STEM LESIONS CAUSED BY EXCESSIVE HEAT

By CARL HARTLEY

Pathologist, Investigations in Forest Pathology, Bureau of Plant Industry, United States Department of Agriculture

WHITESPOT INJURY

During work on the damping-off disease of pines (*Pinus* spp.) in 1909 the writer noticed in a nursery at Halsey, in the Nebraska sand hills, a type of disease closely corresponding to the old published descriptions of damping-off. The stems of very young seedlings developed shrunken areas at the soil surface. Commonly the entire stem was constricted by the lesion, the seedling fell over, and died. The writer has previously referred to this type of injury as "whitespot" (*4, p. 5*).[1] Close examination showed that this trouble differed in several ways from the type of damping-off which the writer and assistants have produced by inoculation with common pine-seedling parasites (*Pythium debaryanum* Hesse, *Corticium vagum* B. and C., and species of Fusarium). The primary whitespot lesions were in all cases limited to the stems, and usually just above the ground line. The whitespot lesion is very light in color, and this characteristic color continues to the very edge, making a sharp line of demarcation from the healthy tissue. Lesions may continue definitely limited for some days, and the upper stem and cotyledons remain turgid. In this early stage most cases of whitespot injury are easily distinguished from damping-off. Typical damping-off in porous soils is primarily a rootrot, which may attack above the ground line, but which more commonly attacks below. Damping-off lesions caused by any of the above-mentioned fungi or by *Botrytis cinerea* vary in color at different stages, gradually shading into the tissue still unaffected, and progress continuously both upward and downward.

This whitespot injury was at first supposed to be merely a special type of damping-off. Cultures made from the whitespot lesions failed to develop regularly any recognizable parasites, while most of the parallel cultures from lesions of the rootrot type yielded *Pythium debaryanum*. *Alternaria* sp. was the only fungus commonly obtained from the white spots.

Further examination showed that, in cases where whitespot lesions affected one side of the stem only, it was nearly always the south or southwest side. On seedlings which had been girdled, the lesions, if at all asymmetrical, extended higher on the south than on the north side. The south margins of the seed beds, imperfectly protected by the shade

[1] Reference is made by number (italic) to "Literature cited," pp. 603–604.

frames, contained more whitespot lesions than other parts of the beds. In a single bed left entirely without shade, most of the seedlings died from whitespot. These observations indicated insolation as at least a contributory cause of whitespot injury. The nursery practice involved as little watering as possible during the damping-off period. In plots given somewhat more frequent watering than the general beds, subsequent counts showed only three-fifths as much whitespot injury as elsewhere. During the three succeeding years, the nurserymen gave the seed beds much more frequent watering and more careful shading than in 1909. In careful examinations during these three years only occasional cases of whitespot were found.

The foregoing data all pointed to a physical rather than a parasitic cause for whitespot injury. Heat and light were the physical factors toward which suspicion was directed. The temperature in the surface layer of soil in the seed beds, even under the half-shade of the lath frame, was found to go as high as 52° C. The apparent preventive effect of frequent watering was believed to be due to the lowering of the soil temperature.

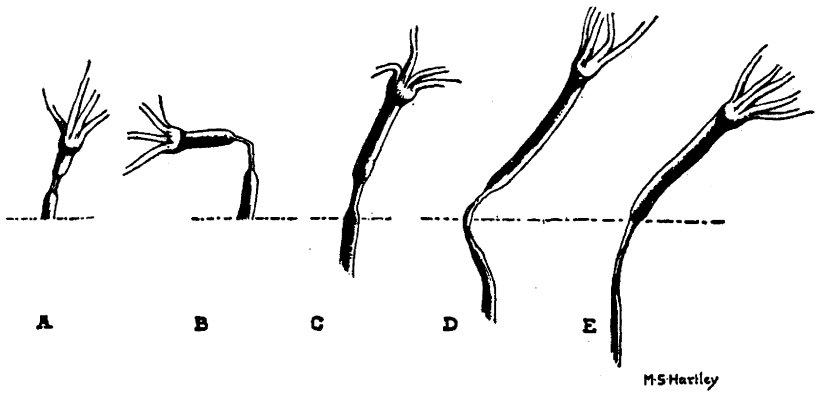

FIG. 1.—Lesions on seedlings of *Pinus ponderosa:* Seedlings A and D were injured by the sun's rays condensed by a lens. B was injured by a hot wire, C by an incandescent lamp, and E by the direct sun. The leaves remained turgid for 5 to 11 days after the lesions were produced. The horizontal line indicates the location of the soil surface at the time the seedlings were subjected to heat. Natural size.

