Additional illumination before and temperature after planting of early tomatoes[1]

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Summary

Tomato plants raised with additional illumination (+L) or without (—L) were planted at four different temperature regimes. Stem- and side-shoot growth was not influenced by additional illumination but was faster at higher temperatures compared with lower ones, resulting in longer internodes.
The number of leaves under a certain truss was diminished by two by the additional illumination. Trusses of +L plants were earlier in flowering but smaller in weight compared with corresponding trusses of —L plants. The same holds true for lower trusses compared with higher ones and trusses grown at higher temperatures compared with those grown at lower temperatures.
The additional illumination speeded up harvest 4—5 days; 2 °C higher a temperature gave a 10—12 days earlier yield. No interaction between the applied light and temperature treatments was found.

1. Introduction

Many studies have been made concerning the effect of additional illumination before planting of early tomatoes (VERKERK, 1955, 1962; VERKERK, GERMING and VAN KOOT, 1960; VERKERK and WELLENSIEK, 1950). Also the effect of temperature after planting in the greenhouse has been studied. (GERMING and VERBERNE, 1962; VERKERK, 1955). Studies about the combined effect of additional illumination before and temperature treatment after planting are scarce. At the Horticultural Laboratory of the Agricultural University at Wageningen an opportunity presented itself to study the effects of four different temperature regimes. Half of the plants were additionally illuminated before planting. Records about earliness and yield of the different objects gave interesting results.

2. Methods

2.1. Additional illumination before planting

The tomato variety *Moneymaker* was used. Two groups sown early in December were additionally illuminated with Philips HPL 80 W lamps (+L), and two groups sown about three weeks earlier were grown without additional illumination (—L) (VERKERK, 1962).

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The light treatment was performed in three steps:
a. Till fourteen days after sowing continuous light of approximately 200 W/m²;
b. during the three following weeks 16 hrs light per day of 100 W/m²;
c. the last three weeks before planting 12 hrs light per day of 65 W/m².

The lamps were hanging about 50 cm above the top of the plants. Soil temperature was 15 °C, air temperature during the dark period 14 °C and during the light period 18 °C.
At planting time, the 1st of February, some measurements were taken. The results are given in TABLE 1. The differences between the two +L groups and the two —L groups appear to be very small. As a consequence both +L groups will be taken together, just as both —L groups. All the parts of the +L plants are larger than the corresponding parts of the —L plants. The large differences between the sturdiness of +L and —L groups have to be emphasized.
At planting time the first truss is clearly visible in the plants of all groups, in the +L plants however it is much larger than in the —L plants.

TABLE 1. Some measurements at planting time in two groups of plants with (+L) and in two groups of plants without (—L) additional illumination

Items	Additional illumination			
	+L		—L	
Number of leaves larger than 2 cm	8,7	8,6	7,9	8,2
Length of largest leaves in cm	22,0	20,6	15,8	13,8
Length between cotyledons and growing points in cm	17,3	14,8	10,7	10,1
Fresh weight in g	18,6		6,9	5,4
Sturdiness [1]	109		64	54

[1] $\frac{\text{Fresh weight in g}}{\text{Length in cm}} \times 100$.

2.2. Temperature treatment after planting

The plants were grown in four greenhouse compartments a, b, c and d, the first three in a light greenhouse where the plants received about 75 % of the outside light and where temperature could be regulated rather well, the last one in a darker greenhouse receiving about 60 % of the outside light, so 75 % of those in the light greenhouse. The temperatures are given in TABLE 2. In compartment c the temperature could not be kept low enough in April and May because no cooling was possible, so the mean temperature went up to 18 °C. In all compartments the night temperature was planned to be 5 °C lower than the day temperature. In compartment d the temperature was not controlled, but regulated by hand as well as possible.

TABLE 2. Temperature in °C in the different compartments

Compartment	Temperature		Mean temperature				Symbol
	day	night	Feb.	March	April	May	
a	23	18	19	19	19	19	19
b	20	15	17	17	18	17	17
c	17	12	15	15	18	18	15(18)
d	?[1]	?[1]	17	20	20	22	17—22

[1] not controlled.

For short, the symbols in the last column of TABLE 2 will be used in the following. Temperature **19** is rather high for a start in early February, **17** was thought to be optimal while **15(18)** turned out to be too low for good fruit setting.

