T H E S I S

THE RELATIONSHIP OF THE DWARF GENE (d_1) TO SEED GERMINATION AND SEEDLING GROWTH IN *LYCOPERSICON ESCULENTUM* Mill.

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY LASZLO HANZELY

ENTITLED THE RELATIONSHIP OF THE DWARF GENE (d_1) TO SEED GERMINATION AND SEEDLING GROWTH IN *LYCOPERSICON ESCULENTUM* Mill.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Chapter I

INTRODUCTION

Commercial interest in dwarf tomatoes has increased considerably in recent years due to the advent of mechanical harvesting in the tomato industry. Their upright type of growth and small plant size make them especially suited for mechanical harvesting. Because of the higher plant population required for dwarf plants, direct seeding in the field, rather than transplanting, is a requirement and thus research on germination and emergence of dwarf tomatoes is necessary.

To facilitate further research studies with dwarf tomatoes, easy means of identification of the dwarf phenotype in seedlings appear to be important.

Objectives.

I. Establish an easy identification for the dwarf phenotype in the seedling stage.

II. Determine the factors affecting seed germination and seedling emergence.

  A. Effects of temperature and moisture conditions on seed germination.

  B. Effects of depth, temperature and growing media on seed germination and seedling emergence.

III. Determine early growth response of dwarf tomatoes to moisture conditions.

Chapter II

REVIEW OF LITERATURE

Dwarf genes

Genetically dwarfed tomato plants were first reported by MacArthur (21) in 1926. He described dwarf (d_1) tomato plants as "having upright growth habit, stocky-shortened stems, short broad cotyledons, leaflets and petioles, peculiar rugose, puckered and down curved leaves, and a deeper green foliage color."

Since 1926, six other genes which have dwarfness as their main phenotypic expression, have been added to the linkage map of the tomato. Butler (7) described the brachytic (br) and dwarf modifier (dm) genes. The br gene shortens the internodes and induces a spreading growth habit, and the dm gene in the presence of d_1 produces an extreme type of dwarfing. Barton (2) and his coworkers list d_1^x, a gene causing extreme dwarfness as being recessive to gene d_1. Three other genes, namely dwarf-1^{crispata} (d_1 crisp), dwarf-2 (d_2) and dwarf-5 (d_5) have been listed by Clayberg (8) and his associates. Dwarf-1^{crispata} is an allele with a phenotype intermediate between d_1 and d_1^x. The gene d_2 causes shortened internodes and leaves, but it is not alletic to d_1. Dwarf-5 is a semi-sterile plant type with normal stem and leaf proportions.

Certain changes in the genetic makeup of other plants have also resulted in the appearance of dwarf individuals. Since the appearance of these dwarfs, numerous studies have been made to study the phenotypic effects of the dwarf genes. Histological studies by Bindloss (3) on dwarf (Dwarf Stone) and normal (Marglobe) races of *Lycopersicon esculentum* and *Zinnia elegans* showed that in dwarf plants the cells directly behind the meristematic region were longer because of earlier maturity. In normal plants, however, there was a longer meristematic region thus making a greater number of cell generations possible. Abbe and Phinney (1) related dwarfness in corn to slower rate of cell division and cell enlargement. Denna and Munger (9) in *Cucurbita pepo* found the bush gene exerted its effect on internode length through an effect upon both cell length and cell number. Houghtaling (16) found differences in size of cortical and pith tissues between a dwarf and normal tomato line due to differences in cell number.

The effects of dwarfism have also been investigated from a physiological standpoint. Van Overbeek (27) noted that nana dwarf in corn contained the same amount of auxin as normal plants, but dwarf-1, dwarf-2, dwarf-3, dwarf-7 and pigmy dwarf had lower auxin production than that of their normal sibs. A differential growth response of single gene dwarf mutants in corn to gibberellic acid was observed by Phinney (23). In peas (*Pisum*), Brian and Hemming (5) found that dwarf varieties responded more to applications of gibberellic acid than the normal, fast growing varieties. They also reported a similar growth response to applications of gibberellic acid between tall and dwarf varieties of broad bean (*Vicia*) and French bean (*Phaseolus*). Von Abrams' (28) investigation of dwarf and normal peas also exhibited a differential growth response to IAA applications. Lee (19), who compared the growth of excised tomato roots carrying dwarf and normal alleles, found some evidence of an auxin differential between the two types of clones. He also investigated the effects of some anti-auxins, but they all reduced the growth of both root types.

Seed germination and growth response to limited moisture conditions

The use of differential concentrations of mannitol solutions and brief exposures to water shortage have provided good basis for investigating the effects of limited moisture conditions on seed germination and plant growth. Evans and Stickler (11) with seeds of grain sorghum, Uhvits (26) and Dotzenko and Dean (10) with alfalfa seeds, Helmerick and Pfeifer (15) with winter wheat seeds, Knipe and Herbel (17) with seeds of grass species and McGinnies (22) with range grass seeds studied germination characters under moisture tensions induced by mannitol solutions of differential atmospheric pressures. Apart from the differential responses of each crop to the various moisture tensions, they all noted that a gradual increase in the moisture stress decreased both the rate and the percentage of germination. McGinnies (22), Evans and Stickler (11) also reported that temperature levels exceeding the optimum for the germination of grass and sorghum seeds initiate a faster germination under moisture stress. They noted a reverse at temperatures lower than the optimum. The importance of air necessary for tomato seed germination was mentioned by Hack (13) in a recent study. Through the use of porous ceramic plates, he tested germination at soil moisture tensions ranging from 0.5 to 20 centimeters of mercury. In the wet treatments of 0.5 and 1 centimeter mercury a severely retarded germination was observed, while at 2 centimeters of mercury germination was good. He associated this small difference in tension to a large difference in the pore space occupied by air. This difference then according to him, was the contributing factor toward the severely retarded germination rates.

According to Kramer (18), water serves four basic functions in plants. It serves as the major constituent of active tissues, participates as a reagent in photosynthesis and several hydrolytic processes, acts as the solvent in which salts, sugars and other solutes move from cell to cell and it also maintains turgidity while cells grow and enlarge. Plant growth, therefore, can be greatly effected by limited moisture conditions. In tomato seedlings, Brix (6) noted that the net rate of photosynthesis decreases when the leaf's diffusion pressure deficit reaches seven atmospheres and a diffusion pressure deficit of fourteen atmospheres decreases it to zero. At a leaf diffusion pressure deficit of eight atmospheres for the same sample, he also observed a decline in the respiration rate, showing that limited moisture conditions influence the rate of photosynthesis before reducing the rate of respiration. Gates and Bonner (12) recorded a suppressed RNA metabolism in leaves of young tomato plants due to brief periods of water shortage. They also showed that moisture stress inhibits the accumulation of nitrogen and phosphorus in young tomato leaves.

Seed size studies in relation to growth and fruit development

The effect of seed size and thus weight on plant growth have been reported by many. Schmidt (25) with corn, soybean, buckwheat and lima bean seeds showed that seeds of high medium weight produce better plants than seeds of lighter or abnormally heavy weight. The relative importance of the embryo and endosperm size in association with wheat growth is reported on by Bremner (4) and his coworkers. Embryo size, according to them has a negligible effect on growth, while endosperm size a considerable effect. In their opinion, therefore, the relationship between seed size and plant size is governed by the amount of reserve material present in seeds.

Germination and early growth also seem to be influenced by seed size. Schmidt (25) observed that light seeds, in general, germinate more rapidly than heavier seeds. Pollack and Larson (24), however, noted a decrease in germination of tomato seeds as seed weight increased. Bremner (4) and his coworkers found early growth of wheat seedlings to be relatively higher when emerging from small embryos than those emerging from large embryos, apparently regardless of the amount of reserve material present in the seed.

In *Lycopersicon esculentum* fruit weight has been shown to be influenced by the number of seeds produced within fruits. Hatcher (14), Pollack and Larson (24) showed that as the number of seeds increased within tomato fruits, fruit size and thus weight also increased. This increased number of seeds, however, also resulted in a decrease of seed size in both investigations. Luckwill (20) made an intensive study on the factors affecting mean seed weight of tomato fruits. He found that variations in the external environment, variations in the number of fruits developing in the truss and variations in the number of seeds developing in the fruit are contributory factors towards differences in seed weights. Hatcher (14) noted that seed size, and hence the size attained by embryos, is negatively correlated with the effectiveness of pollination in tomatoes. Pollack and Larson (24) found that tomato seed weight can also increase with length of time to maturity of the fruit.

Hatcher (14) made a comparative study of seed and embryo size of a dwarf and a normal tomato line, while investigating hybrid vigor between crosses of the two lines. Through measurements of cross sectional areas, he showed both seeds and embryos to be significantly larger for the normal line. In the crosses between these lines, he also observed that the hybrid embryos were always larger than those of their maternal parents. The maternal environment influenced the size of the embryos in such a way that the reciprocal hybrids differed significantly. When the maternal parent was the normal line in the cross, embryos were larger than when the dwarf line was the maternal parent.

Chapter III

MATERIALS AND METHODS

The materials and methods described herein follow the organization of the objectives, as presented in the introduction of the study.

Identification of the dwarf phenotype in seedling stage

It is easy to distinguish between dwarf and normal tomato plants when such characteristics of dwarf plants as rugose leaves, short petioles and leaflets, short internodes and upright growth habit can be observed. This distinction is not as obvious, however, in the cotyledon stage. Therefore, in order to facilitate phenotypic determination in young seedlings such measurements as hypocotyl length, cotyledon length and cotyledon width were taken.

The possibility that low light intensity might differentially affect growth of dwarf and normal phenotypes was considered. It was observed that hypocotyl length of normal seedlings tended to be greater than the hypocotyl length of dwarf seedlings under normal light intensities. Both phenotypes were therefore grown under low light intensity to determine whether or not the hypocotyls of normal seedlings elongated more than those of dwarf seedlings under these adverse conditions.

