THE INFLUENCE OF METEOROLOGICAL EVENTS AND CULTURAL PRACTICES ON SCLEROTINIA CROWN AND STEM ROT OF ALFALFA, CAUSED BY SCLEROTINIA TRIFOLIORUM.

by

Karen L. Reed

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in Plant Pathology, Physiology, and Weed Science

APPROVED:

E. L. Stromberg, Chairman

S. W. Van Scoyoc

P. M. Phipps

January, 1987

Blacksburg, Virginia

THE INFLUENCE OF METEOROLOGICAL EVENTS AND CULTURAL PRACTICES ON SCLEROTINIA CROWN AND STEM ROT OF ALFALFA, CAUSED BY SCLEROTINIA TRIFOLIORUM

by

Karen L. Reed

Committee Chairman: Erik L. Stromberg

Plant Pathology, Physiology and Weed Science

(ABSTRACT)

Sclerotinia crown and stem rot (SCSR), caused by *Sclerotinia trifoliorum* Eriks., causes serious spring losses in some fall-sown, no-tillage alfalfa fields. In microplots artificially infested with sclerotia, greatest numbers of apothecia were found during November and December. Temperature and rainfall had significant impact on apothecium development. A proposed prediction method for apothecium appearance considers monitoring mean soil temperature. For apothecium initiation to occur, it was necessary for sclerotia to be subjected to an estimated 17 days of temperature at or below 15 C before apothecium production occurred. Soil temperatures were usually below 10 C at the time of apothecium appearance. Greatest numbers of apothecia occurred between 5-10 C. Rainfall influenced the number of apothecia, with significant increases occurring early in the 1984-85 production period. The 1985-86 season received more rainfall than the

previous year, and resulted in greatest apothecium production.

Two cultural practices for reducing losses caused by the disease in alfalfa fields were investigated. Time of planting was evaluated by sowing alfalfa in microplots at five different times throughout a one-year period in soil that was infested with sclerotia in October. All seeding dates exhibited reduced plant populations in the spring following infestation. However, the July and August plantings experienced the greatest reductions in population. It was not possible to evaluate direct losses caused by Sclerotinia crown and stem rot due to lack of secondary mycelial spread within the microplots. Reductions in plant population could have been caused by winter injury or *S. trifoliorum* colonization, but it was not possible to distinguish between these two factors. In plant density studies, plant populations of infested plots in May were significantly lower than populations counted the previous January. This reduction could have been caused by winter injury or *S. trifoliorum*. Corresponding control plots did not exhibit a decrease in population from January to May suggesting that S. trifoliorum was the cause of stand reductions in infested plots. The presence of *S. trifoliorum* poses a threat to any plant population density, but mid- to late-summer plantings appear to be the most vulnerable to this disease.

ACKNOWLEDGEMENTS

The author wishes to express gratitude and appreciation to the following people:

Dr. Erik L. Stromberg, for his willingness to serve as Committee Chairman. The author appreciated his support and instruction in conducting this research project. His enthusiasm and interest in the project were very encouraging. The author wishes him well in further research on Sclerotinia crown and stem rot of alfalfa.

Dr. Stephen W. Van Scoyoc, for his willingness to serve as a Committee Member. His advice, cooperation and use of equiptment during the progress of this research project were very much appreciated. His comments upon material in this Thesis during its preparation were very helpful.

Dr. Patrick M. Phipps, for his willingness to serve as a Committee Member. His advice and instruction in the art of writing were greatly appreciated.

Dr. Thomas B. Brumback, Jr., for his assistance in preparation of meteorological data. His advice in data management and presentation were very helpful.

for his assistance with various operations at the research site. His consent to pound trenches with a hand sledge for several long, hot days during August was most admirable.

for his assistance in site preparation and planting of alfalfa. His effort in accomplishing various tasks associated with this research project was very much appreciated.

for his excellent work in maintaining the area of the research plots. His effort and enthusiasm in completing the job were very encouraging.

and for their willingness to help with mundane tasks involved with field research. Their effort and encouragement helped to accomplish the job much more quickly. Their sacrifice of time was appreciated.

for sharing her knowledge and experience in the realm of Extension Plant Pathology. The author was grateful for the opportunity to work with her in the Plant Disease Clinic.

for sharing her enthusiasm and experience in handling materials in the Plant Disease Clinic.

for kindling a keen interest in Plant Pathology within the author while attending Delaware Valley College. Her fine reaching, advice and encouragement to pursue further studies shall always be remembered.

Dr. Seong Hwan Kim, for the opportunity to gain valuable experience in planning and conducting research in Extension Plant Pathology. It was a privelege to have worked with him at the Pennsylvania Department of Agriculture.

my father, who taught me, by his example, to stick at a job until it was finished. He has taught the author well.

my mother, for her generousity, phone calls and encouragement which kept the author going. Her support was very much appreciated.

my uncle and aunts, for precious encouragement, interest and support for my efforts while attending graduate school.

my brother-in-law and sister, for their support and special friendship.

for guidance in and preparation of statistical analyses (I could not have done it without you!). The author thanks him for his encouragement, friendship and acceptance.

My Lord God, whom the author has found ever faithful and sustaining. Thank you for being the strength of my life, today.

TABLE OF CONTENTS

CHAPTER 1

Review of Literature.

Introduction and Research Objectives

Planting alfalfa (*Medicago sativa* L.) by no-tillage methods provides erosion control, increases soil moisture retention, and reduces weed pressure. These advantages have led to recent increases in fall, no-tillage planting of alfalfa in Virginia; from 1,899 acres in 1982 to 5,634 and 4,871 acres in 1983, and 1984, respectively (56,57, and H. E. White, personal communication). However, in recent years, Sclerotinia crown and stem rot (SCSR), caused by *Sclerotinia trifoliorum* Eriks. (13), has been associated with severe losses in spring of some fall, no-tillage alfalfa fields (46). In a survey conducted by Van Scoyoc and Stromberg (50) in the spring of 1984, it was estimated that SCSR caused direct losses of $303,400 in no-tillage alfalfa sown in Virginia the previous fall. Losses associated with SCSR were also observed in the springs of 1985 (unpublished) and 1986 (48).

SCSR is believed to be a more serious problem with no-tillage alfalfa for several reasons. When alfalfa is sown in a site previously planted to a forage legume (such as red or white clover) the pathogen is likely to be present as sclerotia. Secondly, plant debris associated with killed sod creates a rich, moist food base for the fungus. Thirdly, when the normal seeding rate for alfalfa (17 kg/ha or 15 lb/acre) is sown by no-tillage methods, this creates a density of 22-26 plants per 30 cm drill slit

(11). Such plant densities may favor rapid plant to plant spread of *S. trifoliorum* (as mycelium) within plant rows.

For no-tillage alfalfa to be most successful, it is desirable to identify those measures that will reduce the risk of stand failure caused by SCSR.

The objectives of this study were:

1. To define the time of occurrence of *S. trifoliorum* apothecia in Virginia, and the meteorological conditions that induce sclerotia to produce apothecia.

2. To assess the impact of planting date and plant population density on disease severity.

Host Range and Distribution

The host range of *Sclerotinia trifoliorum* includes small-seeded forage legumes such as red and crimson clovers, in addition to alfalfa (53). A few reports have also indicated susceptibility of some large-seeded vegetable legumes (58). SCSR has frequently reduced forage legume production in Europe (5,9) and the United States (51) for many years. Most of the descriptive studies of disease and the causal fungus were conducted in England and the Netherlands (5,9,10,25,59). Recent investigations have been conducted in France (37,38,40) and the United States in Mississippi (34,35), North Carolina (55), and Virginia (50).

Disease Cycle in Alfalfa

Sclerotinia trifoliorum survives in soil and debris as sclerotia that can remain viable for 3 to 8 yr (9,25,31,60). Apothecia emerge from sclerotia during the fall months. Primary infection of alfalfa by ascospores produces small leaf spots (5,26,51). After a host-killing frost, mycelia grow from the lesions and colonize senescent leaf tissues (5). During late winter to spring, mycelia from within the leaves remaining on or at the base of the plant grow to the crown and invade it, frequently killing the plant. The fungus then colonizes adjacent plants causing wilt and a bleached appearance. Seedlings may decay completely. Severely infested fields often contain large patches of dead plants, that are rapidly overtaken by weeds (9). Pectolytic enzymes and oxalic acid produced by the fungus cause tissue maceration and development of a watery soft rot (58). In spring, fluffy white mycelium present at the base of diseased plant stems often forms aggregations that later darken and mature into sclerotia. Under moist conditions, fungal activity may continue into summer. However, harvesting may disrupt disease development by altering the microclimate (9,39,40).

Apothecium Formation

Before methods of controlling SCSR can be formulated and properly applied, it is necessary to study the interaction of *S. trifoliorum* within the microenvironment of an alfalfa field. It would be desirable to identify what meteorological conditions, such as temperature and moisture, stimulate apothecium initiation. Previous researchers have reported that apothecia occur in the field in greatest numbers between August and January (5,15,34,55,59), with occasional sightings reported until May (51). Induction and longevity of apothecia are affected by the amount of rainfall in the fall and winter, with normal to above-normal levels promoting development (34). Longevity was reported to be 3 to 4 wk under field conditions (9,59). In the laboratory, sclerotium incubation at a constant temperature of 14 C for 15-20 days was successful in inducing apothecium initials (15). Constant incubation at 15 C for an unstated length of time resulted in apothecium production (49). Thermoperiods ranging between 7-24 C over several time cycles (42) and a 2 C, 16 hr/8 C, 8 hr cycle, simulating late autumn temperatures, (28) were effective in apothecium induction.

Very little work has been done to evaluate the influence of moisture on apothecium production by *S. trifoliorum* under field conditions. Henson and Valleau (15) noted moisture was necessary for maturation of apothecium initials but amounts were not quantified. Pratt and Knight (34) noted that apothecium longevity was influenced by weather, but specific weather parameters were not defined. Investigators of *Sclerotinia sclerotiorum*, a related species and causal agent of white mold of bean and lettuce drop, have observed that this fungus requires prolonged periods of soil saturation for carpogenic germination to occur (2). It was suggested that moisture tension and temperature interact to affect apothecium production (2) Observations of this type could lead to the development of a prediction program (22,44). This type of evaluation of *S. trifoliorum* activity needs to be performed before a forecasting program may be developed for SCSR.

The secondary or mycelial phase of infection and colonization of alfalfa occurs between the months of January and May. Many investigators have recorded erratic rates of secondary spread (5,9,35). Winter temperatures and rainfall are significant factors that influence this phase of *S. trifoliorum* development. Extreme cold (9,25,37) and dry conditions (9,34,54) were reported to suppress secondary spread, while mild temperatures and normal to abundant rainfall enhance this stage (9,26,34,54). Unfortunately, all of the weather data reported to date are on a macroclimatic scale and therefore are of limited value in pinpointing the precise environmental conditions that trigger apothecium formation and secondary spread of SCSR.

Studies are presently under way to develop a disease-forecasting system for white mold of bean, caused by *S. sclerotiorum* in New York (22). Preliminary observations indicated that soil moisture around the time of bloom and canopy density were key parameters influencing apothecium production. Sclerotia of *S. sclerotiorum* require an average soil moisture between 0 and -30 centibars for about 2 wk for apothecium development to occur. Canopy density directly effects bean microclimate through degree of wind and sunlight penetration, which in turn influences soil moisture. The presence of open blossoms is also an important factor in plant susceptibility to infection. *S. sclerotiorum* ascospores require an available nutrient source for successful plant infection (1). Although this system requires refinement, major steps have been made toward understanding behavior of *S. sclerotiorum* in New York.

Investigators of Sclerotinia stem rot of soybean, caused by *S. sclerotiorum*, in Wisconsin observed that air temperature was a more reliable predictor of disease appearance and severity than rainfall and irrigation levels (14). Over a 3-yr period, the lowest disease severity occurred during the growing season with highest minimum/maximum air temperautres. Irrigation, row spacing and soybean cultivar selection also influenced disease severity.

The previously described white mold-forecasting system identified soil moisture and canopy density as major influential factors (22). Investigators of Sclerotinia stem rot of soybean observed air temperature to be of major importance in that region (14). These observations indicate the necessity for evaluation of disease occurrence and severity under local crop management and weather conditions. Such studies have led to a better understanding of *S. sclerotiorum* biology and management. Investigations of this type are needed for *S. trifoliorum* in forage legume production areas.

Disease Control

Measures for controlling *S. sclerotiorum*, *S. minor* and *S. trifoliorum* under field, greenhouse and storage conditions have been difficult and slow to develop. The majority of research in this area has centered around *S. sclerotiorum* and *S. minor*. Due to lack of knowledge regarding *S. trifoliorum* biology and control, it has often been necessary to cite examples involving these related species to support a point throughout this discussion. The effectiveness of the sclerotium as a dispersal agent and its ability to survive prolonged adverse conditions have allowed *Sclerotinia* spp. to become wide spread. The broad host range of these fungi coupled with their destructive effects on plants of economic importance have made control a challenge (43,44).

The development of disease resistant cultivars would give the most stable as well as economical control of SCSR. Problems in attaining consistent infection due to the sporadic nature of this disease have made it difficult to evaluate plant lines under field conditions (9,26,34,54,55). Reliable greenhouse and field screening methods to evaluate alfalfa germplasm for reaction to SCSR remain to be developed. It has been difficult for investigators to define what resistance mechanism should be sought in this situation. Schmidt (40) has indicated that the ability of red clover to regenerate or recover from an initial attack by *S. trifoliorum* may be a useful resistance trait. This ability to regenerate from crown buds was observed earlier by Dillon-Weston and coworkers (9) in red clover, and by Pratt and Knight in annual *Trifoliorum* spp. (35). Several researchers have found sensitivity to freezing injury to be associated with SCSR resistance or susceptibility. Locally adapted cultivars are more persistent and less susceptible to cold injury and damage by SCSR (5,35,51). Prior and Owen (36) observed that resistance or susceptibility to SCSR appeared to be linked to structural integrity of the cells. The relative solubility of the middle lamella or outer cell wall layers may determine susceptibility (51). Valleau and coworkers (51) suggested that adapted cultivars used food reserves more efficiently, therefore enabling synthesis of a more resistant middle lamella or outer cell wall than nonadapted cultivars. In addition to inherent resistance in bean cultivars to *S. sclerotiorum*, Steadman (43) has proposed the development of architectural disease escape mechanisms. Open bush or upright bean cultivars create a less favorable microenvironment for white mold development than dense bush or vine types (43). The alfalfa/*S. trifoliorum* relationship needs to be evaluated and some possible avenues of resistance identified so that researchers might know what quality to evaluate when screening cultivars for SCSR resistance.

Due to the erratic occurrence of *Sclerotinia* spp. in field crops, routine chemical control is often not economical (43). If epidemics could be predicted with greater precision, more effective fungicide use could be implemented (44). Plant resistance and microclimate modification may be the best control measures for field crops, with chemical control used when high disease pressure is expected (43). Chemical control may be feasible for high value crops such as vegetables, although some fear has been expressed about the development of fungicide-resistant strains of *Sclerotinia* spp. (43).

Chemical control may be aimed at destruction of sclerotia, suppression of carpogenic germination or protection from ascospore infection (43). If the principle source of inoculum is from outside the field, several fungicide applications may be necessary for adequate protection (43). Fungicides evaluated for control of SCSR have included PCNB (39), and benomyl (24,55). Welty and Rawlings (55) observed that benomyl applied as a protectant suppressed severity of SCSR. Application after visible symptoms of secondary spread appeared did not control further spread of SCSR. Materials used to control lettuce drop caused by *S. minor* and *S. sclerotiorum* include benomyl (43), cyanamide (43,58), dazomet (58), DCNA (27,33), dicloran (58), iprodione (33), PCNB

(27), and vinclozolin (33). Benomyl is used for control of white mold of bean, caused by *S. sclerotiorum* (23,44). Hunter and coworkers (23) stress the importance of thorough foliage coverage. Improper coverage may result in control failure. Many parameters, such as plant architecture, irrigation frequency or field location, influence the success of chemical control measures. Some investigators feel that fungicide applications should only be used to supplement other disease control practices (43).

Cultural practices may hold the greatest potential in offering control measures for the near future. Cropping rotations including plant species that are not hosts may prevent further accumulation of sclerotia. Rotations of 3 to 8 yr have been recommended to allow for sufficient sclerotium degradation (9,25,26,31,53,55). Some investigators have questioned the practical value of crop rotation in controlling *Sclerotinia* spp. due to long periods of sclerotium survival, wide host ranges that include many weeds, and ascospore production in nearby locations outside the field (26,43,58). Steadman (43) pointed out that crop rotation does help control other diseases and should be practiced.

Deep plowing may be beneficial in reducing SCSR infestation through reducing numbers of sclerotia at the soil surface. Burial of sclerotia at depths greater than 5 to 8 cm has been shown to prevent sclerotium germination or emergence of apothecia above the soil surface (9,53). However, plowing is not practical in erodible sites which are prevalent in western Virginia. Observations with *S. sclerotiorum* in Nebraska (43) indicate that under low soil moisture conditions, deep plowing may not be effective in encouraging sclerotium degradation as a result of low populations of sclerotium degrading microorganisms.

In Florida, Moore (30) found that flooding resulted in 100% decay of *S. sclerotiorum* sclerotia in 23-45 days. Decay under normal moisture conditions was slow and incomplete. While this practice is not practical in many instances, it may be a control option in appropriate situations. Under greenhouse conditions, Honda and Yunoki (18) found that ultra violet-absorbing vinyl film reduced production of apothecium initials and mature sporocarps. This reduced the rapidity and extent of blighting and stem lesion development in eggplant and cucumber. While not applicable on a large scale, this method may be useful for commercial greenhouse operations.

The importance of weed hosts as sources for sclerotium production by *Sclerotinia* spp. is just beginning to be recognized. Forage legume producers noted that weeds moved into patches killed by SCSR but little thought was given to possible host relationships (9). Valleau and coworkers (51) found *S. trifoliorum* to be associated with plantain (*Plantago lanceolata* L.), wild lettuce (*Lactuca* spp.) and wild clovers. *S. sclerotiorum* has been associated with common ragweed (*Ambrosia artemisiifolia* L.) in cabbage fields (8), and dandelion (*Taraxacum officionale* Weber.) and wild clover in apple orchards (1). Hog-weed (*Hera-*

cleum sphondylium L.) and cow parsley (*Anthriscus sylvestris* (L.) Hoffm.) infected with *S. sclerotiorum* were a source of inoculum for oilseed rape (16). Dillard and Grogan (7) found *S. minor* to be associated with chickweed (*Stellaria media* (L.) Vill.), pig-weed (*Amaranthus retroflexus* L.), pineapple weed (*Matricaria matricariodes* (Less.) Porter), purslane (*Portulaca oleracea* L.) and shepherd's purse (*Capsella bursapastoris* (L.) Medic.) in abandoned lettuce fields. Weed hosts could be a significant factor in production of sclerotia of *Sclerotinia* spp. in the field (3). Further investigations of weed hosts of *S. trifoliorum* need to be pursued.

