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Some Factors Which Influence the Fruiting Habit of Henderson's Bush Lima Bean (*Phaseolus lunatus*)

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SOME FACTORS WHICH INFLUENCE THE FRUITING HABIT OF HENDERSON'S BUSH LIMA BEAN (*Phaseolus lunatus*)

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The bush lima bean is grown extensively for canning, as well as for a home and market garden crop. A number of varieties of both the pole and bush limas is grown for the fresh trade and also dried for winter use, but the Henderson's Bush Lima is preferred for canning because of its high quality, productivity, relative freedom from pests, and also because of the flat shape and small size of the seed. In addition, the fact that the cotyledons of the seed are green when young, rather than white, makes for a more attractive canned product which is preferred by the trade.

Since the entire crop is harvested at one time for canning, it is highly important that the product be uniform, particularly as to size and color. The outstanding weakness of this particular variety is the tendency for certain pods to develop in advance of the others, with the result that some of the seeds are white and necessitate an expensive process of picking them out as they pass over an endless belt. It is a well known fact that in some years there is a much greater variation in maturity of pods than in others.

It was for this reason that the Ohio Experiment Station was asked by members of the canning trade to study this problem and determine, if possible, the cause and the remedy. This preliminary report offers an explanation for the cause of the trouble, but a remedy for it would appear to lie in further selection or breeding.

THE PROBLEM

As stated above, the chief objection to the variety under consideration is the tendency toward a lack of uniformity in the pods at harvest time. It had been noted frequently that this lack of uniformity resulted because the main stem twined instead of remaining a true bush type. Previous, unpublished work by the writer and others has shown that the lima bean is unstable in its growth habit; that is, it has a tendency to revert to its ancestral form and twine if grown under shaded conditions or under certain other abnormal environmental conditions. This was also noted in our greenhouse work, both in winter and during other seasons of the year.

Inquiry was made relative to this matter of canners and others, and there seems to be a general opinion that the trouble lies in the seed, probably in the purity of the strain. Following this suggestion, a survey was made of fields in the vicinity of some canning factories, and in one specific case three fields were visited which had been planted from the same lot of seed. In two cases considerable twining of the plants was noticeable, and in the other there was practically none. These same conditions recurred repeatedly during the progress of this investigation. Such observations would raise a serious question as to whether the cause lies in impure strains of seed, although such might be true in some cases.

With these situations in mind, the first approach to the problem was an attempt at rigid selection of type plants which showed twining and those which did not; but no progress was made by this procedure. Breeding was also attempted by crossing Henderson's Bush Lima with other varieties, but considerable difficulty was experienced because of the small flower parts and the difficulty of large scale operation.

Up to this time no careful study and description of the plant habit had been made, and it seemed that the most logical and scientific approach to the problem must come through a clear understanding of the gross morphology of the plant in order to determine what part or parts elongated during twining and where the pods were borne that matured earliest. Obvious as such details might appear to be, this study has been illuminating and the details are here recorded as a basis for an explanation of the effects of changing the environment upon the accentuating of irregular maturing of the pods.

The chief factors studied were: Distance of planting, date of planting, soil reaction, and light intensity.

MATERIALS AND METHODS

The Henderson's Bush Lima bean was used in all of these experiments, which were conducted during the spring and summer of 1932. With the exception of the soil-reaction experiment, all of the work was done at the University gardens, Columbus. The soil was a silty clay loam.

In studying the effect of time of planting on the plant form, seeds were planted on several different dates during the summer; viz., May 14, June 3, June 17, and June 29. They were planted 12 inches apart in rows which were 36 inches apart and thinned to two plants per hill. The plant habit as affected by these different planting dates was then recorded.

In studying the effect of planting distance on the plant form, plots 10 feet in length and about 9 feet wide, replicated four times, were used, each replicate being systematically distributed. The planting distances used were: 4 inches, 10 inches, 16 inches, and 22 inches apart in rows 28 inches apart, except in one test in which the plants were 4 inches apart with 14 inches between the rows.

