GROWTH STUDIES IN SOME CITRUS SPECIES UNDER SUB-TROPICAL CONDITIONS

S. KRISHNAMURTHI, G. S. RANDHAWA & P. C. SIVARAMAN NAIR

Indian Agricultural Research Institute, New Delhi

In perennial fruit crops, the importance of growth studies needs hardly any emphasis. More precisely, the investigations on the behaviour of the aerial and sub-terranean parts of the tree to different environmental conditions and the relationship between them, are in fact of fundamental nature, and will facilitate the understanding of the complex processes leading to successful crop production. Those who are interested in the broader problem of biology will be concerned with the laws of growth, while those interested in the art of horticulture may gather from such study something that is fundamental to fruit production. The success of fruit production depends on several factors, among which those that favour the growth of roots, are more important since the nature of root growth is a deciding factor of plant's performance.

Crider (6) found that the new growth of citrus, in Arizona, was cyclic and that the three periods of shoot growth alternated with three periods of root growth. Waynick and Walker (20), in California, came to the similar conclusions. Later, Reed and MacDougal (17) found definite cycles of extension growth in shoots, roots and also in radial growth in citrus under California conditions. Webber (22) in California, Randhawa and Dinsa (16) in Punjab and Krishnamurthi and Kulasekharan (11) in South India have also confirmed the above findings.

In Palestine, Cossman (5) reported four 'flushes' in bearing *Jaffa* orange, the major one in late winter, a second in mid-summer, a third in early autumn and a fourth in early winter. Monselise (1944), as quoted by Marloth (12), reported that in Palestine the *Shamouti* orange (*C. sinensis*) had two main root growth periods during the year. Marloth (12), in Transvaal, noted five cycles of root growth and the most active root growth period was in winter which was in agreement with the findings of Monselise (1944) in Palestine, but differed from Crider (6) in Arizona, Waynick and Walker (20) and Reed and MacDougal (17) in California.

MATERIALS AND METHODS

These studies were conducted for a period of 14 months, commencing from 28th March, 1958 on four important citrus species, namely, *Hamlin* (*C. sinensis* Osbeck), *Nagpur Santra* (*C. reticulata* Blanco), Marsh Seedless (*C. paradisi* Macf.) and sweet lime (*C. aurantifolia* Swingle), at the Horticultural Experiment Station of the Indian Agricultural Research Institute, New Delhi.

Hamlin, Nagpur Santra and *Marsh Seedless* were budded on *Jatti khatti* (*C. limon* (Linn.) Burm. f.) *Jamberi* (*C. limon* (Linn.) Burm. f.), Rough lemon (*C. limon* (Linn.) Burm. f.) respectively and sweet lime was propagated by cuttings. These plants were 7-year old and were in bearing. Three trees under each variety, apparently uniform in size, vigour and productivity were selected for the present studies. The selected trees were given uniform cultural care. The station is situated

on a levelled block of land. The soil is sandy loam, deep, of uniform texture and of medium fertility. The pH of the soil varies from 7 to 7.75.

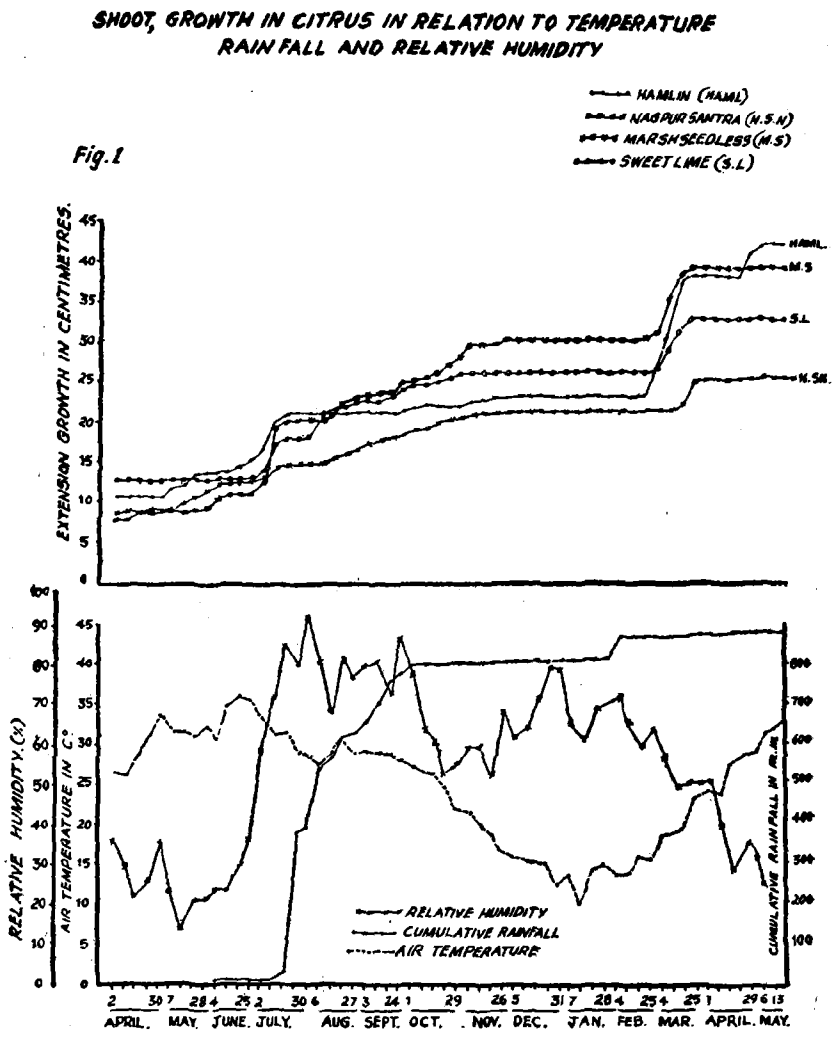
(*a*) *Shoot extension growth* : Three trees under each variety, as mentioned above, were selected for experimantal purposes. Fifteen shoots (9 laterals and 6 terminals), of uniform character, were selected at random in each selected tree. Thus 45 shoots on three trees of each variety were tagged on March 20, 1958. The extension growth of shoots was measured in centimetres with a meter rod from the previous year's leaf scar of the terminal bud without causing them any damage. The first measurement was made on April 2, 1958 and subsequent measurements were recorded at weekly intervals till May 27, 1959.