This experiment was conducted in two parts. For the first part, 25 seeds of each of two dwarf varieties, Puck and Premier, and two normal varieties, Marglobe and Rutgers, were planted one centimeter deep in potting soil. The flats were placed in the laboratory under light intensities of 230 and 660 foot candles, with a 12-hour day length, regulated by a time clock. Laboratory temperature was approximately 80° F.

The second part utilized an F_2 population segregating for dwarf, (VF 36 x (Kenosha x (Puck x Kenosha) F_4) F_2. Fifty seeds of this variety were planted four centimeters apart and one centimeter deep in potting soil. The flats in this part of the experiment were exposed to 230 and 660 foot candles.

In both parts of the experiment, hypocotyl length was measured two and three weeks after planting. Three weeks after planting, cotyledon length and width were also measured. The cotyledon index (length/width) was also determined for each segregate.

<u>Factors affecting seed germination and seedling emergence</u>

A. The effects of temperature and moisture conditions on seed germination.

For the comparison of dwarf and normal phenotypes under induced drought conditions, an F_2 segregating population (VF 36 x (Kenosha x (Puck x Kenosha) F_4) F_2 was tested under a moisture tension of three atmospheres induced by mannitol. Water was used for a control treatment of zero tension. Five replications of 50 seeds each for both tensions were used and surface planted on germinating paper in petri dishes. One petri dish constituted a replication. The seeds in five petri dishes received seven milliliters of the mannitol solution adjusted to three atmospheres. The other five received seven milliliters of water at the start of the experiment. Similar amounts of water and mannitol solution were maintained in all petri dishes. Because of evaporation of water from petri dishes containing mannitol solution some increase in tension could have occurred. Low temperatures and covered petri dishes, however, aided in reducing this danger. The petri dishes were kept at 68° F for germination. For the preparation of the three atmosphere mannitol solution, the formula listed by Helmerick and Pfeifer (15) was used. In this experiment, however, one drop of Ceresan was added to each dish to prevent fungal growth.

Germinating seeds showing radicles were removed daily from the petri dishes, numbered individually, and placed in plastic containers lined with moist blotter paper. The seedlings were then grown at room temperature (75° F) until the shedding of the seed coat occurred. These seedlings were then transplanted into flats containing potting soil, labeled according to date of germination and placed under a continuous light intensity of 660 foot candles until an identification of the dwarf and normal phenotypes became possible.

Upon the completion of the first trial, another trial of the same material was started under a six atmosphere moisture stress level and a zero control level in order to observe differences in germination at a higher level of moisture stress. The procedures used for this trial were the same as those used for the previous trial, except that the mannitol solution was adjusted to six atmospheres.

B. Effects of planting depth, growing media and temperature on seed germination and seedling emergence.

Under some field conditions it had been observed that emergence of dwarf varieties was later than normal varieties in the same trials.

Occasionally even the percent emergence of dwarf varieties was less than that of normal varieties. To determine the conditions under which dwarf seedling emergence was adversely affected, the following variables were studied.

I. Varieties.

A. Dwarf

1. Puck

2. Premier

3. F2-21 (Kenosha x (Puck x Kenosha) F_2) F_6

B. Normal

1. Manalucie

2. Rutgers

3. Red Jacket

II. Planting methods.

1. On germinating paper in petri dishes.

2. ½ inch deep in both sand and soil.

3. 1½ inches deep in both sand and soil.

III. Temperature.

1. 50° F degrees.

2. 68° F degrees.

Each variety was used in each of the treatments. Seeds were surface planted in petri dishes, and in flats at depths of ½ inch and 1½ inches in both sand and soil, at each of the two temperatures. For each treatment, 10 seeds were planted in each of two replications.

After a period of 16 days the trials from the 50° F germinator were transferred to 68° F in order to observe any possible effects of a prolonged cold period on seed germination and seedling emergence. Results were based on the resulting 20 seeds of the combined replications.

Upon completion of the above experiments two other trials were conducted. Three dwarf varieties: Premier, Puck and F2-25 (VF x FO-25) F_6 and three normal varieties: Marglobe, Red Jacket and Rutgers were used. Limited seed source of F2-21 and Manalucie lead to the use of F2-25 and Marglobe in these trials. Using only soil, 25 seeds of each dwarf and normal variety were seeded in flats at depths of ½ inch and 1½ inches. Germination temperatures of 68° F and 50° F were used for each planting depth. Following a period of 16 days, the flats from 50° F were transferred to 68° F.

In the second trial, 25 seeds of each dwarf and normal variety were seeded in four flats at depths of ½ inch and 1½ inches in soil and placed in a greenhouse with both night and day temperature at 75° F. Two flats of each depth were covered to create complete darkness, while the remaining two remained uncovered. Soil temperatures at the two seeding depths in both covered and uncovered flats were also recorded following planting.

Throughout all trials both flats and petri dishes were watered according to needs only.

Early growth response of dwarf and normal seedlings to moisture tension

This study was conducted to compare early seedling growth of dwarf and normal varieties under moisture tension. Since it had been noticed in the field that dwarf seedlings did not show symptoms of wilting at transplanting as did normal seedlings, it was further desirable to determine whether or not dwarf seedlings were otherwise affected by moisture tension as much as normal seedlings. The study was divided into two experiments. In the first, moisture tension was accomplished by using a six atmosphere osmotic pressure mannitol solution added to soil in pots. The solution was prepared according to the formula given by Helmerick and Pfeifer (15). In the second, moisture tension was accomplished by allowing the soil to dry.

Three dwarf varieties: Puck, Premier and F2-26 (VF 36 x FO-25) F_4 and three normal varieties: Rutgers, Manalucie and Fireball were seeded on September 7, 1963. The seedlings were transplanted into four-inch clay pots containing potting soil on September 20 and arranged on a greenhouse bench.

Mannitol.--Each of four replications contained eight plant samples of each of the six varieties. The statistical design was a randomized block design, with sub-blocks containing four pots each of mannitol treatment and a control (water). In both sub-blocks 100 ml. of mannitol solution to the treated plants and water to the control plants were added at each daily watering. Treatment began on September 26 and continued until October 2.

At the conclusion of the seven-day period, fresh weights of tops and roots were recorded for both mannitol treated and control plants.

Dry soil.--This experiment was divided into two parts, each with four replications. Each replication contained four plants of each of the six varieties. In the first part, watering was suspended on September 26. Wilting symptoms were observed after three, six and eight days. On the 8th day all pots were watered and on the 9th day the number of dead plants were recorded.

The plants in the second part were watered normally until October 2, when watering was suspended. Wilting symptoms were observed after five, seven, nine and eleven days. On the 11th day all pots were watered and on the 12th day the number of dead plants were recorded.

No measurement was made of hydraulic tension in the mannitol study and no measurement was made of osmotic tension in the dry soil study. In each study these tensions were assumed to be negligible since conditions were near field capacity in the mannitol study and only normal potting soil and water were used in the dry soil study.

Chapter IV

RESULTS AND DISCUSSION

The arrangement of the objectives listed in the introduction and used as the basis for the organization of the materials and methods section will be followed in the results and discussion section.

Early identification of the dwarf phenotype

In the first planting, using two dwarf and two normal varieties, hypocotyl length was measured under two light intensities (Table 1). The average hypocotyl length was greater at 230 foot and at 660 foot candles for each variety tested and the average hypocotyl length of normal varieties was greater than that of the dwarf varieties when grown at each light intensity. Furthermore, the measurements of both Marglobe and Rutgers, the two normal varieties, were similar in all treatments; and likewise the measurements of Premier and Puck, the two dwarf varieties, were similar.

One of the objectives of this study of effects of low light intensity was to find a suitable means of identification of the dwarf phenotype. If low light intensity causes the hypocotyls of the normal seedlings to elongate consistantly more than the hypocotyls of dwarf seedlings, there would then be less overlapping of the ranges of the two phenotypes. Controlled light intensity could thus be used where phenotype identification is to be accomplished. The results shown in Table 1 indicate that the hypocotyls of dwarf plants do not necessarily elongate more than those of normal plants when grown at 230 foot candles

TABLE 1.--EFFECT OF LIGHT INTENSITY ON HYPOCOTYL LENGTH OF TWO DWARF AND TWO NORMAL VARIETIES.

Age of seedlings	Variety	Average hypocotyl length of seedlings (mm) 230 ft.c.	660 ft.c.	Percent increase of 230 ft.c. over 660 ft.c.
14 days	Dwarf			
	Premier	26	20	30.0
	Puck	24	20	20.0
	Normal			
	Marglobe	38	34	11.8
	Rutgers	40	31	29.0
21 days	Dwarf			
	Premier	29	23	26.1
	Puck	28	22	27.3
	Normal			
	Marglobe	49	41	19.5
	Rutgers	51	38	34.2

instead of 660 foot candles. The normal variety Marglobe produced the least increase in elongation of all four varieties when measured at 14 and 21 days, while the other normal variety Rutgers produced the greatest increase at both dates.

An obvious effect of light intensity in differentiating between dwarf and normal phenotypes is shown in Tables 2 and 3. At 230 foot candles, the ranges of the two phenotypes overlapped more than at 660 foot candles. The range of hypocotyl lengths for each variety, both dwarf and normal, was greater at 230 foot candles than at 660 foot candles when measured at 14 days after planting (Table 2) and also when measured at 21 days after planting (Table 3).

In the second planting, using a segregating F_2 population, hypocotyl length was measured again for its possible use in the determination of dwarf and normal individuals under the two light intensities. Fourteen days after planting, 33 normal and 8 dwarf seedlings were identified at 230 foot candles. At 660 foot candles, 37 normal and 11 dwarf seedlings were identified. The average hypocotyl length was greater for plants of both phenotypes grown at 230 foot candles than for those grown at 660 foot candles, and the average hypocotyl length of the normal phenotype was greater than that of the dwarf phenotype when grown at both light intensities (Table 4).

As shown in Table 4, the percent increase of hypocotyl length at 230 foot candles compared with hypocotyl length at 660 foot candles was greater for the dwarf segregates than for the normal segregates. This comparative rating of dwarf and normal phenotypes was similar when measured at both 14 and 21 days.