Parasitism of sclerotia by microorganisms may have an effect on sclerotium longevity (2). This biological activity will vary between locations and may be responsible for differing reports on survival of sclerotia. There has been interest in utilizing these associations in biocontrol techniques. *Coniothyrium minitans* (3,20,19), *Sporodesmium sclerotivorum* and *Teratosperma oligocladum* (3) have been associated with both *S. minor* and *S. sclerotiorum*. *Talaromyces flavus* has been identified as a hyperparasite of *S. sclerotiorum* (29). *Laterispora brevirama* is a mycoparasite of *S. minor* (32). Steadman (43) points out that many observations record the association of various microorganisms with host sclerotia but parasitic tendencies or potential disease control methods have not been assessed. This area is just beginning to be investigated and may hold some useful application in the future.

Planting alfalfa in spring or early summer would avoid SCSR during the seedling stage, when plants are more susceptible to crown rot and death. Fall seedings are particularly vulnerable to SCSR damage (12,26,51). Reduced seeding rates may improve air circulation within the canopy, thereby reducing humidity in the microenvironment at infection courts and perhaps slowing secondary spread of *S. trifoliorum* to adjacent plants (9,25). The severity of white mold of bean was reduced by row spacings of 76 cm (45). Wider plant spacings has also reduced root transmission of *S. sclerotiorum* in sunflower fields (21,17). The effect of reduced plant populations on yield must be weighed against reduction in disease-related losses for the crop.

Bean plant architecture has had a marked effect in white mold severity. Bush and vine types enhance disease severity while upright, open-bush types reduce severity. Indeterminate flowering enhances white mold development while determinate flowering reduces development. An open bean canopy allows sufficient air circulation to slow or prevent apothecium production, ascospore germination and mycelial colonization (41,43,45,58). Irrigation scheduling in relation to bean flowering and an overall reduction in irrigation frequency has been found to reduce white mold in Nebraska (43,52). Irrigation every 5 days increased apothecium production more than a 10-day irrigation frequency (41). Secondary spread of white mold is dependent upon availabibity and duration of free moisture on leaves (52). Any factor influencing canopy density such as plant spacing, population or irrigation frequency will effect white mold severity. Topography can also influence air circulation (2). White mold was more prevalent in low-lying fields or fields surrounded by noncultivated wooded areas. These situations increase the duration of leaf wetness, which is important in white mold development. Site evaluation in regard to SCSR occurrence needs to be evaluated in forage legumes.

Grazing or mowing in the fall may provide SCSR control by reducing initial amounts of tissue available for ascospore infection, removal of potentially infected tissue, and reduction in humidity by improvement of air circulation (9,25,26). Tissues weakened by freezing appear to be less resistant to colonization by *S. trifoliorum* (5,6,26). Removal of frost injured tissues could therefore slow fungal advancement.

Literature Cited

1. Abawi, G. S., and Grogan, R. G. 1975. Source of primary inoculum and effects of temperature and moisture on infection of beans of *Whetzelinia sclerotiorum*. Phytopathology 65:300-309.

2. Abawi, G. S., and Grogan, R. G. 1979. Epidemiology of diseases caused by *Sclerotinia* species. Phytopathology 69:899-904.

3. Adams, P. B., and Ayers, W. A. 1979. Ecology of *Sclerotinia* species. Phytopathology 69:896-899.

4. Adams, P. B., and Ayers, W. A. 1983. Histological and physiological aspects of infection of sclerotia of *Sclerotinia* species by two mycoparasites. Phytopathology 73:1072-1076.

5. Dijkstra, J. 1964. Inoculation with ascospores of *Sclerotinia trifoliorum* for detection of clover rot resistant red clover. Euphytica 13:314-329.

6. Dijkstra, J. 1966. Rotting by spread of mycelium from ascospore lesions of *Sclerotinia trifoliorum*. Neth. J. Plant Pathol. 72:279-283.

7. Dillard, H. R., and Grogan, R. G. 1985. Influence of green manure crops and lettuce on sclerotial populations of *Sclerotinia minor*. Plant Dis. 69:579-582.

8. Dillard, H. R., and Hunter, J. E. 1986. Association of common ragweed with Sclerotinia rot of cabbage in New York State. Plant Dis. 70:26-28.

9. Dillon-Weston, W. A. R., Loveless, A. R., and Taylor, R. E. 1946. Clover rot. J. Agric. Sci. 36:18-28.

10. Dixon, G. R., and Doodson, J. K. 1974. Techniques for testing the resistance of red clover cultivars to *Sclerotinia trifoliorum* Erikss. Euphytica 23:671-679.

11. Donohue, S. J., Harrison, R. L., and White, H. E., eds. 1984. A Handbook of Agronomy. Va. Coop. Ext. Serv. Pub. 424-100, VPI & SU, Blacksburg. 88 pp.

12. Elgin, J. H., and Beyer, E. H. 1968. Evaluation of selected alfalfa clones for resistance to *Sclerotinia trifoliorum* Eriks. Crop Sci. 8:265-266.

13. Eriksson, J. 1880. Om Klöfverroten med särskilt afsseende

på dess uppträdende ivart fädernesland 1878-1879. Kunge Svensk Landtbr. Akad. Handl. och Tidsskr. 1:28-42.

14. Grau, C. R., and Radke, V. L. 1984. Effects of cultivars and cultural practices on Sclerotinia stem rot of soybean. Plant Dis. 68:56-58.

15. Henson, L., and Valleau, W. D. 1940. The production of apothecia of *Sclerotinia sclerotiorum* and *S. trifoliorum* in culture. Phytopathology 30:869-873.

16. Hims, M. J. 1979. Wild plants as a source of *Sclerotinia sclerotiorum* infecting oilseed rape. Plant Pathol. 28:197-198.

17. Hoes, J. A., and Huang, H. C. 1985. Effect of between-row and within-row spacings on development of Sclerotinia wilt and yield of sunflower. Can. J. Plant Pathol. 7:98-102.

18. Honda, Y., and Yunoki, T. 1977. Control of Sclerotinia disease of greenhouse eggplant and cucumber by inhibition of development of apothecia. Plant Dis. Rep. 61:1036-1040.

19. Huang, H. C. 1981. Distribution of *Coniothyrium minitans* in Manitoba sunflower fields. Can. J. Plant Pathol. 3: 219-222.

20. Huang, H. C., and Hoes, J. A. 1976. Penetration and infection of *Sclerotinia sclerotiorum* by *Coniothyrium minitans*. Can. J. Bot. 54:406-410.

21. Huang, H. C., and Hoes, J. A. 1980. Importance of plant spacing and sclerotial position to development of Sclerotinia wilt of sunflower. Plant Dis. 64:81-84.

22. Hunter, J. E. 1981. Proposal for a forecasting system for white mold of snap beans. Annu. Rep. Bean Improv. Coop. 24:122-123.

23. Hunter, J. E., Abawi, G. S., and Crosier, D. C. 1978. Effects of timing, coverage, and an oil additive on control of white mold of snap bean with benomyl. Plant Dis. Rep. 62:633-637.

24. Jenkyn, J. F. 1975. The effect of benomyl sprays on *Sclerotinia trifoliorum* and yield of red clover. Ann. Appl. Biol. 81:419-423.

25. Lester, E., and Large, E. C. 1958. Surveys of clover rot with incidental observations on eelworm in clover: England and Wales, 1953-55. Plant Pathol. 7:115-124.

26. Loveless, A. R. 1951. Observations on the biology of clover rot. Ann. Appl. Biol. 38:642-664.

27. Marcum, D. B., Grogan, R. G., and Greathead, A. S. 1977. Fungicide control of lettuce drop caused by *Sclerotinia sclerotiorum 'minor'*. Plant Dis. Rep. 61:555-559.

28. McGimpsey, H. C., and Malone, J. P. 1979. Production of apothecia of *Sclerotinia trifoliorum* in the laboratory. Bull. Br. Mycol. Soc. 13:104.

29. McLaren, D. L., Huang, H. C., and Rimmer, S. R. 1986. Hyperparasitism of *Sclerotinia sclerotiorum* by *Talaromyces flavus*. Can. J. Plant Pathol. 8:43-48.

30. Moore, W. D. 1949. Flooding as a means of destroying the sclerotia of *Sclerotinia sclerotiorum*. Phytopathology 39:920-927.

31. Pape, H. 1937. Beitrage zur biologie und bekampfung des kleekrebs (S. trifoliorum). Arb. Biol. Abt. (Anst.-Reichsanst.), Berl. 22:159-247.

32. Parfitt, D., Coley-Smith, J. R., and McHale, T. 1984. *Laterispora brevirama* on sclerotia of *Sclerotinia*. Plant Pathol. 33:441-443.

33. Patterson, C. L., and Grogan, R. G. 1985. Differences in epidemiology and control of lettuce drop caused by *Sclerotinia minor* and *S. sclerotiorum*. Plant Dis. 69:766-770.

34. Pratt, R. G., and Knight, W. E. 1982. Formation of apothecia by *Sclerotinia trifoliorum* and infection of crimson clover in the field. Plant Dis. 66:1021-1023.

35. Pratt, R. G., and Knight, W. E. 1984. Comparative responses of selected cultivars of four annual clover species to *Sclerotinia trifoliorum* at different inoculum levels in the field. Plant Dis. 68:131-134.

36. Prior, G. D., and Owen, J. H. 1964. Pathological anatomy of *Sclerotinia trifoliorum* on clover and alfalfa. Phytopathology 54:784-787.

37. Raynal, G. 1981. Red clover and alfalfa crown rot caused by *Sclerotinia trifoliorum* Eriks. I. Choice of an inoculation method. Agronomie 7:565-572.

38. Raynal, G. 1981. Red clover and alfalfa crown rot caused

by *Sclerotinia trifoliorum* Eriks. II. Pathogen variability and plant resistance in controlled conditions. Agronomie 7:573-578.

39. Reed, H. E., and Felts, J. H. 1965. Crown rot of alfalfa. Tenn. Farm Home Sci. Prog. Rept. 54:14-15. Univ. Tenn., Knoxville.

40. Schmidt, D. 1980. A study of the resistance of red clover to clover rot (*Sclerotinia trifoliorum* Eriks.). Rev. Suisse Agric. 12:197-206.

41. Schwartz, H. F., and Steadman, J. R. 1978. Factors affecting sclerotium populations of, and apothecium production by, *Sclerotinia sclerotiorum*. Phytopathology 68:383-388.

42. Sproston, T., and Pease, D. C. 1957. Thermoperiods and production of apothecial initials in the fungus *Sclerotinia trifoliorum*. Science 125:599-600.

43. Steadman, J. R. 1979. Control of plant diseases caused by *Sclerotinia* species. Phytopathology 69:904-907.

44. Steadman, J. R. 1983. White mold - a serious field-limiting disease of bean. Plant Dis. 67:346-350.

45. Steadman, J. R., Coyne, D. P., and Cooke, G. E. 1973. Reduction of severity of white mold disease on Great Northern beans by wider row spacing and determinate plant growth habit. Plant Dis Rep. 57:1070-1071.

46. Stromberg, E. L. 1983. Death of fall seeded alfalfa stands. Plant Protection Newsletter 2(2):7. Va. Coop. Ext. Serv., VPI & SU, Blacksburg.

47. Stromberg, E. L. 1984. Stand failures in fall no-till planted alfalfa. Plant Protection Newsletter 3(4):8. Va. Coop. Ext. Serv., VPI & SU, Blacksburg.

48. Stromberg, E. L. 1986. Sclerotinia crown and stem rot: Three case histories. Plant Protection Newsletter 5(3):1-2. Va. Coop. Ext. Serv., VPI & SU, Blacksburg.

49. Uhm, J. Y., and Fujii, H. 1983. Ascospore dimorphism in *Sclerotinia trifoliorum* and cultural characters of strains from different-sized spores. Phytopathology 73:565-569.

50. Van Scoyoc, S. W., and Stromberg, E. L. 1984. Results of the 1984 Sclerotinia crown and stem rot survey. Plant Protection Newsletter 2(July):7-13. Va. Coop. Ext. Serv.,

VPI & SU, Blacksburg.

51. Valleau, W. D., Fergus, E. N., and Henson, L. 1933. Resistance of red clovers to *Sclerotinia trifoliorum* Eriks., and infection studies. Ky. Agric. Exp. Stn. Bull. 341:113-131.

52. Weiss, A., Hipps, L. E., Blad, B. L., and Steadman, J. R. 1980. Comparison of with-in canopy microclimate and white mold disease (*Sclerotinia sclerotiorum*) development in dry edible beans as influenced by canopy structure and irrigation. Agric. Meteorol. 22:11-21.

53. Welty, W. E. 1979. Sclerotinia crown and stem rot. Pages 33-34 in: A Compendium of Alfalfa Diseases. J. H. Graham, F. I. Frosheiser, D. L. Stutevill, and D. C. Erwin, eds. Amer. Phytopathol. Soc., St. Paul, Minn.

54. Welty, W. E., and Busbice, T. H. 1978. Field tolerance in alfalfa to Sclerotinia crown and stem rot. Crop Sci. 18:508-509.

55. Welty, W. E., and Rawlings, J. O. 1984. Effect of benomyl on Sclerotinia crown and stem rot of alfalfa. Plant Dis. 68:294-296.

56. White, H. E. 1982. Results of survey of no-till forage seedings. Agronomy Tips 4:7. Va. Coop. Ext. Serv., VPI & SU, Blacksburg.

57. White, H. E. 1984. Results of 1983 no-till forage survey. Agronomy Tips 6:9-10. Va. Coop. Ext. Serv., VPI & SU, Blacksburg.

58. Willetts, H. J., and Wong, J. A.-L. 1980. The biology of *Sclerotinia sclerotiorum*, *S. trifoliorum*, and *S. minor* with emphasis on specific nomenclature. Bot. Rev. 46:101-165.

59. Williams, G. H., and Western, J. H. 1965. The biology of *Sclerotinia trifoliorum* Eriks. and other species of sclerotium-forming fungi. I. Apothecium formation from sclerotia. Ann. Appl. Biol. 56:253-260.

60. Williams, G. H., and Western, J. H. 1965. The biology of *Sclerotinia trifoliorum* Eriks. and other species of sclerotium-forming fungi. II. The survival of sclerotia in soil. Ann. Appl. Biol. 56:261-268.

CHAPTER 2

Influence of Meteorological Events on Formation of Sclerotinia trifoliorum Apothecia in Virginia.

INTRODUCTION

Sclerotinia crown and stem rot (SCSR), caused by *Sclerotinia trifoliorum* Eriks. (4), causes serious spring losses of some fall-seeded, no-tillage alfalfa fields in Virginia (12). For no-tillage alfalfa to be most successful, the risk of stand failure caused by SCSR must be reduced. The host range of *S. trifoliorum* includes forage legumes such as red and crimson clovers, in addition to alfalfa (14). SCSR has frequently reduced forage legume production in parts of Europe (2,3) and the United States (13) for many years.

S. trifoliorum survives in soil as sclerotia that can remain viable for many years (3,7,15). Apothecia emerge from sclerotia in the fall. Primary infection by ascospores produces small leaf spots. After a killing frost, mycelia grow from the lesions and colonize senescent leaf tissue (2). In late winter to spring, mycelia within colonized leaf tissue spread to the crowns, invading them and frequently killing the entire plant. The fungus may spread laterally to adjacent healthy plants by mycelial growth. Fluffy white mycelial mats, present at the base of diseased plant stems, often form aggregations that later mature into sclerotia.

The occurrence of SCSR in alfalfa has typically been erratic and unpredictable (2,3,10). Mild winter temperatures and normal to abundant rainfall have been reported to enhance SCSR severity (3,9,10,13). *S. trifoliorum* has proved difficult to study in the field and laboratory. The objective of this study was to determine when *S. trifoliorum* apothecia occur naturally in southwest Virginia, and identify what environmental conditions induce sclerotia to produce apothecia. Identification of specific temperature or moisture requirements could be useful in future laboratory and greenhouse studies. This information could also lead to prediction of *S. trifoliorum* apothecia occurrence under field conditions, thus facilitating application of measures to control SCSR.

MATERIALS AND METHODS

Field studies were located in a Groseclose silt loam at the Agronomy Farm, VPI & SU, Blacksburg, Virginia. The soil was appropriately limed and fertilized in June 1984 (see Appendix G for soil nutrient analysis). Galvanized steel bands (10-cm wide, 5-cm submerged into soil) were used to establish 0.75-m diameter microplots. EPTC and carbofuran were incorporated into soil at planting for weed and insect control, respectively. Areas between microplots were planted with red fescue (*Festuca rubra* L.). Microplots were seeded with alfalfa (*Medicago sativa* L. 'Arc') in August of 1984 and 1985. Supplemental irrigation was applied as needed for alfalfa establishment. Treatments were arranged in a randomized complete block design with four replications.

Sclerotia of *S. trifoliorum* were collected from several naturally infested fields in western Virginia, rinsed in tap water, air dried and stored at 20-25 C until needed. Field isolates conformed to descriptions provided for *S. trifoliorum* in the monograph by Kohn (6). The identification of field isolates as *S. trifoliorum* was then confirmed by Dr. L. M. Kohn (University of Toronto) in March 1985. Thirty sclerotia were placed on the soil surface in an upright section (10-cm diameter and 7.6-cm long, embedded 5-cm into soil) of polyvinyl chloride (PVC) pipe located within each microplot approximately at 2-wk intervals, beginning 31 Aug and ending 10 Dec in 1984, and beginning 9 Oct and ending 11 Dec in 1985. Narrower (7.6-cm diameter and 10-cm long) PVC pipe sections (embedded 7.5-cm into soil) were used in 1985 and only ten sclerotia were placed in each microplot. The purpose of the calendar schedule for adding sclerotia to the soil was to increase the opportunity to determine climatic events that influence apothecium production. Sclerotia were observed for apothecium development three times per week. Cummulative numbers of apothecia were not available because apothecia were not removed upon observance within each microplot. The total number of visible apothecia were counted in each microplot on any given observation date, and the maximum number was used in statistical analyses. Secondary disease development (mycelial spread) was not assessed due to absence of this phase within the experimental plots.

An on-site weather monitoring system measured parameters each minute and recorded an hourly average or total. Air and soil temperatures were measured by a copper-constantan thermocouple. Air temperature was measured at a 63-cm height and soil temperature was monitored at a 5-cm depth. Rainfall was measured by a tipping-bucket rain guage. Weather parameters were summarized into daily averages. The relationship between meteorological factors and apothecium production were examined with correlation and linear regression procedures (8) using SAS (11).

