SOIL TEMPERATURE AS A FACTOR IN THE FRENCHING OF TOBACCO (*NICOTIANA TABACUM* L.)

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(WITH FOUR FIGURES)

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During a study of the effect of soil temperature on the development of tobacco mosaic, frenching was observed on the plants at the higher soil temperatures. Since this is apparently the first time, JONES (3), that soil temperature has been recognized as a factor in inducing frenching of tobacco, *Nicotiana Tabacum* L., it seemed important that the technique be developed as a possible means of discovering the direct cause of this peculiar physiological malady.

Tobacco plants grown at the high soil temperature, 35° C., always became frenched, characterized by chlorotic, narrow leaves with wavy leaf margins. WOLF (19) expertly describes the symptoms which were also observed in this investigation: "... the internodes remain short, apical dominance is lost, and an unusually large number of leaves appear, sometimes two to three hundred in a single plant. Such plants have the appearance of a rosette or witches’ broom, and therefore the severe form of frenching may properly be called 'polyphyly'...."

WOLF (19) has reviewed the reports and investigations of frenching up to 1935. Apparently the malady is of physiological origin since it has been impossible to isolate an organism or inoculate plants by using virus technique. Among the causes suggested, emphasis is placed upon field conditions, particularly a subsoil of hard-pan nature which prevents root penetration and also results in poor drainage of surface moisture. Frenching has also occurred as an aftermath of heavy rainfall. Investigations conducted with various forms of nitrogen and calcium compounds have given results so inconsistent that lack or excess of these elements forms no basis as a primary cause. Neither does soil reaction offer a good approach to an answer, although beneficial effects have been noted in soils with low pH values and when acids have been applied to soils producing frenched plants. The soil toxin theory has been investigated, but, here again, the experiments led to inconclusive results.

When portions of frenched tobacco plants, containing a growing point, were grafted on to healthy tobacco plants the later growth of the graft lost its frenching habit (17, 18). Such experiments not only indicate the noninfectiousness of the causal agent, but also eliminate the possibility of a genetic character being involved.

McMURTRY (5) and SPENCER (11) have demonstrated that symptoms

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and control of toxicity from thallium are similar to those of frenching. Spencer and Lavin (13) using spectrographic analytical technique did not find thallium in the tops of frenched plants grown in field soil. However, this lack of evidence in the tops of frenched plants did not eliminate thallium as a primary cause, since the action may have taken place in the roots, creating some disturbance which affected the tops. Spencer (12) has demonstrated in both sand and water cultures that sulfanilamide and sulfapyridine, which also contains the sulfanilamide structure, produced a toxic condition in tobacco with leaf shapes similar to those produced when frenching is present. Closely related compounds failed to act in the same manner, which suggests, that frenching of tobacco may result from the production in the soil, or in the plant, of a toxic material with a structure similar to sulfanilamide. Bordering upon the toxin theory are the results of Steinberg (16) that diffusates in agar of products from the activity of presumably nonpathogenic soil bacteria had a deleterious effect on tobacco seedlings expressed in symptoms of abnormality. Steinberg (14, 15) obtained symptoms of frenching on tobacco seedlings in aseptic cultures with the amino acid dl-isoleucine. Other amino acids failed to induce frenching symptoms. Steinberg also suggests that mineral nutrition disturbances may affect protein metabolism and create excesses of amino acids and so lead to formation of charateristic deficiency symptoms.

Evidence now available points to some alterable soil constituent as a factor which disturbs the normal phytochemical balancing processes with the results that growth activity in the apical regions become abnormal and the characteristic shape of the tobacco leaf is changed and the phenomenon is observed as frenching.

Methods

The several experiments with soil have been carried out by utilizing 2-gallon containers which fit into a constant soil-temperature apparatus (1). The seedling tobacco plants were first established in a healthy growing condition at a soil temperature of 21° C. No attempt was made to maintain a definite air temperature other than to set the thermodregulator so that the air temperature would not fall below 21° C. The changing of the soil temperature from low to high, or vice versa, was a matter of about 24 hours. All procedures were kept as simple and as uniform as possible in order not to burden the investigation with complications and uncertainties. Since it was established that the frenching would develop at a soil temperature of 35° C. and that normal growth was always obtained at a soil temperature of 21° C. these two temperatures constitute the high and low values unless otherwise specified. The experiments have been repeated several times for the purpose of checking on various features.