(*b*) *Root extension growth* : A simple and economical method was devised for the study of the extension growth of roots in bearing citrus trees. The roots within the depth of 40 to 50 cm., were used for these studies. Small pits were dug out about two feet away from the trunk of the tree to trace the roots. Then trenches of about 2'x4'x2' were dug two to three feet away from the drip of the branches and the roots were slowly traced out and a zinc tray 90x45x8 cm. (only 3 sides) with holes at the bottom were introduced just in position to accommodate conveniently the growing end of the root in its natural position for the further study. Similarly, three roots under each of the trees were selected for the study. The zinc tray was filled with the same soil up to the rim and after keeping the carefully traced roots in their natural position, soil was again put over the root upto 6 to 8 cm. height. Then it was covered by fine sand and the place was raised above the surrounding level to avoid stagnation of water. The edge of the buried zinc tray and the end of the growing roots were marked with pegs, and the distance between the first peg and the growing end of the root (second peg) was recorded weekly till May 27, 1959 and the actual growth during each week was calculated. The position of the second peg was useful to facilitate easy location and excavation of roots for the subsequent observations.

The new root growth was easily identified by the succulent, white and tapering end, which gradually turned into grey, light brown and finally dark brown on cessation of growth. Care was taken not to expose the root to the direct sunlight during excavation for recording. The time of recording was reduced to the minimum of one to two minutes which apparently had little or no adverse effect on the growth features even though long exposure of the same could bring reduction in growth (Rogers, 1939).

(*c*) *Radial growth* : The same trees, used for the previous observations, were selected for measuring the radial growth of the trunk at weekly intervals. A white marking, was made six inches above the bud union with white paint. The measurement of the girth of the trees was taken at this marking by means of a tape at weekly intervals from May 28, 1958 to study the cycles of radial growth and to correlate the same with the cycles of root and shoot growths. The girth of the citrus trees measured on May 28, 1958, was taken as zero. The increase over this girth was recorded in millimetres at weekly intervals. The girth was measured at 8 A.M. in all recording dates.

(*d*) *Weather records*: Air temperature, rainfall and relative humidity records were taken from the meteorological observatory of Indian Agricultural Research Institute, which is situated within 100 yards of the experimental plots. Soil temperature at 15 centimetres depth was taken at 7 A.M. and 2 P.M. from the root region of the experimental plants.



Results

The mean shoot extension growth in each species is graphically represented in Fig. 1. The cumulative rainfall, relative humidity and air temperature are also presented in the same graph for comparison. The shoot growth in each species is cyclic, i.e., a period of growth is alternated with a period of quiescence. These cycles of shoot, root and radial growths are also presented in Fig. 2.

There were five shoot growth cycles in the course of one year (May 28, 1958 to May 27, 1959) and Figures 1 and 2 reveal that there are individual variations in the duration of the periods of growth and quiescence among the species. Besides this, the average daily increment of growth calculated as millimetres per day also varied among the species as shown in Fig. 2. The mean shoot extension growth in each month as well as the growth expressed as percentage of the total growth for a period of one year is given in Table 1.

