answered (Mirov, 1952; Gentry, 1958; Thompson, 1972; Yermanos, 1974). In addition, research is needed on the feasibility of harvesting natural populations of jojoba (Yermanos, 1974). Native populations may be able to produce enough nuts on some American Indian reservations in the western United States to supplement the inc me of the people. Before this is possible, though, more efficient harvesting techniques need development.

In the realm of plant nutrient requirements nitrogen is the most limiting element to plant growth (Janick, 1972) and consequently the most important element in the nutrient solution of an experimental culture. Therefore, possibly the most frequent question on plant nutrition is the amount of nitrogen which should be supplied to a specific crop on a particular type of soil (Donald, Stangel, and Pesek, 1963). Nitrogen, usually needed in rather large quantities, is expensive to apply, and is depleted from the soil by plant uptake, leaching, and microbial activity (Allison, 1957).

Thus, growers typically want to know the minimum amount of nitrogen fertilizer that can be applied to obtain maximum yield in their crops. Because of this, it is important that optimum nitrogen levels be determined and a sound fertilizer program be established to prevent extremes.

The purpose of this research was to study the growth effects of different concentrations of nitrogen on jojoba, specifically height, weight, and nitrogen content of leaves. Additionally, different techniques were attempted to germinate seeds. Such information would be valuable in determining nitrogen fertilization rates needed to produce optimum growth and seed yield.

LITERATURE REVIEW

Two major methods are used to analyze the effect of nitrogen on plants. The first is a chemical analysis of plant tissue. With this process, plants treated with various concentrations of nutrient nitrogen are grown, harvested, and tissues analyzed (Ulrich et al., 1959). Tissue analysis is accomplished using techniques such as those developed by Kjeldahl and Lindner (Lindner and Harley, 1942; Chapman and Pratt, 1961) to determine total per cent nitrogen content in the leaves and stems. The second technique, a simpler and quicker method used by many growers and researchers, involves weight and height measurements of plants grown under different nitrogen treatments. With this method, it is easy to compare the rate of growth with the fertilizer treatment.

Using the techniques of plant tissue analysis and growth measurements, the optimum nitrogen levels for many herbaceous plants have been established. Unfortunately, only a limited number of nitrogen growth studies have been performed with woody ornamental plants. Carlson and Bergman (1966) obtained data showing nitrogen as the only macronutrient that produced a positive correlation with yield on greenhouse grown roses. Likewise, Dunham and Tatnall (1961) found that nitrogen was the element which affected growth

most rapidly and most severely on three holly species grown in nutrient sand culture. Preston, Shanks, and Pardon (1953) showed with azaleas that increased amounts of nitrogen resulted in a corresponding increase in total nitrogen and phosphorus content of leaves from plants grown in sand culture. Cannon, Chadwick, and Reisch (1960) found with honey locust, Gleditsia triacanthos inermis 'Moraine' that as nitrogen concentration in the nutrient solution was increased the total foliar nitrogen increased. The greatest growth was obtained with 80 ppm nitrogen. Leaves from such plants contained 2.41% nitrogen. One study conducted with Pyracantha coccinea 'Lalandi' and Ilex crenata 'Rotundifolia' showed that moderate rates of nitrogen fertilizer produced the most growth with both plants as determined by number of laterals and total growth per plant (Kelley, 1972). Higher rates produced little or no additional growth of seedlings.

In summary, the most effective rate of nitrogen fertilization depends on many factors: (1) form of nitrogen applied, (2) time of application in the growing season, (3) availability and concentration of other nutrients, (4) soil moisture, (5) type of culture medium, (6) climatic conditions, and (7) plant species.

In studying the effect of different nutrient solutions on plants grown in the greenhouse, water culture techniques are sometimes employed. Using this method,

plants are grown in either a water or sand medium with nutrients supplied periodically or continuously through the watering system. According to Hewitt (1966) either type of culture permits the study of deficiencies and excesses at specific nutrient levels and helps determine relative nutritional requirements of the plant. Shive and Robbins (1937) and Arnon (1943) believed that either culture was invaluable because it made possible the production of a large number of different plants that are at least comparable to those grown in fertile soil.

With the water culture method, plants must be provided mechanical support and forced aeration (Hoagland and Arnon, 1941, 1950; Hewitt, 1966). Because of this, sand culture is often preferred over water culture because the solid medium provides good aeration and support naturally (Shive and Robbins, 1937).

Schwarz and Vaadia (1969) found that limestone gravel was not a satisfactory growth medium for various plants (cucumber, lettuce, tomato, eggplant, and bean) because it reduced yields and induced chlorosis. They explained that the chlorosis was probably due to certain mineral deficiencies caused by the precipitation of phosphates and iron in the nutrient solution, or caused by excess lime from the gravel.

In general, plants grown either in sand or in water culture give higher yields than those grown in soil (Arnon

and Hoagland, 1940). In addition, plants grown in sand culture often remain in a prolonged vegetative state (Preston et al., 1953).