The influence of soil reaction was studied in the Station's greenhouses at Wooster. Eight plots of silt loam soil varying in pH from 4.5 to 8.0 were used. The desired reaction was obtained by the use of aluminum sulfate to acidify the soil and of lime to decrease the acidity. The pH varied little in the plots during the period studied. The seeds were planted May 20 and the plants thinned to about 30 plants per plot. On June 20, at about the middle of the growing period, the characteristics of the plants from each plot were recorded in detail. The plants were removed and individual plant records were made on July 25, the beans at this time being ready to harvest for canning purposes.

Ordinary cheesecloth (40 meshes per inch) was used to shade three plots of 25 plants each, planted 10 inches apart in rows 28 inches apart. These seeds were planted on June 3, and, as soon as the plants appeared above the ground, cheesecloth containers about 4 feet in height were used to enclose them completely. The containers were composed of two, three, and four layers of cheesecloth. Also, a container of the same type composed of two layers of cheesecloth was placed over a plot 32 days after the seed had been planted and 9 days before the first flower appeared. Another shade of the same type was constructed 24 days after planting over a plot in which all the nodes on the axis of the plants were in evidence. Notes were taken of the general differences in form found in plants grown under each of the conditions. It seemed impracticable to analyze these results other than relatively.

PLANT HABIT

Systematic classifications of this plant have already been made (4, 5). Studies on the anatomy of a similar plant, *Phaseolus vulgaris*, have also been reported in some detail (2), but a critical description of the plant habit does not appear in the literature.

In order to present clearly the plant habit of the dwarf lima bean, the plant will be traced from the seedling stage to maturity, node by node. In this way the gross developmental processes can be followed in some detail. The origin of the flowering shoots and the time of flowering are of particular concern. It is, of course, obvious that the climbing lima bean, from which the dwarf one originated, is indeterminate in growth while the dwarf one is determinate—that is, it terminates in a flower cluster and hence is limited to a definite number of nodes. The inflorescence of the bean is a raceme as it is composed of a common peduncle upon which are borne flowers having separate pedicels of about equal length. The order of anthesis is ascending or acropetal.

The main axis of the Henderson's Bush Lima bean usually consists of eight internodes and a terminal inflorescence. Axillary inflorescences develop at the various nodes, as described below, some of which rarely, if ever, mature fruits. The critical situation in the plant is whether the main axis elongates and the plant twines. In such a case it is the sixth and seventh internodes which elongate. Attempts have been made, without success, to eliminate this characteristic by selection of plants which showed no tendency to twine.

1. **Cotyledonary node.**—The point of divergence of the cotyledons constitutes the first node of the plant. The cotyledons remain on the plant 7 to 10 days after it is above the ground; then they slowly lose their turgidity, turn yellow, and abscise. At this period in the plant growth the main axis elongates slowly. In about a month after the plants are above the ground small growing points are seen immediately above the cotyledonary scars. These develop into branches which ordinarily grow very slowly, producing one or sometimes two short internodes terminated by a small raceme, the flowers of which fail to open; the total length of the branches is only ¾ inch to 1½ inches.

In case a part of the main axis is removed, destroying apical dominance, the cotyledonary branches grow rapidly, reaching a total length of from 7 to 9 inches; and flowering racemes are produced in the axils of the three to four leaves. A vigorous raceme also terminates these branches. Very small secondary branches are sometimes produced at the bases of these two primary branches under these conditions, though this is not common. This observation confirms that of McCallum (2), who showed by a large number of similar experiments that by destroying the apical dominance the above results could be expected.

Most of the seedlings were dimerous, having two cotyledons and two primordial leaves, but a few trimerous seedlings were found. The trimerous seedlings had three cotyledons and three primordial leaves.

2. **Second node.**—The first internode is characteristically short. The opposite primordial leaves at this node, which are broadly lanceolate and auriculate, reach their full size of about 3 by 4 inches within a week after the seedling has appeared above ground. A pair of bifid bracts encloses the growing point at the summit of the first internode. These bracts are persistent but become thickened at the bases and inverted so that the tips extend outward and downward on the older plants. Other than this basal thickening, they do not

increase in size with the increasing age of the plant. The very small meristematic tissue or growing point terminating the upper part of the plant and also the growing points in the axils of the leaves are enclosed by bracts, all of which are instances of about the same type. Only the bud in the axil of the primordial leaves is enclosed with bifid bracts, the others being single lobed. All of these bracts are persistent and green and become thickened at the base with the subsequent development of the plant.