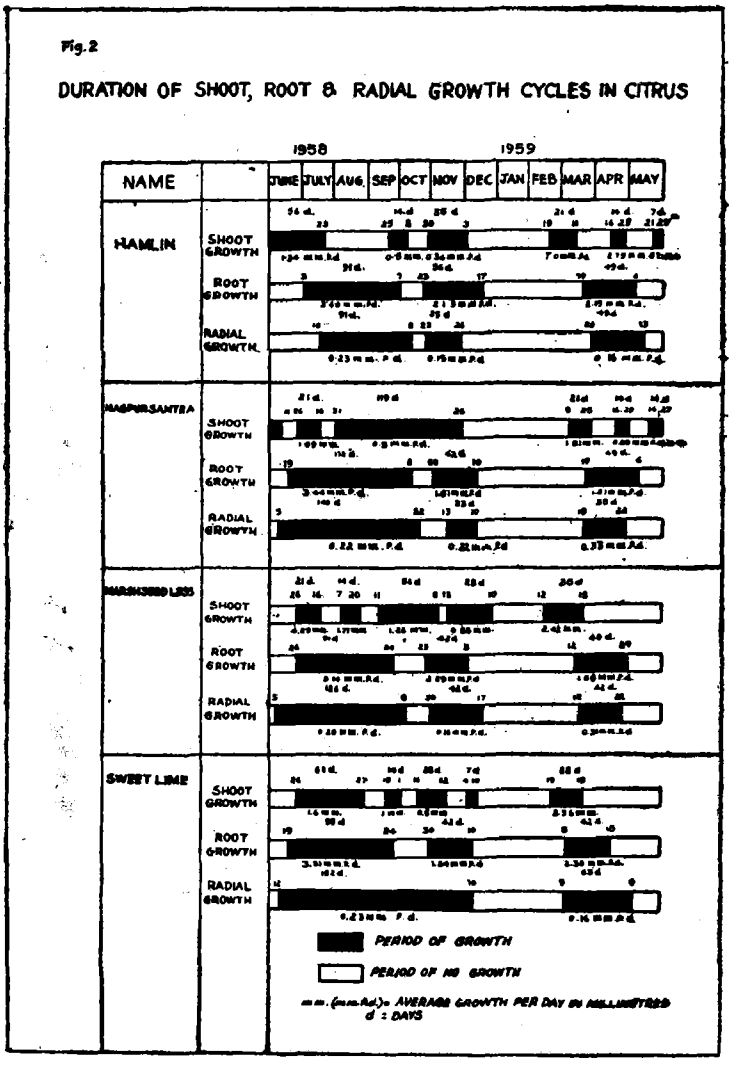


Table I shows that the maximum extension growth was in the month of March in *Hamlin* (42.5%) and *Nagpur Santra* (26.8%) whereas the maximum extension growth was in the month of July in *Marsh Seedless* (30.8%) and sweet lime (39.8%). There was no growth during the months of January, February and December in *Nagpur Santra* whereas in all other species there was only little growth in December and February. But they also showed no growth in January. The maximum total extension growth was noted in *Marsh Seedless* (29. 2 cm.) and the minimum in *Nagpur Santra* (14. 2 cm.). The *Hamlin* (28.7 cm.) and sweet lime (19.6 cm.) were in between the two.

TABLE 1

Monthly shoot extension growth in citrus

Months	Hamlin		Nagpur Santra		Marsh Seedless		Sweet Lime	
	Mean growth (cm.)	Growth expressed as %	Mean growth (cm.)	Growth expressed as %	Mean growth (cm.)	Growth expressed as %	Mean growth (cm.)	Growth expressed as %
1958								
June	1.6	5.6	0.8	5.6	1.5	5.1	—	—
July	5.9	20.6	2.3	16.2	9.0	30.8	7.8	39.8
August	—	—	2.7	19.0	2.3	7.9	2.3	11.7
September	—	—	1.9	13.4	2.8	9.6	1.4	7.1
October	0.7	2.4	1.3	9.2	3.5	12.0	0.8	4.1
November	1.2	4.2	0.4	2.8	1.4	4.8	0.6	3.1
December	0.1	0.3	—	—	0.2	0.7	0.1	0.5
1959								
January	—	—	—	—	—	—	—	—
February	2.6	9.1	—	—	1.1	3.8	0.3	1.5
March	12.2	42.5	3.8	26.8	7.4	25.3	6.3	32.2
April	3.9	13.6	0.4	2.8	—	—	—	—
May	0.5	1.7	0.6	4.2	—	—	—	—
Total	28.7	100.0	14.2	100.0	29.2	100.0	19.6	100.0