Since soil, climate, and plant all interact, the effect of fertilization depends on climate and soil properties (Russell, 1926). That is, the soil must contain the proper nutrient concentrations and the climate (humidity, light intensity, temperature, etc.) must be favorable for optimum growth. Most importantly, Thomas (1932) states that the primary limiting factor in a plant's ability to absorb nutrients and consequently to grow, is the availability of water. Therefore, a proper balance of moisture in the rootzone of growing plants is necessary for healthy, vigorous growth (Taylor, 1957).

The progress made in sand and water culture research has led to the development of a highly productive plant industry referred to as hydroponics (Bentley, 1959). Employing the techniques of controlled environment and nutrition, this industry has been responsible for year-round production of many fruits and vegetables previously field cultivated only in the appropriate growing season.

MATERIALS AND METHODS

Duration of Nutrient Experiments

Two main experiments were conducted on the response of jojoba to different levels of nitrogen. Experiment I was conducted during the summer-fall of 1974 (June 17-October 18) and Experiment II in the winter-spring of 1975 (January 20-March 31). Because of the different time periods, temperatures and light intensities varied greatly between the different experiments.

In both studies, six nutrient solution treatments were compared, with four replications per treatment.

Source and Selection of Seeds

The jojoba seeds used in the experiments were supplied by the Office of Arid Lands Studies, Tucson, Arizona, in February, 1973. The seed was obtained from a heterogeneous group of plants native to the San Carlos Indian Reservation, Arizona. Seeds were sorted and only nondamaged seeds used. Because seeds varied in size, shape, and color they were randomly assigned to treatments in order to eliminate personal bias.

Germination

Before germinating, all seeds were surface sterilized in a 0.5% NaOCl solution for 15 minutes. Germination

was attempted in 4 ways: (1) seeds were allowed to soak three days in water (changed daily) and then placed in a moist chamber at room temperature (25 C); (2) seeds were scarified with emery cloth, soaked 2 days in water, and placed in vermiculite under intermittent mist; (3) seeds were placed under intermittent mist in either vermiculite, peat, silica sand (80 mesh), or a 50-50 mixture of vermiculite and peat; (4) seeds were placed under mist in vermiculite and maintained at a temperature of 29 C to 34 C via heating cables placed under the flat of vermiculite.

Planting

After seeds germinated, they were removed and placed in vermiculite under intermittent mist in a greenhouse until there were enough seedlings to start each experiment. Temperatures ranged from 21 to 27 C. Upon transplanting, seedlings were rinsed in water and planted at a depth of 1-2 cm after the seed radicle length reached 0.5 to 2.5 cm.

Silica sand (20 mesh) was used as the culture medium. It was acid washed in a 19% HCl, 1% oxalic acid solution (Hewitt, 1966) and rinsed thoroughly with distilled water before placing in standard 6 inch plastic pots. Pots were previously washed in a detergent solution, soaked in 0.5% NaOCl, and rinsed thoroughly in tap water. The bottoms of the pots were lined with glass wool to prevent loss of sand thru the drainage holes. Pots were placed on

one-quarter inch wood lathing to provide proper drainage and assure that pots did not sit in run-off solution.

Immediately before and after transplanting seedlings, the sand was flooded with distilled water to prevent dehydration of seedlings.

Nutrient Solutions

Six nutrient solutions with varying concentrations of nitrogen were used to fertilize the plants. The final concentrations of macronutrients and micronutrients (exclusive of nitrogen) in solutions A, B, C, D, E, and F are presented in Table 1. Ammonium nitrate served as the nitrogen source and was added to the solutions to give a final concentration of 50 ppm in solution A, 100 ppm nitrogen in solution B, 200 ppm nitrogen in solution C, 400 ppm nitrogen in solution D. Solution E contained no nitrogen and served as a control. Hoagland's solution, solution F (containing approximately 209 ppm nitrogen), also served as a control as did 20 seedlings that were only fed distilled water. Nutrient feeding solutions were stored in closed 7.5 liter polyethylene bottles in the greenhouse and prepared periodically from stock solutions kept in the laboratory.

Feeding Schedule

After primary leaves on all plants had emerged, stems were measured and nutrient applications were initiated.

Table 1. Concentration of Macronutrients and Micronutrients (Exclusive of Nitrogen) Used to Fertilize Jojoba Plants Grown in a Sand Medium[a]

Treatment A, B, C, D, and E:	
Macronutrients	Micronutrients
0.5 M K_2SO_4	0.5 ppm H_3BO_3
1.0 M $MgSO_4$	0.5 ppm $MnCl_2 \cdot 4H_2O$
0.05 M $Ca(H_2PO_4)_2$	0.05 ppm $ZnSO_4 \cdot 7H_2O$
0.01 M $CaSO_4$	0.02 ppm $CuSO_4 \cdot 5H_2O$
0.5% $FeC_4H_4O_6$	0.01 ppm $H_2MoO_4 \cdot H_2O$

Treatment F (Hoagland's Solution):

1.0 M KH_2PO_4

1.0 M KNO_3

1.0 M $Ca(NO_3)_2$

1.0 M $MgSO_4$

0.5% $FeC_4H_4O_6$

Micronutrients listed above

[a]pH of all solutions was adjusted to approximately 6.0.