TABLE 2.--NUMBER OF SEEDLINGS WITH VARIOUS HYPOCOTYL LENGTHS OF TWO NORMAL AND TWO DWARF VARIETIES GROWN AT TWO LIGHT INTENSITIES AND MEASURED 14 DAYS AFTER PLANTING.

Length	Marglobe		Rutgers		Premier		Puck	
	230	660	230	660	230	660	230	660
(mm)	ft.c.	ft.c.	ft.c.	ft.c.	ft.c.	ft.c.	ft.c.	ft.c.
14								1
15							1	1
16								
17						1		
18						1		2
19						1	1	5
20						9	2	7
21					1	4	1	2
22				2		3	1	4
23						4	5	1
24					3	2	2	2
25	1	1			6		2	
26		2		1	5		2	
27	1			2	4		4	
28	2		1	3	1		2	
29		1		1	2		1	
30		1		4	1		1	
31		1						
32	1	1			1			
33	1	3	1	2				
34	1	2	3	3				
35	2	1	1	1				
36		2	1	2				
37	1	4		2				
38	2	2	3	1				
39	2	1	1					
40				1				
41	3	1	2					
42	1	1	1					
43			3					
44	1	1	1					
45	2		2					
46								
47			3					
48	2							
49								
50	1							
51	1							
52								
53			1					
54			1					
55								
56								

TABLE 3.--NUMBER OF SEEDLINGS WITH VARIOUS HYPOCOTYL LENGTHS OF TWO NORMAL AND TWO DWARF VARIETIES GROWN AT TWO LIGHT INTENSITIES AND MEASURED 21 DAYS AFTER PLANTING.

	Marglobe		Rutgers		Premier		Puck	
Length (mm)	230 ft.c.	660 ft.c.	230 ft.c.	660 ft.c.	230 ft.c.	660 ft.c.	230 ft.c.	660 ft.c.
18								1
19						1	1	
20						3		7
21						1	1	2
22						2		4
23						5		1
24						3	2	6
25						4	3	3
26					1		2	
27					3	3	1	1
28				2	8		4	
29		1			2		1	
30	1				5		1	
31					3		2	
32		1			1		3	
33				2			2	
34							1	
35	2	3		7				
36			1	1	1			
37				1				
38	1	1		1				
39		2						
40		2		3				
41		5						
42		1	1	2				
43	1	2	1					
44	3	1	4	1				
45	1	2	3	1				
46	1							
47	1	1		3				
48	1	1						
49	2		1					
50			1					
51	1	1	1	1				
52			2					
53	1							
54		1	1					
55	3		1					
56			3					
57	1							
58	2							
59			2					
60	2		3					

TABLE 4.--EFFECT OF LIGHT INTENSITY ON HYPOCOTYL LENGTH OF SEGREGATES OF AN F_2 POPULATION.

Age of seedlings	Phenotype	Average hypocotyl length of seedlings (mm) 230 ft.c.	660 ft.c.	Percent increase of 230 ft.c. over 660 ft.c.
14 days	Dwarf	20	15	33.3
	Normal	31	27	14.8
21 days	Dwarf	24	18	33.3
	Normal	36	31	16.1

As in the case of the first planting, the overlapping of the ranges of dwarf and normal phenotypes in the second planting was also less when the seedlings were grown at 660 foot candles than when they were grown at 230 foot candles (Table 5). The results from this second planting differ from those in the first planting in that the ranges of hypocotyl lengths were not always greater at the lower light intensity.

The resulting overlapping at the lower light intensity thus makes growing the seedlings under such conditions less desirable when differentiation of the two phenotypes is to be determined.

Twenty-one days after planting, cotyledon length and width measurements for the identified segregates of the F_2 population were also measured at the two light intensities. Through the obtained cotyledon length and width measurements, the cotyledon index was also determined for each segregate. Table 6 illustrates the average cotyledon length, cotyledon width and cotyledon index for the segregates of the F_2 population. The average cotyledon length, width and index was greater among the normal than among the dwarf segregates when grown at each light intensity. Cotyledon width, however, showed an average difference of only one millimeter at 230 foot candles and two millimeters at 660 foot candles between the dwarf and normal segregates. Thus its use in phenotype identification, with the exception of its role in the determination of the cotyledon index, is less desirable than that of cotyledon length. The results in Table 6 also illustrate that the average cotyledon length, cotyledon width and cotyledon index for each segregate was greater at 660 foot candles than at 230 foot candles.

TABLE 5.--THE NUMBER OF SEGREGATES WITH DIFFERENT HYPOCOTYL LENGTHS OF AN F_2 POPULATION GROWN AT TWO LIGHT INTENSITIES AND MEASURED AFTER TWO PERIODS OF GROWTH.

	Dwarf segregates				Normal segregates			
	14 days		21 days		14 days		21 days	
Length (mm)	230 ft.c.	660 ft.c.	230 ft.c.	660 ft.c.	230 ft.c.	660 ft.c.	230 ft.c.	660 ft.c.
12								
13		2						
14		2		2				
15		1						
16		2		1				
17								
18	2	2		1				
19	1	2		4				
20	1		1	1		1		
21	1		1	1				
22				1				
23	1		1			2		
24	2		2		2	3		
25						7		1
26			1		2	5		1
27			1		2	3	1	4
28					2	2		5
29			1		2	1		6
30					4	4	1	2
31					2	1	3	4
32					4	3	1	2
33					2	2	6	2
34					2		1	
35					6	3	2	2
36					1		2	2
37							6	2
38							2	
39					1		1	1
40							3	
41								1
42							1	1
43							1	
44					1		2	1
45								
46								
47								
48								
49								
50								

TABLE 6.--EFFECT OF LIGHT INTENSITY ON COTYLEDON LENGTH, COTYLEDON WIDTH AND THE COTYLEDON INDEX OF SEGREGATES OF AN F_2 POPULATION. MEASUREMENTS WERE TAKEN 21 DAYS AFTER PLANTING.

	230 foot candles			660 foot candles		
	Average cotyledon			Average cotyledon		
Phenotype	length (mm)	width (mm)	index	length (mm)	width (mm)	index
Dwarf	25	7	3.50	29	8	3.60
Normal	32	8	3.73	41	10	4.06

Table 7 shows the effects of the two light intensities on cotyledon length and width of the dwarf and normal phenotype. The range of cotyledon lengths for the normal segregates was greater at 660 foot candles than at 230 foot candles. However, for the dwarf segregates, the range of cotyledon lengths was greater at 230 foot candles than at 660 foot candles. The range of cotyledon width for each segregate was similar at the two light intensities.

The results presented in Tables 6 and 7 thus indicate that the cotyledon length and cotyledon index of the dwarf and normal phenotypes can also be used for phenotype identification when early growth is subjected to such light intensities as used in this study.

Seed germination and seedling emergence

Temperature and moisture tension.--In the first trial, seeds of an F_2 segregating population were germinated at 68° F under a three atmosphere moisture tension induced by mannitol and a zero atmosphere control. The expected phenotypic distribution from this population was three normal seedlings to one dwarf. Table 8 shows the daily germination rates for both dwarf and normal segregates at zero and three atmospheres. A X^2 test was conducted to determine whether or not the germination produced a true three to one ratio. At the three atmosphere level a X^2 value of 0.19 was obtained, while at the accompanying control level of zero atmosphere a X^2 value of 1.38 was obtained. These values were both below the five percent table X^2 value of 3.841 and indicate that the phenotypic ratios found in the mannitol treated lots and in the control lots were true 3:1 ratios. Therefore, at three atmospheres, total germination of the dwarf

TABLE 7.--THE NUMBER OF SEGREGATES WITH DIFFERENT COTYLEDON LENGTHS AND WIDTHS OF AN F_2 POPULATION GROWN AT TWO LIGHT INTENSITIES AND MEASURED AFTER 21 DAYS OF GROWTH.

Length and width (mm)	Dwarf segregates 230 ft.c.	Dwarf segregates 660 ft.c.	Normal segregates 230 ft.c.	Normal segregates 660 ft.c.
		Cotyledon width		
5				
6	2			
7	2	2	1	
8	4	5	11	1
9		4	17	6
10			4	17
11				10
12				3
13				
14				
15				
		Cotyledon length		
16				
17				
18	1			
19				
20				
21				
22	1			
23				
24	1			
25	1	1		
26	1			
27	1	2		
28		1		
29		2	1	
30	1	3	4	
31	1		4	
32			5	
33		1	9	
34			7	
35		1	3	2
36				2
37				3
38				2
39				4
40				6
41				2
42				1
43				5
44				4
45				4

segregates was not effected either positively or negatively when compared with the total germination of the normal segregates.

The treatment, however, effected the time and rate of germination of both normal and dwarf segregates. As shown in Table 8, at three atmospheres germination for both segregates began six days after planting, while at the control level, germination for both segregates began four days after planting. Furthermore, at three atmospheres a 96% germination was not reached until 19 days after planting, while at the control level a 98% germination was achieved within an 11-day period following planting.

In the second trial, seeds were germinated at 68° F under a six atmosphere moisture tension level, and a control level of zero atmospheres. Table 9 shows the daily germination rates for both normal and dwarf segregates at zero and six atmospheres. At six atmospheres of moisture tension a X^2 value of 0.17 was obtained, while at the accompanying control level a X^2 value of 2.21 was obtained for the two phenotypes. These values were also below the five percent table X^2 value of 3.841, indicating as in the three atmosphere study that six atmospheres of tension did not alter the 3:1 ratio. Thus, total germination of the dwarf segregates was uneffected when compared with total germination of the normal segregates at 68° F at a six atmosphere moisture tension.

This six atmosphere moisture tension, however, caused an even greater delay in the rate and time of germination for both segregates when compared with the three atmosphere moisture tension of the first trial. Seed germination at the six atmosphere moisture tension for both phenotypes began 10 days after planting and only 38%

TABLE 8.--NUMBER OF SEEDS GERMINATED OF DWARF AND NORMAL SEGREGATES OF AN F_2 POPULATION AT 68° F UNDER MOISTURE TENSIONS OF ZERO AND THREE ATMOSPHERES. NOTATIONS BASED ON FIVE REPLICATIONS OF EACH TENSION.

