How Too Much Water Increases Root Diseases of Alfalfa

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Since 1953 we have been interested in what factors cause stand decline in alfalfa in the irrigated desert areas of southwestern U.S.A. The ecosystem in this area is different from any other in the United States principally because of the prevalence of air and soil temperatures that reach 44°C (111°F) to 49°C (120°F) during the summer months. We reported in a previous symposium (Erwin and Lehman, 1974) that the growth of the cultivar Africa was considerably reduced when the soil was continuously maintained at 37°C (99°F. Growth was much better at 22°C (72°F) and 28°C (81°F). Thus, the growth and yield of alfalfa even in absence of disease during the hot summer months in the Imperial Valley is most likely due to the genetic limitation of alfalfa. However, in addition to the genetic limitation, the hot summers and flooding in the Imperial Valley also have deleterious effects on the life of plants. This effect is almost always expressed most severely when soil is flooded for long periods of time. Before the 1950's it was common for growers to stop irrigating alfalfa during the summer months to prevent loss of stand from "scald". At present most alfalfa fields are irrigated thoughout the summer and where management is careful enough, the stand persists throughout the summer.

Since there is little a grower can do about the temperature, I have chosen to examine the role of "too much water" as one of the factors that affects stand decline and root disease of alfalfa. Alfalfa joins tobacco and tomato as one of the crops that "can't stand wet feet".

Scald (high temperature flooding injury) and Rhizoctonia root canker. The term scald is really a misnomer because it is caused by flooding of alfalfa for long periods of time and especially when temperatures are over 40°C (104°F). High temperature flooding injury is a more accurate term but "scald" is now firmly implanted in the language of alfalfa producers. Plants become more susceptible to scald when the flood water completely covers them. This effect is often seen when plants are run down by truck tires before flooding. Also plants that are flooded immediately after mowing are more susceptible.

Scald will kill plants within a week after flooding and often whole fields are lost after one irrigation. Untimely summer rains followed by a hot period of weather will also cause loss of plants. I observed scald in several fields in the Imperial Valley following the unseasonal rain in August 1983. Plants that are flooded for long periods of time at high temperatures wilt quickly and subsequently many of these plants die. However, the plants that do not die suffer from physiological damage. The central water conducting core of tissue (xylem) in the root is ordinarily white, but will turn brown following an episode of excess soil water at a high temperature. The brown color increases in the degree of intensity with an increase in temperature and length of the flooding period. The nature of the material that causes browning is not well understood, but it is likely that the browning material causes plugging of water conducting cells. Although a normal plant continuously produces new xylem tissue, the ability of the scald-injured plant to take up water is severely impared for some time after flooding.

Within the period 1953 to 1983 there has been a gradual change in the irrigation management of alfalfa in the Imperial Valley. Prior to 1953 a large portion of the alfalfa fields were left unirrigated in the summer. Following this long hot dry period, fields were renovated (broken up with a spring tooth harrow) and replanted. At the present time most growers maintain stands by careful irrigation throughout the summer. However, some reseeding in the fall is still done when stands are depleted by summer scald or other root diseases.

The control of the scald problem is associated with proper water management. Lehman et al (1968) found that holding irrigation water on plots for 3 hours after soil suction values of 70-80 cb (very dry) had been reached was most efficient for reduction of both scald and Rhizoctonia root canker. However, when this practice was continued in fall, winter, and spring, salt tended to build up in the soil. Thus, more frequent and longer irrigation periods were necessary in the fall, winter, and spring to move salt downward in the soil profile.

Along with scald, there is also Rhizoctonia root canker (caused by *Rhizoctonia solani*) which is active only in the summer. This disease may kill plants if the cankers extend around the entire root. If the cankers remain small, the plant may recover in the fall and winter months when the disease is dormant. This disease also causes a discoloration and plugging of water conducting tissues in the roots.

There is very little information on control of root canker, however, in the irrigation study reported by Lehman et al (1968) the incidence of Rhizoctonia root canker was only 4.6% in plots flooded for only 3 hrs after soil suction values reached 70-80 cb (normal short). However, when plots were flooded for 3 hr or 6 hr periods after attaining soil suction values of only 30-35 cb (frequent short and frequent long, respectively), the percentages of plants with root canker increased to 14.2 and 19.7%, respectively. Thus it appeared that Rhizoctonia root canker was also favored by increased flooding during the summer months.