The total length of the apparatus is about 25 feet made up of 13 separate tanks. Light conditions differ slightly at either end of the apparatus, but it
was definitely determined it was only soil temperature that was involved in the production of frenched plants. The variety of tobacco, Nicotiana Tabacum L., used in the experiments was Havana Seed, a variety commonly grown in the Connecticut Valley for binder material in cigars.

The soil moisture was replenished with water from the tanks in which the containers were set, a procedure which did not alter the soil temperature. These tanks were lined with either galvanized iron or copper. The containers were galvanized iron. Thus there arose the question of either zinc or copper toxicity. It was, however, established that the nature of the material in the tanks or containers was not involved in the pattern of frenching.

For solution culture experiments it was possible to use the same tanks and their control mechanisms by inserting a temporary shelf to hold the quart preserve jars. Owing to danger of capsizing due to lightening of the jar by loss of water from transpiration it was not advisable to have the tank water level more than half the height of the jar. Temperature readings of the nutrient solution showed that this procedure was satisfactory in maintaining the desired temperature. The jars were in duplicate, one set having plants and the other set reserved for renewing the solutions by filling the jars and placing this reserved set in the tank for at least four hours to adjust the temperature of the solutions before the cultures were shifted. In this way fluctuating temperature were avoided.

**Experimental results**

**FRENCHING MASKS MOSAIC SYMPTOMS**

Tobacco was grown in a range of soil temperatures from 10° C. to 35° C. (50° F. to 95° F. with intervals of 5° F.). Half of the plants at each temperature were inoculated with a mosaic virus. Within a period of 12 days the mosaic symptoms were apparent on all inoculated plants. Gradually frenching symptoms developed at the soil temperatures of 32.5° C. and 35° C. on both the inoculated and uninoculated plants. The nature of the frenching symptoms was such as to obscure the mosaic symptoms (fig. 1). That the frenching did not destroy the virus was demonstrated by inoculating healthy plants with the juice of a frenched leaf from a plant previously inoculated with the virus. Keeping the plant at an ordinary greenhouse temperature, characteristic mosaic symptoms were again obtained, but the frenching features were absent. Healthy plants were similarly inoculated with the juice of a frenched leaf from a plant that had not been inoculated with the virus. Neither mosaic nor frenching symptoms became evident which proved that, since mosaic symptoms did not appear, the original uninoculated plant had not become contaminated by the virus. And, since frenching symptoms did not appear when healthy plants were inoculated with the juice of frenched leaves, it follows that the cause of frenching is not transmissible by the ordinary inoculating technique.
This experiment was supplemented by altering the soil temperatures by a complete reversal of the extremes of the range; i.e., the soil originally at 10° C. was raised to 35° C., and that which had been at 35° C. was lowered to 10° C. Since the high soil temperature of 35° C. had stopped terminal growth and the shift from 10° C. to 35° C. stopped terminal growth, the growth that developed after the shift came from the shoot development of axillary buds. The virus-inoculated plant developed a strong axillary shoot at the new soil temperature of 10° C., the succeeding leaves became more and more normal in shape and the common characteristics of the mosaic disease again became apparent. On the other hand, the plants which had been at the low soil temperature of 10° C. and were later subjected to a soil temperature of 35° C. developed fENCHING symptoms which completely masked any symptoms of mosaic in the inoculated plants. The uninoculated plants at this new temperature of 35° C. also developed equally good fENCHING symptoms.

These experiments demonstrated that the particular fENCHING obtained at the high soil temperatures was independent of the mosaic virus; that it did mask the symptoms of the mosaic virus but did not destroy its virulence.