2.3. Treatment of plants

The pots in which the plants were planted on 1st February had a diameter of 30 cm and many holes enabled the roots to spread in the benches. Good soil was used in the pots as well as in the benches. Pots were dug into the soil till the edges. Plenty of water was given and the plants grew excellently. Much care was taken for good pollination by using a truss vibrator (VERKERK, 1957a; VERKERK and WELLENSIEK, 1950). In each bench of 1,60 × 8,00 m 24 plants of +L and 24 plants of —L were grown. This resulted in 3,7 plants per m^2. The data given in this study are means of 24 plants. It has to be kept in mind that more than half of these plants were border plants, because the benches were surrounded by paths. Several measurements on the growth and the yield were made.

The presentation of the results will be divided in a division on the vegetative growth (3) giving stem-, side-shoot and leaf growth, and one on the generative growth (4) involving place and weight of trusses, flowering, number of fruits, fruit weight and fruit set. The generative growth will be subdivided in a part where time is not (4.1) and a part where time is involved (4.2).

3. Vegetative growth

Stem growth. After planting, the length of the plants was measured once a week till the removal of the top which was done when two leaves above the fourth truss had been formed. FIG. 1 gives the result; **17—22** is omitted because its results were equal to **17**. After about two weeks the stem growth becomes practically constant, depending on temperature and independent of the plant size at planting time: +L

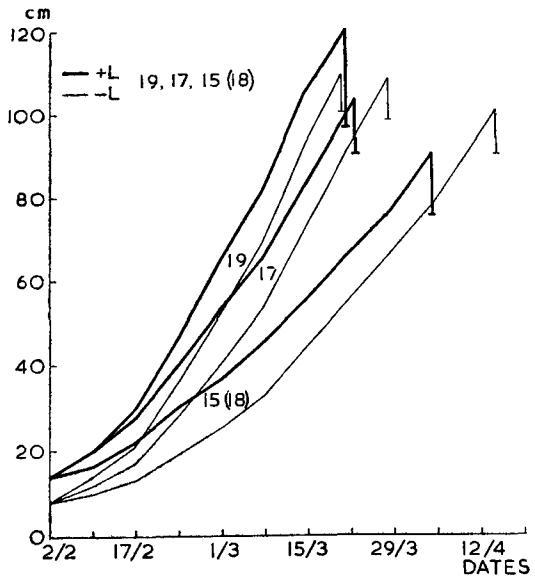

FIG. 1.
Stem lengths of plants grown at different mean temperatures in °C (**19, 17, 15(18)**) and treated before planting with (+L) or without (—L) additional illumination. The vertical lines down from the top of the growth lines indicate the lengths of the stem part which was removed by topping

and —L plants at the same temperature have the same growth speed. Stem growth is strongly correlated with temperature. Differences between **19** and **17** are much smaller than between **17** and **15(18)**.
After topping, the +L plants are smaller than the corresponding —L plants. These +L plants, however, had two leaves less than the —L plants and these two leaves just make the differences in length. At lower temperatures the plants are smaller than at higher temperatures and so are the internodes (VERKERK, *1954* and *1955*).

Side shoots. Closely connected with the length growth of the stem is the growth of the side shoots. Once a week from February onwards the side shoots were taken from the plants and their fresh weight was determined. Differences between +L and —L groups in the same compartment were small and their means are used in FIG. 2 where the cumulative fresh weight is given up to March 22nd. A strong conformity between the growth of the side shoots and the length growth of the stem is clear.

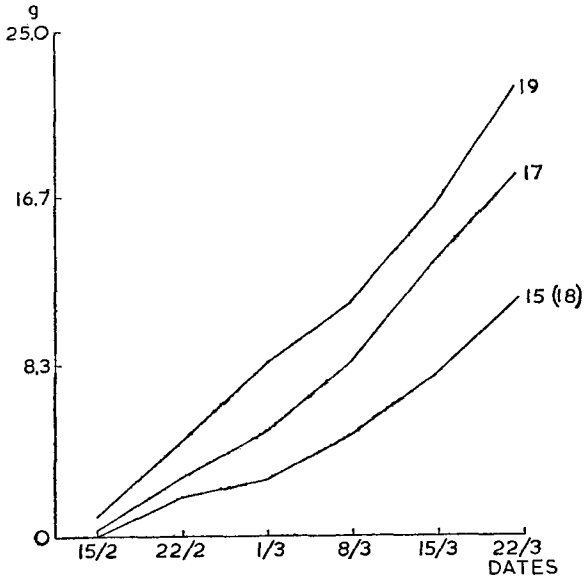

FIG. 2.
Cumulative fresh weight of side shoots of plants at different mean temperatures in °C