Both scald and Rhizoctonia root canker are complex diseases to control. Scald is caused by physiological impairment of the root by asphyxiation, due to a combination of flooding and high soil temperatures, and Rhizoctonia root canker is favored by flooding and high summer temperatures. Both diseases can occur separately or together, but of the two, scald is the more devastating. Careful management of irrigation especially in the summer is essential. To supplement this practice, certain cultivars such as UC Salton, UC66, and UC60 that have been developed in the field by Lehman at the Imperial Valley Field Station, appear to be more tolerant of these two conditions than others (Lehman et al, 1973).

Phytophthora root rot. Phytophthora root rot is caused by the fungus Phytophthora megasperma f.sp. medicaginis, which appears to be highly specific in pathogenicity to alfalfa. This fungus appears to have followed alfalfa throughout the world. The same disease occurs throughout the U.S.A., Canada, Mexico, in the middle east, Australia and almost every place that alfalfa is grown. The fungus is a watermold with a swimming spore stage (Fig. 1) that thrives on free water in soil. The disease is characterized by a rot of the roots which become brown in color. The internal xylem tissue often turns yellow. The leaves of the infected plants turn yellow and sometimes purple. However, the yellow color of leaves is not always present. Stunting of the plants is also an indication that roots are not healthy.

The disease in an intermediate stage can be diagnosed by symptoms and by culturing the pathogen on an agar medium. When the disease is well advanced, the entire root becomes necrotic, and is difficult to identify with certainty. The pathogen is also difficult to culture at this stage. We will be happy to identify root diseases of alfalfa about which you as a grower, service agent, or farm advisor are uncertain. A sample should contain at least four or five roots and a handful of soil placed in a plastic bag mailed to our laboratory as soon as possible at the address below the title of this paper. Adding moisture on paper towels to the sample should be avoided because this favors rapid growth of contaminant fungi and bacteria.

Phytophthora root rot of alfalfa becomes a problem only when soil becomes unduly wet. Remember free water is necessary for the growth and development of Phytophthora. A sporangium emitting swimming zoospores is shown in Figure 1.

A number of factors influence the time the soil stays wet after an irrigation. When long one-half-mile irrigation runs are flooded, free water actually stays on the upper end of the field longer than on the lower end of the field. However, when there is too much run off from an irrigation, the lower end of the field may pond. Loss of stands at the lower end of fields is commonly observed. Some soils have such fine texture that downward penetration of water is slow. Other soils have impervious layers which hold water in a free state for long periods of time. Quite often when one observes Phytophthora root rot in a sandy soil, which supposedly is well drained, a soil tube sample will reveal a clay lens at various levels below the surface.

One of my graduate students Dr. Ta-Li Kuan made a study of the effect of soil moisture on Phytophthora root rot using a model system with which the soil moisture could be controlled precisely. Soil scientists use the term "water potential" to describe the energy state of water in the soil. The soil moisture tensiometer is an instrument that measures the negative pressure exerted by the soil to pull water out of the porous clay cup at the tip of the tensiometer. This negative pressure is measured in bars or millibars. When all of the pores in soil are filled with water, there is no negative pressure in the soil and we say the "water potential" is 0. Water potential can be broken down into matric potential (influenced by the size of the pores in soil) and the osmotic potiential (salts in soil). Several workers such as Sterne et al (1976, 1977) have shown that osmotic potential does not influence the activity of Phytophthora nearly as much as matric potential. Matric potential values are essentially the same as those read on the soil moisture tensiometer, used in many agricultural operations to determine whether to water or not. Since matric potential values are similar to tensiometer values, I would like to summarize the results that Dr. Kuan found in the laboratory about the effect of soil moisture on the root disease of alfalfa caused by Phytophthora megasperma f.sp. medicaginis (Kuan and Erwin, 1982).

Kuan infested a coarse sandy loam soil (69% sand, 20% silt, and 11% clay), with either mycelial fragments or oospores, and packed it in ceramic porous clay cups (100 g/cup). The cups were each attached to columns of water which were adjusted to different heights below the surface of the soil. In this way the matric potential could be precisely adjusted to values of 0 (free water in which the water column or supply was level with the ceramic cup), -10, -50, -100, -200, -350, and -500 millibars (1 millibar = 1/1000 of a bar and 1 bar = approximately 1 atmosphere of pressure). As a reference point, soil at the field capacity generally has a matric potential of about -300 mb.