Fig. 1. Tobacco leaves from plants inoculated and uninoculated with a mosaic virus and grown at the two soil temperatures of 70° F. and 90° F. At right mosaic is masked by fENCHING.
SOIL TEMPERATURE EFFECTS ON FRENCHING

Exploratory experiments demonstrated that frenching would occur in plants at a soil temperature of 35°C and that it never occurred when the soil temperature was 21°C. For convenience in obtaining a sufficient number of replications these two temperatures were preferred to a range of temperatures. As experience in observation of frenching increases, the symptoms are apparent earlier, and such information regarding the length of time to induce frenching must be considered as a longer time interval than was actually the case. The longest interval was 58 days while the shortest was eight. Careful and frequent observation showed that the first symptoms of frenching could be seen as a pin-head chlorosis of a young leaf. This usually became apparent on a morning after observation had shown that such leaves were developing in a normal manner with a normal green color. The disease became more apparent with a greater degree of chlorosis in succeeding leaves, and these succeeding leaves developed with less width, narrowing to a strap-leaf type and then by intermittent stages to the filform shape.

In general, a compost soil was used, since this soil always produced frenching. When two soils from tobacco fields were run parallel with the compost soil the frenching symptoms developed later than in the compost soil and of the two field soils one was 38 days later than the other in producing the frenching symptoms. Respectively, these three soils, compost, field A, and field B, induced frenching in 11, 20, and 58 days under the same experimental environment at 35°C soil temperature. The same soils at 21°C failed to show any signs of frenching.

In any of the experiments thus far performed, it has not been possible to distinguish a clear-cut division between normal and frenched leaves. There appear a series of gradations which gives the impression that a series of physiological reactions takes place during the development or complete elimination of frenching symptoms. While these reactions are slowly taking place new leaves are forming and developing with increasing or decreasing symptoms of frenching. Such a series of lessening symptoms was obtained by shifting to 10°C a soil which had been at 35°C. The plant was well frenched at the top which had lost dominance so far as shoot elongation was concerned. This can be observed in fig. 2 which shows the frenching of leaves obtained at 35°C. (no. 1). At 10°C the axillary shoot (nos. 2–3) developed the leaves being quite frenched at the base of the shoot (no. 2) and becoming less frenched as time and distance increased to point no. 3.

On the other hand a plant grown at the soil temperature of 10°C had normal wide leaves (no. 1 in fig. 3). At 35°C the plant lost dominance in its growing tip where a rosette of frenched leaves, (no. 2) developed. Axillary shoots bore leaves which were decidedly frenched (no. 3).

There was one other way by which the effect of soil temperature
expressed itself by altering the shape of the leaves. Two sets of plants growing in soil respectively at 21° C. and 35° C. were cut back, the soil nitrogen renewed by an application of fish meal, and the soil temperatures reversed. So-called sucker leaves developed and 11 days later these leaves had all the characteristics that had been associated with the soil temperatures before they were reversed. Three days later, i.e., 14 days after shifting, the new or reversed temperatures began to express themselves. The sucker leaves which had started with signs of frenching were so immature that the new temperature of 21° C. was able to express itself by blunting of the apical ends as if an effort was being made to assume a normal width.
basal ends continued to remain narrow, giving the impression that, because of the maturity of these cells, the tissues were fixed and the morphology in this region could not be altered. The suckers eventually elongated to form axillary shoots and at the end of the experimental period, 65 days, of the shifted temperatures the lower leaves, which were formed under the influence of the high soil temperature of 35° C. were frenched, while the upper leaves formed under the influence of the low soil temperature of 21° C. were, to all appearances, quite normal.

Likewise, the same time lag of 14 days was evident in the development of frenching symptoms on sucker leaves of plants which had been grown at 21° C., topped, and shifted to the higher soil temperature of 35° C. The first leaves that developed were normal, but after the 14-day interval there appeared the first symptoms of frenching, i.e., pin-head chlorosis on the newer leaves. As time went on and these axillary shoots elongated the lower leaves remain normal, but the symptoms of frenching became accentuated in succeeding leaves beyond those that first showed the pinhead chlorosis.