Stem weight. After the harvest of the fruits, the fresh weight of the stem per cm was determined. These stem weight were again not very different in one temperature and even not between the different temperatures except in the lowest temperature treatment, resulting there in abnormally heavy stems: 1,8; 1,7; 1,9 and 2,6 g in **19**, **17**, **17—22**, **15(18)** respectively.

Leaf weight. At the end of the harvest also the fresh weight of three leaves between second and fourth truss was determined: 159, 164, 137 and 204 g in **19**, **17**, **17—22** and **15(18)** respectively. At the low temperature the leaves were very heavy, just like the stems were. In **17—22** the leaves have the smallest weight which is probably caused by the relatively low light intensity in this compartment.
The main results concerning the vegetative growth are: At higher temperature the stem growth is faster than at lower temperature. Stem and leaf weight are heavy only at relatively low temperatures, in this case 15 °C. Side shoot growth runs parallel to stem growth.

4. Generative growth

4.1. Generative growth without involving time

Place of trusses. The place of a truss is determined by the number of leaves under this truss. Certainly for three and perhaps even for all four trusses this number is established already before planting time, and so the place of the trusses will be the same in all compartments which turned out to be true. TABLE 3 shows the numbers of leaves under the trusses. The +L plants have about two leaves less than the —L plants probably as a result of the good balance between temperature and light during the raising (VERKERK, 1955).

TABLE 3. Number of leaves under the trusses after having raised the plants with (+L) or without (—L) additional illumination

Truss	+L	—L
1	8,6	9,9
2	12,2	14,1
3	15,4	17,7
4	18,6	20,7

Fresh weight of empty trusses. Post harvest determinations of the fresh weight of the isolated empty trusses indicate the generative power of the plant. TABLE 4 shows the results.

Comparing the corresponding +L and —L trusses within one temperature treatment in 14 out of 16 pairs the +L trusses are less heavy than the —L ones. The two pairs, showing the opposite, have only small differences. Therefore, a strong tendency exists for the —L trusses to be heavier than the corresponding +L ones.

TABLE 4. Fresh weight of empty trusses in 0,1 g of plants at different mean temperatures in °C and before planting with (+L) or without (—L) additional illumination

Truss	Temperature and illumination							
	19		17		17-22		15 (18)	
	+L	—L	+L	—L	+L	—L	+L	—L
1	38	42	39	38	47	64	51	58
2	48	59	48	69	58	81	66	92
3	59	72	63	71	65	78	75	95
4	75	82	72	73	71	69	115	147
Total	219	254	221	251	241	292	305	391

Comparing the consecutive trusses 1, 2, 3 and 4 in one treatment, in 7 out of 8 cases each next truss is heavier than the preceding one. Only **17—22** —L shows a decreasing weight in trusses 3 and 4, probably as a result of exhausting, the second truss being very high.

Comparing from high to low temperature in +L and —L plants, a lower temperature shows a heavier truss as a rule. Summarizing:

1. +L trusses are less heavy than the corresponding —L ones;
2. higher trusses are heavier than lower ones;
3. trusses grown at lower temperatures are heavier than those grown at higher temperatures.

Number of fruits per truss. The quality of the fruits was good and so was the mean fruit weight. All good fruits per truss were counted. TABLE 5 gives the results. A striking conformity exists between table 4 and 5, so that the conclusions can be:

1. +L trusses have less fruits than the corresponding —L ones;
2. higher trusses have more fruits than lower ones;
3. trusses grown at lower temperatures have more fruits than trusses grown at higher temperatures.

The total number of fruits in **17** is about 10 % higher than in **19**.