A bud can be seen in the axil of each primordial leaf at about the same time as the first trifoliate leaf appears on the main axis. These primary axillary branches grow rather slowly at first but develop two to four nodes before they are terminated by a raceme; this occurs about 2 weeks after they are first seen. Small buds appear soon afterward in the axils of the trifoliate leaves on these axillary branches. The most basal of these clusters develops into a vigorous raceme or rarely into a short branch; the other two or three remain as clusters or very short racemes. The primordial leaves abscise about the time that this stage of growth is reached. Such leaves are analogous to juvenile leaves which are characteristic of many species of plants. The internodes of these primary branches elongate slowly, but they ordinarily reach a total length of 7 to 8 inches by the time of anthesis. Very small secondary racemes develop in the axils of the primary branches; these sometimes grow into flowering racemes, but more often the flowers fail to open even though the flower primordia are formed.

3. **Third and fourth nodes.**—The third node is the one at which the first trifoliate leaf diverges. The second internode, which is immediately below, is rarely as long as one inch under field conditions. The petiole of the leaf develops rapidly, forcing the main axis in the opposite direction. Within a day or two after the leaf has expanded a bud can be seen in its axil. The bud here, as well as the terminal one, is primarily enclosed with two very small, leaf-like bracts which are persistent at the node and, like the ones mentioned above, serve as bud scales. The branch from this bud elongates rapidly and three nodes are developed in 7 to 10 days. Three nodes are almost always found on this branch at maturity. A trifoliate leaf is present at each node. This branch also terminates in a raceme, and the flower primordia are developed at the same time elongation is going on at the internodes and slightly before buds can be seen in the axils of the leaves on the branch. This branch is similar to the branches which develop in the axils of the primordial leaves, except that more rapid growth in length and development of the plant parts takes place (Fig. 1).

Secondary branch buds appear in the axil of the primary branch at this node when the primary branches are very small. The total number of nodes (three in this case) is always formed and elongation of the internodes is taking place before the secondary branches appear. The secondary branches at this node elongate rapidly and the flowers on both the primary and secondary branches open at about the same time. The total length reached by these branches is 8 to 10 inches. Small tertiary branches with only one or two short internodes appear at the bases of these secondary branches, although flowers very rarely open on them.

The third internode is slightly longer than the second. There is very little difference in the growth habit of the branches at the third and fourth nodes; the branches are hardly as long but seem to develop slightly more rapidly at the fourth node, with the result that the flowers open at almost the same time on branches from both nodes.