Days after planting	Zero atmosphere: Total daily germination	Zero atmosphere: Dwarf plants	Zero atmosphere: Normal plants	Three atmospheres: Total daily germination	Three atmospheres: Dwarf plants	Three atmospheres: Normal plants
3						
4	25	2	23			
5	81	18	63			
6	80	17	63	9	2	7
7	40	8	32	23	4	19
8	10	3	7	33	9	24
9	8	4	4	31	6	25
10				36	7	29
11	1	1		47	10	37
12				23	6	17
13				17	4	13
14				9	4	5
15				6	2	4
16				2		2
17				1	1	
18				2	2	
19				1		1
20						
21						
Total	245	53	192	240	57	183
Expected (3:1)		61.25	183.75		60.0	180.0
X^2		1.38			0.19	

TABLE 9.--SEED GERMINATION OF DWARF AND NORMAL SEGREGATES OF AN F_2 POPULATION AT 68° F UNDER MOISTURE TENSIONS OF ZERO AND SIX ATMOSPHERES. NOTATIONS BASED ON FIVE REPLICATIONS OF EACH TENSION.

	Zero atmosphere			Six atmospheres		
Days after planting	Total germi- nation	Dwarf plants	Normal plants	Total germi- nation	Dwarf plants	Normal plants
3						
4	22	5	17			
5	144	35	109			
6	59	23	36			
7	19	9	10			
8	3		3			
9						
10				3	1	2
11				1		1
12				3	3	
13				4		4
14				10	2	8
15				5		5
16				5	1	4
17				9	4	5
18				2	1	1
19				4	1	3
20				5		5
21				5	1	4
22				5	1	4
23				6	1	5
24				3		3
25				7	1	6
26				4	2	2
27				1		1
28				5	1	5
29				2	1	1
30				3	1	2
31				1	1	
32				1		1
33						
34				1		1
35						
36						
Total	247	72	175	95	22	73
Expected (3:1)		61.75	185.25		23.75	71.25
X^2		2.21			0.17	

of the seeds germinated by the 36th day following planting. At the accompanying control level, seed germination for both phenotypes began four days after planting and a total of 98% of the seeds germinated by the 8th day following planting.

The effects of the three and six atmosphere moisture tensions and their accompanying control levels of zero atmospheres on the rate and time of germination of both segregates is also illustrated in Figures 1 and 2. Both figures show that germination of the dwarf segregates when compared with the germination of an equal number of randomly selected normal segregates is similar at each moisture tension. While these figures illustrate the delay in germination of both segregates due to high moisture tensions, they do not show percent germination since the population size of the normal segregates was adjusted to equal that of the dwarf population.

Planting depth, growing media and temperature.--The results obtained from seed germination in petri dishes, and seedling emergence from various depths, growing media and temperature levels of the dwarf and normal phenotypes are shown in Tables 10 and 11.

Table 10 shows germination and emergence data, using various treatments at a constant temperature of 68° F. Table 11 shows germination and emergence data, using various treatments at a temperature of 68° F preceded by a 16-day exposure to 50° F. At each temperature, seeds of both phenotypes produced good germination in petri dishes. Seedling emergence, however, resulted in phenotypic, varietal and treatment differences at each temperature.

Figure 1.--The effects of moisture tensions of zero and three atmospheres on tomato seed germination of dwarf and normal segregates of an F_2 population. Based on the total dwarf segregates and an equal number of randomly selected normal segregates.

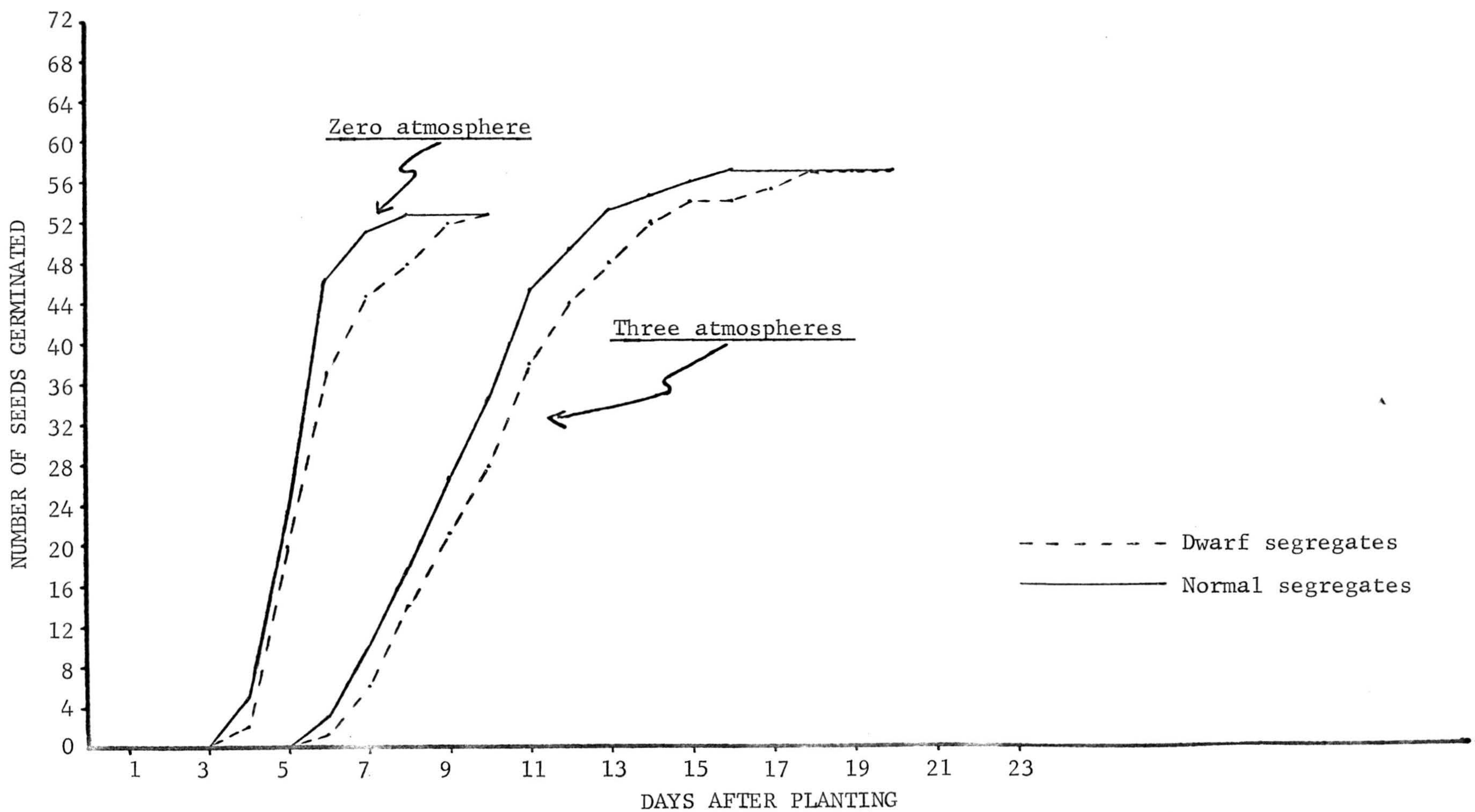

Figure 2.--The effects of moisture tensions of zero and six atmospheres on tomato seed germination of dwarf and normal segregates of an F_2 population. Based on the total dwarf segregates and an equal number of randomly selected normal segregates.