TABLE 5. Number of good fruits per truss of plants at different mean temperatures in °C and before planting with (+L) or without (—L) additional illumination

Truss	Temperature and illumination							
	19		17		17-22		15(18)	
	+L	—L	+L	—L	+L	—L	+L	—L
1	5,2	6,5	6,9	6,9	7,0	7,9	6,8	7,5
2	8,3	9,2	8,3	10,0	8,3	8,9	9,3	10,6
3	8,3	9,5	8,7	9,9	9,2	9,8	9,6	9,2
4	9,1	9,4	9,2	10,6	8,5	9,2	9,7	9,1
Total	30,9	34,5	33,0	37,3	32,9	35,7	35,3	35,9

Fruit yield per truss. The total yield per truss is given in TABLE 6. The regularity here is a little less than in TABLES 4 and 5, the results are nevertheless very pronounced. Only 4 out of 16 times the +L trusses have a heavier yield than the corresponding —L trusses. Two of these four were already exceptions in TABLE 5, namely in the third and fourth truss of **15(18)**. Higher trusses mostly have a heavier yield than lower ones. An exception again is the fourth truss of **17—22**. For **19** and **17** the lower temperature gives higher yields than the higher temperature. In **17—22** the yield is lower than in **17** as a result of the higher temperatures later in the growing period. The *number* of fruits already determined before the start of the higher temperature, was about the same in **17** as in **17—22** (compare total of TABLE 5).

TABLE 6. Fruit yield per truss in 10 g of plants at different mean temperatures in °C and before planting with (+L) or without (—L) additional illumination

Truss	Temperature							
	19		17		17-22		15(18)	
	+L	—L	+L	—L	+L	—L	+L	—L
1	33	44	53	48	41	48	45	48
2	58	62	70	79	53	55	66	77
3	57	71	76	81	62	65	70	69
4	64	74	81	75	56	61	80	67
Total	211	251	279	283	211	228	260	261

Mean fruit weight. The relation between number of fruits and fruit weight is the mean fruit weight. The mean fruit weight of the first ten fruits per plant is about the same for +L and —L in the same compartment.

For the low temperature **15(18)** it is not worth while mentioning the mean fruit weight on an account of the bad fruit set. In **19**, **17** and **17—22** the results are interesting. The strongly forced **17—22** plants following more or less the practical way of growing, gave the smallest fruits of 66 g still good for marketing. The **19** plants starting at a relatively high temperature, later on with higher light intensities with a relatively low temperature, had heavier fruits of 72 g. The **17** plants, however, starting at the right temperature and heaving a relatively low temperature later on, had very heavy fruits of 85 g. The stronger the growth is forced by the temperature, the lower the mean fruit weight (VERKERK, 1955).

Fruit set. In the second and higher trusses the fruit set was exceeding 90 %, **15(18)** excepted. Only the first truss gave interesting results. For **19** and **17**, +L and —L, this will be discussed with the aid of FIG. 3. In each of these four cases from left to right the positions on the truss are indicated, counting from the stem onwards. The part which is not set is shaded.
In the +L plants (upper blocks) the first places have a better set than the third and the fourth; further from the stem the set is better. In the —L plants (lower blocks) however the first place is the worst and the later places are better and better. An explanation is difficult. It may be that the +L plants have some extra power at the start of the flowering of the first truss which the —L plants lack.
A remarkable uniformity is found in the shape of the fruit set lines of the +L plants on the one hand and the —L plants on the other. The lower temperature (right blocks) results in a much better fruit set than the higher (left blocks).

4.2. Generative growth involving time

Till now the generative parts have been discussed without concerning the time. However, in the tomato the time factor is very important for the evaluation of the harvest. In general the harvest has the highest value the earlier the picking starts in the spring. This may even be more important than the height of the total yield.

First flower expressed in days after planting. TABLE 7 shows the time from planting to first flowers in days. The +L plants always flower earlier than the corresponding —L plants, so much that the +L plants are ahead of the —L plants just about one truss. Higher trusses naturally flower later than lower ones. The mean difference between succeeding trusses is about one week. The lower the temperature, the longer it takes before first flowering, of course.