In tests conducted at Washington, D. C., with seedlings of *Pinus ponderosa* typical whitespot lesions have been artificially produced. Five representative experiments are described in the following paragraphs and are illustrated in figure 1.

SEEDLING A.—The stem was subjected for less than two minutes to sunlight passed through a condensing lens at the point indicated by the constriction. The stem immediately collapsed and bent over at the point of the lesion. The soil around the root at the time was dry, and the seedling was distinctly wilted before it was heated. Later the pot was watered, and the seedling restored to a nearly vertical condition by propping. Turgor returned and was maintained for a week, but was followed by the decay of the root and wilting of the plant without extension of the original lesion (fig. 1, A).

SEEDLING B.—A heated wire held 1.5 mm. to the right of the stem for five minutes resulted in the lesion shown in figure 1, B. The plant remained turgid for 11 days and a whorl of new leaves appeared. The stem at the soil surface then decayed, apparently from a root infection, bearing a mat of pink spore masses.

SEEDLING C.—A Mazda incandescent lamp placed beside and slightly above the seedling for nearly two hours killed the tips of the cotyledons and produced a lesion just above the soil surface, without perceptible injury to intermediate tissue. In its location this lesion was thoroughly typical of those commonly found in the seed beds. Five days later fungus hyphæ appeared on the lesion, and the stem broke over at that point. The lesion then progressed both up the stem and into the root, and the seedling wilted. Spores of *Alternaria* spp. were promptly produced on placing the seedling in moist chamber (fig. 1, C).

SEEDLING D.—The stem and surrounding soil were subjected for three minutes to sunlight through a condensing lens, striking both the stem and soil surface at angles of about 45°. The resulting lesion extended about 3 mm. below the soil surface and 4 mm. above it. Mechanical support was required to keep the seedling from falling. Hyphæ soon appeared on the lesion at the soil surface, and in eight days after treatment wilting occurred, a species of Alternaria fruiting on the lesion in moist chamber (fig. 1, D).

SEEDLING E.—On a hot day, seedlings planted in loam in a 3-inch pot were placed immediately south of a brick wall. At night the seedling shown in figure 1, E, and another seedling were leaning slightly, but were apparently uninjured. An examination of the underground parts showed that these were distinctly shriveled from the soil surface to a point 10 mm. below; a third seedling in the pot, still erect and normal in appearance, was also constricted just below the soil surface. The plants were repotted and kept under observation. The tops of all remained entirely healthy for several days. At length the lesion began to extend up the stem, and on the eighth day wilting occurred. The entire root and 10 mm. of the stem above the soil line had become involved in the original lesion. Spores of species of Dactylosporium, Alternaria, and Fusarium appeared on the lesion in moist chamber.

Numerous seedlings of the same original lot were kept in the same room as the seedlings listed above during the period of the tests. None developed lesions which could have been mistaken for whitespot.

In all of the seedlings whose stems were heated directly the lesions were at first a dark grayish green, changing in 24 hours to the light color and shriveled appearance characteristic of whitespot lesions on seedlings in the nurseries. The immediate darkening is supposed to be due to the filling of the intercellular spaces with cell sap, while the ultimate light color presumably indicates the loss of liquid from both the intercellular spaces and the lumina of the cells and its replacement by air. In all cases the lesions remained definitely limited for several days, and were then extended, apparently as a result of infection by fungi not commonly capable of attacking uninjured plants. It appeared that in most cases neither the heat nor the fungi later entering the lesions stopped conduction or evolved toxins in sufficient quantity to cause the death of the leaves, as reported for another plant by Overton (*11*). Wilting finally occurred, it is believed, only when fungi entering at the lesion or at some point below it had penetrated the absorbing portion of the root. It may be remarked that in many cases of damping-off caused by the

ordinary seedling parasites, wilting probably occurs only after the absorbing portions of the root are invaded by the parasite.