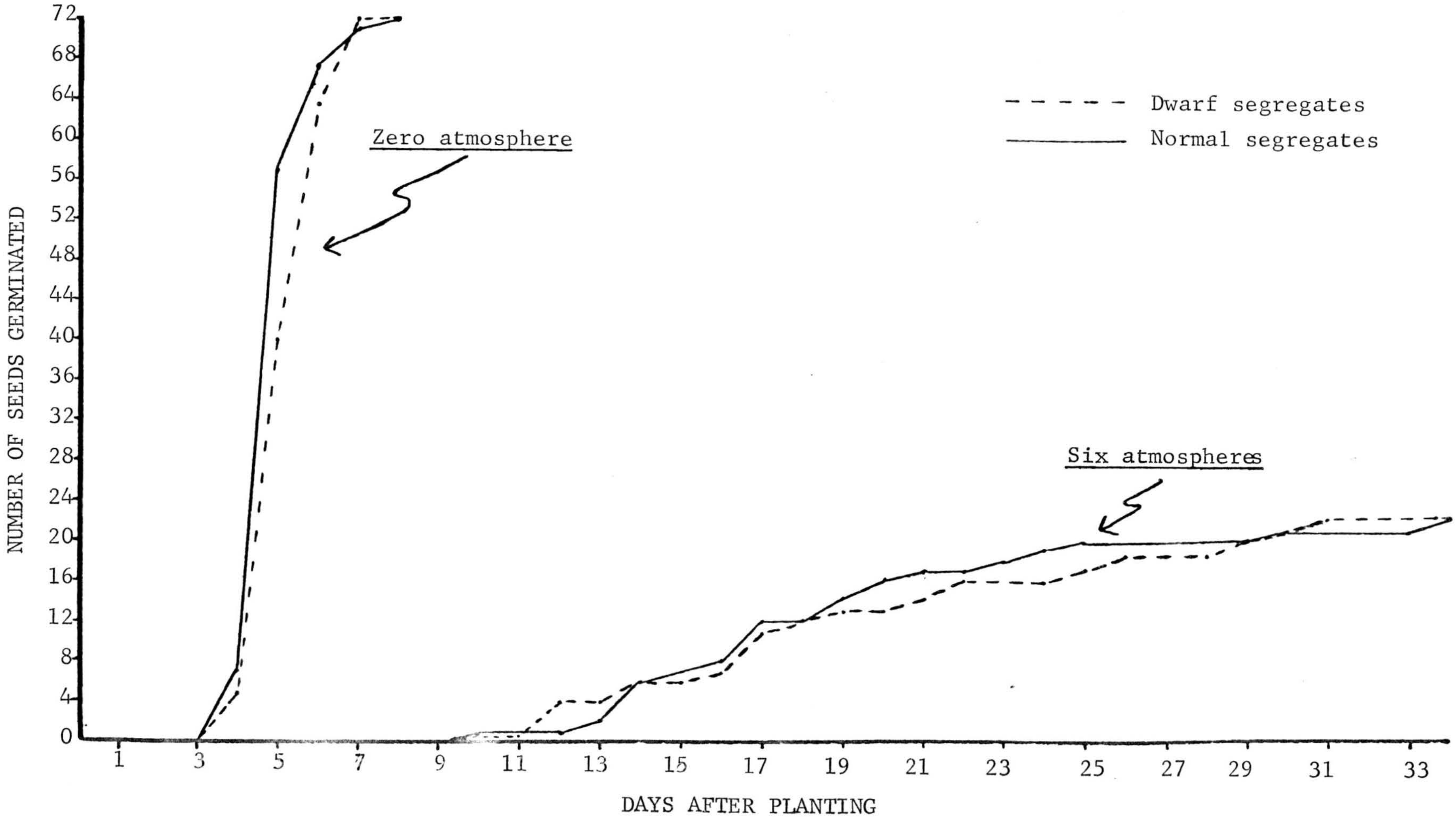

TABLE 10.--PERCENT SEED GERMINATION IN PETRI DISHES AND SEEDLING EMERGENCE AT VARIOUS PLANTING DEPTHS IN SAND AND SOIL OF THREE DWARF AND THREE NORMAL VARIETIES EXPOSED TO A TEMPERATURE OF 68° F. DATA WERE OBTAINED 17 DAYS FOLLOWING PLANTING.

	Treatments				
Varieties	Germinating paper in petri dish	½ inch in sand	1½ inches in sand	½ inch in soil	1½ inches in soil
Dwarf					
Puck	100	70	60	75	45
Premier	100	5	5	20	5
F2-21	75	45	25	55	55
Average	92	40	30	50	35
Normal					
Red Jacket	90	85	80	85	100
Manalucie	95	80	75	100	90
Rutgers	100	90	95	100	95
Average	95	85	83	95	95

TABLE 11.--PERCENT SEED GERMINATION IN PETRI DISHES AND SEEDLING EMERGENCE AT VARIOUS PLANTING DEPTHS IN SAND AND SOIL OF THREE DWARF AND THREE NORMAL VARIETIES EXPOSED TO A TEMPERATURE OF 68° F FOLLOWING A 16-DAY EXPOSURE TO 50° F. DATA WERE OBTAINED 31 DAYS FOLLOWING PLANTING.

	Treatments				
Varieties	Germinating paper in petri dish	½ inch in sand	1½ inches in sand	½ inch in soil	1½ inches in soil
Dwarf					
Puck	100	10	0	35	40
Premier	100	15	0	65	75
F2-21	85	25	0	45	50
Average	95	17	0	48	55
Normal					
Red Jacket	80	45	0	80	55
Manalucie	100	10	5	90	70
Rutgers	100	45	5	100	95
Average	93	33	3	90	73

At 68° F (Table 10), all three normal varieties showed good emergence at each of the two planting depths in sand and soil media. The lowest emergence among the normal varieties, 75%, occurred in sand at 1½ inches planting depth. Among the dwarf varieties at this same temperature (Table 10), Puck and F2-21 showed the highest emergence at the two planting depths in both soil and sand. Premier, although showing a 100% germination in petri dishes, shows the lowest emergence at the various planting depths in soil and sand. Considering all three dwarf varieties, the highest seedling emergence was obtained in soil at ½ inch planting depth, while the lowest seedling emergence was obtained in sand and in soil at 1½ inches planting depth.

In all cases, emergence of dwarf seedlings was inferior to emergence of normal seedlings, despite the good germination of dwarf seeds in petri dishes.

Seed germination percentages from petri dishes obtained after prolonged exposure to 50° F (Table 11) were similar for both normal and dwarf phenotypes, ranging from 80% to 100%. Moreover, seedling emergence of dwarf varieties was not as good as that of normal varieties, as in the previous trial at a constant temperature of 68° F.

All three normal varieties showed good emergence at ½ inch and 1½ inch planting depths in soil. Rutgers showed a 100% emergence at ½ inch, while Red Jacket showed the lowest emergence of 55% at the 1½ inch planting depth in soil.

Emergence from sand was poor for even the normal varieties. At 1½ inches in sand no emergence was noted for Red Jacket and only a 5% emergence was noted for Manalucie and Rutgers. At the ½ inch planting depth in sand a 45% emergence was observed for both Red Jacket and Rutgers, while Manalucie showed the lowest emergence of 10%.

The dwarf varieties at this same temperature level (Table 11) produced even lower emergence percentages than the normal varieties at the various treatments. In sand at 1½ inches planting depth no seedlings emerged, while at ½ inch planting depth, emergence ranged from 10% for Puck to 25% for F2-21. At the two planting depths in soil, higher emergence was observed at 1½ inches than at ½ inch. In both cases, Premier showed the highest emergence, while Puck showed the lowest emergence.

Conclusions concerning effects of depth, growing media and temperature on seedling emergence of dwarf and normal phenotypes are difficult to make because of small sample numbers and variety differences. A few obvious differences, however, can be presented. It is apparent, for instance, that dwarf seedlings did not emerge from soil or sand at as high a rate as normal seedlings. This difference between phenotypes does not appear to be due to germinability as shown by the data from petri dishes. High osmotic pressure of solution also does not appear to be the cause of poor emergence, since various osmotic tensions applied in petri dishes had no appreciable effect.

Tables 12 and 13 present the data from repetitions of part of the trials shown in Tables 10 and 11. The plantings at the same two depths were repeated in soil only, again using three dwarf and three normal varieties. The dwarf variety F2-25 was substituted for F2-21 and the normal variety Marglobe was substituted for Manalucie.

TABLE 12.--SEEDLING EMERGENCE OF THREE DWARF AND THREE NORMAL VARIETIES AT TWO PLANTING DEPTHS IN SOIL AT A TEMPERATURE OF 68° F.

Planting depth	Varieties	Emergence at various number of days following planting							Total percent emergence	Coefficient of velocity[1]
		8	9	10	11	12	13	14		
½ inch	Dwarf									
	F2-25	5	15	1					84	11.35
	Premier	6	10	7	1				96	10.95
	Puck	9	14	1					96	11.53
	Average								92	11.27
	Normal									
	Marglobe	10	13		1				96	11.53
	Red Jacket	8	12						80	11.62
	Rutgers	10	13						82	11.67
	Average								86	11.61
1½ inches	Dwarf									
	F2-25			3	16	5			96	9.02
	Premier			8	14				88	9.40
	Puck		5	9	10				96	9.79
	Average								93	9.40
	Normal									
	Marglobe		17	7	1				100	10.68
	Red Jacket		9	3	7				76	10.10
	Rutgers		18	5	1				96	10.76
	Average								91	10.51

1/ Formula used taken from Kotowski, F. 1926. Proc. Amer. Soc. Hort. Sci. 23:177-184.

$$100 \times \frac{A_1 + A_2 \ldots + A_x}{A_1T_1 + A_2T_2 \ldots\ldots + A_xT_x}$$

, where A is the number of seedlings picked out and T is the number of days after planting, corresponding to A.

TABLE 13.--SEEDLING EMERGENCE OF THREE DWARF AND THREE NORMAL VARIETIES AT TWO PLANTING DEPTHS IN SOIL AT A TEMPERATURE OF 68° F FOLLOWING A 16-DAY EXPOSURE TO 50° F.

Planting depth	Varieties	Emergence at various number of days following planting 22	23	24	25	26	27	28	Total percent emergence	Coefficient of velocity[1]
½ inch	Dwarf									
	F2-25			15	8				92	4.10
	Premier		1	11	5				68	4.12
	Puck		3	5					32	4.23
	Average								64	4.15
	Normal									
	Marglobe	2	19		1				88	4.34
	Red Jacket		22				1		92	4.31
	Rutgers		23	2					100	4.33
	Average								93	4.33
1½ inches	Dwarf									
	F2-25				11	7	1		76	3.92
	Premier				6	13		1	84	3.88
	Puck			5	6	1			48	4.05
	Average								69	3.95
	Normal									
	Marglobe		4	16	2				88	4.18
	Red Jacket		3	17	2				88	4.17
	Rutgers		2	18	2	1			92	4.15
	Average								89	4.17

1/ Formula used taken from Kotowski, F. 1926. Proc. Amer. Soc. Hort. Sci. 23:177-184.

In this trial, emergence of the dwarf varieties at the two planting depths, with the exception of Puck following low temperature exposure, was not severely reduced.

One difference between dwarf and normal varieties, however, is clearly shown in Tables 12 and 13. At each depth at a continuous 68° F temperature (Table 12) and at each depth following exposure to low temperature (Table 13), there was a consistant delay in emergence among the dwarf varieties, as expressed by the coefficients of velocity.

Another repetition of the depth of planting study was made by planting in flats in the greenhouse. One treatment was kept in dark as in the previous studies and one treatment was left uncovered to give natural day-night light conditions. Temperatures at seed level were as high as, or slightly higher than, the 68° F temperature used in the previous studies. Results, together with temperatures for each treatment, are shown in Tables 14 and 15.

In all treatments, Tables 14 and 15, emergence of all varieties, dwarf and normal, was good, although emergence of the dwarf varieties was again slightly delayed. Since emergence from the dark treatment was not low, it is obvious that light is also not the limiting factor for good emergence.