TABLE 7. Time from planting to first flower in days of plants at different mean temperatures in °C and before planting with (+L) or without (—L) additional illumination

Truss	Temperature and illumination							
	19		**17**		**17-22**		**15(18)**	
	+L	—L	+L	—L	+L	—L	+L	—L
1	16	30	22	31	26	34	28	40
2	29	34	33	39	36	42	42	52
3	35	41	40	47	43	49	51	63
4	41	47	47	56	49	56	61	72

Fruit development. The number of days elapsing between anthesis of the first flower and the harvest of the ripe fruit is called fruit development. The relating figures

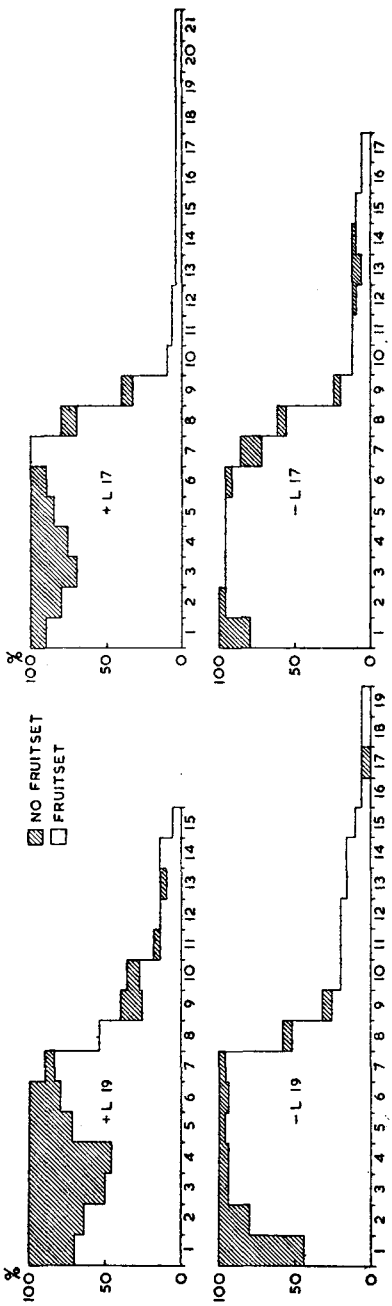

FIG. 3. Fruit set in the first truss of plants at **19°** and **17** °C and before planting with (+L) or without (—L) additional illumination; on abscissa the positions of the fruits on the truss are indicated, counting from the stem

TABLE 8. Fruit development in days of plants at different mean temperatures in °C and before planting with (+L) or without (—L) additional illumination

Truss	Temperature and illumination							
	19		17		17-22		15(18)	
	+L	—L	+L	—L	+L	—L	+L	—L
1	54	51	64	62	59	57	80	76
2	51	51	62	60	57	54	77	72
3	52	51	61	57	54	51	74	68
4	51	53	58	57	51	51	68	64
Mean	52	52	61	59	55	53	75	70

are given in TABLE 8. There is a slight tendency for the fruit development on the +L plants to be slower than on the —L plants. The fruit development is much faster at the higher than at the lower temperatures. In the practically regularly changing temperatures **19** and **17** the fruit development is about the same for all trusses, in **17—22** each next truss has a shorter or equal fruit development than the preceeding one. In **15(18)** the differences between the trusses are enormous.

First ripe fruit. Totalisation of the corresponding figures from TABLES 7 and 8 results in TABLE 9 giving the number of days from planting till the first ripe fruit per truss. Again +L is about one truss ahead of the corresponding —L plants. The +L plants are constantly earlier than the —L plants.

TABLE 9. Days from planting to first ripe fruit per truss of plants at different mean temperatures in °C and before planting with (+L) or without (—L) additional illumination

Truss	Temperature and illumination							
	19		17		17-22		15(18)	
	+L	—L	+L	—L	+L	—L	+L	—L
1	70	81	85	93	85	90	107	115
2	79	85	96	100	93	96	119	124
3	86	92	101	104	96	99	125	131
4	92	100	105	112	99	106	129	136

Cumulative yield. The cumulative yields in fruit weight are given in FIG. 4. Temperature treatments after planting had a much larger effect than the light treatments before planting. Differences between **19** and **17** are about 10 days, between +L and —L only 5 days. The increasing temperature **17—22** showing a relatively steep line, gives a large yield of small fruits in a short time; the total yield, however, is much smaller than in **17**.

5. General discussion

The effects of the additional light before and the temperature after planting can be discussed best with regard to the regularly changing temperature treatments **19** and **17** (compare TABLE 1 on p. 58). A recapitulation of some of the earlier results will follow.