ROOT GROWTH IN CITRUS IN RELATION TO SOIL TEMPERATURE AND RAINFALL

Fig. 3

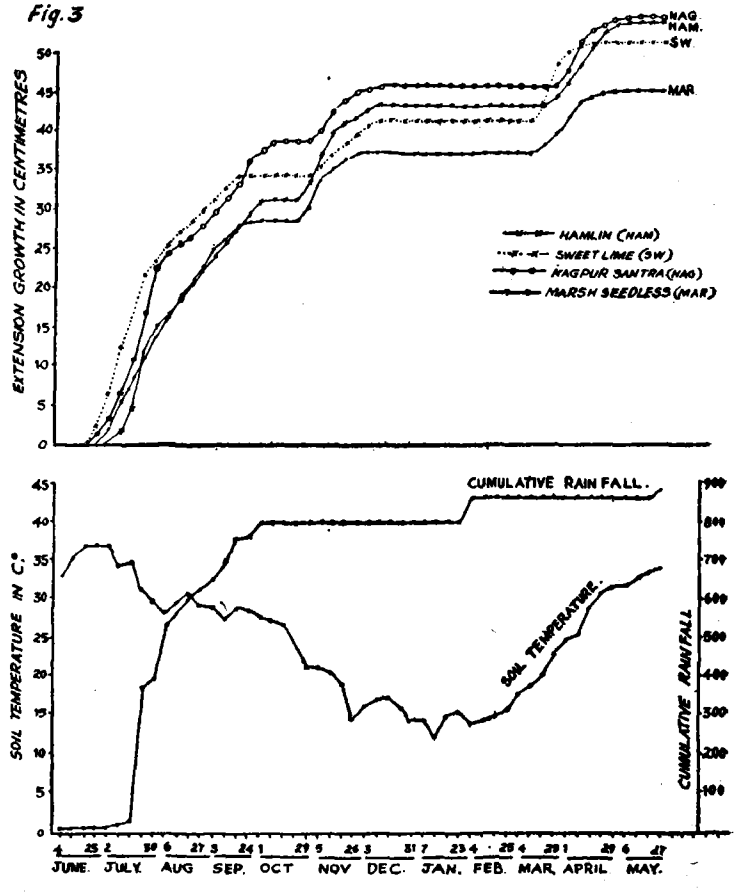


TABLE 2

Monthly root extension growth in citrus

Months	Hamlin		Nagpur Santra		Marsh Seedless		Sweet lime	
	Mean growth (cm.)	Growth expressed as %	Mean growth (cm.)	Growth expressed as %	Mean growth (cm.)	Growth expressed as %	Mean growth (cm.)	Growth expressed as %
1958								
June	—	—	1.4	2.6	—	—	2.0	3.9
July	14.7	27.2	21.2	38.9	13.6	30.2	21.6	42.2
August	7.3	13.5	6.9	12.7	8.9	19.8	6.3	12.1
September	9.0	16.7	8.0	14.7	6.0	13.3	4.9	9.6
October	2.3	4.3	1.1	2.0	1.8	4.0	—	—
November	8.1	15.1	5.8	10.6	6.7	15.0	4.9	9.6
December	1.9	3.5	1.2	2.2	0.2	0.4	1.6	3.1
1959								
January	—	—	—	—	—	—	—	—
February	—	—	—	—	—	—	—	—
March	3.0	5.5	2.2	4.0	2.3	5.1	8.7	17.0
April	7.2	13.3	6.2	11.4	5.5	12.2	1.3	2.5
May	0.5	0.9	0.5	0.9	—	—	—	—
Total	54.0	100.0	54.5	100.0	45.0	100.0	51.3	100.0

(ii) *Root Growth* : The mean root extension growth of all the species is presented graphically in Fig. 3. There were three cycles of root growth in all the species. They were initiated in March, June-July and October. The time of initiation and cessation of growth, extent of growth and average growth per day varied slightly from species to species. In all the cases the June-July growth cycle was the longest and most intense (Fig. 2). The monthly growth of roots and the growth expressed as percentage of the total growth are presented in Table II. There was no root growth in the months of January and February in all the species and the growth during May, June and December was either very low or absent.

(iii) *Radial Growth* : The mean weekly radial growth of the trunk of all the citrus species and the monthly radial growth and the same expressed as percentage of the total growth are presented in Fig. 2 and Table III respectively. There were three cycles of radial growth in all the species except in sweet lime where only two were observed. As in the case of shoot and root growth radial growth also differed from species to species regarding the duration, extent of growth and time of initiation and cessation of growth cycles as observed in Fig. 2. Among the growth cycles, June-July growth cycle produced the maximum growth and it was longest in duration.