Considering all trials, the results of which appear in Tables 10-15, it appears there are factors influencing emergence of dwarf tomato seedlings which have not been found. Germination *per se* was shown, Tables 10 and 11, to be similar for dwarf and normal phenotypes, regardless of temperature and moisture tension. The emergence results, however, have been erratic. In the two trials including low

TABLE 14.--SEEDLING EMERGENCE OF THREE DWARF AND THREE NORMAL VARIETIES AT TWO PLANTING DEPTHS UNDER NATURAL DAY-NIGHT GREENHOUSE CONDITIONS AND VARIOUS SOIL TEMPERATURES.

Planting depth	Temperature at seed depth	Variety	Emergence at various number of days following planting									Total percent emergence	Coefficient of velocity[1]
			6	7	8	9	10	11	12	13	14		
½ inch	Day: 71° F	Dwarf											
	Night: 71° F	F2-25			14	7	1	1				92	11.73
		Premier		1	16	5						88	12.22
		Puck	1	2	16	6						100	12.37
		Average										93	12.11
		Normal											
		Marglobe	2	12	6	1	2					92	13.29
		Red Jacket	1	17	3		1		1			92	14.02
		Rutgers		4	20	1						100	12.69
		Average										95	13.33
1½ inches	Day: 69° F	Dwarf											
	Night: 69° F	F2-25					8	5	7	4		96	8.85
		Premier				8	12	2	2			100	10.50
		Puck				8	9	6	1			96	10.00
		Average										97	9.78
		Normal											
		Marglobe			5	15	3	2				100	11.02
		Red Jacket			5	10	3	1	2			84	10.76
		Rutgers			4	18	2		1			100	11.06
		Average										95	10.95

1/ Formula used taken from Kotowski, F. 1926. Proc. Amer. Soc. Hort. Sci. 23:177-184.

TABLE 15.--SEEDLING EMERGENCE OF THREE DWARF AND THREE NORMAL VARIETIES AT TWO PLANTING DEPTHS UNDER INDUCED DARK CONDITIONS AND VARIOUS SOIL TEMPERATURES.

Planting depth	Temperature at seed depth	Variety	Emergence at various number of days following planting: 6	7	8	9	10	11	12	13	14	Total percent emergence	Coefficient of velocity 1/
½ inch	Day: 69° F	Dwarf											
	Night: 69° F	F2-25		5	16	4						100	12.56
		Premier		18	4	1	1					96	13.56
		Puck	1	18	5		1					100	13.74
		Average										99	13.29
		Normal											
		Marglobe	10	8	2							80	15.15
		Red Jacket	7	9	3	4			1			96	13.56
		Rutgers		18	6							96	13.79
		Average										91	14.17
1½ inches	Day: 68° F	Dwarf											
	Night: 68° F	F2-25			2	9	3	6	3			92	10.04
		Premier			1	8	5	7	1			88	10.05
		Puck			9	14	1		1			100	11.36
		Average										93	10.48
		Normal											
		Marglobe		9	7	4	1					84	12.73
		Red Jacket		5	12	1	3					84	12.35
		Rutgers			8	6	1	1	2			72	11.04
		Average										80	12.04

1/ Formula used taken from Kotowski, F. 1926. Proc. Amer. Soc. Hort. Sci. 23:177-184.

temperature treatment, percent emergence was lower for dwarf varieties than for normal varieties (Tables 11 and 13), regardless of planting depths and growing media. Total percent emergence of all dwarf varieties in the trial reported in Table 10 (a constant 68° F) was poor. In a similar trial (Table 12), however, the percent emergence of dwarf varieties was similar to that of normal varieties. These same results, showing good emergence of dwarf varieties, were also reported in the greenhouse trials (Tables 14 and 15).

In all trials in which coefficients of velocity were calculated, dwarf varieties tended to emerge slightly more slowly than the normal varieties.

Early growth response

Mannitol.--Following the seven-day treatments of the dwarf and normal seedlings at both high and normal levels of moisture tension, comparisons on fresh plant weight, top weight, root weight and root-top ratio were made. The results are presented in Table 16.

The mannitol treatment reduced total fresh plant weight of all six varieties tested (Table 16). In neither the treated group nor the control group, were the dwarf varieties consistantly different from the normal varieties. The percent decrease in plant weight for each variety was calculated to determine whether or not dwarf varieties reacted to high moisture tension in a manner different from normal varieties. Again there was not a consistent difference.

It was thought that perhaps the top weight or the root weight of dwarf plants might be affected following high moisture tension in a manner different from normal plants. Again there was no

TABLE 16.--WEIGHTS OF ENTIRE PLANTS AND PLANT PARTS FOLLOWING MOISTURE STRESS AT TWO LEVELS. THE MANNITOL TREATMENT WAS WATERED WITH A SOLUTION OF SIX ATMOSPHERES. WATER ALONE WAS USED FOR THE CONTROL. WEIGHTS SHOWN ARE TOTALS OF FOUR REPLICATIONS, FOUR PLANTS EACH. STATISTICAL ANALYSIS WAS DUNCAN'S MULTIPLE RANGE TEST.

Plant weight (grams)				
Control		Mannitol		
Fireball	4.65)	Fireball	1.29	72.3**
F2-26*	4.60)	F2-26*	1.03)	77.7
Rutgers	4.30	Puck*	0.99))	72.3
Manalucie	3.84	Manalucie	0.99))	74.3
Puck*	3.57	Rutgers	0.93))	78.4
Premier*	3.32	Premier*	0.90)	72.9

Top weight (grams)				
Control		Mannitol		
Fireball	3.80	Fireball	0.78	79.5**
F2-26*	3.64)	F2-26*	0.63	82.7
Rutgers	3.56)	Rutgers	0.58)	83.7
Manalucie	3.05	Manalucie	0.58)	81.0
Puck*	2.64	Puck*	0.54)	79.6
Premier*	2.56	Premier*	0.51)	80.1

Root weight (grams)				
Control		Mannitol		
F2-26*	0.96)	Fireball	0.51	40.0**
Puck*	0.93)	Puck*	0.45	51.6
Fireball	0.85)	Manalucie	0.41)	48.1
Manalucie	0.79))	F2-26*	0.40)	58.3
Premier*	0.76)	Premier*	0.39)	48.7
Rutgers	0.74)	Rutgers	0.35	52.7

Root-top ratio				
Control		Mannitol		
Puck*	1.35	Puck*	3.25	58.5**
Premier*	1.18	Premier*	3.06)	61.4
F2-26*	1.04)	Manalucie	3.01)	66.4
Manalucie	1.01)	F2-26*	2.69)	61.3
Fireball	0.88	Fireball	2.60)	66.2
Rutgers	0.81	Rutgers	2.44	66.8

Any means contained within a bracket are not significantly different.

* Dwarf varieties.

** Percent increase or decrease of treatment values from control of the same variety.

consistant behavior among dwarf varieties, either treated or untreated. There was also not a consistant percentage increase or decrease in either top or root weight because of the treatment.

There was a consistant difference between dwarf and normal varieties studied in the root-top ratio. Among the control plants the dwarf varieties had higher ratios than the normal varieties, although the dwarf variety with the lowest ratio, F2-26, was not statistically different from the normal variety with the highest ratio, Manalucie.

All six varieties, dwarf and normal, had higher root-top ratios when grown under high moisture tension than when grown under control conditions. Although the ratios of dwarf plants under high moisture tension tended to be higher than those of normal plants, only two of the three varieties with the highest ratios are dwarf varieties. The percentage increase in root-top ratio, however, was clearly lower for all dwarf varieties. Among the normal mannitol treated plants, there was some decrease in root weight and a great decrease in top weight compared with the control normal plants. Among the dwarf plants, on the other hand, there was also a decrease in root weight but the decrease in top weight was proportionately not as great.

Dry soil.--Following the mannitol study, three dwarf and three normal varieties were subjected to several days of dry soil. Watering was suspended after the seedlings were 19 days old in one trial and after they were 23 days old in another. These studies were conducted to show whether or not there are differences in wilting symptoms between dwarf and normal phenotypes. The results are shown in Table 17.

Among seedlings from which water was withheld 19 days after planting, and also among those from which it was withheld 23 days after planting, the normal varieties consistantly produced wilting symptoms first. They also had a higher percentage of plants showing wilting symptoms at the completion of each trial.

After resumption of watering the recovered and dead plants were counted to determine possible differences between dwarf and normal phenotypes in ability to recover from severe wilting. The average percent recovery of the dwarf varieties was better in both trials than the average of the normal varieties. The normal variety, Fireball, however, was at least as good in this respect as two of the dwarf varieties in the first trial and better than any of the dwarf varieties in the second trial.

There was a direct relationship among the varieties within each plant type between early development of wilting symptoms and percent recovery. This relationship occurred in both trials. For example, in the first trial F2-26 exhibited the greatest amount of early wilting among dwarf varieties and also had the highest percentage of recovered plants. Fireball was likewise the variety which was first to wilt and recover the best among the normal varieties.

In comparing plant types, however, the dwarf varieties wilted later than the normal varieties and also a lower percent of them wilted; yet, as mentioned above, they also tended to recover better than the normal varieties. The reason for this discrepancy in the

TABLE 17.--RELATIVE DROUGHT TOLERANCE OF SEEDLINGS OF THREE DWARF AND THREE NORMAL VARIETIES AFTER AN EXPOSURE TO VARIOUS NUMBER OF WATERING FREE DAYS. NOTATIONS BASED ON FOUR REPLICATIONS.