Each plant received the same volume of solution. At the beginning of the study, plants daily received 200 mls of a specific solution. As plants grew and root systems developed, the frequency of application was gradually reduced. Application frequency was different between Experiments I and II because of differences in air temperatures and light intensities. The schedules were as follows: Experiment I, 0-2 weeks, 200 mls daily; 2-4 weeks, 200 mls every other day; 4-8 weeks, 200 mls every third day; 8 weeks to conclusion, 200 mls every fourth day. Experiment II, 0-10 weeks, 200 mls every third day.

Growth Measurements

Vertical growth of plant stems was determined at the time nutrients were applied. This was accomplished by measuring in cm the distance between the apical meristem and the cotyledon scar. At the conclusion of the growth period the fresh weight of each plant (exclusive of the roots) was taken and dry weight determined after drying for 48 hours at 65 C.

Cotyledon Removal

Under the premise that seedlings use the nutrients contained in their cotyledons, it was felt that a greater growth response would be observed if cotyledons were removed from seedlings fed the different nutrient solutions. In a separate experiment after seedlings emerged and several

secondary leaves had developed (3-4 weeks), cotyledons were removed from the plant using surgical scissors. Care was taken not to injure the young plant. Feeding was continued as described previously.

Nitrogen Analysis

The nitrogen content of leaves from plants fed the different nutrient solutions was determined at the end of the growing period (124 days for Experiment I, 71 days for Experiment II). To prepare tissue samples for each plant, all leaves were removed from stems, dried at 65 C for 48 hours, and ground in a mortar and pestle. The procedure used for nitrogen analysis was conducted according to Lindner and Harley (1942). $(MH_4)SO_4$ was used to prepare a standard curve of nitrogen concentration (0, 100, 200, 300, and 400 ppm) as recommended by Lindner and Harley.

RESULTS

Germination Studies

Approximately 60% of the seeds soaked three days in water and then placed in a moist chamber (sterile covered tray) germinated within 3-7 days. However, approximately one-half of these decayed when transferred to the sand medium. Because of the decay and the increased amount of time needed to produce an adequate number of healthy seedlings, this method was eliminated. Likewise, the majority of seeds scarified, soaked two days in water, and placed under mist in vermiculite; or those placed either directly into vermiculite, peat, silica sand, or a 50-50 mixture of peat and vermiculite decayed within a short time. These germination methods were also eliminated for seed germination.

Approximately 75% seed germination was achieved after ten days by placing surface sterilized seeds in vermiculite under mist with bottom heat at a temperature ranging from 29 to 34 C. Very few seeds decayed in the vermiculite or when transplanted to the silica sand. This method was used to produce seedlings for Experiment II. Plants for Experiment I were collected from surviving seedlings of the other germination experiments.

Cotyledon Removal

After several secondary leaves appeared on seedlings cotyledons were carefully removed. Eighteen jojoba plants were selected for this experiment (three plants per nitrogen treatment). Height measurements, continued for two weeks after cotyledon removal, showed little or no further increase in growth in any of the fertilizer treatments. Two to three weeks after removal, plants became chlorotic, and rapidly died.

Experiment I (Summer-Fall Growth)

Height Measurements

Jojoba seedlings were transplanted into silica sand in early June and given their first nutrient solution feeding June 17. Air temperatures in the greenhouse ranged from 21 C at night to 30 C during the day. In addition, there was approximately 14 hours of light during the summer. Duration of light during late summer and fall gradually decreased to approximately 12 hours of light per day when plants were removed for analysis October 18, 1974.

Plants fed only distilled water survived 30-60 days, until the time cotyledons decayed and plants became chlorotic and rapidly declined.

Plants fed the different nutrient solutions were allowed to grow 124 days. Height of seedlings at initial measurement ranged from 0.5 to 2.5 cm. Variability in

height was partly due to the heterogeneous nature of the plants from which the seeds were collected. However, selection of seedlings for each nutrient solution treatment was random to overcome personal bias. Height measurements of plants grown in the different nutrient solutions are presented in Figure 1. Differences in growth rate became evident after the fourth week. At 18 weeks, the height of plants grown in 100 ppm nitrogen was over four times greater than those grown at 0 ppm nitrogen and markedly higher than any of the other treatments. An analysis of variance on height differences is presented in Table 2. Since the required F value was 2.90, and the calculated F value was 2.51 at the 5% level of probability, it must be concluded that there was no significant difference in height measurements between treatments.

Fresh and Dry Weight Measurements

Fresh and dry weight measurements, determined at the end of the 124 day growing period, gave results similar to those obtained from height measurements. Results are presented in Table 3. All plants contained approximately 59-67% water. Weight of roots were not determined because it was impossible to separate roots that had grown into the glasswool lining the bottoms of pots. Analysis of variance conducted on fresh and dry weight measurements (Tables 4 and 5) showed no significant difference between treatments.