The limitation of the whitespot lesions to the stem just above the soil surface in seedling C and in most of those observed in the nurseries, indicates that the combined radiation from the heated soil and from the sun direct ordinarily results in a temperature in the stem at that point higher than the temperature in the surface soil. In an experiment not described above, in which the source of heat was directly above the seedling, the lesion was, as might be expected, just below the soil surface rather than above it. The pot containing seedling E was also so placed that the sun's rays were more nearly perpendicular to the soil surface than in level seed beds, with the same result. It is probable that in at least some cases heat lesions will occur in the nurseries partly or entirely below the soil surface, as in seedlings D and E. It will be impossible, by any ordinary method of field observation, to distinguish from damping-off cases such as that of seedling E. Both the angle of the sun's rays, and the absorbing, conducting, and radiating capacity of the soil and of the stem will, of course, help determine whether the stem will be hottest above or just below the soil surface.

Münch (*8*, *9*) has described the same type of injury to tree seedlings in Germany, attributing it positively to heat at the soil surface. With a thermometer having a thin, flat bulb he obtained very high temperatures in the surface soil (*10*). Others have also reported surface temperatures in unprotected soil from 55° to 68° C., or even higher (*2*, *p. 55*; *7*, *p. 13*; *12*; *17*). Münch made an incubator test in which coniferous seedlings survived for two to three hours at temperatures not exceeding 52°, but were killed by maxima of 54° to 55° C. This seems in general to agree with the temperatures reported as being fatal to most growing plants.

Typical whitespot injury to seedlings has been found in several different States, though nowhere has it been observed to cause as heavy losses as at the Nebraska nursery, where it was first seen. Whitespot is not limited to conifers. In the vicinity of the Nebraska nursery an examination of fields of rye (*Secale cereale*) and cowpeas (*Vigna sinensis*) showed that both were affected in the seedling stage in much the same way as the pines. In the cowpeas the localization of the white, constricted lesions just above the soil surface was very marked. Plate cultures yielded no fungus suspected of parasitism. The rye seedlings were affected in the same way, though constriction was less in evidence than in the more fleshy plants. The relation between the disease and exposure to sun was very evident in the case of the rye. In the level portion of the field a moderate proportion, perhaps 5 per cent, of the shoots were affected. Where a dead furrow crossed the field from east to west this uniform distribution of disease was broken. On the wall of the dead furrow having a north exposure the disease was not noticeable.

On the other wall, exposed to the south, the percentage of affected shoots was much greater than on the level surface of the rest of the field. Wind action was not excluded as a possible cause of the cowpea lesions, but the protected location of the nursery, so far as south winds are concerned, made the evidence rather conclusive that insolation rather than wind was responsible for the lesions on the rye. Münch (*8*) reports whitespot on maple, vetch, and peas, and believes that in some cases germinating seeds, as well as seedlings which have already broken soil, are killed by overheated soil.

Whitespot is not always fatal, even when the lesion girdles the stem. Two seedlings of *Pinus ponderosa* which had been girdled by definite whitespot lesions, slightly shrunken but not severe enough to cause breaking over, were marked for later observation. At the end of the season the lesions had disappeared and the plants seemed in every way normal. In leaf lesions due to heat, Sorauer (*15, p. 638*) has after several weeks observed a regeneration of chloroplasts in slightly affected tissues.

All things considered, whitespot lesions are believed to be caused mainly by excessive heat. While light as such may possibly take part in some cases, it evidently does not enter into all cases of injury. The relative unimportance of light as distinguished from heat is indicated by the numerous lesions under slat frames, the extension of all serious lesions to the north sides of stems, and the experimental production of lesions below the soil surface (seedlings D, E, and others). The preliminary experiments here reported were mostly at excessive temperatures, and absolute proof that heat alone is the cause of the common lesions in the seed beds must await further experiments at temperatures which more commonly occur in nature.