Seedling age	Varieties	Percent of seedlings showing wilting symptoms at various number of days following suspension of watering							Percent of recovered seedlings following rewatering
		3	5	6	7	8	9	11	
19 days	Dwarf								
	Premier	0		18		75			87
	Puck	0		18		75			81
	F2-26	0		43		56			93
	Average	0		26		68			87
	Normal								
	Manalucie	0		81		93			75
	Fireball	50		100		100			87
	Rutgers	0		68		93			56
	Average	16		83		95			72
23 days	Dwarf								
	Premier		6		12		50	100	87
	Puck		0		6		50	93	75
	F2-26		0		12		56	87	81
	Average		2		10		52	93	81
	Normal								
	Manalucie		18		50		93	100	62
	Fireball		43		62		100	100	93
	Rutgers		31		62		87	100	75
	Average		30		58		93	100	76

results must lie in some as yet untested difference between dwarf and normal phenotypes. Perhaps dwarf tomato plants do not exhibit wilting symptoms as readily because of more mechanical rigidity in the stems and petioles. Anatomical examination would be necessary to show whether or not this is the reason for the difference in wilting symptoms but gross morphological characteristics of dwarf plants indicate that this rigidity is sufficient to delay and reduce wilting. But the reason for their better recovery is more difficult to explain. This ability of dwarf plants to regain turgidity might be somewhat due to their higher root-top ratio. This higher ratio, with its high proportion of roots to tops, should cause dwarf plants to develop wilting symptoms more slowly and also to recover better because of their ability to supply water for their comparatively smaller tops. This explanation does not explain the varietal ratings, though, within each of the two plant types. In both trials using dry soil, the variety Puck, for instance, showed the poorest recovery but had the highest root-top ratio in the mannitol study. Since root-top ratios were not calculated for the wilting trials some changes in ratio could have taken place due to the slight difference in plant ages.

Another response of the dwarf seedlings to moisture tension was their ability to withstand extensive foliage damage. The seedlings of both dwarf and normal varieties that regained turgidity following the eight days, during which water was withheld, did not show any foliage damage or discoloration. Among the seedlings that regained turgidity after the 11-day period, the dwarf seedlings showed less foliage damage and discoloration than the normal seedlings

(Table 18). Foliage damage and discoloration which was restricted to the first pair of true leaves on both dwarf and normal seedlings consisted of various amounts of dead leaf portions and yellow discoloration.

Table 18 shows that dwarf seedlings have a smaller percent of leaves with dead portions, and with the exception of Puck seedlings, a smaller percent of yellow leaf coloration than seedlings of the normal varieties. Seedlings of the normal varieties show similar percentages of leaves with dead portions and yellow discoloration.

Since such symptoms as partial death of leaves and leaf discoloration are indications of a reduced chlorophyll content, it appears that dwarf seedlings either lose less chlorophyll under moisture tension or their leaves contain more. The darker green appearance of dwarf tomato plants indicates a higher chlorophyll content. Thus following recovery from high moisture tensions, dwarf seedlings can reassume photosynthesis on a larger chlorophyll containing area.

TABLE 18.--RELATIVE DROUGHT TOLERANCE OF SEEDLINGS OF THREE DWARF AND THREE NORMAL VARIETIES EXPRESSED THROUGH VARIOUS DEGREES OF FOLIAGE DAMAGE AND DISCOLORATION FOLLOWING RECOVERY FROM A WATER FREE PERIOD OF 11 DAYS. NOTATIONS BASED ON FOUR REPLICATIONS.

Variety	Number of recovered seedlings	Percent of seedlings showing dead leaf portions	Percent of seedlings showing yellow discoloration
Dwarf			
Premier	14	57	71
Puck	12	50	91
F2-26	13	53	61
Normal			
Manalucie	10	80	90
Fireball	15	80	100
Rutgers	12	83	91

Chapter V

SUMMARY

Means for identifying more positively the dwarf phenotype in seedling stage have been found. Characters, such as hypocotyl length, cotyledon length and cotyledon index (length/width) were found to be easy and precise methods of distinguishing dwarf from normal seedlings.

The germination rate and time of dwarf seeds when compared with normal seeds was found to be similar in petri dishes under moisture tensions of zero, three and six atmospheres and at various temperature levels. Slower emergence from soil and sand was observed for dwarf seedlings, regardless of temperature, planting depth or light conditions. Percent emergence of dwarf seedlings was lower than that of normal seedlings, particularly following planting at low temperature.

Dwarf and normal seedlings were similar for fresh plant weight, top weight and root weight at high moisture tensions induced by mannitol and at control conditions. Root-top ratios were found to be higher for dwarf seedlings than for normal seedlings when grown under both high and low moisture tensions.

A slower development of wilting symptoms at various number of days following suspension of watering, a higher percent of recovery following rewatering and a smaller percent of foliage damage resulting in chlorophyll destruction was shown to occur for the dwarf seedlings at moisture tensions achieved through the gradual water loss by soil.

LITERATURE CITED

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1. Abbe, E. C. and B. O. Phinney. 1942. The action of the gene dwarf-1 in the ontogeny of the stem in maize. (Abstract) Genetics 27:129.

2. Barton, D. W., L. Butler, J. A. Jenkins, C. M. Rick and P. A. Young. 1955. Rules for nomenclature in tomato genetics. J. Heredity 46:22-26.

3. Bindloss, E. A. 1942. A developmental analysis of cell length as related to stem length. Am. J. Botany 29:179-188.

4. Bremner, P. M., R. N. Eckersall and R. K. Scott. 1963. The relative importance of embryo size and endosperm size in causing the effects associated with seed size in wheat. J. Agr. Sci. 61:139-145.

5. Brian, P. W. and H. G. Hemming. 1955. The effect of gibberellic acid on shoot growth of pea seedlings. Physiologia Plantarum 8:669-681.

6. Brix, Holger. 1962. The effect of water stress on the rates of photosynthesis and respiration in tomato plants and loblolly pine seedlings. Physiologia Plantarum 15:10-20.

7. Butler, L. 1952. The linkage map of the tomato. J. Heredity 43:25-35.

8. Clayberg, C. D., L. Butler, C. M. Rick and P. A. Young. 1960. Second list of known genes in the tomato. J. Heredity 51:167-174.

9. Denna, D. W. and H. M. Munger. 1963. Morphology of the bush and vine habits and the allelism of the bush genes in *Cucurbita maxima* and *C. pepo* squash. Am. Soc. Hort. Sci. Proc. 82:370-377.

10. Dotzenko, A. D. and J. G. Dean. 1959. Germination of six alfalfa varieties at three levels of osmotic pressure. Agron. J. 51:308-309.

11. Evans, W. F. and F. C. Stickler. 1961. Grain sorghum seed germination under moisture and temperature stresses. Agron. J. 53:369-372.

12. Gates, C. T. and J. Bonner. 1959. The response of the young tomato plant to a brief period of water shortage. IV. Effects of water stress on the ribonucleic acid metabolism of tomato leaves. Plant Physiol. 34:49-55.

13. Hack, H. R. B. 1963. Tomato seed germination and emergence at controlled soil-moisture tensions from 0.5 to 20 cm. mercury. Ann. Appl. Biol. 51:473-484.

14. Hatcher, E. S. J. 1940. Studies in the inheritance of physiological characters. V. Hybrid vigour in the tomato. Pt. III. A critical examination of the relation of embryo development to the manifestation of hybrid vigour. Ann. Botany. N. S. 4:735-764.

15. Helmerick, R. H. and R. P. Pfeifer. 1954. Differential varietal responses of winter wheat germination and early growth to controlled limited moisture conditions. Agron. J. 46:560-562.

16. Houghtaling, H. B. 1940. Stem morphogenesis in Lycopersicum: A quantitative study of cell size and number in the tomato. Torrey Botan. Club Bull. 67:33-55.

17. Knipe, D. and C. H. Herbel. 1960. The effects of limited moisture on germination and initial growth of six grass species. J. Range Mgmt. 13:297-301.

18. Kramer, P. J. 1962. Water stress and plant growth. Agron. J. 55:31-35.

19. Lee, A. E. 1959. The effects of various substances on the comparative growth of excised tomato roots of clones carrying dwarf and normal alleles. Am. J. Botany 46:16-21.

20. Luckwill, L. C. 1939. On the factors affecting the mean seed weight of tomato fruits. New Phytologist 38:181-189.

21. MacArthur, J. W. 1926. Linkage studies with the tomato. Genetics 11:387-405.

22. McGinnies, W. J. 1960. Effects of moisture stress and temperature on germination of six range grasses. Agron. J. 52: 159-162.

23. Phinney, B. O. 1956. Growth response of single-gene dwarf mutants in maize to gibberellic acid. Proc. Nat. Acad. Sci. 42:185-189.

24. Pollack, B. L. and R. E. Larson. 1955. Factors affecting embryo size, and the influence of embryo size on germination, time to maturity, and productivity in F_2 generation tomatoes. Pa. Agr. Expt. Sta. Bull. 606. p. 34.

25. Schmidt, D. 1924. The effect of the weight of the seed on the growth of the plant. N. J. Agr. Expt. Sta. Bull. 404. p. 19.

26. Uhvits, Rachael. 1946. Effects of osmotic pressure on water absorption and germination of alfalfa seed. Am. J. Botany 33:278-283.

27. Van Overbeek, J. 1938. Auxin production in seedlings of dwarf maize. Plant Physiol. 13:587-598.

28. Von Abrams, G. J. 1953. Auxin relations of a dwarf pea. Plant Physiol. 28:443-456.

A P P E N D I X

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - TREATED PLANT WEIGHTS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_j X^2_{ij}$
Manalucie	0.20	0.30	0.27	0.22	0.99	0.2513
Fireball	0.35	0.33	0.34	0.27	1.29	0.4199
Rutgers	0.22	0.25	0.26	0.20	0.93	0.2185
F2-26	0.19	0.29	0.35	0.20	1.03	0.2827
Premier	0.23	0.24	0.22	0.21	0.90	0.2030
Puck	0.36	0.18	0.21	0.24	0.99	0.2637
Block X_j	1.55	1.59	1.65	1.34	6.13	
Totals $\Sigma_i X^2_{ij}$	0.4295	0.4355	0.4711	0.3030		1.6391

Correction term	1.56
Total SS	0.07
Block SS	0.01
Treatment SS	0.03
Error SS	0.03

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	*F* value
Blocks	3	0.01	0.003	
Treatment	5	0.03	0.006	3.00*
Error	15	0.03	0.002	
Total	23	0.07		

F value from table 0.5 - 2.90
* Significant difference.