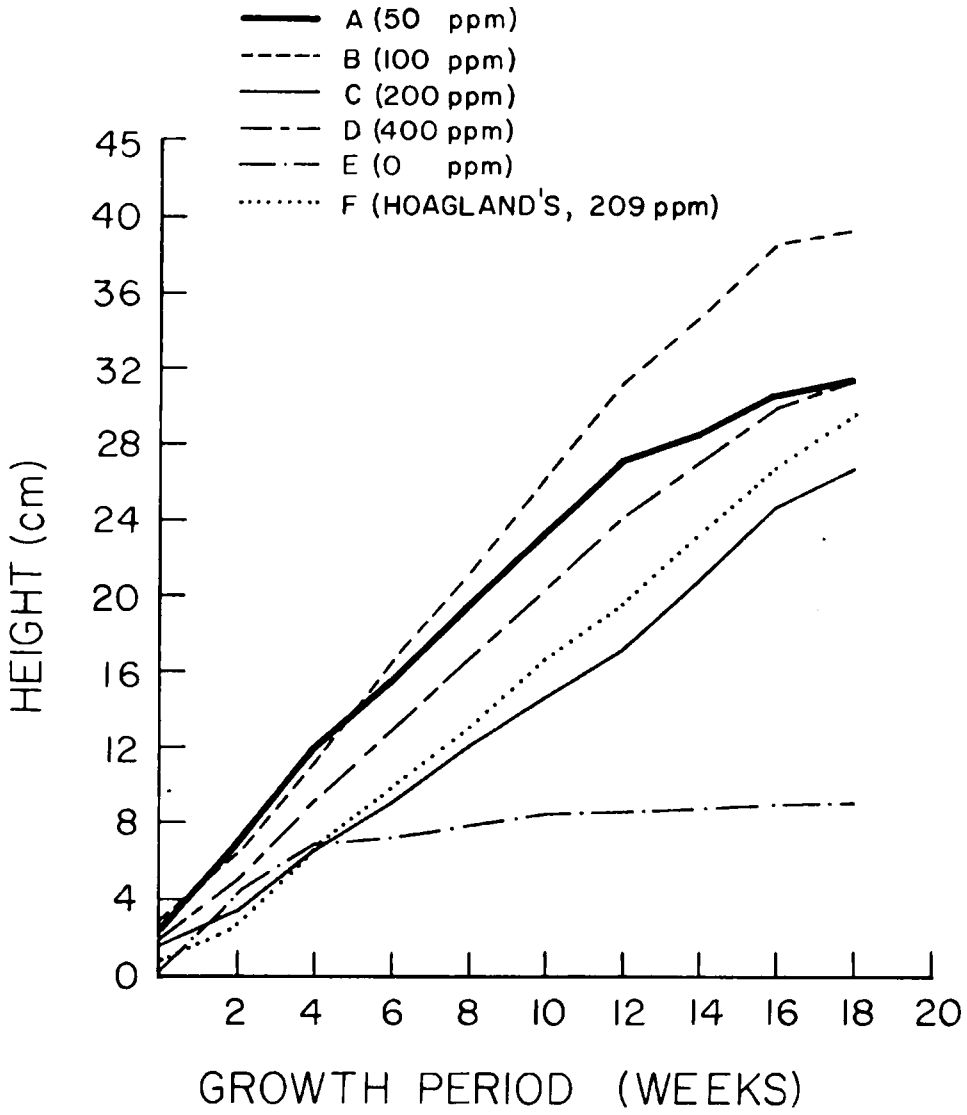

Figure 1. The Effects of Six Different Nitrogen Treatments on the Height of Jojoba Plants Grown for 124 Days in the Summer-Fall of 1974 (Experiment I)

Table 2. The Effects of Six Different Nitrogen Treatments on the Change in Height of Jojoba Plants Grown for 124 Days in the Summer-Fall of 1974 (Experiment I)

Nitrogen Concentration (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	22.0 cm	28.0	39.5	29.2	118.7	29.68
B (100 ppm)	40.0	56.8	19.5	30.0	146.3	36.58
C (200 ppm)	37.6	25.2	20.0	18.6	101.4	25.35
D (400 ppm)	23.8	47.0	11.0	36.5	118.3	29.58
E (0 ppm)	10.5	10.5	7.8	5.0	33.8	8.45
F (Hoagland's, 209 ppm)	16.5	15.5	39.2	33.5	104.7	26.18
Total	150.4	183.0	137.0	152.8	623.2	
Mean	25.06	30.5	22.83	25.47		

Analysis of Variance

Source of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	4106.13		
Replications	3	188.57	62.86	0.44 ns
Treatments	5	1786.26	357.32	2.51 ns
Error	15	2131.30	142.09	

Standard Deviation = 10.109; LSD 5% = 17.96; 1% = 24.90.