BASAL LESIONS ON SEEDLINGS SEVERAL MONTHS OLD

A type of trouble which is probably related to the whitespot described in the foregoing was observed in 1915 in the seed beds of a nursery of the United States Forest Service, located at an elevation of 7,300 feet in the Wasatch Mountains, Utah. The plants affected were spruce and Douglas fir which had been raised from seed the preceding year. They had made a normal height growth during their first season and remained green throughout the winter under a heavy coating of snow which covered them for more than five months. Two or three weeks after the snow melted many of the seedlings began to turn yellow and ultimately died. Examination showed dead bark, beginning at the soil surface and extending up the stem from 3 to 9 mm. In many cases the lesion extended farther up the stem on the south than on the north side, and on some seedlings lesions were found which were entirely limited to the south side of the stem, and had started to heal over from the edges. In no case was there found any such swelling above the lesion as occurs above stem-girdle lesions on older stock. In many of the advanced cases the cortex

from the base of the stem was partly or entirely gone. Careful examination, however, indicated that even these lesions could not be attributed to any biting insect. The affected seedlings were distributed rather evenly over the beds, but in no case were any diseased plants found immediately north of posts, or on the north exposed slopes at the ends of beds, where the seedlings were somewhat protected from the sun during the hottest part of the day. Spruce, a more shade-loving tree than Douglas fir, also suffered more from the disease. The observations made indicate that the death of these seedlings was due to whitespot lesions occurring during the latter part of the preceding summer. The altitude of the nursery at first thought renders it improbable that excessive heat should have been concerned in causing the injury. While, of course, the temperature of the air at such elevations is never very high, the heat of rocks and gravel exposed to the sun at high altitudes is well known. Tubeuf (*17*) reports a surface soil temperature of 60° C. (140° F.) at an elevation of 10,000 feet in Yellowstone Park, 200 miles directly north of the Wasatch region.

BASAL STEM-GIRDLE ON OLDER STOCK

Münch and others (*5, 7, p. 13; 12, 13, p. 397; 14, 15, p. 638*) have further attributed to excessive surface temperatures of the soil the "*Einschnürungskrankheit*," or stem-girdle, of older nursery stock or young forest trees of both conifers and broad-leaved trees. Dr. B. T. Galloway, of the Bureau of Plant Industry, told the writer that he had found basal lesions on young willows at Chico, Cal., which he attributed to excessive heat. In conifers this disease involves death of the base of the stem of 2-to-4-year-old seedlings and transplants. Lesions are definitely limited, and the swollen growth of the stem just above the lesion, which results from the girdling and interference with food movement, gives an appearance of constriction at the lesion itself. This disease is figured by Tubeuf (*16, p. 492*) and ascribed to *Pestalozzia hartigii*. Hartig (*3*) had originally ascribed it to the freezing of thin pools of water standing on the surface of the beds. The parasitism of *P. hartigii* has failed of confirmation (*1*), and Tubeuf (*17*) now seems to favor the view of Münch, that heat of the soil is responsible. This disease has been found at widely separated points in the United States. The writer has seen what appeared to be stem-girdle on two species of the white and three of the pitch pines, two spruces, *Abies concolor* (Gord) Parry, *Pseudotsuga taxifolia* (Poir.) Brit. *Thuja* sp., and *Juniperus* sp.[1] Its appearance and its ability to attack representatives of so many different genera favor a nonparasitic diagnosis. The thicker cortical tissues of the woody stems should make the cambium slower to reach maximum temperature, and prevent quite as high a temperature being reached, as in the case of the younger stems,

[1] Several of these observations as to coniferous species affected were communicated by Dr. J. V. Hoffman, of the Forest Service, and confirmed by the writer's examination of his specimens.

which are subject to whitespot. It is worthy of note that no cases of stem girdle have been found in four seasons' examinations of the Nebraska nursery at which whitespot has been so frequent. The heat hypothesis nevertheless seems the best explanation of stem-girdle so far offered. Tubeuf's experiments with warm water (*18*) are of interest in this connection as indicating that moderately high, long-continued temperatures do not necessarily kill simply by their drying effect, as has sometimes been claimed.