Duncan's Test: $s_{\bar{x}}$ 0.0223

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.06	0.06	0.07	0.07	0.07

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - TREATED TOP WEIGHTS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_j X^2_{ij}$
Manalucie	0.09	0.18	0.17	0.14	0.58	0.0890
Fireball	0.19	0.21	0.21	0.17	0.78	0.1532
Rutgers	0.12	0.16	0.17	0.13	0.58	0.0858
F2-26	0.10	0.18	0.23	0.12	0.63	0.1097
Premier	0.12	0.14	0.13	0.12	0.51	0.0653
Puck	0.18	0.10	0.12	0.14	0.54	0.0764
Block X_j	0.80	0.97	1.03	0.82	3.62	
Totals $\Sigma_i X^2_{ij}$	0.1154	0.1641	0.1861	0.1138		0.5794

Correction term	0.54
Total SS	0.03
Block SS	0.01
Treatment SS	0.01
Error SS	0.01

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	*F* value
Blocks	3	0.01	0.003	
Treatment	5	0.01	0.002	3.33*
Error	15	0.01	0.0006	
Total	23	0.03		

F value from table 0.5 - 2.90
* Significant difference.

Duncan's Test: $s_{\bar{x}} = 0.01225$

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.03	0.03	0.03	0.04	0.04

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - TREATED ROOT WEIGHTS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_j X^2_{ij}$
Manalucie	0.11	0.12	0.10	0.08	0.41	0.0429
Fireball	0.16	0.12	0.13	0.10	0.51	0.0669
Rutgers	0.10	0.09	0.09	0.07	0.35	0.0311
F2-26	0.09	0.11	0.12	0.08	0.40	0.0410
Premier	0.11	0.10	0.09	0.09	0.39	0.0383
Puck	0.18	0.08	0.09	0.10	0.45	0.0569
Block X_j	0.75	0.62	0.62	0.52	2.51	
Totals $\Sigma_i X^2_{ij}$	0.1003	0.0654	0.0656	0.0458		0.2771
		Correction term		0.2625		
		Total SS		0.0146		
		Block SS		0.0044		
		Treatment SS		0.0038		
		Error SS		0.0064		

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F value
Blocks	3	0.0044	0.0014	
Treatment	5	0.0038	0.0007	1.75*
Error	15	0.0064	0.0004	
Total	23	0.0146		

F value from table 0.5 - 2.90
* No significant difference.

Duncan's Test: $s_{\bar{x}} = 0.01$

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.02	0.03	0.03	0.03	0.03

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - TREATED ROOT-TOP RATIOS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_i X^2_{ij}$
Manalucie	1.20	0.66	0.58	0.57	3.01	2.53
Fireball	0.84	0.57	0.61	0.58	2.60	1.73
Rutgers	0.83	0.56	0.52	0.53	2.44	1.55
F2-26	0.90	0.61	0.52	0.66	2.69	1.88
Premier	0.91	0.71	0.69	0.75	3.06	2.37
Puck	1.00	0.80	0.75	0.70	3.25	2.69
Block X_j	5.68	3.91	3.67	3.79	17.05	
Totals $\Sigma_i X^2_{ij}$	5.47	2.59	2.28	2.43		12.77

Correction term	12.11
Total SS	0.66
Block SS	0.45
Treatment SS	0.12
Error SS	0.09

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	*F* value
Blocks	3	0.45	0.15	
Treatment	5	0.12	0.024	4.00*
Error	15	0.09	0.006	
Total	23	0.66		

F value from table 0.5 - 2.90
* Significant difference

Duncan's Test: $s_{\bar{x}}$ = 0.0387

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.11	0.11	0.12	0.12	0.12

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - UNTREATED PLANT WEIGHTS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_j X^2_{ij}$
Manalucie	1.09	0.86	0.82	1.07	3.84	3.74
Fireball	1.17	1.20	1.13	1.15	4.65	5.40
Rutgers	0.97	1.23	1.13	0.97	4.30	4.67
F2-26	1.11	1.29	1.12	1.08	4.60	5.31
Premier	0.85	0.79	0.71	0.97	3.32	2.79
Puck	1.25	0.75	0.86	0.71	3.57	3.36
Block X_j	6.44	6.12	5.77	5.95	24.28	
Totals $\Sigma_i X^2_{ij}$	7.01	6.54	5.72	6.01		25.28

Correction term	24.56
Total SS	0.72
Block SS	0.04
Treatment SS	0.38
Error SS	0.30

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F value
Blocks	3	0.04	0.013	
Treatment	5	0.38	0.076	3.80*
Error	15	0.30		
Total	23	0.72		

F value from table 0.5 - 2.90

* Significant difference.

Duncan's Test: $s_{\bar{x}}$ = 0.07079

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.20	0.21	0.22	0.22	0.23

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - UNTREATED TOP WEIGHTS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_j X^2_{ij}$
Manalucie	0.83	0.69	0.67	0.86	3.05	2.35
Fireball	0.93	1.00	0.94	0.93	3.80	3.61
Rutgers	0.79	1.03	0.93	0.81	3.56	3.20
F2-26	0.83	1.03	0.90	0.88	3.64	3.33
Premier	0.63	0.62	0.54	0.77	2.56	1.66
Puck	0.85	0.58	0.67	0.54	2.64	1.79
Block X_j	4.86	4.95	4.65	4.79	19.25	
Totals $\Sigma_i X^2_{ij}$	3.98	4.31	3.74	3.91		15.94

Correction term	15.44
Total SS	0.50
Block SS	0.00
Treatment SS	0.35
Error SS	0.15

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F value
Blocks	3	0.00	0.00	
Treatment	5	0.35	0.07	7.00*
Error	15	0.15	0.01	
Total	23	0.50		

F value from table 0.5 - 2.90
* Significant difference

Duncan's Test: $s_{\bar{x}}$ = 0.05

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.14	0.14	0.15	0.15	0.16

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - UNTREATED ROOT WEIGHTS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_j X^2_{ij}$
Manalucie	0.26	0.17	0.15	0.21	0.79	0.1631
Fireball	0.24	0.20	0.19	0.22	0.85	0.1821
Rutgers	0.18	0.20	0.20	0.16	0.74	0.1380
F2-26	0.28	0.26	0.22	0.20	0.96	0.2344
Premier	0.22	0.17	0.17	0.20	0.76	0.1462
Puck	0.40	0.17	0.19	0.17	0.93	0.2539
Block X_j	1.58	1.17	1.12	1.16	5.03	
Totals $\Sigma_i X^2_{ij}$	0.4444	0.2343	0.2120	0.2270		1.1177

Correction term	1.05
Total SS	0.06
Block SS	0.02
Treatment SS	0.01
Error SS	0.03

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F value
Blocks	3	0.02	0.006	
Treatment	5	0.01	0.002	1.00*
Error	15	0.03	0.002	
Total	23	0.06		

F value from table 0.5 - 2.90
* No significant difference.

Duncan's Test: $s_{\bar{x}}$ = 0.0223

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.06	0.06	0.07	0.07	0.07

APPENDIX.--STATISTICAL ANALYSIS FOR MANNITOL STUDY (TABLE 16) - UNTREATED ROOT-TOP RATIOS.

	Blocks				Varietal Totals	
Variety	1	2	3	4	X_i	$\Sigma_j X^2_{ij}$
Manalucie	0.31	0.24	0.22	0.24	1.01	0.2597
Fireball	0.25	0.20	0.20	0.23	0.88	0.1954
Rutgers	0.22	0.19	0.21	0.19	0.81	0.1647
F2-26	0.33	0.25	0.24	0.22	1.04	0.2774
Premier	0.34	0.27	0.31	0.26	1.18	0.3522
Puck	0.47	0.29	0.28	0.31	1.35	0.4795
Block X_j	1.92	1.44	1.46	1.45	6.27	
Totals $\Sigma_i X^2_{ij}$	0.6524	0.3532	0.3646	0.3587		1.7289

Correction term	1.63
Total SS	0.09
Block SS	0.03
Treatment SS	0.05
Error SS	0.01

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	*F* value
Blocks	3	0.03	0.01	
Treatment	5	0.05	0.01	16.66*
Error	15	0.01	0.0006	
Total	23	0.09		

F value from table 0.5 - 2.90
* Significant difference.

Duncan's Test: $s_{\bar{x}}$ = 0.01225

Value of p	2	3	4	5	6
SSR	2.92	3.07	3.15	3.22	3.28
LSR	0.03	0.03	0.03	0.04	0.04

ABSTRACT OF THESIS

THE RELATIONSHIP OF THE DWARF GENE (d_1) TO SEED GERMINATION AND SEEDLING GROWTH IN LYCOPERSICON ESCULENTUM Mill.

Submitted by

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In partial fulfillment of the requirements
for the Degree of Master of Science
Colorado State University
Fort Collins, Colorado

June, 1964

ABSTRACT OF THESIS

A study of identification of the dwarf phenotype in seedling stage, of various factors affecting seed germination and seedling emergence and of growth response to various moisture conditions in seedling stage of the dwarf phenotype was made.

Characters, such as hypocotyl length, cotyledon length and cotyledon index (length/width) were found to be easy and precise methods of distinguishing dwarf and normal seedlings.

The germination rate and time of dwarf seeds when compared with normal seeds was found to be similar in petri dishes under moisture tensions of zero, three and six atmospheres and at various temperature levels. Slower emergence from soil and sand was observed for dwarf seedlings, regardless of temperature, planting depth or light conditions. Percent emergence of dwarf seedlings was lower than that of normal seedlings, particularly following planting at low temperature.

Dwarf and normal seedlings were similar for fresh plant weight, top weight and root weight at high moisture tensions induced by mannitol and at control conditions. Root-top ratios were found to be higher for dwarf seedlings than for normal seedlings when grown under both high and low moisture tensions.

A slower development of wilting symptoms at various number of days following suspension of watering, a higher percent of recovery following rewatering and a smaller percent of foliage damage resulting in chlorophyll destruction was shown to occur for the dwarf seedlings at moisture tensions achieved through the gradual water loss by soil.