RESULTS

In the 1984-85 experiment, sclerotia seeded in October exhibited greatest maximum apothecium production (Table 1). These applications also produced apothecia more quickly and were among the longest in duration of production (39.8-45 days). The time between sclerotium application and apothecium appearance was correlated with maximum apothecium production ($r=-0.71$, $P \leq 0.01$). Long periods of apothecium production also were associated with maximum numbers of apothecia produced ($r=0.57$, $P \leq 0.05$). In addition, short apothecium initiation periods were associated with longer periods of apothecium production ($r=-0.54$, $P \leq 0.05$). Statistical analyses were carried with the 12 Oct, 26 Oct, 23 Nov, and 10 Dec 84 sclerotia applications. The 9 Nov 84 application never produced apothecia.

During the period 1-4 weeks after sclerotia application (WASA), sclerotia were conditioned for apothecium production. Greatest apothecium production occurred during 5-8 WASA. Thus, for preliminary analyses, summation of meteorological factors was divided into 1-4 WASA and 5-8 WASA periods. Mean soil tempera-

Table 1. *Sclerotinia trifoliorum* apothecium appearance, number, and duration of production of approximately biweekly sclerotium applications to microplots located at the Agronomy Farm, VPI&SU, Blacksburg, Virginia in 1984-95.

Sclerotium application date	First apothecium appearance	Maximum apothecium production	Duration of apothecium production
31 Aug 84[w]	21 Nov (83.0)[x]	0.056[y]	1.0[z]
14 Sep 84[w]	15 Nov (61.7)	0.13	10.5
28 Sep 84	18 Nov (50.5)	1.48	41.5
12 Oct 84	11 Nov (29.8)	4.35	45.0
26 Oct 84	17 Nov (21.5)	4.14	39.8
9 Nov 84[w]	----- (0.0)	0.0	0.0
23 Nov 84[w]	4 Jan (42.0)	0.97	28.0
10 Dec 84[w]	3 Feb (55.0)	0.89	25.8

[w] Apothecia were produced in less than four replicates of this sclerotium application date.

[x] Number of days (average of non-zero replicates) between seeding sclerotia and apothecium appearance.

[y] Apothecia production expressed as average maximum number of apothecia/10 sclerotia in 5-8 WASA.

[z] Expressed as number of days apothecia were produced within microplots.

tures during 5-8 WASA (Appendix B) were usually lower than 1-4 WASA (Appendix B). In 1984, mean soil temperatures 14 days before apothecium appearance ranged from 12.6 to 1.5 C, mean air temperatures ranged from 10.2 to 0.6 C (Appendix B). Mean air and soil temperatures (for 12 Oct, 26 Oct, 23 Nov, and 10 Dec 84 sclerotia applications) during this 14-day period were correlated with number of days to apothecium appearance (air, $r=-0.71$, $P\leq0.01$; soil, $r=-0.79$, $P\leq0.001$). Warmer temperatures within the given range were conducive to more rapid apothecium development. The number of days between sclerotia application and appearance of apothecia was associated with number of days of mean soil temperature below 15 C ($r=0.93$, $P\leq0.001$) and 10 C ($r=0.93$, $P\leq0.001$). Mean minimum soil temperatures fell below 10 C at some point before apothecium production began (Appendix D).

Maximum apothecium production was correlated with mean soil temperature during both 1-4 WASA ($r=0.61$, $P\leq0.01$) and 5-8 WASA ($r=0.60$, $P\leq0.01$), and with mean air temperature during 5-8 WASA ($r=0.49$, $P\leq0.05$), but not with 1-4 WASA ($r=0.41$, $P=0.11$). Figure 1 illustrates the relationship between soil temperature and apothecium production during 5-8 WASA. Greater apothecium production coincided with higher temperatures within the given range. Spearman's coefficient of rank correlation ($r_s=0.76$, $P\leq0.001$) was substantially higher than the coefficient of simple linear correlation ($r=0.60$), indicating that some sort of curvilinear relationship exists. However, quadratic regression analysis yielded an anomolous curve. A multiple correlation analysis

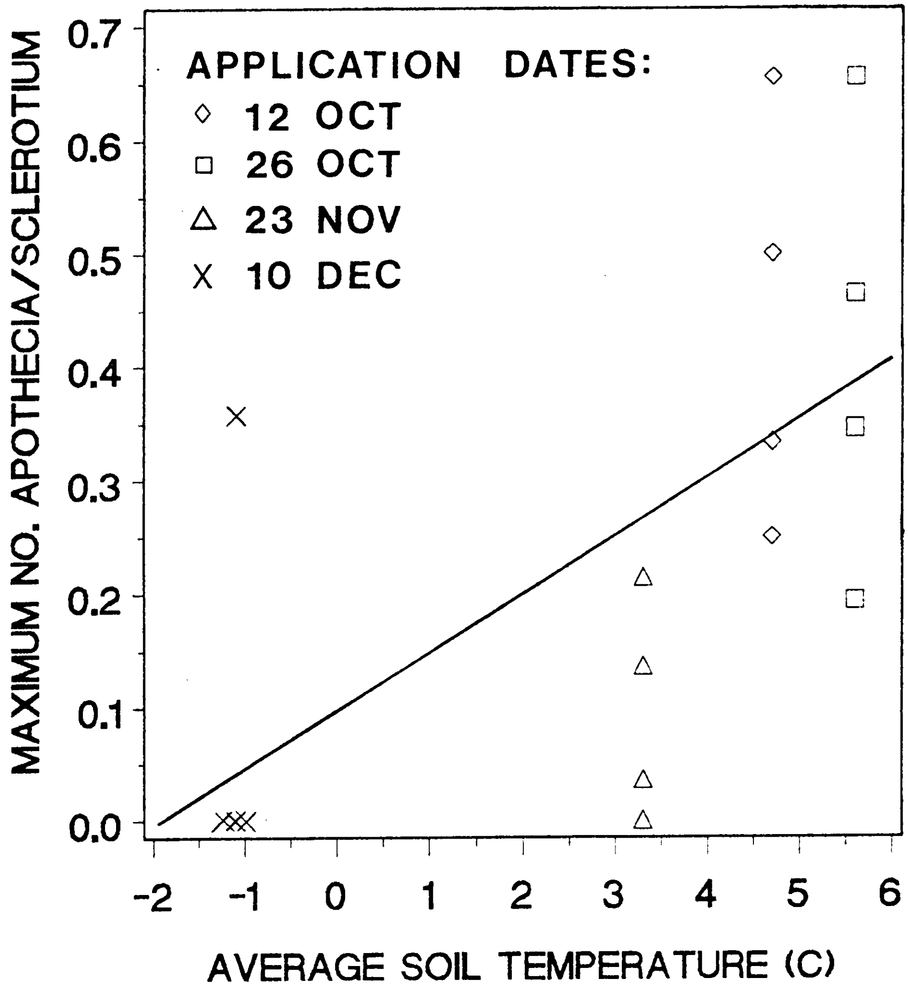


Figure 1. Relationship between maximum apothecium production and mean soil temperature during 5-8 WASA in 1984. The coefficient of simple linear correlation (r) between the factors is 0.60 (P=0.015). The equation for linear regression is $Y=0.0995 + 0.0510X$ ($r^2=0.35$). Spearman's coefficient of rank correlation (r_s) is 0.76 ($P \leq 0.001$).

between maximum apothecium production and average soil temperatures in 1-4 WASA and 5-8 WASA gave an R value of 0.70 ($P \leq 0.01$). Compared to simple correlation coefficients for mean soil temperature in 1-4 WASA (r=0.61) and 5-8 WASA (r=0.60) with apothecium production, there was improvement in the R value (0.70) when mean soil temperatures for 1-4 WASA and 5-8 WASA were considered simultaneously in multiple correlation. The beta weights for mean soil temperatures during 1-4 WASA and 5-8 WASA were 0.43 and 0.40 respectively. This indicates that mean soil temperatures for 1-4 WASA and 5-8 WASA were of equal importance in explaining apothecium production. The number of days over which apothecia were produced was not correlated with temperature.

Rainfall during the autumn of 1984 was below normal (Table 2). However, total rainfall in the 4 wks prior to apothecium appearance was negatively correlated with number of days between sclerotia application and apothecium production (r=-0.51, P=0.065). Sclerotia subjected to greater total rainfall produced apothecia more quickly. Rainfall received at the beginning of apothecium production resulted in significant increases in the number of apothecia (Appendix C). However, rainfall failed to exert a positive influence upon apothecium production later in the season. Maximum numbers of apothecia or duration of apothecium production were not correlated with rainfall.

In the 1985-86 experiment, the October sclerotia applications again exhibited the greatest maximum apothecium production (Table 3). The time until apothecium production began was much less

Table 2. Rainfall data in 1984 and 1985 at microplots located on the Agronomy Farm, VPI&SU, Blacksburg, Virginia.

		Rainfall (cm)	
Year	Month	Total	Departure from normal[z]
1984	Sep 84	---	---
	Oct 84	4.3	-2.8
	Nov 84	5.5	-0.7
	Dec 84	5.8	-1.4
1985	Sep 85	0.7	-7.3
	Oct 85	7.1	0.0
	Nov 85	24.4	+18.2
	Dec 85	1.8	-5.4

[z]Normal monthly precipitation for Montgomery County, Virginia, monitored at the Horticulture Farm, VPI&SU, Blacksburg, 6.4 km from Agronomy Farm, was used for comparison with rainfall received at microplots.

variable than the previous year, and the number of days until apothecia appeared correlated poorly with maximum apothecium production. The length of time over which apothecia were produced was correlated with maximum apothecium production (r=0.74, $P \leq 0.001$). The 23 Nov and 11 Dec 85 sclerotia applications failed to produce apothecia.

Apothecium production occurred mainly during 5-8 WASA following sclerotia application (Table 3). Again, mean soil temperatures were lower during 5-8 WASA (Appendix B) than 1-4 WASA (Appendix B). Mean soil temperature 14 days prior to apothecium appearance ranged from 11.1 to 8.6 C, mean air temperatures ranged from 10.6 to 8.8 C in 1985 (Appendix B). Mean air temperatures (14 days prior to apothecium appearance) were correlated with the number of days until apothecium appearance (r=-0.63, $P \leq 0.05$), whereas no correlation occurred with mean soil temperatures (r=-0.43, P=0.21). The number of days with mean air temperature below 15 C (r=0.86, $P \leq 0.01$) and 12 C (r=0.77, $P \leq 0.01$) between sclerotia application and apothecium appearance were correlated with number of days until apothecia were observed. The occurrence of a period of consecutive days with mean minimum soil temperature below 10 C preceded the appearance of apothecia (Appendix D). These cold periods were much more distinct in the 1985-86 experiment.

Maximum apothecium production was correlated with both mean air and soil temperatures in 1-4 WASA (air, r=0.76, $P \leq 0.001$; soil, r=0.76, $P \leq 0.001$) and 5-8 WASA (air, r=0.72, $P \leq 0.001$; soil,

Table 3. *Sclerotinia trifoliorum* apothecium appearance, number, and duration of production of approximately biweekly sclerotium applications to microplots located at the Agronomy Farm, VPI&SU, Blacksburg, Virginia in 1985-86.

Sclerotium application date	First apothecium appearance	Maximum apothecium production	Duration of apothecium production
9 Oct 85	7 Nov (29.3)[w]	9.08[x]	43.5[y]
23 Oct 85	16 Nov (24.1)	10.58	28.5
7 Nov 85[z]	2 Dec (25.0)	2.06	13.6
23 Nov 85[z]	--- (0.0)	0.0	0.0
11 Dec 85[z]	--- (0.0)	0.0	0.0

[w]Number of days (average of non-zero replicates) between seeding sclerotia and apothecium appearance.

[x]Apothecia production expressed as average maximum number of apothecia/10 sclerotia in wk 5-8.

[y]Expressed as number of days apothecia were produced within microplots.

[z]Apothecia were produced in less than four replicates of this sclerotium application date.

r=0.82, $P \leq 0.001$). Figure 2 illustrates the relationship between mean soil temperature and apothecium production in 5-8 WASA. Warmer temperatures in the indicated range (10 to -2 C) enhanced apothecium development. The coefficient of multiple correlation (R) was 0.85 ($P \leq 0.001$). Compared to simple correlation coefficients for mean soil temperature in 1-4 WASA (r=0.76) and 5-8 WASA (r=0.82) with apothecium production, there was not much improvement for the R value (0.85) when mean soil temperatures for 1-4 WASA and 5-8 WASA were considered simultaneously in multiple correlation. These results were not surprising because of the high correlation between mean soil temperatures in 1-4 WASA and 5-8 WASA (r=0.75, $P \leq 0.001$). The beta weights for mean soil temperatures during 1-4 WASA and 5-8 WASA were 0.30 and 0.60 respectively, indicating that 5-8 WASA was more important than 1-4 WASA in explaining apothecium production. The duration of apothecium production was also correlated with mean air and soil temperatures during 5-8 WASA (air, r=0.72, $P \leq 0.001$; soil, r=0.80, $P \leq 0.001$).

Total rainfall during November 1985 was above normal (Table 2). The number of days with rainfall 3 wks prior to apothecium appearance did correlate with number of days between sclerotia application and apothecium production (r=0.61, P=0.06). Rainfall throughout the period of apothecium production did not result in significant increases in numbers of apothecia (Appendix C). Maximum apothecium development was greater in 1985-86 (Table 3) than in 1984-85 (Table 1). Maximum apothecium production was corre-

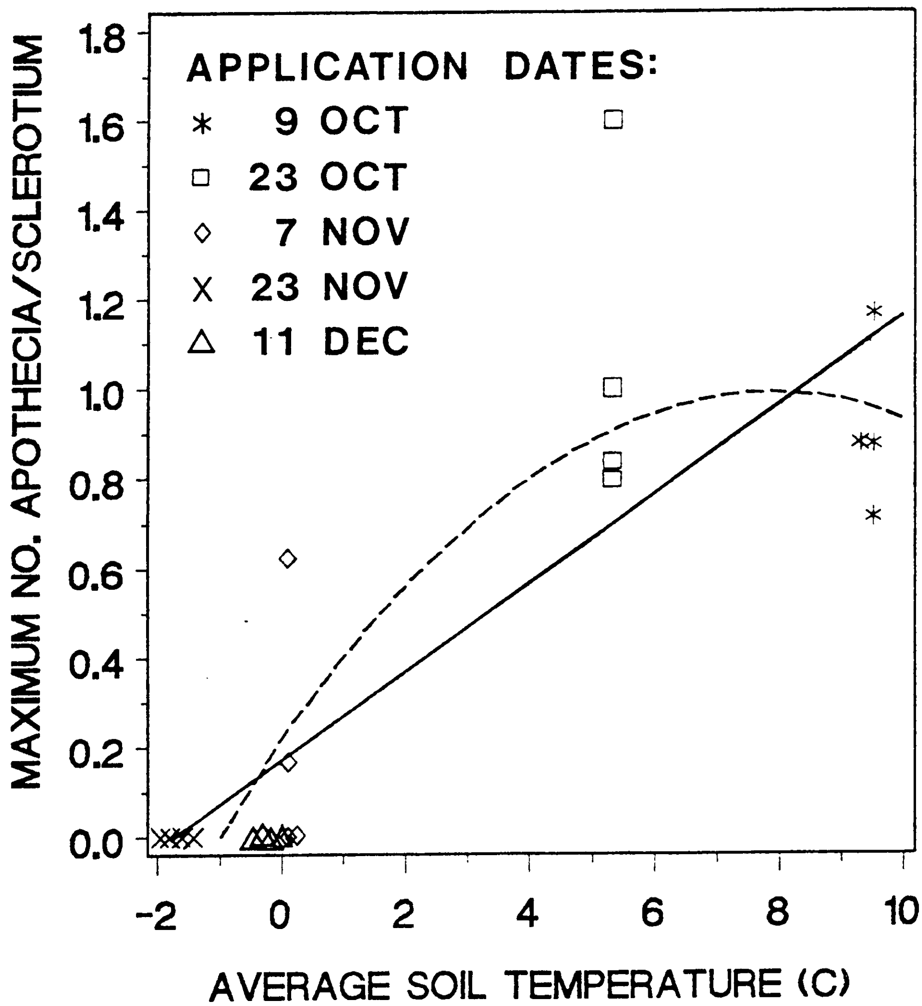


Figure 2. Relationship between maximum apothecium production and mean soil temperature during 5-8 WASA in 1985. The coefficient of simple linear correlation (r) between the factors is 0.82 ($P \leq 0.001$). The equation for linear regression (solid line) is $Y=0.175 + 0.984X$ ($r^2=0.68$). The equation for quadratic regression (dotted line) is $Y=0.2213 + 0.1931X - 0.0121X^2$ ($R^2=0.76$); the linear and quadratic terms were both significant at $P \leq 0.001$.

lated with total rainfall during 5-8 WASA (r=0.82, $P \leq 0.001$) and the number of days with rainfall during that same time period (r=0.79, $P \leq 0.01$). The duration of apothecium production was correlated with the number of days with rainfall >5 mm during 5-8 WASA (r=0.56, P=0.06) following sclerotia application.

DISCUSSION

Results of this study indicate that weather conditions in southwest Virginia are most favorable for apothecium production by *S. trifoliorum* during the months of November and December. The meteorological parameters found to have a significant impact upon apothecium development where temperature and rainfall. The October 1984 and 1985 sclerotia applications exhibited the shortest apothecium initiation periods. This also indicates that the most favorable meteorological conditions for sclerotial apothecium initiation occurred during and after October. Reduced or delayed apothecium production of seedings of sclerotia in August and September 1984 was thought to be associated with heat stress. This problem was observed in *S. sclerotiorum* by prevoius researchers (1). The 9 Nov 84 sclerotium application never produced apothecia, no explanation could be found for this. The lack of apothecium formation in the 23 Nov 85 and 11 Dec 85 sclerotium applications was associated with the cold temperatures that occurred immediately following seeding plots with sclerotia. Apothecium production usually did not occur until mean soil temperatures were below 10 C. Temperatures near 0 C appeared to be the lower limit for apothecium development. Extended periods of mean minimum soil temperature below 10 C may be critical in stimulating sclerotia to produce apothecia. The role of sclerotial chilling periods requires further investigation with regard to apothecium formation. This phenomenon needs to be confirmed in laboratory tests. Field observations presented here should provide direction in manipulating sclerotia for apothecium production, allowing study of *S. trifoliorum* behavior within the laboratory or in greenhouse screening for cultivar resistance to SCSR.