Table 3. The Effects of Six Different Nitrogen Treatments on the Fresh and Dry Weight and Per Cent Moisture of Jojoba Plants Grown for 124 Days in the Summer-Fall of 1974 (Experiment I)

Treatment	Fresh Weight	Dry Weight	% Moisture
A (50 ppm)	6.64 g[a]	2.38	64
B (100 ppm)	6.97	2.64	62
C (200 ppm)	5.24	1.72	67
D (400 ppm)	5.73	2.17	62
E (0 ppm)	1.43	0.59	59
F (Hoagland's 209 ppm)	5.47	2.01	63

[a]Values represent averages of 4 replications per treatment.

Table 4. The Effects of Six Different Nitrogen Treatments on the Fresh Weight of Jojoba Plants Grown 124 Days in the Summer-Fall of 1974 (Experiment I)

Nitrogen Concentration (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	7.15 g	8.20	7.09	4.12	26.56	6.64
B (100 ppm)	6.40	10.09	6.80	4.57	27.86	6.97
C (200 ppm)	10.40	3.46	5.06	2.05	20.97	5.24
D (400 ppm)	3.48	8.02	1.60	9.83	22.93	5.73
E (0 ppm)	1.46	1.60	1.24	1.40	5.70	1.43
F (Hoagland's, 209 ppm)	4.38	4.64	7.52	4.12	20.66	5.17
Total	33.27	36.01	29.31	26.09	124.68	
Mean	5.55	6.0	4.89	4.35		

Analysis of Variance

Sources of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	195.78		
Replications	3	9.53	3.17	0.44 ns
Treatments	5	78.92	15.78	2.20 ns
Error	15	107.33	7.16	

Standard Deviation = 1.989; LSD 5% = 4.03; 1% = 5.58.

Table 5. The Effects of Six Different Nitrogen Treatments on the Dry Weight of Jojoba Plants Grown 124 Days in the Summer-Fall of 1974 (Experiment I)

Nitrogen Concentration (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	2.49 g	3.00	2.59	1 42	9.50	2.38
B (100 ppm)	2.45	3.92	2.34	1.85	10.56	2.64
C (200 ppm)	3.39	1.05	1.68	0.74	6.86	1.72
D (400 ppm)	1.15	2.78	0.90	3.84	8.67	2.17
E (0 ppm)	0.60	0.68	0.52	0.55	2:35	0.59
F (Hoagland's, 209 ppm)	1.63	1.69	2.55	1.50	7.37	1.84
Total	11.71	13.12	10.58	9.90	45.31	
Mean	1.95	2.19	1.76	1.65		

Analysis of Variance

Sources of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	24.9		
Replications	3	1.03	0.34	0.38 ns
Treatments	5	10.46	2.09	
Error	15	13.41	0.89	

Standard Deviation = 0.72; LSD 5% = 1.42; 1% = 1.97.

For fresh weight measurements the calculated F value was 2.20 and the required F value was 2.90 at the 5% level. For dry weight measurements the calculated F value was 2.34 and the required F value was 2.90 at the 5% level.

Nitrogen Analysis of Leaves

The concentration of nitrogen in leaves corresponded to the concentration of nitrogen in the nutrient solutions. The per cent nitrogen per gram of dried leaves and an analysis of variance on the data are presented in Table 6. There was no statistical difference among replications in each treatment, but there was a highly significant difference between different nitrogen treatments at the .01 confidence level. The calculated F value was 14.80, and the required F value was 4.56. As shown in the table, the least significant difference at the 1% probability level was 0.65. Treatments A, B, C, D, and F were all highly significant over treatment E. No significant difference was found between treatments containing nitrogen at the 1% level. But at the 5% level, treatments C and D were significant over treatments A and F.

Experiment II (Winter-Spring Growth)

Height Measurements

Seedlings were transplanted in early January, 1975, and nutrient applications begun January 20. Greenhouse air

Table 6. The Effects of Six Different Nitrogen Treatments on the Per Cent Nitrogen per Gram of Dried Leaf Tissue of Jojoba Plants Grown 124 Days in the Summer-Fall of 1974 (Experiment I)

Nitrogen Concentration (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	2.09%	2.0	1.70	2.10	7.89	1.97
B (100 ppm)	2.09	2.20	2.05	2.55	8.89	2.22
C (200 ppm)	2.37	2.60	2.80	2.48	10.25	2.56
D (400 ppm)	3.33	2.12	2.38	2.22	10.05	2.51
E (0 ppm)	1.28	0.72	0.76	0.86	3.62	0.91
F (Hoagland's, 209 ppm)	1.88	2.09	1.59	2.34	7.90	1.98
Total	13.04	11.73	11.28	12.55	48.60	
Mean	2.17	1.95	1.88	2.09		

Analysis of Variance

Sources of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	9.09		
Replications	3	0.314	0.11	1.10 ns
Treatments	5	7.30	1.46	14.80**
Error	15	1.476	0.09	

Standard Deviation = 0.60; LSD 5% = 0.47; 1% = 0.65.