ROOT, SHOOT & RADIAL GROWTH CYCLES IN CITRUS

Fig. 4

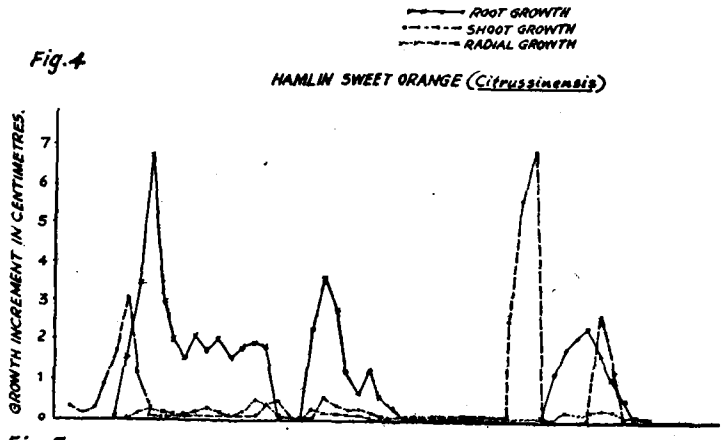


Fig. 5

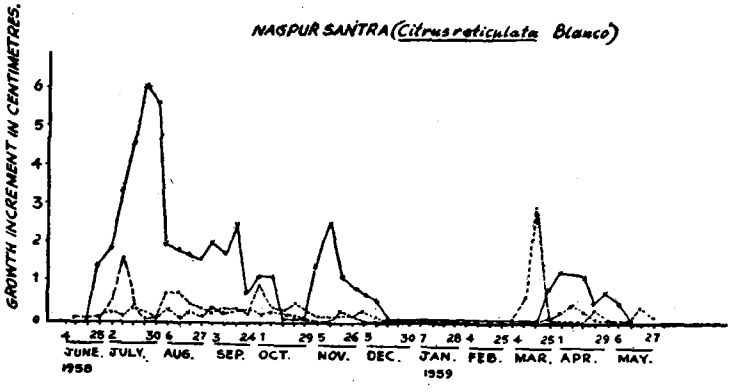


TABLE 3

Monthly radial growth of the trunk in citrus

Months	Hamlin		Nagpur Santra		Marsh Seedless		Sweet lime	
	Mean growth (mm.)	Growth expressed as %	Mean growth (mm.)	Growth expressed as %	Mean growth (mm.)	Growth expressed as %	Mean growth (mm.)	Growth expressed as %
1958								
June	—	—	2.0	4.0	4.7	10.1	2.7	5.2
July	4.7	13.8	8.0	16.1	5.3	11.3	7.6	14.5
August	5.0	14.7	5.3	10.7	5.7	12.2	4.7	9.0
September	11.0	32.4	11.4	23.0	9.6	20.5	11.3	21.6
October	2.6	7.6	5.0	10.0	0.4	0.9	6.7	12.8
November	2.7	7.9	3.0	6.0	4.0	8.6	8.3	15.9
December	—	—	3.3	6.7	4.0	8.6	1.0	1.9
1959								
January	—	—	—	—	—	—	—	—
February	—	—	—	—	—	—	—	—
March	—	—	1.0	2.0	5.3	11.3	4.4	8.4
April	7.0	20.6	10.7	21.5	7.7	16.5	5.3	10.1
May	1.0	3.9	—	—	—	—	0.3	0.6
Total	34.0	100.0	49.7	100.0	46.7	100.0	52.3	100.0

ROOT, SHOOT & RADIAL GROWTH CYCLES IN CITRUS

Fig. 6

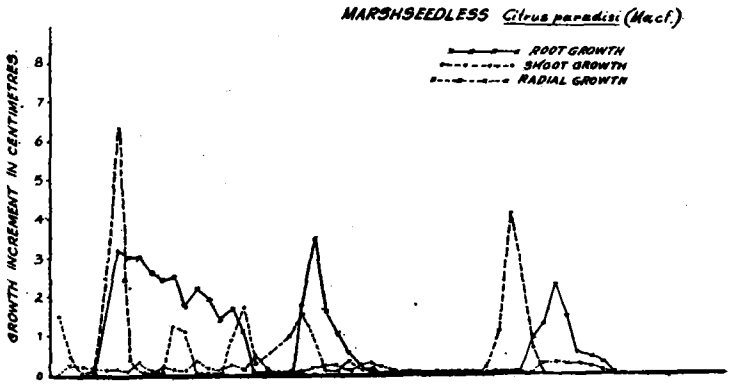
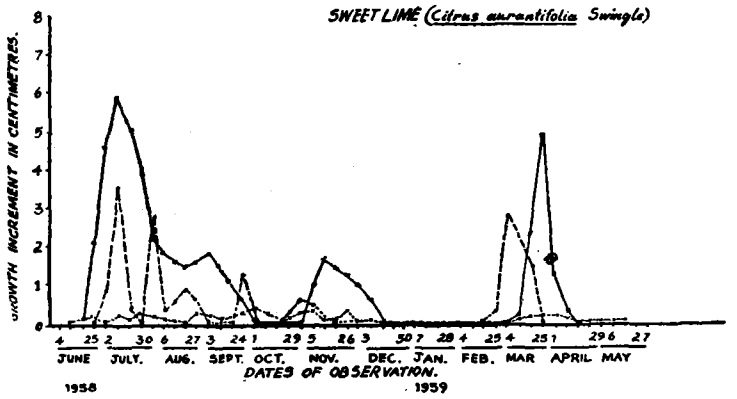


Fig. 7



Cycles of shoot, root and radial growth : The relationship among shoot, root and radial growth cycles in all the species are presented in Figs. 4 to 7. It is clear that there are five cycles of shoot growth, three of root growth and three of radial growth in citrus except in sweet lime where only two radial growth cycles were observed. The root growth cycle had a tendency to alternate with that of shoot growth cycle. But they were not actually alternating. Especially during the months of June, July and August, the root growth coincided with the shoot growth. But in all cases it was seen, that when the shoot was in a rank growth, the root growth was either slow or absent. The radial growth also had a tendency to alternate with that of shoot. But it almost coincided with the root growth except that it stopped growth earlier than the root growth at the end of the growing season.

Discussion

Crider (6), Reed and MacDougal (17), Webber (22), Randhawa and Dinsa (16), Marloth (12), and Krishnamurthi and Kulasekharan (11) have observed growth cycles or periods of growth in citrus. The results obtained in the present studies also confirm that under the sub-tropical conditions of Delhi, there are definite cycles of shoot growth as found in California, Arizona, Punjab (N. India), South India (Tropical condition) and Transvaal (S. Africa).