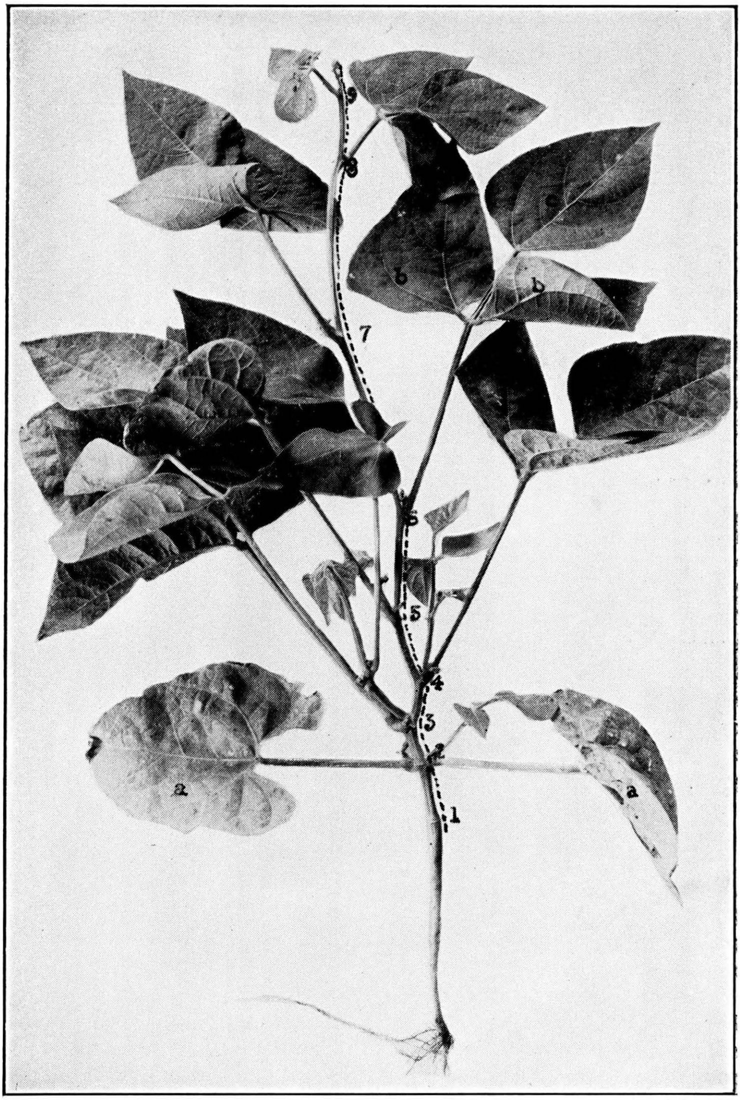

Fig. 1.—Plant about 5 weeks after planting of seed. Growth in length of main axis has almost ceased and branches are developing rapidly. Nodes on main axis (indicated by dotted line) are numbered in order. Types of leaves are shown: a, primordial leaves; b, lateral leaflet of trifoliate leaf; c, terminal leaflet of trifoliate leaf.

4. **Fifth and sixth nodes.**—The fourth internode is about twice as long as the second and the third ones. The bud appears at the fifth node 2 to 3 days later than at the fourth one. If a branch is formed it is only composed of from one to two internodes. In most cases only a raceme is formed in the axil of this leaf. The flowers open on this raceme at the same time as on the terminal racemes of the primary and secondary branches of the third and fourth nodes. Buds develop in the axil of the primary raceme, and sometimes grow into branches with greater total length than the primary raceme. A few flowers are often borne on the terminal raceme of these branches. It is not uncommon to find very short, weak, tertiary branches at this node.

The fifth internode is about twice as long as the fourth. At the sixth node a raceme is borne, which is usually shorter than the one at the fifth. Secondary branches appear commonly but rarely develop so far as to flower; in the latter case they are later than the flowers on the primary raceme. Very rarely do tertiary buds appear. It is characteristic for the first flowers on the racemes at the fifth and sixth nodes to open at the same time, and they are simultaneous with the first flowers on the branches at the third and fourth nodes.

5. **Seventh and eighth nodes.**—The sixth internode is one of the longest of the plant, being about twice as long as the fifth and about four times as long as the third or fourth (Fig. 1). A raceme slightly later in flowering and shorter than at the sixth node develops at the seventh node. Secondary branches are not common at this node.

The seventh internode is hardly as long as the sixth under most conditions. The flowers at the eighth node are borne on a very short raceme which appears as a cluster in the axil of the leaf on the main axis. As on the other racemes, the order of flowering is acropetal. The pedicels are more elongated on these two or three lower flowers, which, in most cases, are the only ones of the cluster to open. They open at the same time as, or slightly earlier than, flowers on the lower branches; the first flower opens about 44 days after the seed is planted.

6. **Ninth node and terminal inflorescence.**—The last node, which is usually the ninth, is the one just below the terminal raceme of the main axis. The internode just below it is about the same length as the fifth one under most conditions and only about half as long as the sixth and seventh. The flower cluster is similar to the one at the eighth node except that fewer flowers develop, although these open earlier. The flowers in this cluster open at the same time as do the flowers on the base of the terminal raceme of the main axis, being the first on the plant to open. Within one or two days afterwards flowers open on the racemes of the lateral branches. In this study the first flowers opened on July 16, or on the 43rd day after the seed was planted.