These experiments demonstrate that there is a pattern of the physiological disease of frenching of tobacco related to soil temperature. In general, a soil temperature of 35° C. will induce frenching, but a soil temperature of 21° C. will not induce it. This latter temperature will also
cause the failure of frenching symptoms, on a frenched plant, to appear on leaves developed after the soil temperature has been altered from the high of 35° C. to 21° C. This general statement should be qualified with the knowledge that the appearance of symptoms, as well as the failure of symptoms to appear, is subject to a time lag. That this pattern can be altered by air-drying of soil will be reported in another section of this paper. This pattern was not altered by the addition or withholding of applications of nitrogen, although there were cases where the intensity of the symptoms was mitigated when nitrogen was applied. Since most of the experiments were carried out with a compost soil which is a mixture of good top soil with animal manure and consequently of a high level of fertility there was little gain to be expected from the addition of nitrogen which was proved when such applications were made.

A discussion of the nitrogen factor as well as some other factors that altered the pattern of the onset of the disease will be considered in another part of this paper. The point involved is that soil temperature can play an important role in inducing the disease. However, temperature is not a substance that can enter into the composition of matter as a tangible constituent. Its function is of a regulatory nature. Any demonstration that results in altering the pattern to any considerable degree should give a basis for understanding what factor, or factors, is involved in the regulating effects of temperature and lead more directly to the true cause of frenching.

**Varietal susceptibility to frenching**

Although Wolf (19) recognizes that “all varieties of cultivated tobacco are susceptible to frenching” it was deemed desirable to check the variety used in these experiments (Havana Seed, a cigar tobacco), against a variety not commonly grown in the Connecticut Valley. Plants of the variety, Yellow Mammoth, a cigarette tobacco, were grown from seed obtained from Georgia. Both varieties were grown at the two soil temperatures of 35° C. and 21° C. The first frenching symptoms, pinhead chlorosis and recurved leaves, were observed on both varieties in eight days at the higher soil temperature. Thirteen days later terminal growth of the main stalks had apparently stopped and rosetting at the tip was well established with many small leaves appearing at the same time. Fig. 4 shows the condition of the plants 34 days after the experiment was started. It was interesting to note that the symptoms of frenching developed within the same time interval on both varieties and were equally intensified as the time period increased. No frenching symptoms were observed on either variety grown at the lower soil temperature of 21° C. It would appear that any frenching symptoms observed on the variety Havana Seed used as an indicator plant in these experiments will probably hold for other varieties as the Havana Seed is not a variety more susceptible to frenching than Yellow Mammoth.
FIG. 4. Showing frenching symptoms on two varieties of tobacco. Havana Seed (HS) and Yellow Mammoth (YM).

**Solution culture for frenching symptoms**

The almost unfailing procedure of obtaining frenching by a soil temperature of 35° C. and the experimental results indicating that excesses or deficiencies of mineral elements were not involved prompted the suggestion that temperature might exert its influence on the metabolic processes taking place in the roots. If soil temperature could be narrowed down to root temperature the problem of the cause of frenching might also be narrowed. Consequently tobacco plants were grown by solution culture technique, using Shive's R₃S₇ (9) as a basic formula for a nutrient solution. The same two temperatures of 35° C. and 21° C. were used and obtained by placing a platform in the water bath. The results were negative.

Even the introduction of soil extracts from soils containing frenched plants failed to produce frenching of plants growing in a nutrient solution with a solution temperature of 35° C. The extracts were made by shaking the frenching soil with about twice its volume of distilled water and passing the extract through filter paper. Shear (8) obtained frenching of tobacco grown in sand cultures by using the leachings from a soil that produced frenching. Wolf (19) tried the same experiment with three soils known to produce frenching and although he failed to obtain frenching with the leachates, he did obtain frenching on the check plants on which he used distilled water. Shear's (8) results prompted him to conclude that frenching is a toxicity disease and not a deficiency disease.