LESIONS ON UPPER PARTS OF STEMS

Older 2-needled pines and herbaceous plans as well have been observed by the writer to develop typical shrunken, definitely limited whitespot lesions on young growth of the upper parts of their stems, usually at points where an abnormal bend had made the surface nearly perpendicular to the sun's rays. Such lesions seldom girdle stems, and are rarely, if ever, of economic importance.

In the case of *Pinus strobus* the unusual amount of attention which pathologists have given it in the last two years has resulted in the finding by blister-rust scouts at five different places of yellowish lesions on young stems, sunken, and in all or nearly all cases limited to one side of the stem. Sections made by Dr. R. H. Colley, of the Bureau of Plant Industry, showed a collapsed condition of the tissues, but with absence of mycelium. Observations on these lesions in northern Wisconsin by Mr. R. G. Pierce, of the Bureau of Plant Industry, showed that practically all occur on the upper sides of bent shoots or on the west sides of vertical shoots, though a single case was found on the north side. The greater number of the affected plants were on the west sides of the nursery beds.

Most of these lesions are presumed to be due to heat. In the few cases in which soft young shoots of *Pinus banksiana* have been found girdled and bent over at the point of the lesion, mechanical bending is also suggested as a possible cause.

LESIONS DUE TO EXCESSIVE BENDING

Following cold weather with high winds, pine seedlings 1 to 2 weeks old have been found with white constricted basal lesions in some ways not like those produced by heat. There is reason to believe that these are due to the constant bending in high wind, at length causing the collapse of the cortical tissues without the stress being sufficient at any one time to rupture the epidermis or break the fibrovascular bundles. This is apparently an analogous case to the death of tissue between the veins of sugar maple leaves exposed to storm (*6, p. 27–28*). A few cases of lesions on shoots of older pines have already been mentioned as possibly the results of mechanical bending rather than of heat, and it is entirely possible that the whitespot lesions observed on cowpea seedlings should

be attributed to bending rather than to heat. Basal stem-girdle lesions found on 4-months-old wild olive seedlings (*Elaeagnus* sp.) and characterized by very slight vertical extension may be due to excessive bending. However, stem lesions caused by bending without breakage are not believed to be common enough to give rise to serious confusion with those caused by heat.

PREVENTIVE MEASURES

Assuming the correctness of the hypothesis that most of them are caused by heat, the logical procedure for preventing whitespot and the basal lesions on older stems is to avoid soils especially liable to overheating, and in established nurseries where trouble occurs, to artificially prevent heating. Soil with loose texture or dark surface is presumed most likely to overheat at the surface. Shading and frequent light watering have already been found helpful in preventing whitespot. Encouraging free air movement and artificially compacting the soil to increase its conducting capacity have been suggested as having prophylactic value.

SUMMARY

(1) Very young seedlings of conifers and certain other plants were found dying in large numbers in a Nebraska nursery from a disease which, because of its characteristic lesions, the writer has called "whitespot." The trouble has been found, though less commonly, in other localities. It is distinct from the common damping-off disease, but resembles it so closely that it is very likely to be confused with it. The lesions do not seriously interfere with the upward movement of water.

(2) The location of the whitespot lesions on the stems, their observed relation to insolation and to dry surface soil, and the production of typical lesions by artificial heating, indicate excessive heat as the cause of most of the whitespot trouble.

(3) The observation in the surface soil in the seed beds in question, and by other investigators in other places, of temperatures well over 50° C., with reported maxima as high as 68°, further substantiates the hypothesis that whitespot is due to excessive heat.

(4) Killing lesions on stems of older conifers ranging in age from several months to 4 years, are also attributed to heat. The causal importance of heat in these lesions on woody or semiwoody stems is less well established than in the case of whitespot. Further experimental work at temperatures such as actually occur in nature is necessary to settle finally the pathological importance of high soil temperature.

(5) Lesions involving young cortex and resembling those attributed to heat are probably in some cases caused by repeated bending in heavy wind without visible breakage. These are believed to be too rare to give rise to serious confusion.