The terminal inflorescence consists, at flowering, of 15 to 20 small clusters, each composed of three to six flower buds of which only the outer two or three open. A small, inverted, *V*-shaped bract encloses each cluster of the inflorescence as the flower primordia are formed. Then, as the pedicels lengthen and the buds grow larger, three other bracts can be seen which enclose the individual buds, one of them remaining at the base of each pedicel. The other two are attached at the base of the flower parts inclosing them for some time. Only the basal four to six clusters on the peduncle bear fruit and rarely do more than two or three flowers of each cluster develop to maturity. The outside or basal flowers of the cluster develop first and the inner two or three buds fail to mature unless the outside ones are destroyed.

PLANTING DISTANCE (3)

The planting distances used in this work produced a very noticeable effect on the plant habit. The greater height in the thicker plantings was due to more rapid internode elongation, little being due to increase in number of internodes. The thickly-planted beans grew more rapidly in height, especially at first, than the more thinly-planted ones. No twining of the main axis was found, however, in any of these plants regardless of planting distance.

The primary branches in the axils of the primordial leaves grew more rapidly in the thinly-planted plots, although they appeared at the same time as the others. There was a large amount of variation in the length of these branches in all of the plots. The secondary and tertiary branches were greater in number and showed more vigor on the plants in the thinly-planted plots. There were only a few tertiary branches found on the plants which were 4 inches apart; whereas they were very common on the plants which were 10 inches apart. More flowers were produced per plant in the thinner plantings, but no difference could be seen in date of anthesis or in the maturity of the fruit on July 26th when the experiment was ended. The petioles of the leaves of the plants 4 inches apart were as much as twice as long as they were on the plants grown 16 and 22 inches apart. The greater lengths of the internodes of the branches in the thinner plantings were consistent.

PLANTING DATES

The seed which was planted May 14 did not germinate quickly and the seedlings did not appear above the ground until 12 days after planting. The plants grew slowly, probably because of rather cool weather conditions, but they were short and much branched. Many secondary and tertiary branches appeared. Fifty-five days elapsed after the seed was planted before the first flowers appeared on the plants. As usual, the flowers opened a day or two earlier in the axil of the upper leaf and at the base of the terminal inflorescence, but, as a whole, the fruit matured at about the same time on all parts of the plant. Rarely did flowers form on the tertiary branches or on the cotyledonary branches.

The seed planted June 3 sprouted more quickly and the plants were above the ground on June 10. The plants grew more rapidly and to a greater height than the May 14 planting. The lateral branches were as numerous and more vigorous and more flowers were produced than on the plants of the previous planting. No other differences could be noted. None of the plants twined in either of these plots. The flowers opened 44 days after the seed was planted. The same growth habit was found to exist in the June 17 planting as in the June 3 one.

The seed of the June 29 planting sprouted and the plants appeared in 6 to 7 days. The plants were exposed to good growing conditions from the first, and by July 21 all the internodes on the main axis were formed, although the upper two were only a few millimeters in length. July 21 and part of July 22 were cloudy and a light rain fell. During these 2 days, as well as during the following 2 or 3 days, the sixth and seventh internodes elongated rapidly, until on July 26 many of these plants showed a tendency to twine (Fig. 2). The records showed that the plants in the previously studied plots were not exposed to cloudy weather and rainfall during this period in their growth. It is concluded from the above results, together with other field observations, that either a reduction in light intensity, increase in soil moisture causing a better growing condition, or both of these factors working together will cause the sixth and seventh internodes to elongate so rapidly as to cause twining or circumnutation of the main axis if the plant is exposed to these conditions during a definite period in its growth. The fruit on the terminal raceme matures more rapidly and ripens first, even though flowering may occur at the same time as other racemes.