Solution culture tests were made by exploring several possibilities. The NH₄-ion was introduced by ammonium sulfate and various proportions of the NH₄-ion and the NO₃-ion (from calcium nitrate) were tested. The NH₃-
ion from ammonium hydroxide was tried in the absence of the NO$_2$-ion, the calcium being obtained from calcium chloride. The nitrite radical from sodium nitrite was tested in the absence of the NO$_3$-ion. Iron from ferrous and ferric compounds failed to induce symptoms of frenching in solution culture. The only evidence of symptoms of frenching was obtained by leaving iron out of the culture solution. At the end of the experimental period of 44 days the minus iron cultures showed narrower leaves, a slight general chlorosis, wavy margins, greater turgidity, and a slight stunting.

**Effect of zinc, copper, calcium, and boron**

The tanks for maintaining constant soil temperatures were lined with either copper or galvanized iron and the containers in which the plants were grown were of galvanized iron. This suggested that, at the higher temperature, 35° C., copper or zinc ions might have some influence on frenching. Copper or zinc ions could come from the tank water which, because it was at the same temperature as the soil in the cultures, was used to replenish the water supply of the soil in which the plants were growing. Zinc ions were common to all the containers since they would be in contact with the soil from the galvanized iron of the containers.

Calcium and boron ions were considered along with copper and zinc, more as an exploratory experiment than with the thought that they are important in the frenching of tobacco. Wolf (19) observed severe frenching of tobacco where limestone had been used on a field. Plants grown on the strip where the limestone was applied had previously always been normal, and the areas adjacent to the limed and frenched strip grew normal tobacco plants.

Some of the symptoms of boron deficiency are not so unlike symptoms of frenching as to be entirely excluded from consideration. McMurtry (4) noted the yellow color and leaf distortion when there is a deficiency of boron. Lack of boron prevented the setting of seed pods, but in this investigation failure to set seed pods was not apparent with frenching induced by soil temperature. To isolate the soil from contact with galvanized iron, thereby eliminating contact with zinc, one-gallon glazed crocks were set into the two-gallon galvanized containers and surrounded with water. This amounted to a double water bath, the temperature of the smaller one controlled by the larger. Ordinary tap water was used for replenishing soil moisture, but this was heated to the required soil temperature before it was applied.

The exclusion of copper and zinc ions from the soil did not alter the pattern of the onset of frenching, for frenching appeared on plants at the high soil temperature of 35° C. and did not appear at the lower soil temperature of 21° C. By reversing the soil temperatures the new growth on the frenched plants developed without frenching characteristics and the nonfrenched plants became frenched when the soil temperature was raised from 21° C. to 35° C. When calcium hydroxide was added to the soil the plants showed
benefit in the form of better growth, but in no way was there an alteration in the pattern of temperature-induced frenching.

The results with boron were slightly different, borax being the source of the B-ion. The application was a little too heavy as some of the plants were killed shortly after being transplanted into the soil. Replacements usually lived, but frequently the leaves had burned margins and interveinal areas. Frenching later appeared according to the pattern of soil temperature influence. Delay in appearance of frenching symptoms may have been due to the slow growth of the plants caused by toxicity from too much borax, or the borax may have affected some biological activity in the soil. Reversing the soil temperatures resulted in the elimination of symptoms on new growth and the appearance of symptoms on the original nonfrenched plants.

**SOIL REACTION RELATIONSHIPS**

Wolf (19) gives an adequate review of the literature concerning the observations and experiments with the frenching of tobacco and hydrogen-ion concentration of the soil. In general, the evidence shows that as the pH values of the soil approach the neutral point of 7.0 frenching symptoms are commonly found earlier than on more acid soils. The acidification of the soils by acids delayed frenching but an application of sulfur to a soil one year in advance of setting the plants seemed to have eliminated frenching on this soil while the plants in the adjacent area developed frenching symptoms.

Although soil reaction may possibly be altered by high temperatures, there was no evidence that frenching induced by soil temperature was traceable to a soil reaction relationship. A compost soil which produced frenching in eight days at a soil temperature of 35° C. was sampled from two containers in two water baths. One soil had a pH value of 5.1, the other 4.9. Similar samples were taken from check containers at 21° C.—a soil temperature that does not produce frenching—and these had pH values of 5.1 and 4.95.