Timing and total amount of rainfall influenced the magnitude of apothecium production. In the 1984-85 experiment, rainfall events which occurred soon after sclerotia application resulted in significant early increases in numbers of apothecia. Overall, the 1985-86 experiment received more rainfall than did the 1984-85 experiment and also exhibited greater maximum apothecium production. In 1985-86, rainfall received during apothecium production did not result in significant increases in apothecia, however, an unusually large amount of rain was received just prior to the first observance of apothecia in 1985. This may have provided sufficient soil moisture for apothecium development so that additional rainfall failed to result in increased apothecium production. Due to the sporadic nature of rainfall occurrence, this data was difficult to correlate with *S. trifoliorum* activity. Another method of monitoring moisture, such as a tensiometer, may be a more appropriate in assessing the role of water in apothecium production. Hunter (5) has found a portable tensiometer very useful in monitoring soil moisture in a prediction scheme for *S. sclerotiorum* activity in New York. This instrument could easily be incorporated into a system for monitoring *S. trifoliorum* activity.

Data from this study can be used to predict the occurrence of apothecia in the field. One model suggested by the October 1984 and 1985 sclerotium applications (which produced the most apothecia) indicates that 17 days of mean soil temperature at or below 15 C are required to initiate *S. trifoliorum* apothecium production (Appendix D). This model could easily be tested in the field by monitoring daily mean soil temperatures and predicting apothecium appearance based upon the number of favorable temperature readings. The model could be confirmed in controlled temperature studies. Monitoring duration of mean minimum soil temperatures below 10 C, total rainfall, number of days with rainfall, and/or soil tensiometer readings would also be useful for model verification and refinement as would further observation of *S. trifoliorum* activity. A fall-sown forage legume crop is at risk to *S. trifoliorum* infection if sclerotia are present in or near the field. Therefore, it is necessary to take steps to reduce risk of stand failure. The ability to predict apothecium appearance in the field would provide guidance in timing of fungicide applications to protect a susceptible leguminous forage crop in the seedling stage.

Literature Cited

1. Abawi, G. S., and Grogan, R. G. 1979. Epidemiology of diseases caused by *Sclerotinia* species. Phytopathology 69:899-904.

2. Dijkstra, J. 1964. Inoculation with ascospores of *Sclerotinia trifolioum* for detection of clover rot resistant red clover. Euphytica 13:314-329.

3. Dillon-Weston, W. A. R., Loveless, A. R., and Taylor, R. E. 1946. Clover rot. J. Agric. Sci. 36:18-28.

4. Eriksson, J. 1880. Om Klöfverroten med särskilt afesseende pä dess uppträdende ivart fädernesland 1878-1879. Kunge Svensk Landtbr. Akad. Handl. och Tidsskr. 1:28-42.

5. Hunter, J. E. 1981. Proposal for a forecasting system for white mold of snap beans. Annu. Rep. Bean Improv. Coop. 24: 122-123.

6. Kohn, L. M. 1979. A monographic revision of the genus *Sclerotinia*. Mycotaxon 9:365-444.

7. Lester, E., and Large, E. C. 1958. Surveys of clover rot with incidental observations on eelworm in clover: England and Wales, 1953-55. Plant Pathol. 7:115-124.

8. Little, T. M., and Hills, F. J. 1978. Agricultural experimentation. John Wiley and Sons, New York. 350 pp.

9. Pratt, R. G., and Knight, W. E. 1982. Formation of apothecia by *Sclerotinia trifoliorum* and infection of crimson clover in the field. Plant Dis. 66:1021-1023.

10. Pratt, R. G., and Knight, W. E. 1984. Comparative responses of selected cultivars of four annual clover species to *Sclerotinia trifoliorum* at different inoculum levels in the field. Plant Dis. 68:131-134.

11. SAS Institute Inc. SAS User's Guide: Statistics, Version 5. Edition. Cary, NC: SAS Institute Inc., 1985. 956 pp.

12. Stromberg, E. L. 1983. Death of fall seeded alfalfa stands. Plant Protection Newsletter 2(2):7. Va. Coop. Ext. Serv.

13. Valleau, W. D., Fergus, E. N., and Henson, L. 1933. Resistance of red clovers to *Sclerotinia trifoliorum* Eriks., and infection studies. Ky. Agric. Exp. Sta. Bull. 341:113-131.

14. Welty, W. E. 1979. Sclerotinia crown and stem rot. Pages 33-34 in: A Compendium of Alfalfa Diseases. J. H. Graham, F. I. Frosheiser, D. L. Stuteville, and D. C. Erwin, eds. Amer. Phytopathol. Soc., St. Paul, MN.

15. Williams, G. H., and Western, J. H. 1965. The biology of *Sclerotinia trifoliorum* Eriks. and other specis of sclerotium-forming fungi. II. The survival of sclerotia in soil. Ann. Appl. Biol. 56:261-268.

CHAPTER 3

Cultural Practices for Control of Sclerotinia Crown and Stem Rot.

INTRODUCTION

A number of cultural control techniques have been suggested which involve specific management practices aimed at reducing losses caused by Sclerotinia crown and stem rot (SCSR) in alfalfa fields. These techniques might include planting date, seeding rate, row spacing and tillage practices. These measures are alternatives to fungicide application. However, a combination of fungicide use and cultural control techniques may give the most effective disease control (7). The intent of such management practices is to create a less favorable environment for SCSR development, while still maintaining economically profitable crop production.

Several researchers have noted that fall forage legume seedings are particularly vulnerable to SCSR damage (2,6,9). Spring planting would avoid *Sclerotinia trifoliorum* Eriks. ascospore infection during the seedling stage, when plants are most susceptible to crown rot and death. Plant density (within rows as well as row spacing) affects the microenvironment within the plant canopy which may, in turn, influence *S. trifoliorum* apothecium development, ascospore dispersal and secondary mycelial spread. A reduced seeding rate may improve air circulation within the canopy, thereby reducing humidity in the microenvironment which may slow secondary spread of *S. trifoliorum* to adjacent plants (1,5). Wider row spacings reduced the severity of white mold of bean, caused by *Sclerotinia sclerotiorum* (8), and wider within-row plant spacing reduced root transmission of *S. sclerotiorum* in sunflower fields (3,4). The effect of reduced plant populations on yield must be weighed against disease-related losses.

In this study, several alfalfa plant population densities were evaluated under the presence of *S. trifoliorum* in Virginia. Plant density may be a very economical means of reducing potential losses from SCSR. An experiment was also conducted to evaluate influence of planting date upon SCSR severity under conditions in southwestern Virginia. This could eventually lead to a recommended planting date for fields potentially at risk from *S. trifoliorum*.

MATERIALS AND METHODS

Two different experiments are described in this chapter. The first experiment, referred to as the Plant Age Study, consisted of planting alfalfa at five different times throughout a one-year period. Microplots were then infested with sclerotia of *S. trifoliorum* at the end of that time period. The second experiment consisted of planting alfalfa with a no-tillage planter in a single row lattice pattern with rows intersecting every 2.4 m. Different plant populations were created by thinning emerged seedlings. This experiment is referred to as the Plant Population Density Study.

Plant Age Study

This field study was located on a Groseclose silt loam at the Agronomy Farm, VPI & SU, Blacksburg, Virginia. The general site and individual microplots were prepared as stated in the preceding chapter. Alfalfa (*Medicago sativa* L. 'Arc') was sown in microplots on the following dates:

1 Sep 84

19 Mar 85

14 May 85

15 Jul 85

23 Aug 85

Eight microplots were planted to alfalfa on each planting date. Four microplots were infested with sclerotia, the remaining four microplots were non-infested check plots. Treatments were arranged in a randomized complete block design with four replications. Microplots were infested with sclerotia on 16 Oct 85. Thirty sclerotia were distributed as evenly as possible throughout the microplot and pushed into the soil surface. Plant populations were counted 10 Jan and 17 Jan 86. In the spring, alfalfa populations were counted 1 May, 2 May and 10 May 86. Two quadrants from each microplot were counted, and then averaged and multiplied by four to yield a whole-plot population. This population was then expressed as number of plants/m^2. The experiment was analyzed by analysis of variance as a two-way factorial with planting date and infestation as the class variables. Orthogonal comparisons were then used to test the effect of soil infestation with sclerotia for each planting date.

Plant Population Density Study

The field study was located in a Landisburg/Greendale silt loam at the Agronomy Farm. General site preparation was as stated previously. On 4 Sep 85 alfalfa, cultivar 'Arc' was sown with a Tye Pasture Pleaser (Tye Co., Box 218, Lockney, TX 79241) into a sod of creeping red fescue that had been killed with two applications of paraquat. A seeding rate of 34 kg/ha (30 lb/acre) was used. The seed was sown in a lattice pattern with rows intersecting every 2.4 m. Plants were removed within the rows (creating spaces 30 cm long) to form individual cross-shaped, 1.83 m plots. The vacant space between plots served as a buffer zone to prevent mycelial spread between plots. Twenty-five sclerotia were pushed into the soil surface near the intersect of each plot on 11 Nov 85.

Originally, plots were to be thinned to the following densities; one plant every 1 cm, 3 cm, 15 cm, and original germination rate. Only the 15-cm population and a portion of the original germination rate were completed during November and early December 1985. The thinning procedure proved to be tedious and time-consuming so that it was not possible to complete all plant densities as originally planned. Completed treatments consisted of seven infested plots at the original germination rate, four non-infested and twelve infested plots at the 15-cm population. Foliage removal was not carried out as had been previously planned. Plant populations were counted in November and early

December 1985 and again 10 May 86. A paired t-test procedure was used to test for a significant decrease from Jan 86 to May 86 population counts within each treatment.

RESULTS

Plant Age Study

Highly significant differences were observed between alfalfa populations counted in January and May 1986 (Table 4, A). When averaged over all planting dates, significant reductions in population occurred between January and May 1986 for both infested and non-infested treatments (Table 4, B). When planting dates were considered seperately, ignoring infestation treatment, significant reductions in population from January to May 1986 were detected in the 15 Jul 85 and 23 Aug 85 plantings (Table 4, C). When all treatment combinations were considered seperately, significant population reductions from January to May 1986 occurred in the non-infested and infested 23 Aug 85 planting (Table 5). The infested 15 Jul 85 treatment exhibited a nearly significant reduction in population (Table 5). Overall, micro-plots infested with sclerotia exhibited significantly lower plant populations than non-infested plots (Table 6, A). Infestation treatment did not significantly affect plant population within each counting date, when averaged over planting dates (Table 6, B). Infestation resulted in a significant population reduction, compared with non-infested plots, only for the July planting date. The August planting date, however, did exhibit a substantial reduction in population (Table 6, C). When non-infested and

Table 4. Differences among alfalfa plant populations recorded at two different counting dates, Jan 86 and May 86, when averaged over *S. trifoliorum* infestation treatment.

	Plant population[y]		Orthogonal contrast F value[z]	
A. Count date	Jan 86	583.1		
	May 86	482.2	26.51	***
B. Infestation				
Non-infested	Jan 86	607.0		
	May 86	501.5	14.53	***
Infested	Jan 86	558.9		
	May 86	462.8	12.04	**
C. Planting dates				
1 Sep 84				
	Jan 86	409.1		
	May 86	342.4	2.32	NS
19 Mar 85				
	Jan 86	478.6		
	May 86	430.5	1.20	NS
14 May 85				
	Jan 86	510.8		
	May 86	432.2	3.22 (P=0.064)	NS
15 Jul 85				
	Jan 86	735.6		
	May 86	635.1	5.28	*
23 Aug 85				
	Jan 86	780.8		
	May 86	570.7	23.05	***

[y] Alfalfa population expressed as number of plants/m^2.
[z] Orthogonal contrast,
*Reduction in plant population was significant at $P \leq 0.05$.
**Reduction in plant population was significant at $P \leq 0.01$.
***Reduction in plant population was significant at $P \leq 0.001$.
NS=No significant reduction in plant population occurred.

Table 5. Differences among alfalfa plant populations recorded at two different counting dates, Jan 86 and May 86, for non-infested microplots and microplots infested with *S. trifoliorum* sclerotia.

Planting date and infestation[x]		Plant population[y]		Orthogonal contrast F value[z]	
1 Sep 84	N	Jan 86	452.0		
	N	May 86	344.7	3.01	NS
	I	Jan 86	366.1		
	I	May 86	340.1	0.18	NS
19 Mar 85	N	Jan 86	516.4		
	N	May 86	461.0	0.80	NS
	I	Jan 86	440.7		
	I	May 86	400.0	0.43	NS
14 May 85	N	Jan 86	498.3		
	N	May 86	443.1	0.80	NS
	I	Jan 86	523.2		
	I	May 86	421.5	2.70	NS
15 Jul 85	N	Jan 86	821.5		
	N	May 86	734.5	1.98	NS
	I	Jan 86	649.8		
	I	May 86	535.6	3.40 (P=0.079)	NS
23 Aug 85	N	Jan 86	746.9		
	N	May 86	524.3	12.93	**
	I	Jan 86	814.7		
	I	May 86	617.1	10.20	**

[x] I=infested with sclerotia, N=non-infested.
[y] Expressed as number of plants/m^2.
[z] Orthogonal contrast,
  **Reduction in plant population was significant at $P \leq 0.01$.
  NS=No significant reduction in plant population occurred.

Table 6. Differences among non-infested microplots and microplots infested with *S. trifoliorum* sclerotia when averaged over Jan 86 and May 86 counting dates.

		Plant population[x]	Orthogonal contrast F value[y]
A. Infestation treatment			
	N[z]	554.3	
	I	510.9	4.91 *
B. Counting date			
Jan 86	N	607.0	
Jan 86	I	558.9	3.02 NS (P=0.06)
May 86	N	501.5	
May 86	I	462.8	1.95 NS
C. Planting dates			
1 Sep 84			
	N	398.3	
	I	353.1	1.07 NS
19 Mar 85			
	N	488.7	
	I	420.4	2.44 NS
14 May 85			
	N	470.6	
	I	472.3	0.00 NS
15 Jul 85			
	N	778.0	
	I	592.7	17.92 ***
23 Aug 85			
	N	635.6	
	I	715.9	3.36 NS (P=0.07)

[x] I=infested with sclerotia, N=non-infested.
[y] Expressed as number of plants/m^2.
[z] Orthogonal contrast,
*Reduction in plant population was significant at $P \leq 0.05$.
***Reduction in plant population was significant at $P \leq 0.001$.
NS=No significant reduction in plant population occurred.

infested plots were compared for each planting date and counting date, significant population reductions in infested plots versus non-infested plots occurred only in the 15 Jul 85 planting date (Table 7). The reduction was detected in both the January and May 1986 counts for the 15 Jul 85 planting.

Information for the individual replicates within each planting date is given in Appendix E. Examination of plant populations of infested microplots over planting dates distinguished two distinct groups: 1 Sep 84, 19 Mar 85, and 14 May 85 seedings; and 15 Jul 85 and 23 Aug 85 seedings (Table 8). A similar grouping was noted in data from non-infested plots, but differences were less obvious in the May 1986 count (Table 8). In addition to plant population counts, an SCSR disease rating was to be made for each microplot. However, due to lack of secondary spread within the microplots, no disease rating could be made. Severe frost heaving of plants within microplots occurred during the winter of 1985-86. All alfalfa plantings exhibited a decrease in plant population between January and May 1986, whether infested or non-infested. However, the 15 Jul 85 and 23 Aug 85 plantings exhibited the most noticeable damage from frost and generally also the greatest decrease in plant population. It was difficult to distinguish between loss caused by SCSR and frost-heaving. Groups of plants killed by SCSR were not obvious within the microplots, but some areas were devoid of plants apparently due to frost-heaving. These barren areas were all located in a similar region of affected microplots. The spring

Table 7. Differences among alfalfa plant populations for non-infested microplots and microplots infested with *S. trifoliorum* sclerotia with the Jan 86 and May 86 counting dates considered seperately.

Planting date and date of counting			Plant population[x]	Orthogonal contrast F value[y]	
1 Sep 84					
	Jan 86	N[z]	452.0		
		I	366.1	1.92	NS
	May 86	N	344.7		
		I	340.1	0.01	NS
19 Mar 85					
	Jan 86	N	516.4		
		I	440.7	1.50	NS
	May 86	N	461.0		
		I	400.0	0.97	NS
14 May 85					
	Jan 86	N	498.3		
		I	523.2	0.16	NS
	May 86	N	443.1		
		I	421.5	0.12	NS
15 Jul 85					
	Jan 86	N	821.5		
		I	649.8	7.70	**
	May 86	N	734.5		
		I	535.6	10.32	**
23 Aug 85					
	Jan 86	N	746.9		
		I	814.7	1.20	NS
	May 86	N	524.3		
		I	617.1	2.24	NS

[x]Expressed as number of plants/m^2.
[y]Orthogonal contrast,
**Reduction in plant population was significant at $P \leq 0.01$.
NS=No significant reduction in plant population occurred.
[z]I=infested with sclerotia, N=non-infested.

Table 8. Differences among alfalfa plant populations of infested and non-infested microplots, planted at five different planting dates. Populations were counted in Jan 86 and again in May 86.

A. Infested with sclerotia

Planting date	Counting date Jan 86		May 86	
1 Sep 84	366.1[y]	d[z]	340.1	c
19 Mar 85	440.7	cd	400.0	bc
14 May 85	523.2	c	421.5	bc
15 Jul 85	649.8	b	535.6	ab
23 Aug 85	814.7	a	617.1	a

B. Non-infested

Planting date	Counting date Jan 86		May 86	
1 Sep 84	452.0	c	344.7	b
19 Mar 85	516.4	bc	461.0	b
14 May 85	498.3	bc	443.1	b
15 Jul 85	821.5	a	734.5	a
23 Aug 85	746.9	ab	524.3	b

[y] Average population of four microplots.
[z] Within each column, numbers followed by the same letter are not significantly different according to the Duncan's Multiple Range Test ($P \leq 0.05$).

and early-summer plantings appeared to be more resistant to population reductions over the winter season. This experiment was repeated in the 1986-87 season. Further observation would help to strengthen any conclusions which may be drawn from this first year of observation.

Plant Population Density Study

Original alfalfa population densities, infested with sclerotia, decreased significantly from Nov 85 to May 86 (Table 9). The infested, 15-cm alfalfa plant density exhibited a significant decrease in plant population from Nov 85 to May 86 (Table 10, A), but a significant decrease in population did not occur in the non-infested 15-cm plant density (Table 10, B). It should be noted that frost-heaving may have caused some loss in plant numbers in this experiment.

DISCUSSION

Analysis of the Plant Age Study indicated that planting dates fell into 2 categories; one including 1 Sep 84, 19 Mar 85, and 14 May 85; a second including 15 Jul 85 and 23 Aug 85. All planting dates exhibited a reduction in plant population over the winter of 1985-86, however, the 15 Jul 85 and 23 Aug 85 plantings experienced the greatest population reductions. Reductions in plant population could have been caused by winter injury or *S. trifoliorum* colonization, but it was not possible to distinguish between these two factors. Lack of adequate rainfall in spring may have prevented significant secondary mycelial spread within the microplots. Since late-summer plantings experience a decline

Table 9. Effect of sclerotium infestation upon plant population of original seeding density of alfalfa in 1985-86 Plant Density Study. Population counts were recorded in Nov 85 and again in May 86.