LITERATURE CITED

(1) FISCHER, C. E. C.
1909. NOTE ON THE BIOLOGY OF PESTALOZZIA HARTIGII, TUBEUF. *In* Jour. Econ. Biol., v. 4, no. 3, p. 72–77, pl. 7. Literature, p. 76.

(2) HANN, J.
1906. LEHRBUCH DER METEOROLOGIE. Aufl. 2, 643 p., 89 fig., 14 pl. Leipzig.

(3) HARTIG, Robert.
1883. EINE NEUE ART DER FROSTBESCHÄDIGUNG IN FICHTEN- UND TANNENSAAT- UND PFLANZBEETEN. *In* Allg. Forst. u. Jagdztg., n. F., Jahrg. 59, p. 406–409, 2 fig.

(4) HARTLEY, Carl.
1913. THE BLIGHTS OF CONIFEROUS NURSERY STOCK. U. S. Dept. Agr. Bull. 44, 21 p.

(5) ———
1916. NON-PARASITIC STEM LESIONS ON SEEDLINGS. (Abstract.) *In* Phytopathology, v. 6, no. 3, p. 308–309.

(6) ——— and MERRILL, T. C.
1915. STORM AND DROUGHT INJURY TO THE FOLIAGE OF ORNAMENTAL TREES. *In* Phytopathology, v. 5, no. 1, p. 20–29.

(7) MAYR, Heinrich.
1909. WALDBAU AUF NATURGESETZLICHER GRUNDLAGE. 568 p., 27 fig., 3 pl. (partly col.) Berlin.

(8) MÜNCH, E.
1913. HITZESCHÄDEN AN WALDPFLANZEN. *In* Naturw. Ztschr. Forst. u. Landw., Jahrg. 11, Heft 12, p. 557–562, 2 fig.

(9) ———
1914. NOCHMALS HITZESCHÄDEN AN WALDPFLANZEN. *In* Naturw. Ztschr. Forst. u. Landw., Jahrg. 12, Heft 4, p. 169–188.

(10) ———
1915. BEOBACHTUNGEN ÜBER ERHITZUNG DER BODENOBERFLÄCHE IN JAHRE 1914. *In* Naturw. Ztschr. Forst. u. Landw., Jahrg. 13, Heft 6/7, p. 249–260.

(11) OVERTON, J. B.
1911. STUDIES ON THE RELATION OF THE LIVING CELLS TO TRANSPIRATION AND SAP-FLOW IN CYPERUS. *In* Bot. Gaz., v. 51, no. 1, p. 28–63; no. 2, p. 102–120. Literature cited, p. 118–120.

(12) POOL, R. J.
1914. A STUDY OF THE VEGETATION OF THE SANDHILLS OF NEBRASKA. *In* Minn. Bot. Studies, v. 4, pt. 3, p. 189–312, illus., pl. 26–40, map. Literature cited, p. 308–312.

(13) RAMANN, E.
1911. BODENKUNDE. Aufl. 3, 699 p., 63 fig. Berlin.

(14) SCHUSTER, Ludwig.
1914. HITZETOD JUNGER PFLANZEN. *In* Naturw. Ztschr. Forst. u. Landw., Jahrg. 12, Heft 8, p. 377–379, 2 fig.

(15) SORAUER, Paul.
1909. HANDBUCH DER PFLANZENKRANKHEITEN. Aufl. 3, Bd. 1. Berlin.

(16) TUBEUF, Karl von.
1897. DISEASES OF PLANTS INDUCED BY CRYPTOGAMIC PARASITES. English ed. by W. G. Smith. 598 p., 330 fig. London, New York.

(17) ———

1914. HITZETOT UND EINSCHNÜRUNGSKRANKHEITEN DER PFLANZEN. *In* Naturw. Ztschr. Forst. u. Landw., Jahrg. 12, Heft 1, p. 19–36, 4 fig.

(18) ———

1914. ERKRANKUNGEN DURCH LUFTABSCHLUSS UND ÜBERHITZUNG. *In* Naturw. Ztschr. Forst. u. Landw., Jahrg. 12, Heft 2, p. 67–88; Heft 4, p. 161–169, 2 fig.