When small alfalfa seedlings were transplanted to each cup of soil maintained at these different matric potential values, the greatest amount of disease occurred at 0 matric potential (free water in soil). At -50 mb the incidence of disease was down to only 20% after 19 days and at -100 mb there was no perceptible disease (Fig. 2). The increase in the percent of diseased plants was correlated (r = 0.97-0.99) with an increase in germination of the fungal spores (oospores) in the soil. Since soil at the field capacity has a matric potential value of about -300 mb, it appeared that *Phytophthora* was not capable of causing root damage except at very high (less negative) matric potential values.

Sporangia (see Fig. 1) form from oospores that germinate in soil (Fig. 3). The oospores appear to be the primary inoculum and the sporangia and zoospores are the secondary or spreading inoculum. In addition to the increase in germination of oospores at higher matric potential values, the formation of sporangia with subsequent production of swimming zoospores (see Fig. 1) developed on infected root pieces only in free water. Drying the soil to only -10 mb decreased the formation of sporangia from about 112/root to 5/root and at -50 mb no sporangia were formed. Many studies summarized by Duniway (1983) indicate that free soil water favors all *Phytophthora* spp. in soil, however, *P. megasperma* f.sp. *medicaginis* is one of the most sensitive to reduced matric potential values.

Flooding also directly affects the physiology of the plant, and in turn the roots become more susceptible to infection by *Phytophthora* (Kuan and Erwin, 1980). Kuan grew plants in steam sterilized soil in the absence of *Phytophthora megasperma* f.sp. *medicaginis*. After about 3 weeks of growth, some plants were kept flooded for 7 days and others were watered but not flooded. When these plants were inoculated after the flooding period and watered uniformly thereafter, the disease index (0 = no disease to 5 = plant dead) was increased from 2.5 for those plants not flooded before inoculation to 4.5 for those flooded before inoculation. Representative plants from these treatments are shown in Fig. 4. Preinoculation flooding of seedlings also showed that the percentage of seedlings killed increased from 50% for the unflooded seedlings to 90% for seedlings preflooded for 5 days before being inoculated (Fig. 5).

Roots of plants which had been flooded became more leaky than non-flooded plants. When zoospores were added to water in which there were roots from both saturated and unsaturated soil, zoospores preferentially swam toward the roots that had been in saturated soil (Fig. 6). Chemical analysis of the exudates from flooded and unflooded roots indicated that both amino acids and carbohydrates were increased as the time of flooding was increased. We think that nutrients from leaky roots probably increase germination of oospores, production of sporangia and attract zoospores toward roots. This may explain why *Phytophthora* can increase so rapidly in soil.

Discussion. - I have given a brief resume of some of the ways that "too much" water can encourage root diseases of alfalfa derived from both field and laboratory experiments. These examples support principles from which field practices can be improved. How much water is "too much" is a difficult question since the soil on every farm is a little different. The tensiometer is a useful instrument to measure soil water potential but is time consuming to manage. However, growers should strive for optimal water management as a first line of defense against root diseases of alfalfa because excessive water not only favors the pathogens but also makes alfalfa plants more susceptible to Phytophthora root rot. The second line of defense is the resistant cultivar. Most new commercial cultivars of alfalfa have varying degrees of resistance to *Phytophthora*. However, there are no cultivars with resistance to scald or *Rhizoctonia* root canker. Although some cultivars may be resistant to Phythophthora root rot, good water management must still be maintained. We have seen fields planted to a resistant cultivar which were severely affected by Phytophthora root rot. When water management was improved, the problem was controlled. Alfalfa is a normally heterozygous (not genetically uniform) crop in which rarely are there more than 50% of the plants which are resistant. Also, resistance in alfalfa is relative. No plants are immune. In addition, excessive flooding of soil will break or reduce the resistance of alfalfa cultivars (Donna Zook and D. C. Erwin, unpublished information). These studies, which are not yet completed, strongly suggest that physiological resistance to flooding might be another parameter to be added to the research goals of plant breeders and plant pathologists.

Literature Cited

Duniway, J. M. 1983. Role of physical factors in the development of Phytophthora diseases. Pages 175-187 in: D. C. Erwin, S. Bartnicki-Garcia, and P. H. Tsao, eds. Phytophthora: Its Biology, Taxonomy, Ecology and Pathology. Amer. Phytopathol. Soc., St. Paul, MN.

Erwin, D. C., Kennedy, B. W. and Lehman, W. F. 1954. Xylem necrosis and root rot of alfalfa associated with excessive irrigation and high temperatures. Phytopathology 49: 572-578.

Erwin, D. C. and Lehman, W. F. 1974. Stand depletion of alfalfa in the low desert valleys of southern California. California Alfalfa Symposium. 1974. pp 58-64.