Plot	Count[y] Nov 85	Count[y] May 86	Difference	Paired t-test value[z]
1	53.0	48.7	4.3	4.59 **
2	61.1	35.8	25.3	
3	64.5	47.3	17.2	
4	64.5	30.9	33.6	
5	39.9	33.4	6.5	
6	52.2	35.3	16.9	
7	43.7	23.8	19.9	

[y]Expressed as number of plants/m.
[z]Paired t-test,
**Reduction in plant population over winter was significant at $P \leq 0.01$.

Table 10. Effect of infestation treatment upon 15-cm alfalfa plant population density of the 1985-86 Plant Population Density Study. Population counts were recorded in Nov 85 and again in May 86.

A. Infested with sclerotia

Plot	Count[y] Nov 85	Count[y] May 86	Difference	Paired t-test value[z]
1	6.6	6.0	0.6	2.15 *
2	6.6	7.1	-0.5	
3	6.6	7.1	-0.5	
4	5.7	6.0	-0.3	
5	6.8	4.6	2.2	
6	6.0	6.3	-0.3	
7	6.6	5.2	1.4	
8	7.1	7.1	0.0	
9	5.7	5.7	0.0	
10	6.3	4.9	1.4	
11	6.8	3.8	3.0	
12	6.6	4.6	2.0	

B. Non-infested

Plot	Count[y] Nov 85	Count[y] May 86	Difference	Paired t-test value[z]
1	5.5	3.8	1.7	1.954 NS
2	6.6	6.8	-0.2	
3	6.8	6.3	0.5	
4	6.8	4.9	1.9	

[y]Expressed as number of plants/m.
[z]Paired t-test,
*Reduction in plant population over winter was significant at $P \leq 0.05$.
NS=No significant reduction in plant population occurred.

in plant population during the winter, additional losses caused by *S. trifoliorum* would only worsen the situation. The results of this study indicate that mid- to late-summer plantings of alfalfa are more at risk to losses caused by winter injury and SCSR than are spring and early-summer plantings. Care must be taken in managing sites which may contain *S. trifoliorum*. It would be best to avoid fall planting of alfalfa on such sites.

Some reduction in plant population was observed over the winter of 1985-86 for the infested original and 15-cm plant densities of the Plant Population Density Study. From these sparse results, it would appear that presence of *S. trifoliorum* in any population density could lead to plant loss. Presumably, wider plant spacing should reduce the spread of *S. trifoliorum* to adjacent plants. A greater number of plant densities would need to be evaluated under field conditions before sound conclusions regarding seeding rate could be formulated.

Literature Cited

1. Dillon-Weston, W. A. R., Loveless, A. R., and Taylor, R. E. 1946. Clover rot. J. Agric. Sci. 36:18-28.

2. Elgin, J. H., and Beyer, E. H. 1968. Evaluation of selected alfalfa clones for resistance to *Sclerotinia trifoliorum* Eriks.. Crop Sci. 8:265-266.

3. Hoes, J. A., and Huang, H. C. 1985. Effect of between-row spacings on development of Sclerotinia wilt and yield of sunflower. Can. J. Plant Pathol. 7:98-102.

4. Huang, H. C., and Hoes, J. A. 1980. Importance of plant spacing and sclerotial position to development of Sclerotinia wilt of sunflower. Plant Dis. 64:81-84.

5. Lester, E., and Large, E. C. 1958. Surveys of clover rot with incidental observations on eelworm in clover: England and Wales, 1953-55. Plant Pathol. 7:115-124.

6. Loveless, A. R. 1951. Observations on the biology of clover rot. Ann. Appl. Biol. 38:642-664.

7. Steadman, J. R. 1979. Control of plant diseases caused by *Sclerotinia* species. Phytopathology 69:904-907.

8. Steadman, J. R., Coyne, D. P., and Cooke, G. E. 1973. Reduction of severity of white mold disease on Great Northern beans by wider row spacing and determinate plant growth habit. Plant Dis. Rep. 57:1070-1071.

9. Valleau, W. D., Fergus, E. N., and Henson, L. 1933. Resistance of red clover to *Sclerotinia trifoliorum* Eriks., and infection studies. Ky. Agric. Exp. Stn. Bull. 314: 113-131.

CHAPTER 4

SUMMARY

Sclerotinia crown and stem rot (SCSR), caused by *Sclerotinia trifoliorum* Eriks., has recently been associated with serious first year losses in spring, of some fall-sown, no-tillage alfalfa fields in Virginia. For no-tillage alfalfa to be most successful, it is desirable to identify those control measures that will reduce risk of stand failure caused by SCSR. *S. trifoliorum* has proved difficult to study in the field and laboratory. The first objective of this study was to determine when *S. trifoliorum* apothecia occur naturally in the field in southwest Virginia, and identify what meteorological conditions induce sclerotia to produce apothecia. This information would facilitate development of measures to economically control SCSR.

In order to characterize the phenology of *S. trifoliorum*, sclerotia were set out in field microplots at approximately 2-wk intervals August through December in 1984, and October through December in 1985. Sclerotia were observed for apothecium development. Weather parameters measured by an on-site monitoring system were correlated with apothecium production. Greatest numbers of apothecia were produced during the months of November and December. Temperature and rainfall were observed to have the greatest impact, of those parameters measured, upon apothecium development. When apothecium production occurred, mean soil temperatures were usually below 10 C. Temperatures near 0 C

appeared to be the lower limit for apothecium development. Extended periods of mean minimum soil temperature below 10 C, but above 0 C, may be critical in stimulating sclerotia to produce apothecia. The greatest number of apothecia were produced within a mean soil temperature range of 5-10 C.

Timing and amount of rainfall influenced the magnitude of apothecium production. Rainfall occurring at the beginning of apothecium production resulted in significant increases in numbers of apothecia in the 1984-85 Phenology Study. Overall, the 1985-86 Phenology Study received more rainfall than the previous year and exhibited greater maximum apothecium production.

The relationship detected between apothecium production and the temperature and rainfall at the microplots suggest that it may be possible to predict the occurrence of naturally occurring *S. trifoliorum* apothecia in the field. A possible method consists of monitoring number of days that mean soil temperature falls at or below 15 C. Results of this study indicate about 17 days of favorable temperature readings are necessary for apothecium initiation. The ability to predict apothecium appearance in the field would provide guidance in timing of fungicide applications to protect a susceptible leguminous forage crop in the seedling stage.

Cultural control studies comprised the other phase of this research. These techniques involve specific management practices aimed at reducing losses caused by SCSR in alfalfa fields. The intent of such practices is to create a less favorable environment for SCSR development, while still maintaining profitable crop production.

The Plant Age Study consisted of planting alfalfa at five different times throughout a one-year period ending in August, at which time these microplots were then infested with *S. trifoliorum* sclerotia. All planting dates exhibited a reduction in plant population over the winter, however, the infested July and August 1985 plantings experienced the greatest losses. This study indicated that mid- to late-summer alfalfa plantings are more at risk to losses caused by SCSR and winter injury than are fields sown in spring or early summer. If *S. trifoliorum* is known to be present, it would be best to avoid mid- to late-summer planting of alfalfa on such sites. Diseases associated with spring-planted alfalfa should be considered and appropriate control measures applied.

The Plant Population Density Study plots consisted of two intersecting 1.83 m rows of alfalfa. The original seeding rate and the 15-cm plant populations were established and a portion of the experiment was infested with sclerotia in November 1985. Alfalfa populations in infested plots exhibited significant reductions in number of plants. Preliminary results suggest that presence of *S. trifoliorum* may pose a threat to any plant population density, although presumably, wider within row plant spacing should reduce the spread of *S. trifoliorum* to adjacent plants.

The Phenology study has led to a better understanding of the biology of *S. trifoliorum.* These observations will provide direction in manipulating sclerotia for apothecium production in the laboratory. Observation of apothecium occurrence in southwest Virginia will guide further research in control measures for SCSR. The cultural control studies did indicate planting dates which could minimize exposure of forage seedings to infection by *S. trifoliorum.* These studies also indicated some direction for future research in SCSR control strategies.

Appendix A. Occurrence of Sclerotinia trifoliorum Apothecia in Microplots for All Replicates of Each Sclerotium Application Date of the Phenology Study.

In the 1984-85 Phenology Study, thirty sclerotia were placed in each microplot at the respective application date. In the 1985-86 study, only ten sclerotia were applied per microplot. The following is a summary, for both seasons, of apothecium occurrence for sclerotia in each individual microplot within the Phenology Study.

Table 11. *S. trifoliorum* apothecium occurrence in all replicates of the 1984-85 Phenology Study.

Sclerotium application date	First apothecium appearance	Duration of apotheciun production (days)	Maximum apothecium production[y]
31 Aug 84			
Rep 1	---	---	0
Rep 2	---	---	0
Rep 3	21 Nov (83)[z]	21 Nov (1)	0.0556
Rep 4	---	---	0
14 Sep 84			
Rep 1	---	---	0
Rep 2	9 Nov (56)	9 Nov-17 Dec (38)	0.0588
Rep 3	14 Nov (61)	14 Nov-17 Nov (3)	o.0435
Rep 4	21 Nov (68)	21 Nov (1)	0.1111
28 Sep 84			
Rep 1	28 Nov (61)	28 Nov-19 Dec (21)	0.1290
Rep 2	7 Nov (40)	7 Nov-8 Jan (62)	0.1250
Rep 3	12 Nov (45)	12 Nov-8 Jan (57)	0.2500
Rep 4	23 Nov (56)	23 Nov-10 Dec (26)	0.1739
12 Oct 84			
Rep 1	12 Nov (31)	12 Nov-21 Dec (39)	0.3500
Rep 2	7 Nov (26)	7 Nov-8 Jan (62)	0.8214
Rep 3	12 Nov (31)	12 Nov-24 Dec (42)	0.2500
Rep 4	12 Nov (31)	12 Nov-19 Dec (37)	0.7241
26 Oct 84			
Rep 1	12 Nov (17)	12 Nov-10 Jan (59)	0.2069
Rep 2	19 Nov (24)	19 Nov-19 Dec (30)	0.6552
Rep 3	21 Nov (26)	21 Nov-21 Dec (30)	0.3448
Rep 4	14 Nov (19)	14 Nov-24 Dec (40)	0.4643
9 Oct 84			
Rep 1	---	---	0
Rep 2	---	---	0
Rep 3	---	---	0
Rep 4	---	---	0
23 Nov 84			
Rep 1	---	---	0
Rep 2	8 Jan (46)	8 Jan-1 Mar (52)	0.3600
Rep 3	2 Jan (40)	2 Jan-23 Feb (52)	0.1364
Rep 4	2 Jan (40)	2 Jan-10 Jan (8)	0.0400
10 Dec 84			
Rep 1	7 Feb (59)	7 Feb (1)	0.2000
Rep 2	10 Jan (31)	10 Jan-16 Apr (96)	0.6250
Rep 3	---	---	0
Rep 4	23 Feb (75)	23 Feb-1 Mar (6)	0.3214

[y]Expressed as number of apothecia per sclerotium.
[z]Number of days after sclerotium application date in which apothecia appeared.

Table 12. *S. trifoliorum* apothecium occurrence in all replicates of the 1985-86 Phenology Study.

Sclerotium application date	First apothecium appearance	Duration of apothecium production (days)	Maximum apothecium production[y]
9 Oct 85			
Rep 1	6 Nov (28)[z]	6 Nov-18 Dec (42)	0.7143
Rep 2	6 Nov (28)	6 Nov-22 Jan (77)	0.8750
Rep 3	6 Nov (28)	6 Nov-14 Dec (38)	1.167
Rep 4	11 Nov (33)	11 Nov-28 Nov (17)	0.8750
23 Oct 85			
Rep 1	15 Nov (23)	15 Nov-14 Dec (29)	1.600
Rep 2	15 Nov (23)	15 Nov-11 Dec (26)	1.000
Rep 3	20 Nov (28)	20 Nov-11 Dec (21)	0.8000
Rep 4	13 Nov (21)	13 Nov-18 Dec (35)	0.8333
7 Nov 85			
Rep 1	---	---	0
Rep 2	11 Dec (34)	11 Dec-8 Jan (28)	0.2000
Rep 3	23 Nov (16)	23 Nov-18 Dec (25)	0.6250
Rep 4	---	---	0
23 Nov 85			
Rep 1	---	---	0
Rep 2	---	---	0
Rep 3	---	---	0
Rep 4	---	---	0
11 Dec 85			
Rep 1	---	---	0
Rep 2	---	---	0
Rep 3	---	---	0
Rep 4	---	---	0

[y] Expressed as number of apothecia per sclerotium.
[z] Number of days after sclerotium application date in which apothecia appeared.

Appendix B. Summary of temperature data collected at the Agronomy Farm, VPI&SU, Blacksburg, Virginia.

Temperature was found to play a critical role in initiation of *S. trifoliorum* apothecia (Chapter 2). Supplementary temperature information, in addition to that provided in Chapter 2, is presented here. A temperature summary during the major period of apothecium production is given in Figure 3 and Figure 4 for each season of the Phenology Study. Mean maximum/minimum temperatures are presented in Figure 5 and Figure 6.

Sclerotia produced apothecia approximately 4 wks after sclerotium application to microplots. For statistical analyses, temperature data was divided into 2-wk or 4-wk intervals and a mean temperature was calculated. Mean air and soil temperatures for 1-4 weeks after sclerotium application (WASA) are presented in Table 13 and Table 15 for both seasons. Mean temperatures for 5-8 WASA following sclerotium application are presented on Table 14 and Table 16 for both seasons. Daily temperature averages are presented in Appendix F. In some instances, use of mean air and soil temperatures 2 wks prior for first observation of apothecia were more appropriate in some analyses. These mean 2-wk temperatures are presented in Table 17 and Table 18.

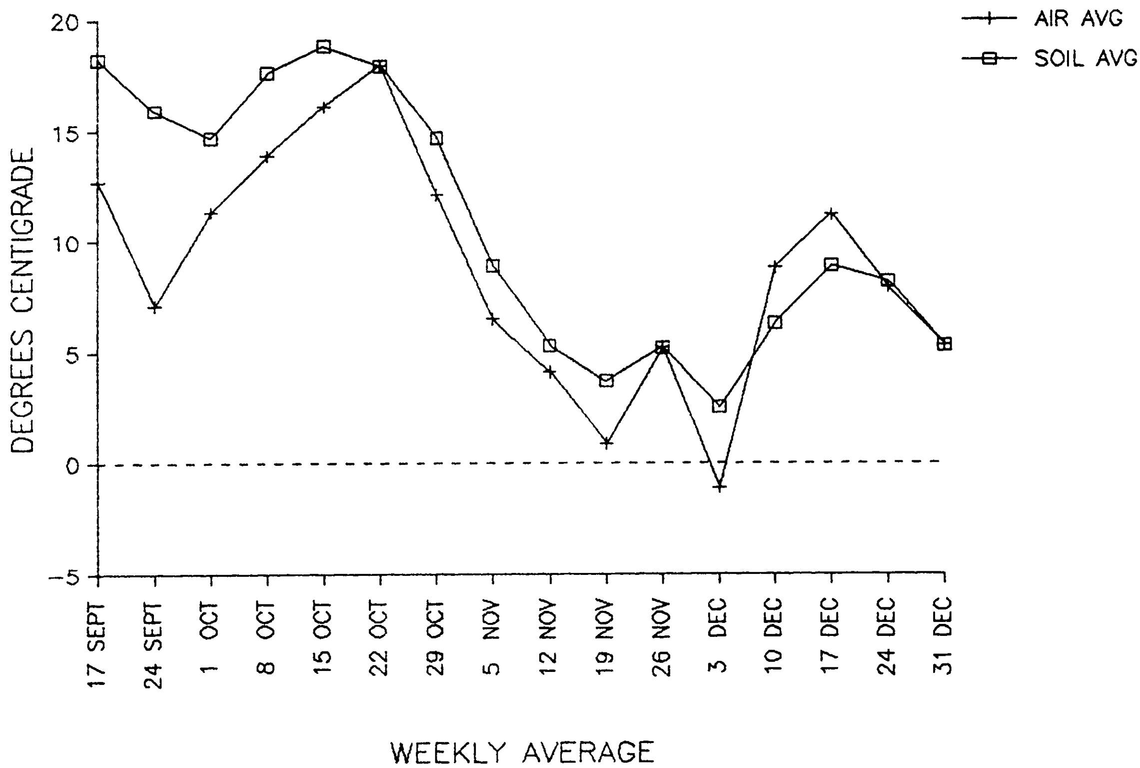


Figure 3. Weekly mean air (at 63-cm height) and soil (at 5-cm depth) temperatures Sep-Dec 1984 at microplots of the 1984-85 Phenology Study.