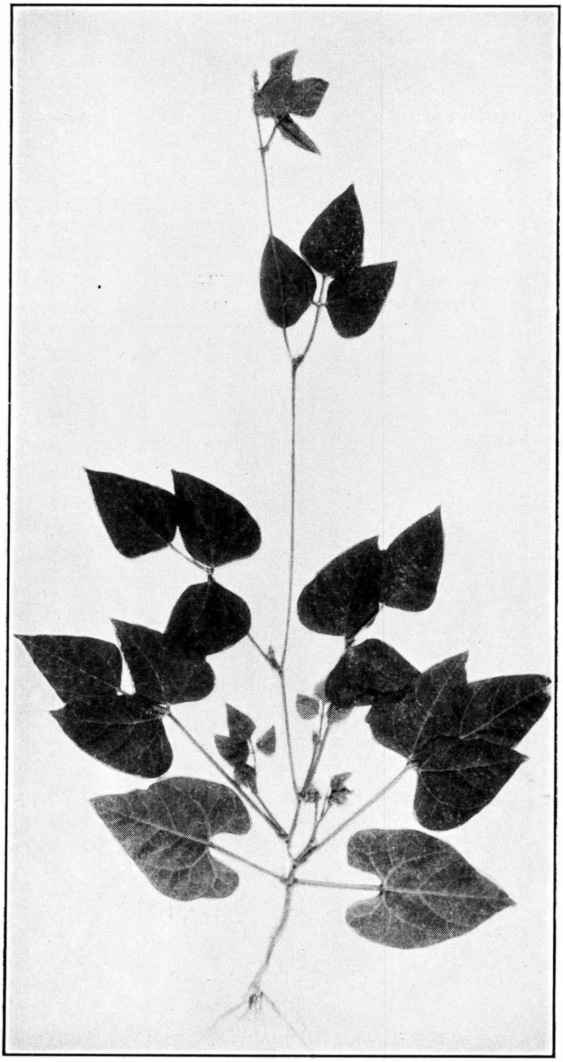

Fig. 2.—Lima bean plant. Upper internodes much elongated. Lateral branches developing slowly

SOIL REACTION

In the studies of plants grown under greenhouse conditions in Wooster silt loam soil the plants were definitely affected in their general plant habit by the different soil reactions.

The plants developed most rapidly in the plots with a pH of from 7.0 to 8.0 (Fig. 3), the fruits reaching maturity in these plots first. The length of time

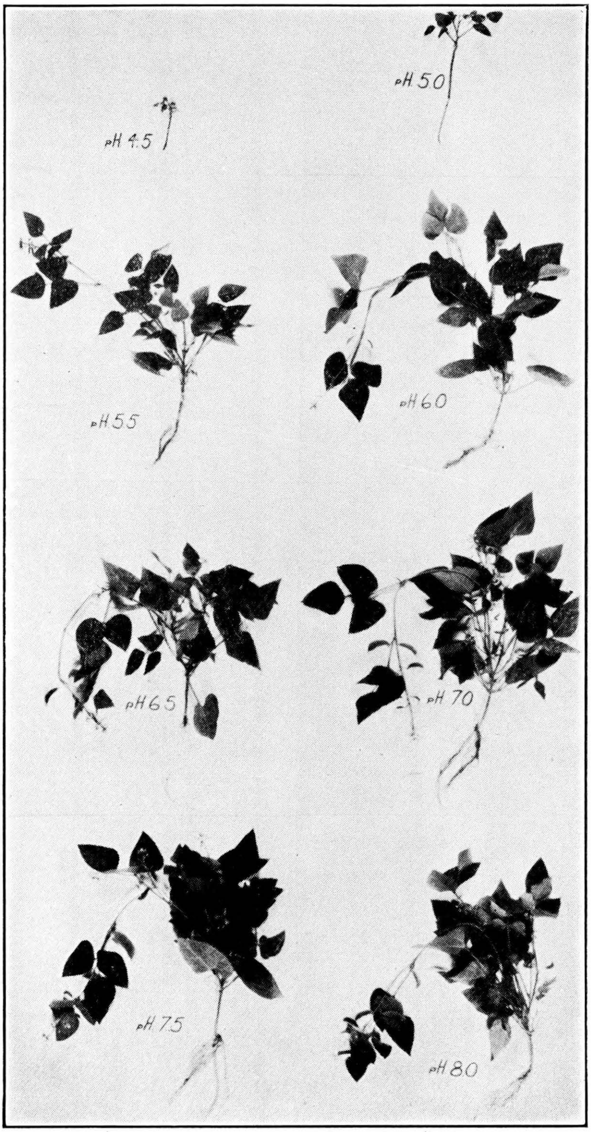

Fig. 3.—Showing differences in growth habit when grown at the various pH values indicated