**Significant at the 1% level.

temperatures ranged from approximately 18 C to 24 C. Heating mats maintained sand temperatures at approximately 22-28 C. Duration of light per day gradually increased from approximately 11 hours in January to approximately 12-1/2 hours on March 31.

A comparison of height versus nitrogen concentration in the nutrient solution is presented in Figure 2. Little difference in growth rates was observed during the length of the experiment, although it did appear that by the tenth week, plants fed 0 ppm nitrogen were stunted. An analysis of variance (Table 7) showed that the required F value was 2.90 at the 5% level of probability and the calculated F value 0.52. Therefore there was no significant difference.

Fresh and Dry Weight Measurements

Fresh and dry weight of plants after 71 days growth are presented in Table 8. Results corresponded to height measurements, in that little difference occurred. Plants contained approximately 65-68% water. The analysis of variance showed no significant difference between treatments (Tables 9 and 10). At the 5% level the required F value was 2.90, and the calculated F value was 0.102 for fresh weight. For dry weight, a required F value of 2.90 was obtained, and a calculated F value of zero.

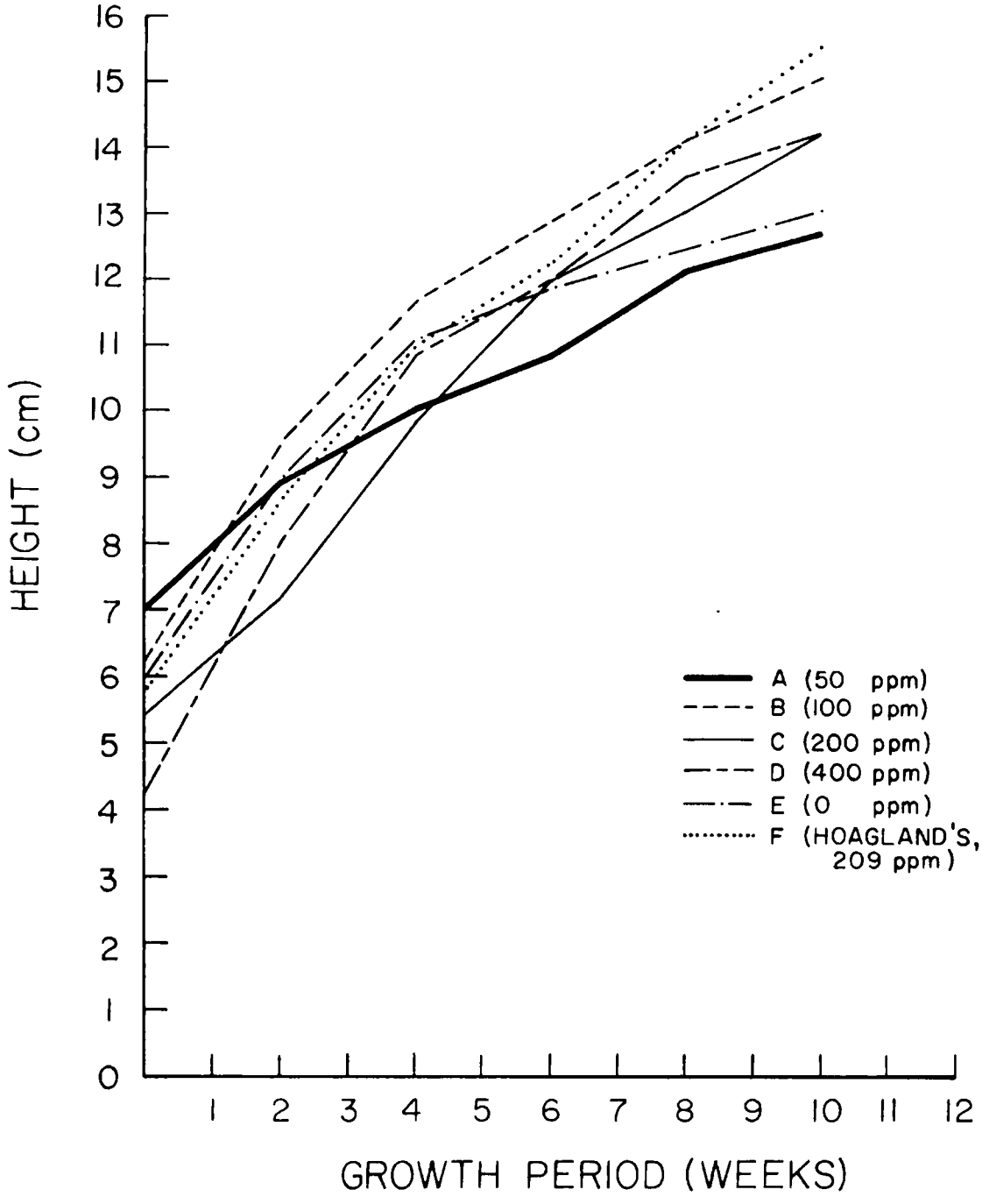

Figure 2. The Effects of Six Different Nitrogen Treatments on the Height of Jojoba Plants Grown for 71 Days in the Winter-Spring of 1975 (Experiment II)