Förster, Helga, Ribeiro, O.K., and Erwin, D. C. 1983. Factors affecting oospore germination of Phytophthora megasperma f.sp. medicaginis. Phytopathology 73: 442-448.

Kuan, T. L. and Erwin, D. C. 1980. Predisposition effect of water saturation of soil on Phytophthora root rot of alfalfa. Phytopathology 70: 981-986.

Kuan, T. L. and Erwin, D. C. 1982. Effect of soil matric potential on Phytophthora root rot of alfalfa. Phytopathology 72: 543-548.

Lehman, W. F., Richards, S. J., Erwin, D. C., and Marsh, A. W. Effect of irrigation treatments on alfalfa (Medicago sativa L.) production, persistence, and soil salinity in southern California. Hilgardia 39: 277-295.

Lehman, W. F., Stanford, E. H., Erwin, D. C., Marble, V. L., and Isom, W. H. 1973. U C Salton - a new cultivar of alfalfa in low desert valley areas of southern California. Univ. of Calif. Agr. Exp. Sta. Bull. 864. 14 pp.

Sterne, R. E., Zentmyer, G. A., and Bingham, F. J. 1976. The effect of osmotic potential and specific ions on growth of Phytophthora cinnamomi. Phytopathology 66: 1398-1402.

Sterne, R. E., Zentmyer, G. A., and Kaufmann, M. R. 1977. The effect of matric and osmotic potential of soil on Phytophthora root diseases of Persea indica. Phytopathology 67: 1491-1494.

Figure Legends

Fig. 1. Germination of a sporangium of Phytophthora megasperma f.sp. medicaginis from alfalfa by production of zoospores (swimming spores). This event occurs only in free water. (Photograph by T-. L. Kuan).

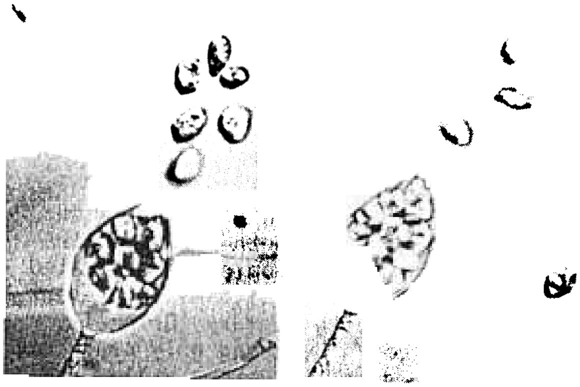
Fig. 2. Effect of soil matric potential on incidence of Phytophthora root rot of alfalfa and on germination of oospores of Phytophthora megasperma f.sp. medicaginis. Alfalfa seedlings (3 days old) were planted in soil infested with oospores (10 oospores per gram dry soil). Data are means of 12 replications of disease incidence and six replications of oospore germination. (From Kuan and Erwin, 1982).

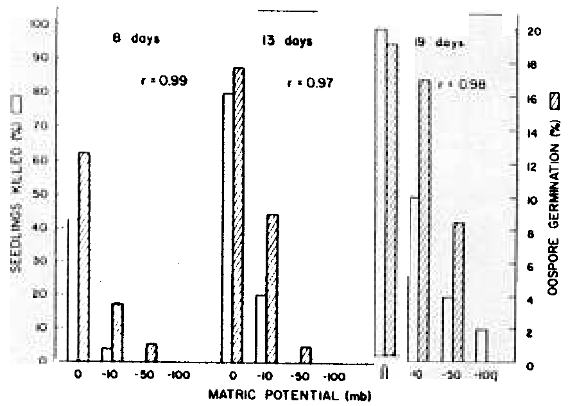
Fig. 3. Germination of an oospore of Phytophthora megasperma f.sp. medicaginis from which three sporangia have formed. The sporangia are empty and have already emitted zoospores when the photograph was taken.

Fig. 4. Symptoms on alfalfa roots infected with Phytophthora megasperma f.sp. medicaginis. Left: uninoculated control; roots grown in unsaturated soil. Middle: inoculated roots grown in unsaturated soil prior to inoculation. Right: inoculated roots grown in soil saturated for 1 wk prior to inoculation with minced agar and mycelium of a 7-day-old culture on V8A. Uninoculated roots grown in unsaturated soil were identical in appearance tc those in the control shown here. (From Kuan and Erwin, 1980).