for the plants to reach maturity varied inversely with the pH values in the plots throughout the experiment. There was very little difference in the maturity of the pods produced on the pH 7.0 to 8.0, but a great deal of difference could be seen in the pods from pH 6.0 to 7.0, as shown by the figure.

The roots of the plants in the most acid soils were brittle, and there were very few lateral ones produced. Little difference could be seen in the root habit of the plants in soil above pH 6.0, all the roots being very spreading and numerous. There was an increase in the average root weights with the increase in pH to 7.5, but the top-root ratios also increased. The roots were dug rather than washed out with the result that the complete root systems were not obtained.

The total length of the main axis increased with the increase in pH of the soil up to pH 7.0 (Fig. 3). This is probably a measure of the vegetative extension of the plants, but the general habit is not comparable with plants grown under field conditions. All the plants twined where they grew even moderately well although they always remained of determinate growth. This type of growth is common in these beans, when grown in the greenhouse, both in winter and summer as found in preliminary experiments.

The proportion of lateral branches to the general height of the main axis was about the same in all cases, the primary lateral branches reaching only about half the height of the main axis. Fruit developed at about the same time on all the lateral branches of a single plant and in the same soil reaction plot. The first flowers to open as well as the first fruits to mature were found on the base of the terminal raceme of the main axis or in the axil of the uppermost leaf. The average number of flowers decreased with the increase of pH from 6.5 to 8.0, but the weight of the fruit from each plant increased (Table 1).

It is probable that the results secured at the lower pH values may have been due, at least in part, to toxicity of the aluminum salts which had been applied. This point was not determined.

LIGHT INTENSITY

The general effect of light intensity on plants is well known, and the plant habit has been found to be greatly affected by this factor.

The leaves were much larger and thinner on the plants grown under the three shades of different densities which were used in this experiment. Many of the leaves measured as much as 4 x 6 inches at maturity. No differences in size were found between the plants under two, three, and four layers of cheesecloth.

The first flower appeared on the plants under two and also under three layers of cheesecloth only one day later than the flowers appeared on the plants exposed to full sunlight. In the case of the plot covered with four layers of cheesecloth the plants were 6 to 7 days later in flowering, but the first flower appeared at the same position on the plant, which was in the axil of the uppermost leaf and at the base of the terminal raceme.

In general, plants grown in the shade differed from those in the sun in the following details:

1. Roots were less woody and had a smaller diameter.
2. Stems were thinner and more succulent and were much elongated.
3. The top-root ratio was increased.

TABLE 1.—Effect of Soil Reaction on the Plant Habit

Plot No.	pH value desired	Reading electro-metrically April 23	Reading electro-metrically June 21	Recorded June 21, 1932				Recorded July 25, 1932				
				Length of plant axis	Primor-dial leaf area	Lateral leaflet of tri-foliate leaf	Terminal leaflet of tri-foliate leaf	Length of plant axis	Av. top weight	Av. root weight	Av. fruit weight	Root-top ratio
				In.	*Sq. In.*	*Sq. In.*	*Sq. In.*	*In.*	*Gm.*	*Gm.*	*Gm.*	
1	4.5	4.49	4.49	*	*	*	*	2.0	3.2	0.26	none	1 : 12.3
2	5.0	4.76	4.86	3.7	2.5	0.5	0.4	5.5	9.8	0.68	3.6	1 : 14.4
3	5.5	5.68	5.46	15.2	5.4	2.7	2.4	17.2	24.3	1.7	24.1	1 : 14.3
4	6.0	6.27	6.05	21.2	5.5	3.9	2.5	21.6	33.6	2.2	33.3	1 : 15.7
5	6.5	6.68	6.48	24.0	5.7	4.9	4.5	24.6	35.3	1.9	38.4	1 : 18.6
6	7.0	6.84	6.56	24.8	6.1	4.9	3.5	25.5	37.5	2.3	34.7	1 : 16.3
7	7.5	8.02	7.93	21.6	5.8	3.7	3.8	24.6	43.6	2.4	41.7	1 : 18.2
8	8.0	8.16	7.84	22.1	5.8	4.4	4.2	23.4	45.1	2.7	44.5	1 : 16.7