Table 7. The Effects of Six Different Nitrogen Treatments on the Change in Height of Jojoba Plants Grown for 71 Days in the Winter-Spring of 1975 (Experiment II)

Nitrogen Conc. (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	14.3 cm	6.7	5.0	3.2	29.2	7.3
B (100 ppm)	12.8	8.5	7.1	8.1	36.5	9.13
C (200 ppm)	3.5	14.0	7.7	11.3	36.5	9.13
D (400 ppm)	16.0	9.3	4.9	10.7	40.9	10.23
E (0 ppm)	2.6	8.2	14.9	2.5	28.2	7.05
F (Hoagland's, 209 ppm	11.9	9.5	13.5	4.0	38.9	9.73
Total	61.1	56.2	53.1	39.8	210.2	
Mean	10.18	9.37	8.85	5.97		

Analysis of Variance

Sources of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	269.47		
Replications	3	41.55	13.85	1.07 ns
Treatments	5	33.60	6.72	0.52 ns
Error	15	194.32	12.95	

Standard Deviation = 1.29; LSD 5% = 5.42; 1% = 7.49.

Table 8. The Effects of Six Different Nitrogen Treatments on the Fresh and Dry Weight and Per Cent Moisture of Jojoba Plants Grown for 71 Days in the Winter-Spring of 1975 (Experiment II)

Treatment	Fresh Weight	Dry Weight	% Moisture
A (50 ppm)	1.42 g[a]	.46	68
B (100 ppm)	1.36	.48	65
C (200 ppm)	1.28	.41	68
D (400 ppm)	1.57	.49	68
E (0 ppm)	1.24	.44	65
F (Hoagland's, 209 ppm)	2.02	.71	65

[a]Values represent averages of 4 replications per treatment.

Table 9. The Effects of Six Different Nitrogen Treatments on the Fresh Weight of Jojoba Plants Grown 71 Days in the Winter-Spring of 1975 (Experiment II)

Nitrogen Concentration (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	2.42 g	1.08	1.39	0.78	5.67	1.42
B (100 ppm)	1.34	1.45	1.44	1.22	5.45	1.36
C (200 ppm)	0.93	1.78	1.35	1.06	5.12	1.28
D (400 ppm)	1.90	1.88	1.18	1.30	6.26	1.57
E (0 ppm)	0.73	1.52	1.80	0.92	4.97	1.24
F (Hoagland's, 209 ppm)	2.25	0.46	2.20	3.18	8.09	2.02
Total	9.57	8.17	9.36	8.46	35.36	
Mean	1.595	1.36	1.56	1.41		

Analysis of Variance

Sources of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	8.66		
Replications	3	1.66	0.553	1.22 ns
Treatments	5	0.23	0.460	0.10 ns
Error	15	6.77	0.452	

Standard Deviation = 0.29; LSD 5% = 1.01; 1% = 1.40.

Table 10. The Effects of Six Different Nitrogen Treatments on the Dry Weight of Jojoba Plants Grown 71 Days in the Winter-Spring of 1975 (Experiment II)

Nitrogen Concentration (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	0.74 g	0.37	0.43	0.31	1.85	0.46
B (100 ppm	0.40	0.59	0.49	0.45	1.93	0.48
C (200 ppm)	0.30	0.57	0.42	0.35	1.64	0.41
D (400 ppm)	0.60	0.58	0.35	0.46	1.99	0.49
E (0 ppm)	0.23	0.57	0.58	0.39	1.77	0.44
F (Hoagland's, 209 ppm)	0.75	0.25	0.73	1.09	2.82	0.71
Total	3.02	2.93	3.00	3.05	12.00	
Mean	0.50	0.49	0.50	0.51		

Analysis of Variance

Sources of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	0.87		
Replications	3	0.22	0.07	1.7 ns
Treatments	5	0.00	0.00	0.0 ns
Error	15	0.65	0.04	

Standard Deviation = 0.109; LSD 5% = 0.31; 1% = 0.44.

Nitrogen Analysis of Leaves

The per cent nitrogen per gram of dry leaf tissue, and an analysis of variance is shown in Table 11. There was no statistical difference among replications or between nitrogen treatments at the 5% confidence level. The required F value was 2.90, and the calculated F value was 1.0.