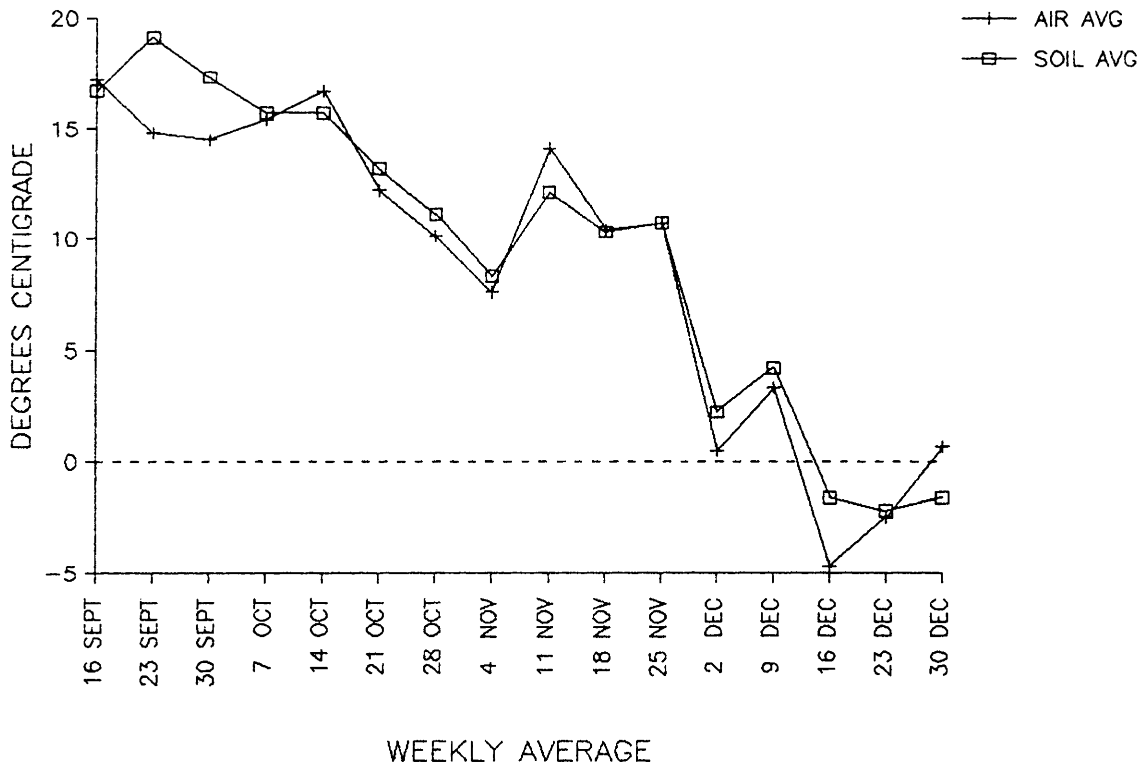
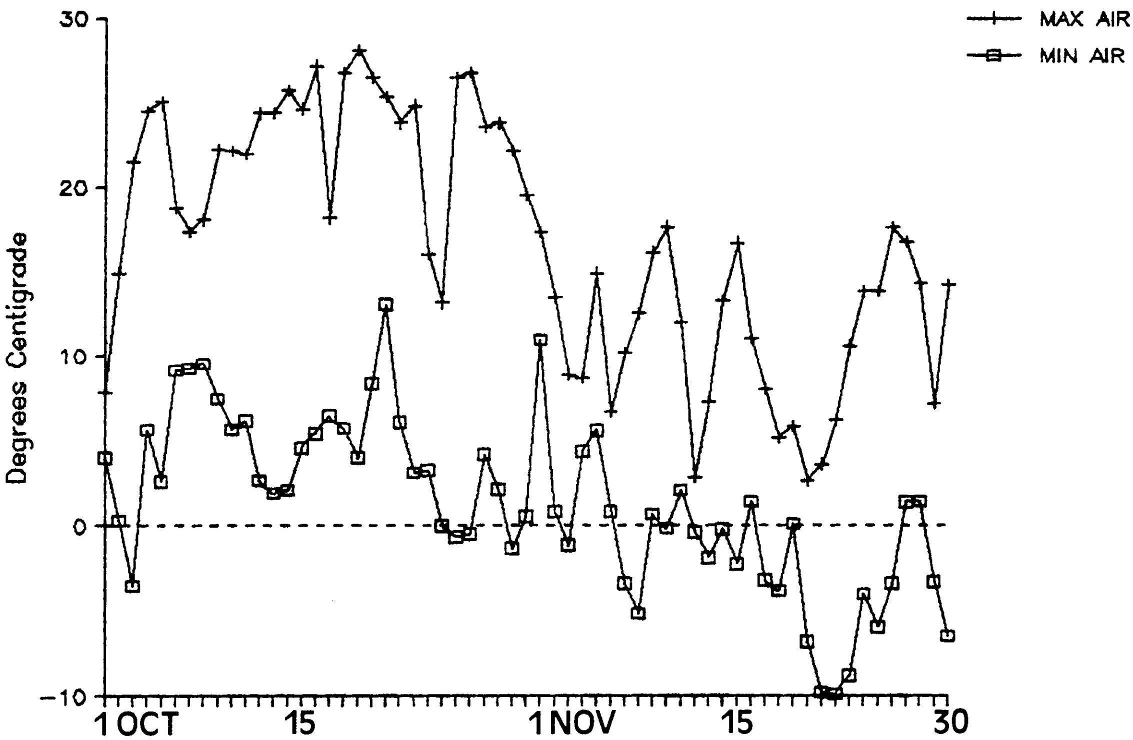


Figure 4. Weekly mean air (at 63-cm height) and soil (at 5-cm depth) temperatures Sep-Dec 1985 at microplots of the 1985-86 Phenology Study.

Figure 5. Daily mean maximum/minimum air (top) and soil (bottom) temperatures Oct-Nov 1984 at microplots of the 1984-85 Phenology Study.


MAX AIR
MIN AIR
Degrees Centigrade
30
20
10
0
-10
1 OCT
15
1 NOV
15
30

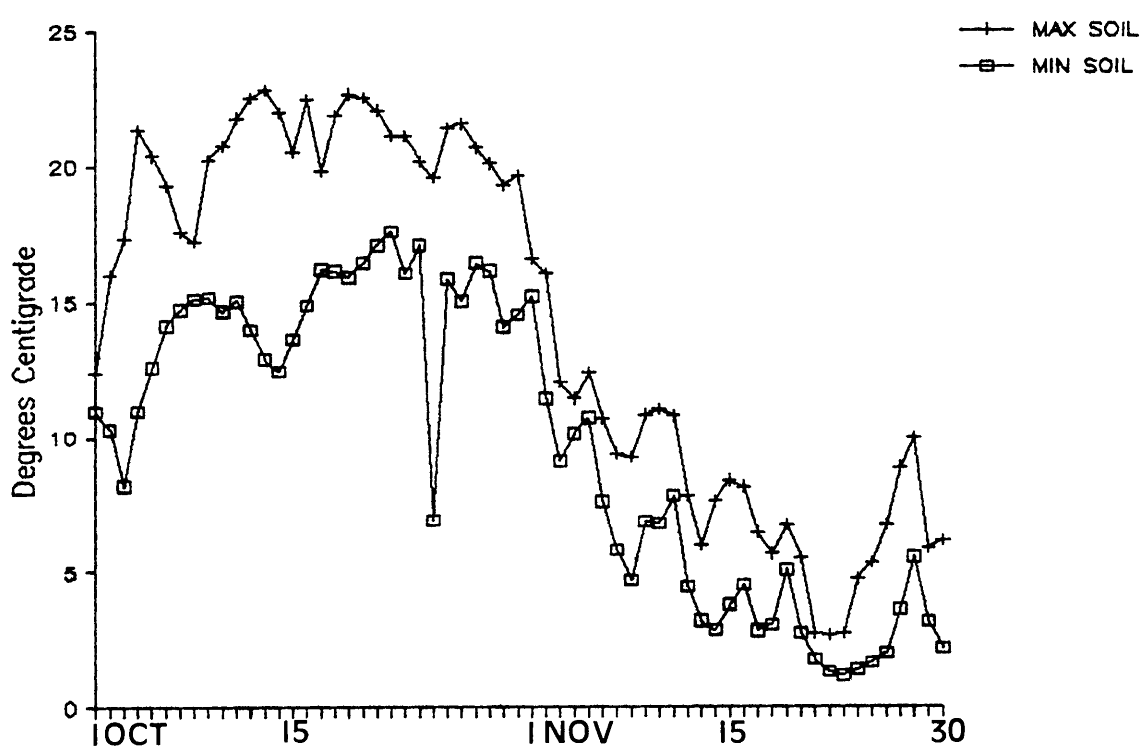
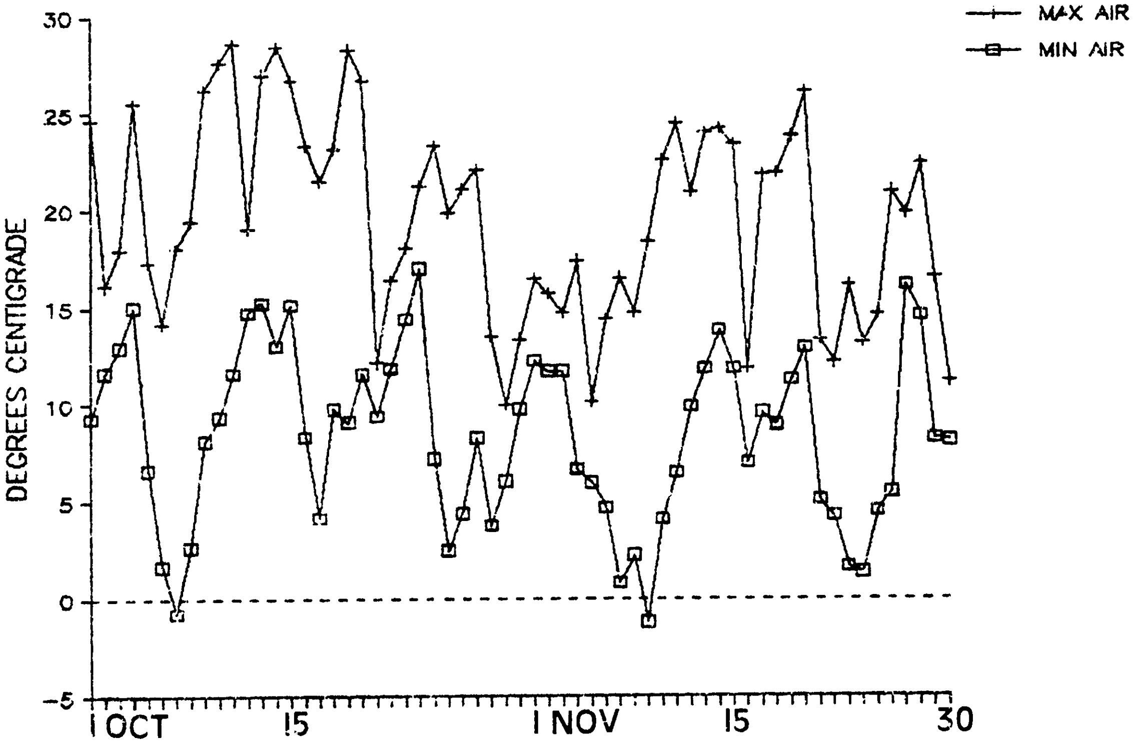

MAX SOIL
MIN SOIL
Degrees Centigrade
25
20
15
10
5
0
1 OCT
15
1 NOV
15
30

Figure 6. Daily mean maximum/minimum air (top) and soil (bottom) temperatures Oct-Nov 1985 at microplots of the 1985-86 Phenology Study.


MAX AIR
MIN AIR
DEGREES CENTIGRADE
30
25
20
15
10
5
0
-5
1 OCT
15
1 NOV
15
30

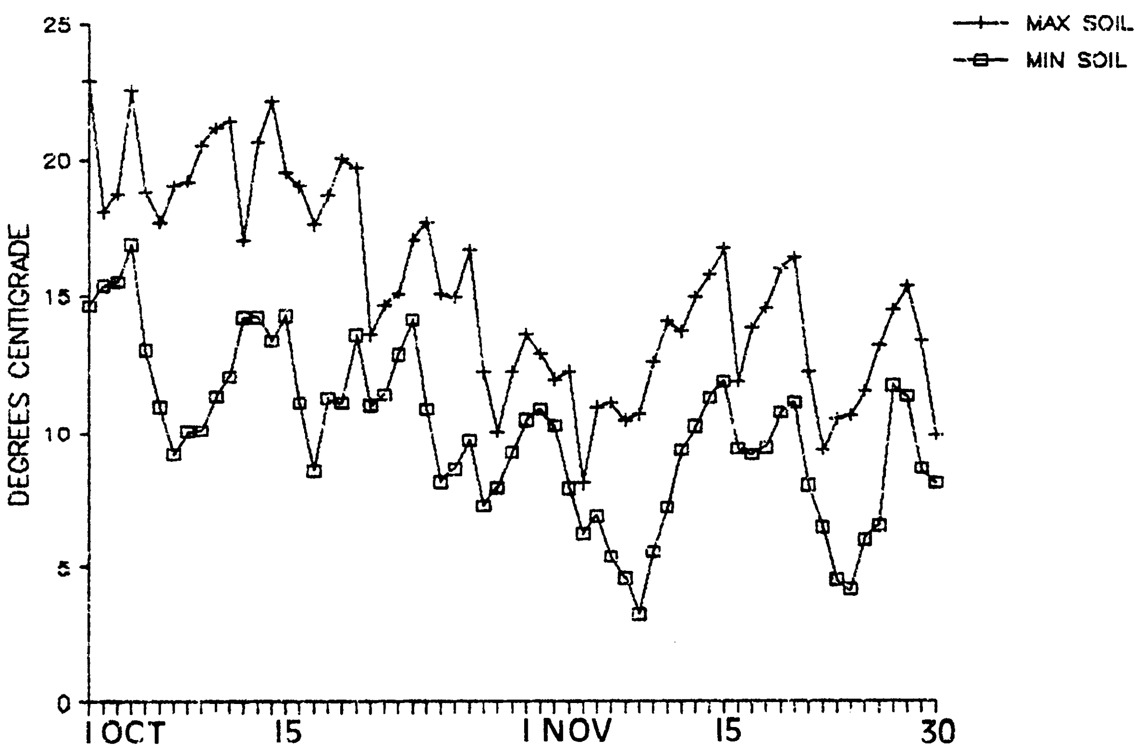

MAX SOIL
MIN SOIL
DEGREES CENTIGRADE
25
20
15
10
5
0
1 OCT
15
1 NOV
15
30

Table 13. Mean air and soil temperatures during 1-4 WASA for each sclerotium application date of the 1984-85 Phenology Study.

Sclerotium application date	Mean air temperature[w] (C)			Mean soil temperature[x] (C)		
	Max[y]	Min[y]	Avg[y]	Max	Min	Avg
31 Aug 84[z]	17.5	2.7	10.1	21.5	13.8	17.7
14 Sep 84[z]	18.2	4.1	11.2	19.4	13.2	16.3
28 Sep 84	21.1	4.6	13.9	20.1	13.9	17.1
12 Oct 84	19.9	3.1	13.5	18.2	13.1	15.7
26 Oct 84	12.4	-0.87	6.8	10.8	7.5	9.1
9 Nov 84	9.1	-3.7	2.7	6.1	3.1	4.7
23 Nov 84	12.1	-3.8	5.9	6.9	4.1	5.6
10 Dec 84	13.5	3.1	8.3	8.8	5.1	7.0

[w]Mean air temperature at 63-cm height.
[x]Mean soil temperature at 5-cm depth.
[y]Max=mean maximum temperature, Min=mean minimum temperature, Avg=mean temperature calculated from daily Max/Min temperatures.
[z]Data for mean air and soil temperature were incomplete for this sclerotium application date. Mean temperature was calculated with less than four weeks of data.

Table 14. Mean air and soil temperatures during 5-8 WASA for each sclerotium application date of 1984-85 Phenology Study.

Sclerotium application date	Mean air temperature[w] (C)			Mean soil temperature[x] (C)		
	Max[y]	Min[y]	Avg[y]	Max	Min	Avg
31 Aug 84[z]	21.1	4.6	13.9	20.1	13.9	9.1
14 Sep 84[z]	19.9	3.1	13.4	18.2	13.1	4.5
28 Sep 84	12.4	-0.87	6.8	10.8	7.5	5.6
12 Oct 84	9.1	-3.7	2.7	6.1	3.1	7.1
26 Oct 84	12.1	-3.8	5.9	6.9	4.1	3.1
9 Nov 84	13.7	2.8	8.3	8.8	5.2	-1.1
23 Nov 84	7.7	-1.8	3.1	5.1	1.9	-1.5
10 Dec 84	1.2	-8.6	-4.1	0.09	-3.4	1.7

[w]Mean air temperature at 63-cm height.
[x]Mean soil temperature at 5-cm depth.
[y]Max=mean maximum temperature, Min=mean minimum temperature, Avg=mean temperature calculated from daily Max/Min temperatures.
[z]Data for mean air and soil temperature were incomplete for this sclerotium application date. Mean temperature was calculated with less than four weeks of data.

Table 15. Mean air and soil temperatures during 1-4 WASA for each sclerotium application date of the 1985-86 Phenology Study.

Sclerotium application date	Mean air temperature[x] (C)			Mean soil temperature[y] (C)		
	Max[z]	Min[z]	Avg[z]	Max	Min	Avg
9 Oct 85	20.0	9.6	13.0	15.9	10.7	13.3
23 Oct 85	18.9	7.9	11.4	13.5	8.8	11.2
7 Nov 85	17.2	6.1	9.7	11.7	6.9	9.4
23 Nov 85	10.1	-0.35	2.9	6.2	2.2	4.2
11 Dec 85	5.1	-6.2	-1.9	0.11	-2.3	-1.1

[x]Mean air temperature at 63-cm height.
[y]Mean soil temperature at 5-cm depth.
[z]Max=mean maximum temperature, Min=mean minimum temperature, Avg=mean temperature calculated from daily Max/Min temperatures.

Table 16. Mean air and soil temperatures during 5-8 WASA for each sclerotium application date of the 1985-86 Phenology Study.

Sclerotium application date	Mean air temperature[x] (C)			Mean soil temperature[y] (C)		
	Max[z]	Min[z]	Avg[z]	Max	Min	Avg
9 Oct 85	17.5	5.9	9.7	11.9	7.1	9.5
23 Oct 85	11.6	1.2	4.5	7.5	3.2	5.3
7 Nov 85	6.6	-5.1	-0.76	1.7	-1.5	0.1
23 Nov 85	6.8	-6.3	-0.96	-0.61	-3.0	-1.8
11 Dec 85	-6.3	-3.6	2.2	1.4	-1.4	0.01

[x]Mean air temperature at 63-cm height.
[y]Mean soil temperature at 5-cm depth.
[z]Max=mean maximum temperature, Min=mean minimum temperature, Avg=mean temperature calculated from daily Max/Min temperatures.

Table 17. Mean air and soil temperatures 14 days prior to first observation of apothecia in microplots of each sclerotium application date of 1984-85 Phenology Study.

Sclerotium application date	Mean temperature (C)[w]	
	Air[x]	Soil[y]
31 Aug 84[z]	4.3	6.3
14 Sep 84[z]	7.6	10.1
28 Sep 84	7.3	9.3
12 Oct 84	10.2	12.6
26 Oct 84	6.4	8.8
9 Nov 84[z]	---	---
23 Nov 84[z]	8.4	7.4
10 Dec 84[z]	0.6	1.5

[w]Average over productive microplots within each sclerotium application date.
[x]Mean air temperature at 63-cm height.
[y]Mean soil temperature at 5-cm depth.
[z]Less than four microplots of this sclerotium application date produced apothecia.

Table 18. Mean air and soil temperatures 14 days prior to first observation of apothecia in microplots of each sclerotium application date of 1985-86 Phenology Study.

Sclerotium application date	Mean temperature (C)[w]	
	Air[x]	Soil[y]
9 Oct 85	10.2	11.1
23 Oct 85	10.6	10.2
7 Nov 85[z]	8.8	8.6
23 Nov 85[z]	---	---
11 Dec 85[z]	---	---

[w]Average over productive microplots within each sclerotium application date.
[x]Mean air temperature at 63-cm height.
[y]Mean soil temperature at 5-cm depth.
[z]Less than four microplots of this sclerotium application date produced apothecia.

Appendix C. Summary of rainfall data collected at the Agronomy Farm, VPI&SU, Blacksburg, Virginia.