The time of occurrence of growth cycles, their duration and comparative growth, however, varied considerably depending upon the locality and the environmental factors. Crider's (6) experiments in Arizona showed that the first shoot

growth started about February 15th and ended approximately on April 7th and thus had a duration of 50 days. The second cycle of shoot growth started on 6th June and was completed on 23rd June, a period of 17 days. The third cycle began about 13th August and continued until 26th August, for a period of 14 days. The work of Waynick and Walker (20) and Webber (22) in California, confirmed the findings of Crider (6). Under Delhi condition, in all the citrus species under study, as many as five cycles of shoot growth were observed during the course of one year (28th May, 1958 to 27th May, 1959) and average growth rate per day varied with the growth cycle. In *Hamlin* (*Citrus sinensis*), the duration of growth cycles varied from 14 to 56 days with an average daily growth increment variation of 0.5 mm. to 7.01 mm. In *Nagpur Santra* (*Citrus reticulata*), *Marsh Seedless* (*Citrus paradisi*) and sweet lime (*Citrus aurantifolia*) the duration of the growth cycles varied from 14 to 119 days, 14 to 56 days and 14 to 63 days respectively. The duration of the spring cycle (February-March) was 21 days with a daily growth increment of 1.81 mm. in *Nagpur Santra*, 35 days in *Marsh Seedless* with a daily growth increment of 2.42 mm., 21 days in *Hamlin* with a daily growth increment of 7.01 mm. and 28 days in sweet lime with a daily growth increment of 2.36 mm. In Arizona, however, the duration of the spring growth cycle was 50 days only.

Under Delhi conditions, the growth cycles which were observed in June, July and August were found to be of longest duration. It was not the case in Palestine, where the maximum growth and duration of growth cycles were in winter. Under tropical conditions of South India, Krishnamurthy and Kulasekharan (11) found October-November cycle to be of the longest duration.

Delhi is a sub-tropical region, like California and Arizona, and the winter is comparatively mild. Infact, the weather in Delhi warms up early in February which accounts for early resumption of growth. The optimum growth temperature, however, prevails only for a short period (February and March) and the temperature shoots up in April and is at its maximum during May and June, unlike in California. The relative humidity during this period is also very low. Therefore, the growth slows down or completely stops during this period which reduces the duration of spring growth cycle. However, the maximum growth per day, as in California, is observed during this period of optimum growth temperature.

Under Delhi conditions, June, July and August growth cycles are long, but rate of growth is low. The rainfall occurs by the end of June and temperature is brought down between 28 to 34.2°C, which is slightly above optimum growth temperature for citrus. This condition along with high relative humidity, prevails for a longer time which explains the reason for a long growth period during these months with a low rate of growth. The initiation of growth in the spring, in Delhi, takes place by 4th February in sweet lime, 12th and 19th February in *Marsh Seedless* and *Hamlin* respectively. Growth initiation in *Nagpur Santra*, however, takes place only by 5th March, may be because it requires higher heat unit for growth initiation. The citrus species used in the present studies can be arranged in the following order according to the degree of dormancy exhibited by them during the winter, *Nagpur Santra*, *Hamlin*, sweet lime and *Marsh Seedless* with *Nagpur Santra* showing the maximum period of dormancy and *Marsh Seedless* the least. These observations are in accord with those of Webber (22).

When compared to the mean extension growth produced by each growth cycle, there exist wide differences. The maximum mean extension growth (14.8 cm.) was produced in the spring cycle in *Hamlin* during a period of 21 days, whereas in *Nagpur Santra* the maximum mean extension growth was in

July growth cycle which produced a mean extension growth of 6.4 cm., in 119 days. *Marsh Seedless* produced the maximum growth (9.0 cm.) in 21 days during the June-July growth cycle whereas in sweet lime the maximum extension growth (10.1 cm.) was in the June growth cycle which lasted for a period of 63 days. But it was found that all species produced the maximum growth per day during the spring cycle (February, March) except in grapefruit which produced the maximum daily growth in June-July cycle. The number of laterals produced was more in the spring cycle in all the citrus species. Therefore, the spring cycle had produced the maximum total growth. These results are in agreement with the findings of Crider (6) in Arizona, Waynick and Walker (20), and Reed and MacDougal (17) in California, and Randhawa and Dinsa (16) in the Punjab (West Pakistan).

With regard to the cycles of shoot growth, much variation exists in a species in different seasons and with different species in the same season. There was no growth in *Hamlin* during April, 1958, but the same trees initiated a growth cycle for 14 days from 16th April to 29th April in 1959. Similarly the growth started by first May in *Hamlin* in 1958, which lasted till 23rd July whereas in 1959 the growth initiated only by 21st May. Such differences in the time and duration of growth cycles were noted even in other species of citrus. Such variations were also observed by Crider (6) in Arizona and Webber in (22) California. These variations may, therefore, be due to the combined effects of environments and the internal physiological condition of the trees.