*No record because of difficulty in getting plants to come up.

Careful records of numbers of internodes of the plants under the different light intensities were taken, but no consistent differences were found even though the main axis of the plants under the shades was much longer (Table 2).

TABLE 2.—Variations of Plants Under Different Shade Conditions*

Density of cheese-cloth	Length of plant axis July 4	Length of plant axis July 30	Root weight July 30	Top weight July 30	Root-top ratio July 30
Layers	*In.*	*In.*	*Gm.*	*Gm.*	
2	19.2	28.9	6.6	127.9	1 : 19.4
3	20.0	29.2	5.9	123.9	1 : 21.0
4	22.3	31.0	3.5	88.2	1 : 25.1

*Roots dug.

The internodes were consistently longer under the shades from the beginning of the growth period, but the true twining effect did not occur until the total number of nodes had been formed. Lengthening of the sixth and seventh internodes, especially, then took place so rapidly that the plants showed very definite counter-clock-wise circumnutation. This period was reached 20 to 25 days after the seeds were planted. The racemes were much elongated under shaded conditions, lengthening of the peduncle taking place largely while the flower buds were developing.

When the experiment was ended on July 30, the plants under the two and three layers of cheesecloth were of about the same maturity, having just passed the stage of anthesis; whereas those under four layers were in full anthesis.

In the case of the plot shaded 32 days after planting, the primary branches elongated rapidly, but the terminal axis elongated only a small amount and no twining occurred. This was probably because the tissues of the axis had already become nearly mature while the lateral branches were still growing at this time.

When a shade of the same type was constructed over a plot in which the plants were 24 days old, the axis elongated rapidly at the sixth and seventh internodes, and a tendency to twine was seen in 3 to 4 days.

DISCUSSION OF RESULTS

The principal objectives of these studies have been to determine the cause of the lack of uniformity of these lima beans at time of harvest, as well as any possible remedy. A critical study of the plant habit was essential before an intelligent study of its variations under different conditions could well be made. Without doubt the reason an explanation of this peculiar situation had not already been made was because a careful analysis had not been made of the plant habit.

The explanation for the lack of uniformity now appears clear, insofar as the conditions under which the plant was studied are concerned. As already noted, if the plants are artificially shaded at about 23 to 25 days after the seedlings appear above the ground, there is an elongation of the seventh and eighth internodes with a consequent twining of the main axis of the plant.

However, it is important to note that this condition did not occur if the shade was delayed for even a few days beyond the above date. Shading at this critical date results in an early maturity of the pods developing from the terminal inflorescence, which does not occur if the plant retains its normal bush form. If, then, the crop is harvested at a time when most of the seeds are green in color, those of the terminal raceme will be white and undesirable for canning.

A few days of cloudy or rainy weather when the plants are at this critical stage in their development result in a condition similar to that which was obtained when the plants were shaded artificially and with the same undesirable consequences. In the light of these observations, it becomes clear how seed planted from the same lot on different dates may show twining and irregular maturity in some cases and not in others. In contrast to this situation, a condition has been noted (1), caused by dry weather conditions, in which the cotyledons of the seed became white before they had reached their normal size. This condition causes a rapid maturity of the pods over the entire plant rather than only on the terminal raceme.

Weather conditions cannot, of course, be forecast, and, hence, no practical remedy can be suggested unless further selection and breeding result in strains of such a genetic constitution that the plants are not so unstable and sensitive to conditions of shade or low light intensity.

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