Rainfall was observed to influence the magnitude of apothecium development (Chapter 2). A summary of total weekly rainfall during September through December, the main period of apothecium production, is presented in Figure 7 and Figure 8. The total amount of rainfall 1-4 weeks after sclerotium application (WASA) and 5-8 WASA is presented in Table 19 for 1984-85 and in Table 20 for 1985-86.

The affect of rainfall upon numbers of apothecia was examined for 12 Oct 84 and 26 Oct 84 and for 9 Oct 85 and 23 Oct 85 sclerotium applications. These applications of sclerotia produced the most apothecia. Therefore, these sclerotium applications were chosen for studying influence of rainfall. Table 21 and Table 22 summarize rainfall analyses for both seasons. Periods of rainfall and periods of drought were examined for influence upon numbers of apothecia. Overall, it appears that rainfall results in significant increases in numbers of apothecia early in apothecium production but exerts less effect later in production.

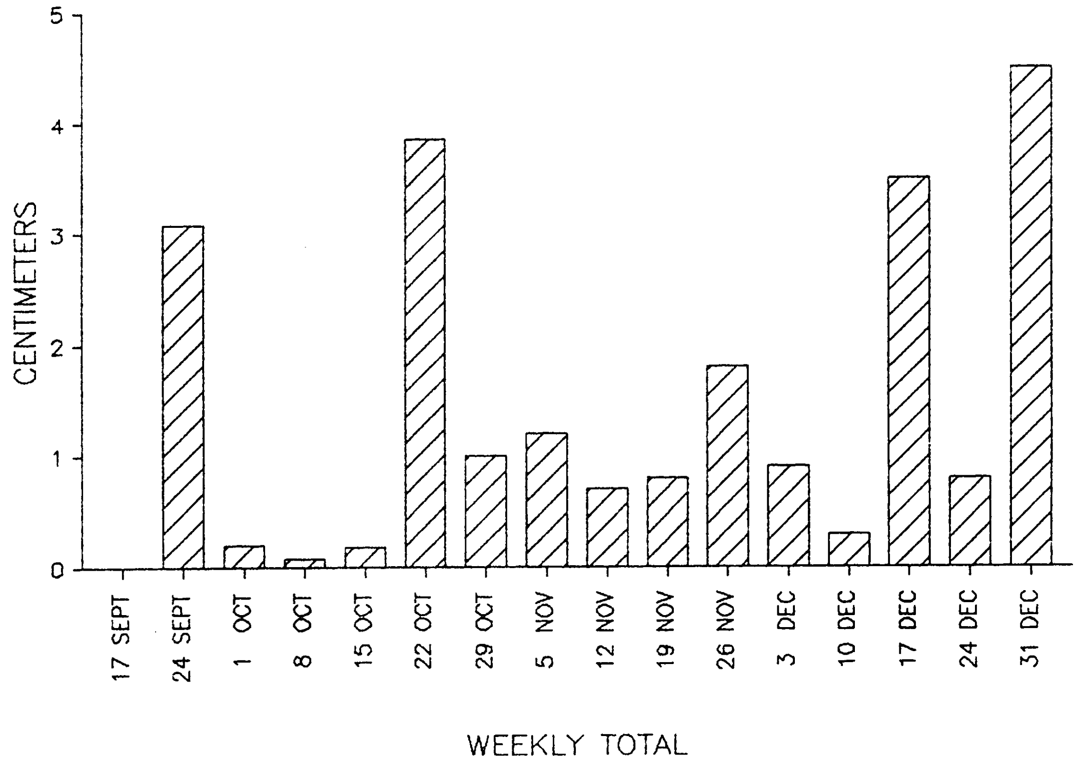


Figure 7. Weekly total rainfall September-December 1984, at the 1984-85 Phenology Study site.

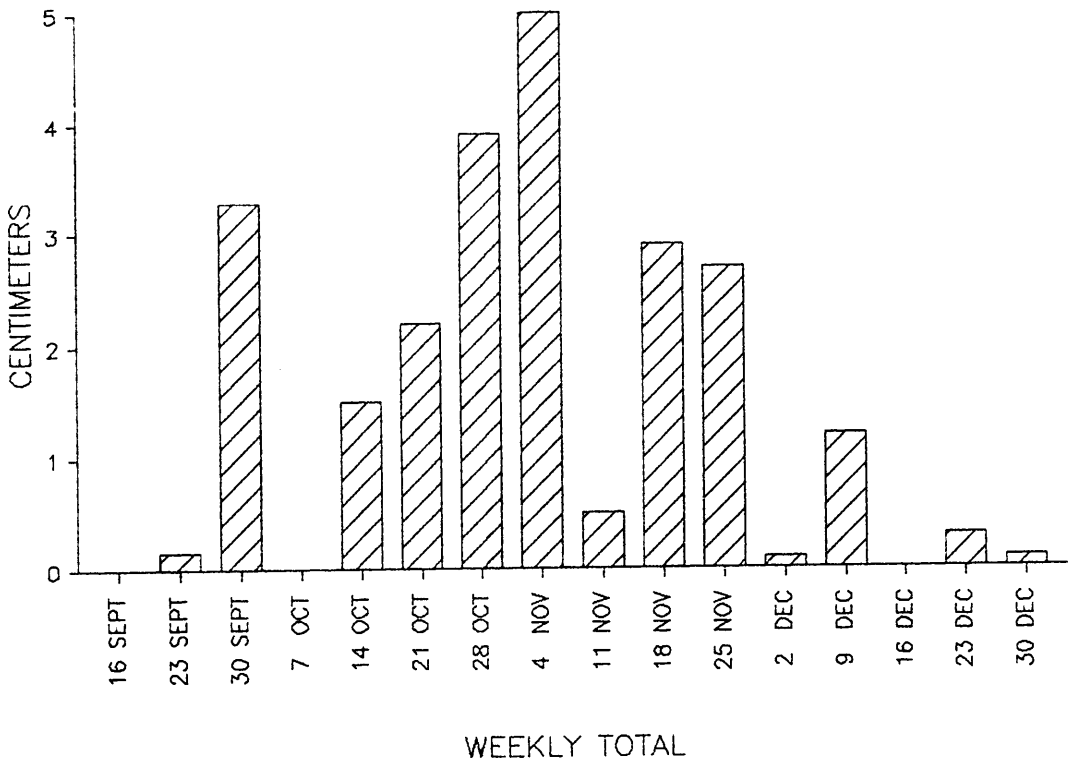


Figure 8. Weekly total rainfall September-December 1985, at the 1985-86 Phenology site.

Table 19. Rainfall data during 1-4 and 5-8 WASA at microplots of the 1984-85 Phenology Study.

	1-4 WASA			5-8 WASA		
Sclerotium application date	Total rainfall (cm)	No. Days with rainfall	No. Days with >0.5 cm	Total rainfall (cm)	No. Days with rainfall	No. Days with >0.5 cm
31 Aug 84	---	---	---	6.2	9	3
14 Sep 84	---	---	---	5.5	11	4
28 Sep 84	6.2	9	3	4.7	9	5
12 Oct 84	5.5	11	4	4.1	6	4
26 Oct 84	4.7	9	5	6.1	9	4
9 Nov 84	4.1	6	4	9.9	14	7
23 Nov 84	6.1	9	4	6.2	8	5
19 Dec 84	8.9	12	6	8.0	4	1

Table 20. Rainfall data during 1-4 and 5-8 WASA at microplots of the 1985-86 Phenology Study.

	1-4 WASA			5-8 WASA		
Sclerotium application date	Total rainfall (cm)	No. Days with rainfall	No. Days with >0.5 cm	Total rainfall (cm)	No. Days with rainfall	No. Days with >0.5 cm
9 Oct 85	22.2	12	5	6.1	9	6
23 Oct 85	19.3	8	4	6.9	12	6
7 Nov 85	6.2	10	6	1.6	5	1
23 Nov 85	4.0	10	4	0.4	2	0
11 Dec 85	1.5	4	1	3.9	6	2

Table 21. Comparison of apothecium count immediately before and after a rainfall event for the 12 Oct 84 and 26 Oct 84 sclerotium applications of the 1984-85 Phenology Study.

Date	Rainfall (cm)[y]		Apothecium count[z]
9 Nov 84			0.029
10 Nov 84	0.7	**	
12 Nov 84			0.090
13 Nov 84	0.1	NS	
14 Nov 84			0.107
16 Nov 84	0.0	NS	
17 Nov 84			0.141
18 Nov 84	0.6	*	
19 Nov 84			0.283
21 Nov 84			0.276
22 Nov 84	0.0	NS	
23 Nov 84			0.362
25 Nov 84	0.0	NS	
26 Nov 84			0.263
28 Nov 84	1.8	NS	
30 Nov 84			0.294
2 Dec 84	0.0	NS	
3 Dec 84			0.263
8 Dec 84	0.8	NS	
10 Dec 84			0.337
17 Dec 84			0.295
18 Dec 84	1.6	NS	
19 Dec 84			0.287
27 Dec 84			0.044
30 Dec 84	0.6	NS	
2 Jan 85			0.033

[y] One-sided t-test,
*Increase in number of apothecia was significant at $P \leq 0.05$.
**Increase in number of apothecia was significant at $P \leq 0.001$.
NS=No significant increase in number of apothecia.
[z] Expressed as number of apothecia/sclerotium.

Table 22. Comparison of apothecium count immediately before and after a rainfall event for the 9 Oct 85 and 23 Oct 85 sclerotium applications of the 1985-86 Phenology Study.

Date	Rainfall (cm)[y]		Apothecium counts[z]
1 Nov 85	1.0		
2 Nov 85	0.4		
3 Nov 85	2.4		
4 Nov 85	14.2		
5 Noc 85	0.4		
6 Nov 85	0.0		0.152
11 Nov 85			0.382
12 Nov 85	0.0	NS	
13 Nov 85			0.417
14 Nov 85	0.0	*	
15 Nov 85			0.592
18 Nov 85	0.0	NS	
20 Nov 85			0.751
21 Nov 85	1.1	NS	
22 Nov 85	1.8	NS	
23 Nov 85			0.719
27 Nov 85	0.6	NS	
28 Nov 85	1.2	NS	0.704
30 Nov 85	0.1		
1 Dec 85	0.1		
2 Dec 85	0.0		
3 Dec 85	0.0		
4 Dec 85			0.366
8 Dec 85	0.0	*	
11 Dec 85			0.448
12 Dec 85	0.4	NS	
13 Dec 85	0.7	NS	
14 Dec 85			0.266
16 Dec 85	0.0	NS	
18 Dec 85			0.179

[y]One-sided t-test,
*Increase in number of apothecia was significant at $P \leq 0.05$.
NS=No significant increase in number of apothecia.
[z]Expressed as number of apothecia/sclerotia.

Appendix D. A Proposed Model for Prediction of Sclerotinia trifoliorum Apothecium Appearance in the Field.

Prediction of occurrence of *S. trifoliorum* apothecia would assist in application timing of fungicide treatments for susceptible crops. Temperature was observed to have significant impact upon apothecium appearance, particularly temperatures below 15 or 10 C. Table 23 and Table 24 present number of days mean soil temperature fell below 15 or 10 C between sclerotium application and first apothecium appearance (Appendix A) for the 1984-85 and 1985-86 experimental seasons, respectively. The number of days with mean soil temperature below 15 C for 12 Oct 84 and 26 Oct 84 sclerotium applications, and for the 9 Oct 85 and 26 Oct 85 applications, indicated that an average of 17 days (<15 C) were necessary to induce apothecium formation. The October sclerotium applications were chosen because they usually produced apothecia more quickly and in greater numbers than other application dates. Monitoring daily mean soil temperature in the field would be a fairly simple way to plan SCSR control measures.

Table 23. Number of days mean soil temperature fell below 10 or 15 C before apothecium appearance within individual microplots of each sclerotium application date of the 1984-85 Phenology Study.

Sclerotium date	Mean soil temperature <15 C	Mean soil temperature <10 C
31 Aug 84		
Rep 1	26	16
Rep 2	---	---
Rep 3	---	---
Rep 4	---	---
14 Sep 85		
Rep 1	---	---
Rep 2	14	4
Rep 3	19	9
Rep 4	26	16
28 Sep 85		
Rep 1	33	23
Rep 2	12	2
Rep 3	17	7
Rep 4	28	18
12 Oct 85		
Rep 1	11	7
Rep 2	6	2
Rep 3	11	7
Rep 4	11	7
26 Oct 85		
Rep 1	11	7
Rep 2	18	14
Rep 3	20	16
Rep 4	13	9
9 Nov 85		
Rep 1	---	---
Rep 2	---	---
Rep 3	---	---
Rep 4	---	---
23 Nov 85		
Rep 1	---	---
Rep 2	47	43
Rep 3	40	37
Rep 4	40	37
10 Dec 85		
Rep 1	59	55
Rep 2	31	28
Rep 3	---	---
Rep 4	75	71

Table 24. Number of days mean soil temperature fell below 10 or 15 C before apothecium appearance within individual microplots of each sclerotium application date of the 1985-86 Phenology Study.

Sclerotium date	Mean soil temperature <15 C	<10 C
9 Oct 85		
Rep 1	17	8
Rep 2	17	8
Rep 3	17	4
Rep 4	22	8
23 Oct 85		
Rep 1	23	8
Rep 2	23	8
Rep 3	28	8
Rep 4	21	8
7 Nov 85		
Rep 1	--	--
Rep 2	34	21
Rep 3	16	6
Rep 4	--	--
23 Nov 85		
Rep 1	--	--
Rep 2	--	--
Rep 3	--	--
Rep 4	--	--
11 Dec 85		
Rep 1	--	--
Rep 2	--	--
Rep 3	--	--
Rep 4	--	--

Appendix E. Plant Population Counts for Individual Microplots of the 1985-86 Plant Age Study.

Table 25. Plant population counts for individual microplots of each planting date the 1985-86 Plant Age Study. For each planting date, four microplots were infested with *S. trifoliorum* sclerotia, and an additional four microplots served as non-infested check plots.

Planting date	Infested with sclerotia Jan 86[w]	Infested with sclerotia May 86[x]	Non-infested Jan 86	Non-infested May 86
1 Sep 84[y]				
I	335[z]	213	362	267
II	430	444	503	349
III	376	376	389	398
IV	326	331	557	367
19 Mar 85				
I	421	380	580	530
II	394	321	494	412
III	462	457	552	521
IV	489	444	444	385
14 May 85				
I	480	412	580	453
II	548	521	371	258
III	439	389	439	475
IV	629	367	607	589
15 Jul 85				
I	738	625	711	761
II	552	435	964	706
III	724	598	883	878
IV	589	489	734	598
23 Aug 85				
I	906	743	1060	398
II	711	507	688	688
III	860	561	824	643
IV	788	661	21	371

[w]Population counted 10 Jan and 17 Jan 86.
[x]Population counted 1 May through 10 May 86.
[y]There were four replicates per infestation treatment for each planting date.
[z]Expressed as number of plants/m^2.

Appendix F. Daily Summary of Meteorological Parameters at the Agronomy Farm, VPI&SU, Blacksburg, Virginia, for the 1984-85 and 1985-86 Phenology Study.

Weather parameters were monitored by an on-site monitoring system located within the Phenology Study site, the Argonomy Farm, VPI & SU, Blacksburg, Virginia. Air and soil temperatures were measured using a copper-constantan thermocouple. Air temperature was measured by three sensors at approximately 63 cm above the soil surface. Soil temperature was measured at a 5-cm depth within three microplots, three sensors were buried within each microplot. Rainfall was monitored by a tipping-bucket rain guage. Leaf wetness was measured by a Leaf Wetness Grid (Campbell Scientific). Parameter readings were taken each minute and an hourly average was recorded by a Data Logger (Model 21X, Campbell Scientific). The data for each parameter was summarized into a daily average for further analyses.

In the pages that follow, Day (first column), refers to number of days from beginning of Phenology Study experiment. In 1984, this first day was 31 Aug. In 1985, this was 1 Sep In summarizing the data, it was easier to work with Day number rather than Date. Date is provided here for a point of reference. Daily mean air and soil temperatures were calculated from arithmetic mean of daily maximum plus minimum temperature. In 1985-86, mean air temperature was calculated from maximum/minimum temperatures immediately above the microplots while maximum and minimum temperatures listed for 1985-86 were recorded within the instrument shelter. Hence, air temperature mean in 1985-86 was taken is not the mean of the Air Max and Air Min listed. Leaf wetness (Lfw) is presented as number of hours of wetness during that 24 hr period. Rainfall is expressed in centimeters.