In California and Arizona, between the beginning of December and the end of February, the mean daily temperature is not likely to be much above 55°F, which is the vital temperature for growth. In Delhi, the winter is comparatively mild and a mean temperature above 55°F is experienced even early in February and the mean temperature goes down below 55°F only by the middle of December. Therefore, growth initiation takes place early and it extends even up to the middle of December in certain citrus species like the grapefruit.

In citrus, the shoot growth initiates approximately by 15th February, when the mean weekly temperature is 13.6°C. (56.5°F). The maximum total growth was found in the month of March when the weekly mean temperature range was between 18 to 24.1°C. (64.4 to 75.4°F). The growth continued between 24.1 and 36°C. (96.8°F) but was rather slow compared to the spring cycle. Therefore, under Delhi conditions, a temperature range of 13.6°C (55.5°F) is considered to be the minimum and 18 to 24.1°C. (64.4 to 75.4°F.) as optimum for growth in citrus. Webber (22) considered 55°F. as the correct 'zero' or vital temperature-the lowest temperature at which growth takes place on the basis of results obtained by Girton (9), Fawcett (8) and Camp *et al* (2).

The root growth in citrus is found to be cyclic, just like the shoot growth. In citrus, a trend in general towards alternation in periodicity of root and top growth was noticed, although not completely so. In fact, these growth cycles sometimes overlap. It is seen that when the roots are growing vigorously, the shoots are either dormant or exhibit only weak growth and *vice versa*. This is in accord with the findings of Crider (6) in Arizona, Reed and MacDougal (17) and Marloth (12) in Transvaal (S. Africa).

Crider (6) observed that the root and top activity was very evident in 3-4 years old trees, but was less evident in large old trees. Waynick and Walker (20) also confirmed these results and further observed that the cycle of shoot

growth, which followed the second cycle of shoot growth, overlapped the entire cycle of shoot growth. The present findings confirm the results of North and Wallace (13) in California who, working with bearing citrus trees in glass house, found that the root elongation slowed down when there was a vigorous leaf flush but did not always completely stop.

As regards the difference between species, there was not much marked difference although the tendency for alternation was comparatively less in sweet lime. It may, however, be stated that the sweet lime was propagated by cuttings while rest of the citrus species were all budded on *Citrus limon* rootstock. This may, perhaps, be the possible reason why alternating tendency was less pronounced in this case.

Regarding the time, duration and extension growth of different cycles in citrus, there exists some difference between the observations recorded by the authors and those recorded by workers in Arizona, California and Transvaal (S. Africa). Shoot growth in citrus is found to precede root growth in the spring by 14 to 28 days which confirms the findings of Crider (6) in Arizona, Waynick and Walker (20), and North and Wallace (13) in California. The low soil temperature during the early February is not favourable for root growth. But the air temperature is comparatively high (above 55°F), so the shoot growth initiates earlier than the root growth.

The spring root growth cycle in 1959, which corresponds to the first cycle of Crider (6) in Arizona, started on the 19th March in *Hamlin* at Delhi as against 8th April in Arizona. The cycle lasted for 49 days, producing an average daily growth of 2.19 cm., in India as against 57 days producing an average daily growth of 4.32 mm. in Arizona. The July cycle which corresponds to the second cycle of Arizona started on the 3rd July and continued upto 1st October covering 91 days and producing a maximum root elongation (31 cm.) with an average growth increment of 3.40 mm. per day whereas the corresponding growth cycle in Arizona lasted for 30 days, beginning on 5th July and ending on 5th August, with an average growth elongation of 1.33 mm., which was the lowest growth rate per day. The third and the last cycle began on 22nd September and ended on 5th November in Arizona, covering a period of 45 days with an average root elongation of 2·44 mm., per day. The corresponding October root growth cycle started on 23rd October and ended on the 17th December in Delhi, covering a period of 56 days. The rate of growth per day was 2.19 mm.

The maximum elongation (31 cm.) and the maximum daily growth increment were noted during July growth cycle whereas in Arizona it was the spring cycle which had the maximum elongation and maximum daily growth increment (4.32). The July growth cycle in Arizona was the shortest (30 days), with the least growth per day. The higher temperature prevailing in Arizona during this time may be responsible for less growth and short duration. But in Delhi, due to the rains in July-August, the temperature is brought down to about 28°C. which is the most favourable soil temperature for optimum root elongation (Girton, 1927). The root growth starts earlier under Delhi conditions and the cessation of growth at the end of the season is late, as compared to California and Arizona, which is possibly due to the mild winter experienced at Delhi.

These results, however, differ with the findings of Monselise (12) in Palestine and Marloth (12) in Transvaal. They observed active and longest period of root growth in winter which is due to the very mild winter experienced in those regions compared to Delhi. In the present studies, the time of initiation, duration

of the cycle, and cessation of growth varied slightly from species to species and also, even, from tree to tree. The shoot growth stopped earlier than the root growth at the end of the season. This confirms the results of Goff (10) and Barker (1) in apple and Reed and MacDougal (17) in citrus.