Table 11. The Effects of Six Different Nitrogen Treatments on the Per Cent Nitrogen per Gram of Dried Leaf Tissue of Jojoba Plants Grown 71 Days in the Winter-Spring of 1975 (Experiment II)

Nitrogen Concentration (ppm)	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	Mean
A (50 ppm)	2.82%	2.17	2.17	1.97	9.13	2.28
B (100 ppm)	2.09	2.17	2.22	2.90	9.38	2.35
C (200 ppm)	2.39	2.09	3.42	3.23	11.13	2.78
D (400 ppm)	3.42	2.35	2.77	1.03	9.57	2.39
E (0 ppm)	2.03	1.05	2.43	1.23	6.74	1.69
F (Hoagland's, 209 ppm)	1.20	3.23	1.85	2.03	8.31	2.07
Total	13.95	13.06	14.86	12.39	54.26	
Mean	2.33	2.18	2.48	2.07		

Analysis of Variance

Sources of Variation	D.F.	Sum of Squares	Mean Square	F
Total	23	11.2		
Replications	3	0.58	0.193	0.36 ns
Treatments	5	2.65	0.53	1.00 ns
Error	15	7.97	0.53	

Standard Deviation = 0.36; LSD 5% = 1.09; 1% = 1.52.

DISCUSSION

The heterogenous nature of the jojoba seeds as selected, made it impossible to achieve simultaneous germination or a simultaneous growth rate after germination. In addition many seeds did not germinate, and many of those that germinated, did not continue to grow. Viability problems could have been due to age or immaturity of seeds. If further studies are conducted it is suggested that fresh, mature seeds from plants growing in the same locality and selected for uniformity be used for a more homogenous selection of seeds.

Temperature is a critical factor in seed germination. From observations in this study, a temperature of approximately 29 to 34 C is recommended for optimum germination. In addition, vermiculite seems to be the most satisfactory germination medium because it is easily steam sterilized and drains well. Seedlings are also easily removed from it without damaging roots, because it does not compact. Other materials similar to vermiculite, such as foam chips or perlite, might also be acceptable.

Observations also revealed that excess moisture in the sand medium seemed to decrease growth of seedlings. For this reason, it is suggested that pots be raised off the

bench to provide better drainage and aeration than provided by placing pots directly on the greenhouse bench.

In a separate experiment conducted in conjunction with germination studies, it was observed that with seeds planted directly into a mixture of 1/3 soil, 1/3 peat, and 1/3 sand, approximately 90 to 95% germination was achieved. Such seedlings grew more rapidly than those planted in sand and fed the different nutrient solutions. Because the parameters of this thesis dictated that the concentration of all macronutrients and micronutrients be known, the use of a mixture of soil, peat, and sand was precluded. But, it is recommended in further nitrogen studies that such a medium be used.

Removal of cotyledons before the plant naturally abscisses them, was definitely detrimental. The root system on those seedlings with several secondary leaves appeared large enough to absorb enough nutrients for further growth. Apparently it was not, even though it obviously absorbed sufficient water for the plant when cotyledons were present. If nutrients were being used from the cotyledons, and then cotyledons removed, possibly plants were unable to adapt quickly enough to use nutrients in the medium. Or, possibly the shock of premature abscission caused plants to die.

It is obvious from the results in Experiment I that the duration of growing time was not long enough for nitrogen treatment differences to appear. As pointed out

previously, decreased temperatures and light undoubtedly slowed growth rates. This is emphasized by comparing height of plants at ten weeks in Experiment I (Figure 1) and Experiment II (Figure 2). In Experiment I, the greatest height at ten weeks was 26 cm (treatment B), while the greatest height in Experiment II at ten weeks was 15.5 cm (treatment F). In fact, plants in treatments A and B in Experiment I reached 15.5 cm by the sixth week. To speed plant growth in winter months it is recommended that plants be grown in growth chambers with summer temperatures and light conditions simulated.

Although the analysis of variance on height and weight differences (Experiments I and II) revealed no significant differences in treatments, examination of Figure 1 showed that plants definitely responded to different rates of nitrogen in Experiment I. (Differences were approaching significance with a calculated F value of 2.51 and a required F value of 2.90.) Treatment B, 100 ppm nitrogen, appeared to produce the best vertical growth rate over the other nitrogen treatments. The higher nitrogen treatments C (200 ppm), F (Hoagland's, 209 ppm), and D (400 ppm) might have been expected to produce a better growth response than B (100 ppm), but did not. Possibly these results are similar to Cain's (1953) who showed with apple that intermediate nitrogen rates are more productive than higher or lower rates because excess or deficiency interferes with

the plant's process of converting ammonium and nitrate ions into amino acids.

Differences in fresh and dry weights of plants in Experiment I were also approaching significance. Tables 4 and 5 show that plants fed 0 ppm nitrogen weighed very little in comparison to plants fed nitrogen. Since the height of plants treated with 100 ppm (B) was greater than those of other treatments, it was expected that "B" plants would also weigh more.

In Experiment I nitrogen content of leaves did not correspond with height measurements, in that plants grown in 100 ppm nitrogen had the greatest height, but not the greatest concentration of nitrogen in leaves. It is unknown if size of plants or nitrogen content of leaves is related to seed production in Simmondsia chinensis. Possibly the higher nitrogen rates of 200 and 400 ppm would increase size and/or oil content of seeds. Probably such determinations would have to be made on field plantings of jojoba.

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