In another case in which two field soils were tested parallel with the compost soil there appeared no differences in pH values of the same soil at the different temperatures, but there were differences between soil.

<table>
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<tr>
<th>Soil</th>
<th>Days to french</th>
<th>pH value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>17</td>
<td>5.6</td>
</tr>
<tr>
<td>Field (A)</td>
<td>28</td>
<td>4.6</td>
</tr>
<tr>
<td>Field (B)</td>
<td>58</td>
<td>4.45</td>
</tr>
</tbody>
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Though frenching is apparently delayed by a greater hydrogen-ion concentration in the soil, the fact remains that its appearance was associated with a high soil temperature.

**SOIL MOISTURE RELATIONSHIPS**

The growing of plants in nonporous containers was attended with the problem of maintaining suitable soil moisture. Not only did soil tempera-
ture play a significant role in loss of water, but the size of the plant became an important consideration. The vagaries of New England weather, even with greenhouse culture, do not allow advance planning for water replenishment. Since it was not convenient to remove the containers for the purpose of adding water by weighing, the best system was to add water daily on the basis of judging what would be sufficient for a 24-hour period. When the plants were large the water was frequently added twice daily since the whole amount in one application might cause injury by saturating the soil.

There were occasions when the soil seemed relatively dry, although the plants were seldom observed to be in a wilted condition. Such dry soils were always at the high soil temperature of 35° C. This is the temperature that induces frenching symptoms. Several times following the drying of the soil new growth exhibited less severe symptoms of frenching. Such plants could always be thrown back to more intense symptoms of frenching by more frequent and copious watering.

The drying of the soil as a preventive of frenching was tested. A fresh sample of field soil was obtained, divided into two portions, one of which was kept moist and the other air dried. This field soil was used parallel with a compost soil which was known to produce frenching at the high soil temperature of 35° C. In this experiment the compost soil produced frenching in 20 days and the moistened field soil in 24 days, but the air-dried portion of field soil did not produce frenching within the experimental period of 67 days. All soils were at the temperature of 35° C.

Wolf (19) made a similar observation concerning the inability of three sandy soils to produce frenching after storage in a greenhouse for a few months. On the other hand, he reports that two clayey soils did not lose the frenching quality after a year in storage. He further noted that Schweizer (7) dried frenching soils in the sunlight thereby nearly eliminating frenching symptoms when later tested. Schweizer interpreted these results as indicative of the presence of a toxin as the cause of frenching.

**Nitrogen Relationships**

Valleau and Johnson (17) made an exhaustive study with various inorganic and organic nitrogenous substances as a cure for frenching. They had observed that frenching followed nitrogen deficiency symptoms, and for the most part, obtained complete recovery of plants by applying nitrogen after the onset of frenching. Spencer (10) controlled frenching by repeated applications of a nitrogenous fertilizer. Shear (8) obtained recovery of frenching plants after adding nitrogen to the soil.

In these experiments, in which frenching has been induced by soil temperature, nitrogen, added to the soil, has not effected any cure nor prevented the appearance of frenching symptoms. Fish meal plus a little potassium nitrate has been the source of nitrogen. On some plants
it was noted that the quite yellow frenched leaves assumed a darker color after an application of nitrogen, but the new growth continued to show all the symptoms of frenching. Nitrogen was frequently added to the soil, since it was part of the experimental program to maintain a fairly high level of this nutrient. Leaf tissue tests for nitrates were made with diphenylamine (2, 6). These tests showed that the plants were not deficient in nitrogen. Check plants, purposely starved, gave negative tests for nitrates, thereby demonstrating that the chemicals and procedure were not at fault.

In one experiment one half the plants were allowed to exhaust the soil of nitrogen. The other half had the nitrogenous fertilizer added to the soil at two-week intervals. The added nitrogen had no effect on the height of the plants at the high soil temperature of 35°C. because the frenching interfered with growth. At the lower temperature of 21°C., where frenching was absent, the added nitrogen materially increased the size of the plants. Frequently the tests for nitrates showed up more strongly in the tissues of frenched plants. This indicated an ability of the plant to absorb nitrogen, but an inability to transform such nitrogen into protein materials.