FIG. 5. Plants grown at a mean temperature of **19** °C before planting with additional illumination (+L) on the left or without (—L) on the right. Note the lower first truss in the +L plant which is about one truss ahead of the —L plant

TABLE 10. Fresh weight of empty trusses in 0,1 g, number of good fruits per truss and fruit yield per truss in 10 g of plants at mean temperatures of **19°** and **17** °C and before planting with (+L) or without (—L) additional illumination

Truss	Weight of truss in treatment				Number of good fruits in treatment				Fruit yield per truss in treatment			
	19		17		19		17		19		17	
	+L	—L	+L	—L	+L	—L	+L	—L	+L	—L	+L	—L
1	38	42	39	38	5,2	6,5	6,9	6,9	33	44	53	48
2	48	59	48	69	8,3	9,2	8,3	10,0	58	62	70	79
3	59	72	63	71	8,3	9,5	8,7	9,9	57	71	76	81
4	75	82	72	73	9,1	9,4	9,2	10,6	64	74	81	75
Total	219	254	221	251	30,9	34,5	33,0	37,3	211	251	279	283

First flower, fruit development and first ripe fruit are combined in TABLE 11, showing that:

1. the +L plants are about one week ahead of the —L plants at the same temperature with their first flower as well as with their first ripe fruit (see FIG. 5);
2. higher trusses flower and fruit later than lower ones, about 6 days at **19** and at least 7 days at **17**;
3. differences in fruit development between +L and —L are small at the same temperature;
4. fruit development is about the same for all trusses as a result of the regularly changing temperatures;
5. fruit development takes approximately 8 days less at **19** than at **17**;
6. first ripe fruit at **19** is roughly 14 days ahead compared with **17**.

TABLE 11. First flower, fruit development and first ripe fruit in days after planting of plants at mean temperatures of **19°** and **17** °C and before planting with (+L) or without (—L) additional illumination

Truss	First flower in treatment				Fruit development in treatment				First ripe fruit in treatment			
	19		17		19		17		19		17	
	+L	—L	+L	—L	+L	—L	+L	—L	+L	—L	+L	—L
1	16	30	22	31	54	51	64	62	70	81	85	93
2	29	34	33	39	51	51	62	60	79	85	96	100
3	35	41	40	47	52	51	61	57	86	92	101	104
4	41	47	47	56	51	53	58	57	92	100	105	112

From TABLE 10 and 11 together the following conclusions can be drawn:

1. the +L plants which are one week ahead of the —L plants for flowering and fruiting, have less heavy trusses and a smaller number of fruits and a smaller fruit weight per truss;
2. higher trusses which are later than the lower ones are heavier and larger in all aspects than lower ones;
3. plants at **17** being later than those at **19**, have a higher yield mainly by heavier fruits combined with a 10 % larger number of fruits.

The general picture is that a development earlier in the year results in a smaller yield of the corresponding truss in comparison to a later development. Probably the low amount of light available earlier in the year is the cause of this phenomenon. Besides being earlier, the +L plants have two leaves less than the —L plants which also results in less assimilates. These two factors will work together and it is impossible to distinguish the effect of one or another separately.

At the lower temperature flowering starts later, hence at a better time of the year with regard to light. Also, the lower temperature induces a slower vegetative growth than the higher one and consequently more material is left for fruit growth, resulting in a better fruit set, larger fruits and a heavier total yield (VERKERK, 1955).

The gain in earliness from additional illumination or a higher temperature is lost in total yield when the same number of trusses is kept in all the treatments. However, this loss can be prevented when the growth of plants in different treatments is stopped at the same moment.

All the effects mentioned result in the subtotalised yields shown in FIG. 4 on p. 66. The temperature difference of 2 °C between **19** and **17** has a much larger effect in earliness than the light effect before planting, namely 10—12 days and 4—5 days respectively. The bad set of the first truss in +L **19** results in the small yield in the first 10 days and the low total yield in comparison to —L **19**.

No interaction whatsoever was found between the light treatment before planting and the temperature treatments after planting. The absence of this interaction is not surprising, since the tomato plant adapts itself to new circumstances quite easily.

The results of this experiment are in complete agreement with earlier work (VERKERK, *1954, 1955, 1956, 1957b, 1962*).

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