Fig. 5. Incidence of Phytophthora root rot on alfalfa seedlings after different periods of time in saturated soil before inoculation with zoospores. Data were recorded 6 days later. Each point represents the mean of three replications and the bar represents the standard deviation. (From Kuan and Erwin, 1980).

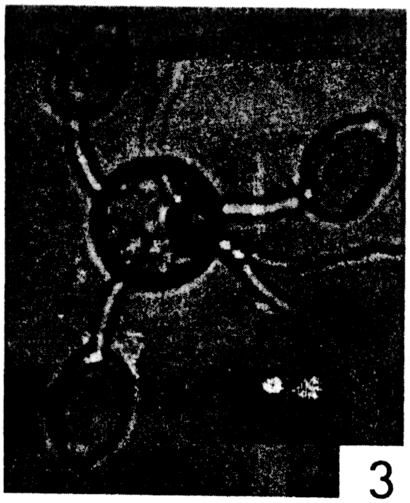
Fig. 6. Attraction of zoospores of Phytophthora megasperma f.sp. medicaginis to alfalfa roots grown in saturated soil (S) and in unsaturated soil (US). Area between arrows = zone of encysted zoospores. (From Kuan and Erwin, 1980).





SEEDLINGS KILLED (%)
OOSPORE GERMINATION (%)
8 days
13 days
19 days
r = 0.99
r = 0.97
r = 0.98
MATRIC POTENTIAL (mb)
0
-10
-50
-100

2



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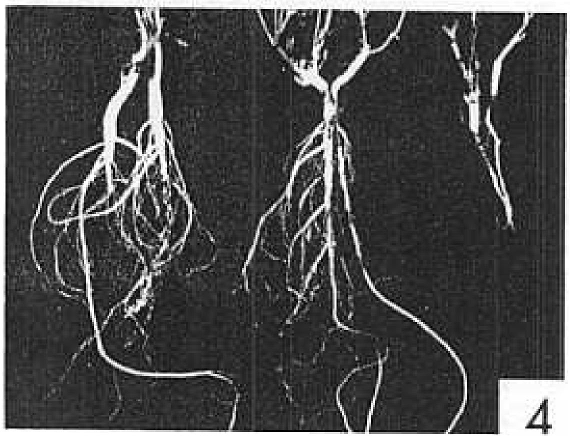

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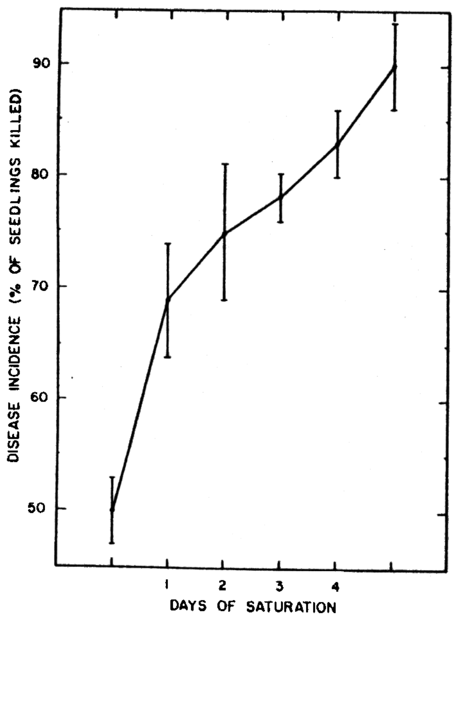
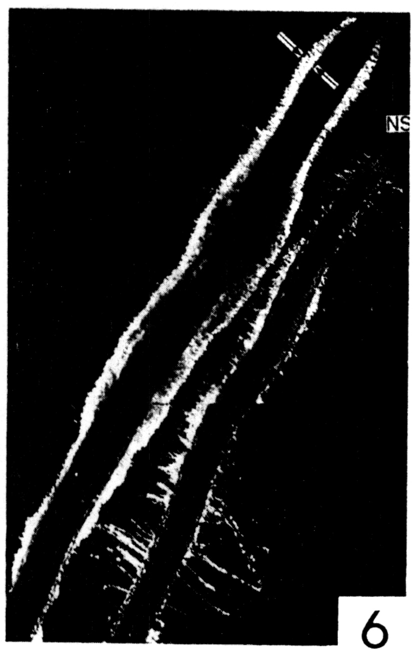


DISEASE INCIDENCE (% OF SEEDLINGS KILLED)
50
60
70
80
90
DAYS OF SATURATION
1
2
3
4

5



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