Discussion

Although it has been possible to demonstrate with a compost soil that a relatively high temperature, 35°C., will consistently induce frenching of tobacco, no claim is made or implied that temperature is the primary cause. Whatever the primary cause may be, the results of this investigation strengthen the conclusions of other investigators who believe the primary cause to be a soil constituent. The fact that frenching may be induced by raising the soil temperature, and normal growth resumed by lowering the soil temperature, without the addition or subtraction of any soil constituent, other than water, strongly indicates that the ability of a soil to cause frenching is a latent quality which can and does become active under the impetus of exciting agents which are unrelated, but which produce a common end point, the primary cause of frenching.

Temperature is not a constituent. Its role can be only that of regulating physico-chemical reactions or influencing some biological activity of soil flora. This latter speculation is supported by the evidence that, even at a high soil temperature, plants develop growth less symptomatic of frenching in soil on the dry side than in soil with a high moisture content. Air drying of the soil also rids the soil of frenching potentialities. While it is possible to interpret this information as suggesting the presence of a toxin which might come from biological activity, it also suggests that such biological activity could cause a competition between soil flora and higher plants for certain nutritive requirements. Soil temperature could alter the balance of soil flora which, to a great extent, affects the rate of mineralization and the amount of elements available for nutrition of higher plants.
Summary

1. Tobacco plants were grown in a compost soil in a constant soil temperature apparatus. Frenching was induced at the high soil temperature of 35° C. and was absent at the soil temperature of 21° C. or lower. Frenching symptoms masked the symptoms of a mosaic virus, but did not destroy its virulence. It was not possible to transmit frenching symptoms by the ordinary technique of inoculation.

2. The first symptoms of frenching appear as a pinhead chlorosis and a narrowing of the developing leaf. In one case the symptoms appeared as early as eight days in the soil temperature apparatus and in another case as late as 58 days, induced by the high soil temperature of 35° C.

3. Altering the soil temperature from a high 35° C. to 21° C., or lower, caused a progressive lessening to complete disappearance of frenching symptoms on the subsequent growth of the plant.

4. There was a considerable time lag between the exposure to soil temperature and the appearance or lessening of the frenching symptoms.

5. The variety Yellow Mammoth (a cigarette tobacco) and the variety Havana Seed (a cigar tobacco) were equally susceptible to temperature-induced frenching.

6. Plants grown at a root temperature of 35° C. by solution culture technique failed to develop symptoms of frenching. Nutrient solutions into which filtered water extracts from frenching soils were introduced failed to show that the cause of frenching could be transmitted by this procedure.

7. Slight symptoms of frenching were observed when iron was left out of the nutrient solution.

8. The elimination of copper and zinc ions from the applied water did not alter the pattern of temperature-induced frenching.

9. Calcium hydroxide benefited the growth of tobacco plants but had no apparent influence on the onset of frenching.

10. Borax affected growth and delayed the onset of frenching but did not affect the pattern of the temperature influence.

11. There was no relationship between the pattern of frenching induced by soil temperature and soil pH values, but it was confirmed that lower pH values delayed the onset of frenching symptoms.

12. Air drying of a soil destroyed its ability to produce frenching symptoms. Growing the plants in a soil with a lowered average moisture content lessened the symptoms of frenching on new growth.

13. The addition of a nitrogenous fertilizer in the form of fish meal reinforced with potassium nitrate failed to prevent or cure frenching induced by a soil temperature of 35° C.

14. Plant tissue tests for the nitrate ion gave positive results on frenched plants. The qualitative tests were more intense with frenched plants than with nonfrenched plants, which indicated an ability on the
part of the frenched plant to absorb nitrogen, but an inability to transform all the nitrogen to protein materials.

The seed of the cigarette tobacco variety, Yellow Mammoth, was supplied by J. G. Gaines, Associate Pathologist, Division of Tobacco Investigations, U.S.D.A., B.P.I., at Tifton, Ga.

LITERATURE CITED