There was not much varietal difference in the growth periods and duration except that the time of initiation and cessation of growth may sometimes differ slightly in different species. It was found that the minimum temperature at which the root growth occured in citrus was 16°C. and the optimum for root growth was between 28 and 35°C. Camp *et al.* (2) found 15°C , 31-35°C. are 40°C. as minimum, optimum and maximum temperature respectively for grapefruit (*C. paradisi*) and sweet orange (*Citrus sinensis*). However, results of the present studies which are more or less in agreement with the findings of Camp *et al* (1933) and different from those of Peltier (14) and Girton (9). In fact, Girton (9) found 12°C., 26°C and 37°C as minimum, optimum and maximum temperatures for root elongation ins our orange (*Citrus aurantium*), grapefruit (*Citrus paradisi*) and sweet orange (*Citrus sinensis*).

The present studies show that sweet lime requires comparatively lower minimum temperature for root growth. The minimum temperature for root growth in *Nagpur Santra* is a little higher than the other species, namely, sweet lime, (*C. aurantifolia*), sweet orange (*C. sinensis*) and grapefruit (*C. paradisi*). The soil temperature, from the middle of December to early March, drops to the level which does not favour root growth and thus the root growth ceases during this period.

The root growth in citrus during the summer months is reduced or checked completely. This is due to the high temperature accompanied by low relative humidity and low soil moisture. While a small moisture content in the soil is certainly a stimulant to root growth, the optimum gradient is readily passed in summer so that the root, with the heavy summer transpiration, falls behind and it is unable to grow fast enough to keep with the optimum moisture supply and check, therefore, results.

Roots are always found to grow longer and as such they are always found to extend far beyond the drip of branches. Goff (10), Rogers (18), Crider (6, 7), Weaver (21), and Cannon (3) agree with the above observation. It seems impossible at present to explain the cyclic growth of roots on any simple basis, although it is probably affected by temperature and hormonic communications between root and shoot. It is also possible that the rhythm of growth process is closely bound up with the metabolic rhythm in the meristem of the growing point of roots as found by Celjniker (4) in shoots.

Three cycles of raidial growth were found in citrus except in the sweet lime (*C. aurantifolia*) where only two were observed. Reed and MacDougal (17) also found three radial growth cycles in sweet orange (*Citrus sinensis*). The difference in sweet lime may be due to the difference in species or due to the internal physiological conditions of the trees. In sweet lime, no rest period was observed between July and October radial growth cycles, as was the case in other citrus species. But it is to be noted that the duration of the period of no growth, between July and October growth cycles was only 14 to 21 days in case of *Hamlin, Marsh Seedless* and *Nagpur Santra.*

In citrus, the radial growth showed a strong tendency to alternate with the shoot growth and it almost coincided with the root growth except at the end or beginning of the season. This confirms the findings of Reed and MacDougal

(17) in citrus in California. The radial growth in citrus, always starts only after 15 to 28 days of shoot growth initiation in the spring and radial growth of the trunk ceases before the roots stop growth. The results are in conformity with the findings of Reed and MacDougal (17) and Prestley (15).

Summary

1. The shoot, root and radial growths in citrus were found to be cyclic i.e., period of growth is alternated by a period of no growth or quiescence.

2. There were five distinct cycles of shoot growth in citrus under Delhi conditions during the course of one year. The duration and the time of initiation and cessation of growth cycles varied with the cycle, season as well as with the species.

3. The growing season in citrus started by the middle of February and extended upto the middle of December. The maximum total growth was in the month of March, followed by July, August and September in descending order.

4. No shoot growth took place below 13.6°C. (56.5°F) and the maximum shoot elongation was found to be within a temperature range of 18-24.1°C. (64.4 to 75.4°F.). The growth slowed down considerably above 24.1°C.

5. Three root growth cycles were observed during the course of one year. These cycles initiated growth in the months of March, June-July and October. The maximum root extension growth and the maximum growth per day were noticed in June-July cycle.

6. The main root extension growth was found in July, August, September and March-April. No root growth was observed from the middle of December to the first week of March in citrus. The actual period of root growth during the year was only for 161 to 182 days.

7. There exists a negative correlation between root and shoot extension growth. The shoot growth preceded root growth by 14 to 28 days in the spring in all citrus species.

8. The minimum and optimum soil temperature for root growth in citrus were found to be 16°C. and 28 to 35°C. respectively. The absence of root growth from 17th December to 5th March was due to low soil temperature, which went below 16°C. The root growth during the hottest part of the year (May and June) was reduced or checked completely. It was due to the high temperature accompanied by low soil moisture.

9. There were three cycles of radial growth in all the citrus species except in sweet lime where only two cycles were observed. The main radial growth was observed during the months of April, July, August and September. The radial growth of the trunk started only 15 to 28 days after the shoot growth initiation in the spring and it generally ceased to grow before the root growth ceased at the end of the season.

10. A strong tendency for the root growth cycle to alternate with the shoot growth cycle was observed. But sometimes, especially in the months of July, August and September, the growth in shoot and root continued simultaneously. In general, it can be concluded that during the time when the shoots are actively growing, the roots are quiescent or make very little growth and *vice versa*. The radial growth cycles also showed a tendency to alternate with that of shoot, but it almost corresponded with the growth of roots.

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