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
	1984								
19	18 Sep	20.4	13.6	17.1	18.1	3.1	10.5	0.0	---
20	19 Sep	24.1	12.5	18.3	24.5	-0.4	12.1	0.0	---
21	20 Sep	24.6	14.1	19.3	27.7	3.4	15.6	0.0	---
22	21 Sep	----	----	----	----	----	----	---	---
23	22 Sep	----	----	----	----	----	----	---	---
24	23 Sep	----	----	----	----	----	----	---	---
25	24 Sep	----	----	----	----	----	----	---	---
26	25 Sep	----	----	----	----	----	----	---	---
27	26 Sep	22.7	16.6	19.7	19.2	7.4	13.6	0.0	---
28	27 Sep	19.1	13.4	16.2	10.1	2.6	6.4	0.23	---
29	28 Sep	18.2	12.5	15.3	5.1	0.2	2.5	0.03	---
30	29 Sep	16.1	12.5	14.3	11.1	3.1	7.1	0.0	---
31	30 Sep	15.6	12.3	14.1	8.3	3.9	6.1	2.82	---
32	1 Oct	12.4	11.1	11.7	7.8	4.0	5.9	0.20	---
33	2 Oct	16.1	10.3	13.1	14.9	0.3	7.6	0.0	---
34	3 Oct	17.4	8.2	12.8	21.5	-3.6	9.1	0.0	---
35	4 Oct	21.3	11.1	16.2	24.5	5.7	15.1	0.0	---
36	5 Oct	20.4	12.6	16.5	25.0	2.6	13.8	0.0	---
37	6 Oct	19.3	14.1	16.7	18.8	9.2	14.1	0.0	---
38	7 Oct	17.6	14.7	16.2	17.4	9.3	13.3	0.0	---
39	8 Oct	17.2	15.1	16.2	18.1	9.5	13.8	0.0	---
40	9 Oct	20.2	15.2	17.7	22.2	7.5	14.9	0.08	---
41	10 Oct	20.7	14.6	17.7	22.2	5.7	13.9	0.0	---
42	11 Oct	21.8	15.0	18.4	22.1	6.2	14.1	0.0	---
43	12 Oct	22.5	14.1	18.3	24.4	2.7	13.5	0.0	---
44	13 Oct	22.8	12.9	17.8	24.4	1.9	13.2	0.0	---
45	14 Oct	22.1	12.4	17.2	25.7	2.1	13.9	0.0	---
46	15 Oct	20.5	13.6	17.1	24.6	4.6	14.6	0.05	---
47	16 Oct	22.4	14.9	18.7	27.2	5.5	16.3	0.0	---
48	17 Oct	19.8	16.2	18.1	18.2	6.5	12.3	0.10	---
49	18 Oct	21.8	16.1	19.1	26.8	5.8	16.3	0.03	---
50	19 Oct	22.7	16.1	19.3	28.1	4.0	16.1	0.0	---
51	20 Oct	22.5	16.4	19.5	26.5	8.4	17.4	0.0	---
52	21 Oct	22.1	17.1	19.6	25.4	13.1	19.6	0.0	---
53	22 Oct	21.1	17.6	19.4	23.8	6.1	19.4	1.90	---
54	23 Oct	21.1	16.0	18.6	24.8	3.1	18.6	0.84	---
55	24 Oct	20.2	17.1	18.6	16.1	3.3	18.6	0.0	---
56	25 Oct	19.6	6.9	13.3	13.2	0.0	13.3	0.15	---
57	26 Oct	21.4	15.8	18.6	26.5	-0.7	18.6	0.0	---
58	27 Oct	21.6	15.0	18.3	26.8	-0.5	18.3	0.03	---
59	28 Oct	20.7	16.4	18.5	23.6	4.2	18.5	0.94	---
60	29 Oct	20.1	16.1	18.1	23.8	2.1	18.1	0.0	---
61	30 Oct	19.3	14.1	16.7	22.2	-0.4	16.7	0.0	---
62	31 Oct	19.6	14.5	17.1	19.5	0.6	17.1	0.0	---
63	1 Nov	16.6	15.2	15.9	17.3	10.9	14.1	0.0	18.8
64	2 Nov	16.3	11.4	13.7	13.5	0.8	7.2	0.0	12.9
65	3 Nov	12.3	9.1	10.6	8.9	-1.2	3.9	0.0	2.8

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
66	4 Nov	11.4	10.1	10.8	8.7	4.4	6.6	1.00	19.2
67	5 Nov	12.4	10.7	11.6	14.9	5.6	10.3	0.40	17.6
68	6 Nov	10.7	7.6	9.2	6.7	0.8	3.8	0.10	11.2
69	7 Nov	9.3	5.8	7.6	10.2	-3.4	3.4	0.0	2.3
70	8 Nov	9.2	4.7	7.1	12.5	-5.2	3.7	0.0	2.6
71	9 Nov	10.8	6.9	8.8	16.2	0.7	8.4	0.0	8.1
72	10 Nov	11.0	6.8	8.9	17.7	-0.2	8.8	0.70	14.4
73	11 Nov	10.8	7.8	9.3	12.0	2.1	7.1	0.0	11.1
74	12 Nov	7.8	4.4	6.1	2.8	-0.4	1.2	0.0	0.05
75	13 Nov	6.1	3.2	4.6	7.3	-1.9	2.7	0.10	0.0
76	14 Nov	7.6	2.9	5.1	13.3	-0.2	7.2	0.0	0.0
77	15 Nov	8.4	3.7	6.1	16.7	-2.3	7.2	0.0	0.65
78	16 Nov	8.1	4.5	6.3	11.1	1.4	6.3	0.0	6.7
79	17 Nov	6.5	2.8	4.6	8.1	-3.2	2.4	0.0	0.0
80	18 Nov	5.6	3.0	4.3	5.2	-3.9	0.7	0.60	10.9
81	19 Nov	6.7	5.1	5.9	5.8	0.1	3.1	0.80	14.4
82	20 Nov	5.5	2.7	4.1	2.7	-6.8	-2.1	0.0	0.0
83	21 Nov	2.7	1.8	2.3	3.6	-9.8	-3.1	0.0	1.2
84	22 Nov	2.7	1.3	2.0	6.2	-9.9	-1.8	0.0	2.2
85	23 Nov	2.7	1.2	2.1	10.6	-8.8	1.0	0.0	1.6
86	24 Nov	4.7	1.4	6.1	13.8	-4.0	4.9	0.0	0.0
87	25 Nov	5.3	1.7	3.5	13.9	-6.1	4.1	0.0	1.3
88	26 Nov	6.7	2.0	4.4	17.6	-3.4	7.1	0.0	1.2
89	27 Nov	8.8	3.6	6.2	16.8	1.4	9.1	0.0	2.4
90	28 Nov	10.1	5.5	7.8	14.3	1.4	7.9	1.80	13.1
91	29 Nov	5.9	3.1	4.5	7.2	-3.3	1.9	0.0	0.0
92	30 Nov	6.2	2.2	4.2	14.2	-6.5	3.9	0.0	2.1
93	1 Dec	7.2	3.9	5.5	10.1	-2.5	3.7	0.0	0.0
94	1 Dec	5.8	2.4	4.1	11.9	-5.7	3.1	0.0	6.5
95	3 Dec	7.1	3.5	5.3	10.9	-0.6	5.2	0.10	10.1
96	4 Dec	3.5	2.1	2.8	2.4	-4.2	-0.9	0.0	0.0
97	5 Dec	2.9	2.1	2.5	1.1	-2.3	-0.6	0.0	12.9
98	6 Dec	2.8	1.7	2.3	0.4	-11.8	-5.7	0.0	24.0
99	7 Dec	1.7	1.2	1.5	-3.3	-12.8	-8.1	0.0	24.0
100	8 Dec	1.5	1.1	1.3	8.1	-8.1	0.1	0.80	12.9
101	9 Dec	2.3	0.9	1.6	10.7	-6.0	2.4	0.0	2.2
102	10 Dec	2.8	1.1	2.1	6.9	-1.9	2.5	0.20	19.1
103	11 Dec	7.3	2.8	5.0	14.6	0.3	7.5	0.0	10.6
104	12 Dec	6.5	2.5	4.5	15.3	-2.1	6.6	0.0	14.9
105	13 Dec	9.4	4.5	7.1	20.1	4.6	12.3	0.0	14.2
106	14 Dec	9.2	5.3	7.3	15.6	1.5	8.6	0.10	20.2
107	15 Dec	11.1	6.5	8.7	22.3	4.7	13.5	0.0	17.6
108	16 Dec	10.5	7.8	9.2	15.8	5.6	10.7	0.0	18.8
109	17 Dec	11.3	8.1	9.7	18.3	8.1	13.2	0.0	16.5
110	18 Dec	11.6	9.8	10.7	16.3	11.3	13.8	1.60	17.5
111	19 Dec	11.9	11.1	11.4	15.7	14.3	15.0	0.30	19.6
112	20 Dec	10.6	8.9	9.8	12.7	9.1	10.9	0.10	24.0
113	21 Dec	9.6	8.0	8.8	15.5	8.4	11.9	1.10	24.0

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
114	22 Dec	10.3	3.9	7.1	15.9	1.8	8.9	0.40	8.4
115	23 Dec	7.4	2.0	4.7	11.1	-2.7	4.6	0.0	1.3
116	24 Dec	9.0	4.0	6.5	6.3	-7.9	-0.8	0.20	10.1
117	25 Dec	9.0	4.0	6.5	7.1	-6.3	0.4	0.0	4.6
118	26 Dec	9.0	4.0	6.5	10.7	-9.9	0.4	0.0	7.6
119	27 Dec	8.9	5.8	7.3	18.2	9.9	14.0	0.0	9.3
120	28 Dec	11.4	4.1	7.7	23.0	5.1	14.1	0.0	15.2
121	29 Dec	12.1	5.7	8.9	22.2	8.0	15.1	0.0	12.1
122	30 Dec	10.1	7.8	8.9	14.7	8.9	11.8	0.60	23.1
123	31 Dec	9.1	7.0	8.1	9.2	6.1	7.7	0.30	24.0
	1985								
124	1 Jan	13.4	7.8	10.6	20.3	8.7	14.5	0.0	8.1
125	2 Jan2	9.9	6.5	8.2	8.4	4.0	6.2	0.80	22.8
126	3 Jan	6.5	3.2	4.9	5.3	1.3	3.3	2.50	24.0
127	4 Jan	4.9	1.8	3.4	3.5	0.8	2.2	0.90	21.0
128	5 Jan	1.9	0.5	1.2	1.5	-1.6	-0.1	0.0	0.0
129	6 Jan	1.8	0.0	0.9	11.9	-5.3	3.3	0.0	1.4
130	7 Jan	2.7	0.5	1.6	6.8	-1.0	2.9	0.0	0.0
131	8 Jan	3.9	0.2	2.1	3.8	-4.4	-0.3	0.0	0.0
132	9 Jan	0.2	-0.4	-0.1	1.8	-7.7	-3.1	0.0	0.0
133	10 Jan	0.0	-0.3	-0.2	-2.3	-4.7	-3.5	0.0	0.0
134	11 Jan	0.0	-0.4	-0.2	1.9	-5.7	-1.9	0.0	1.78
135	12 Jan	-0.3	-2.1	-1.2	-2.5	-8.1	-5.3	0.0	0.0
136	13 Jan	-0.2	-2.2	-1.2	4.1	-6.7	-1.3	0.0	0.0
137	14 Jan	-0.1	-2.2	-1.2	6.8	-5.5	0.7	0.0	0.0
138	15 Jan	-0.4	-2.6	-1.5	-3.6	-9.5	-6.6	0.0	0.0
139	16 Jan	-0.3	-3.3	-1.8	5.2	-11.6	-3.2	0.0	0.0
140	17 Jan	-0.3	-0.7	-0.5	3.3	-2.7	0.3	0.50	9.5
141	18 Jan	-0.3	-0.5	-0.4	1.7	-2.5	-0.4	0.0	0.0
142	19 Jan	-0.2	-0.4	-0.3	2.0	-3.7	-0.9	0.0	0.0
143	20 Jan	5.1	-20.4	-7.7	-3.8	-34.0	-18.9	0.0	0.0
144	21 Jan	2.0	-24.7	-11.4	-14.5	-35.4	-25.1	0.0	0.0
145	22 Jan	-1.7	-4.6	-3.2	-5.6	-14.6	-10.1	0.0	0.0
146	23 Jan	-1.4	-3.0	-2.2	-0.3	-10.0	-5.2	0.0	0.0
147	24 Jan	-0.6	-2.4	-1.5	3.5	-4.8	-0.7	0.0	0.0
148	25 Jan	-0.3	-3.4	-1.9	4.8	-9.1	-2.2	0.0	0.0
149	26 Jan	-1.9	-5.1	3.5	-4.8	-11.8	-8.3	0.0	0.0
150	27 Jan	-0.8	-5.5	3.2	4.9	-13.1	-4.1	0.0	0.67
151	28 Jan	-0.6	-2.1	-1.4	0.3	-3.8	-1.8	0.0	2.3
152	29 Jan	-0.4	-2.8	-1.6	2.1	-6.6	-3.3	0.0	0.0
153	30 Jan	-0.4	-3.8	-2.1	4.1	-10.1	-5.1	0.0	5.7
154	31 Jan	0.1	-0.4	-1.5	7.5	1.2	1.1	0.10	20.2
155	1 Feb	0.7	-0.1	0.3	6.7	3.1	2.1	0.10	24.0
156	2 Feb	1.1	-0.2	4.5	4.2	-4.2	-2.1	0.0	18.4
157	3 Feb	-0.1	-0.5	-0.3	1.7	-9.1	-4.1	0.10	0.0
158	4 Feb	-0.2	-0.9	-0.6	-0.5	-5.6	-2.8	0.0	0.0
159	5 Feb	-0.3	-1.3	-0.8	-0.8	-4.4	-2.2	0.0	14.3
160	6 Feb	0.0	-0.6	-0.3	5.6	-1.7	-0.9	0.0	9.6

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
161	7 Feb	-0.3	-4.3	-2.3	1.4	-9.1	-4.6	0.0	0.0
162	8 Feb	-1.5	-5.9	-3.7	-4.9	-10.4	-5.2	0.0	0.0
163	9 Feb	-0.7	-7.2	-4.1	0.6	-11.1	-5.6	0.0	0.0
164	10 Feb	0.2	-4.1	-2.1	12.2	-6.6	-3.3	0.0	0.0
165	11 Feb	0.0	-2.5	-1.3	8.3	-3.3	-1.7	0.0	2.8
166	12 Feb	-0.1	-0.3	-0.2	3.1	-6.1	4.5	1.50	12.2
167	13 Feb	-0.2	-0.8	-0.5	-2.7	-6.5	-3.3	0.0	0.0
168	14 Feb	-0.4	-1.7	-1.1	2.7	-5.3	-2.7	0.0	0.0
169	15 Feb	-0.9	-2.8	-1.9	-0.5	-8.0	-4.0	0.0	0.0
170	16 Feb	-0.9	-4.1	-2.5	2.2	-10.3	-5.2	0.0	0.0
171	17 Feb	-0.3	-2.7	-1.5	5.4	-4.2	-2.1	0.0	0.0
172	18 Feb	-0.1	-2.9	-1.5	10.4	-5.3	-2.7	0.0	1.1
173	19 Feb	0.2	-0.3	-0.1	7.0	-2.3	-1.2	0.0	13.3
174	20 Feb	---	---	2.5	10.3	-9.1	-4.6	0.0	3.6
175	21 Feb	---	---	2.5	13.6	-8.4	4.7	1.78	0.0
176	22 Feb	---	---	2.5	18.7	-0.3	-0.2	0.0	4.6
177	23 Feb	10.8	-0.4	5.2	20.8	4.0	2.0	0.0	2.5
178	24 Feb	12.1	0.6	6.4	22.2	7.1	3.6	0.0	9.6
179	25 Feb	12.5	6.6	9.6	17.8	9.7	13.4	1.70	7.2
180	26 Feb	14.4	6.1	8.8	18.8	7.6	4.3	0.10	15.3
181	27 Feb	9.8	0.9	5.4	11.9	-0.2	-0.1	0.0	7.5
182	28 Feb	10.6	0.2	5.4	13.6	-3.3	-1.7	0.0	0.81
183	1 Mar	8.3	0.2	4.3	12.8	-3.4	-1.7	0.0	0.62
184	2 Mar	12.5	2.3	7.4	14.1	0.9	0.5	0.0	3.1
185	3 Mar	12.6	0.4	6.5	14.9	-3.0	6.1	0.0	1.3
186	4 Mar	10.9	4.2	7.6	17.6	6.1	3.1	0.0	0.0
187	5 Mar	13.6	2.6	8.1	17.5	2.3	1.2	0.0	4.5
188	6 Mar	10.8	0.3	5.6	8.4	-2.8	2.8	0.0	0.0
189	7 Mar	12.3	0.2	6.3	13.7	-4.5	4.6	0.0	0.0
190	8 Mar	8.6	1.5	5.1	14.4	0.8	2.9	0.50	10.7
191	9 Mar	13.1	3.5	8.3	16.2	6.5	3.3	0.0	0.0

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
	1985								
1	1 Sep	26.9	16.1	21.5	25.9	15.8	21.1	0.0	14.3
2	2 Sep	29.5	15.7	22.6	29.9	15.3	23.2	0.0	15.3
3	3 Sep	29.8	16.4	23.1	31.9	16.3	25.0	0.1	14.9
4	4 Sep	28.9	19.5	24.2	31.8	19.7	17.6	0.0	14.7
5	5 Sep	29.2	17.6	23.4	32.2	17.5	24.3	0.0	17.5
6	6 Sep	27.5	18.2	22.9	29.4	19.3	22.7	0.0	16.2
7	7 Sep	29.9	18.4	24.2	31.9	20.7	25.7	0.0	14.7
8	8 Sep	30.3	19.1	24.7	33.6	20.2	26.1	0.0	15.7
9	9 Sep	28.8	19.5	24.2	32.3	20.1	24.8	0.0	14.6
10	10 Sep	27.2	18.5	22.9	30.5	19.2	23.1	0.0	14.8
11	11 Sep	22.9	17.6	20.3	24.9	16.2	19.2	0.0	13.8
12	12 Sep	17.9	14.0	16.1	17.3	11.3	11.7	0.0	18.8
13	13 Sep	20.7	10.8	15.8	18.6	5.1	11.1	0.3	14.0
14	14 Sep	20.9	8.7	14.8	19.5	1.8	10.2	0.0	15.1
15	15 Sep	21.3	9.1	15.2	21.4	3.0	12.1	0.1	15.2
16	16 Sep	21.4	9.6	15.5	24.0	4.7	14.2	0.0	15.2
17	17 Sep	21.8	9.7	15.8	24.5	5.1	14.7	0.0	15.1
18	18 Sep	21.8	10.3	16.1	25.8	6.1	15.6	0.0	15.1
19	19 Sep	21.8	11.8	16.8	27.3	8.8	17.4	0.0	15.6
20	20 Sep	21.7	12.4	17.1	26.7	10.3	18.6	0.0	14.3
21	21 Sep	21.6	12.7	17.2	26.4	11.1	18.9	0.0	13.5
22	22 Sep	21.2	14.7	18.1	26.4	14.5	21.0	0.0	15.0
23	23 Sep	25.4	17.1	21.3	25.5	12.2	18.8	0.0	15.0
24	24 Sep	23.1	16.8	20.1	23.1	8.4	15.7	0.15	14.1
25	25 Sep	23.5	14.2	18.9	20.9	5.8	13.4	0.0	8.5
26	26 Sep	22.6	17.2	19.9	21.3	13.3	17.3	0.0	5.2
27	27 Sep	20.9	15.1	18.0	18.1	7.4	12.7	0.0	2.7
28	28 Sep	23.0	12.4	17.7	20.9	4.1	12.5	0.0	13.9
29	29 Sep	23.2	12.4	17.8	21.9	3.8	12.9	0.0	13.6
30	30 Sep	23.8	12.7	18.3	25.1	4.6	14.8	0.0	14.1
31	1 Oct	22.9	14.6	18.8	24.6	9.3	17.1	0.1	15.7
32	2 Oct	18.1	15.4	16.8	16.1	11.6	13.9	2.87	24.0
33	3 Oct	18.7	15.5	17.1	17.1	13.1	15.5	0.18	16.5
34	4 Oct	22.6	16.9	19.8	25.5	15.0	20.3	0.13	13.5
35	5 Oct	18.8	13.0	15.9	17.3	6.6	12.1	0.0	5.3
36	6 Oct	17.7	10.9	14.3	14.2	1.7	7.9	0.0	6.0
37	7 Oct	19.0	9.2	14.1	18.0	-0.78	8.6	0.0	10.0
38	8 Ovt	19.2	10.1	14.7	19.4	2.7	11.0	0.0	9.8
39	9 Oct	20.5	10.1	15.3	26.2	8.1	17.3	0.0	15.4
40	10 Oct	21.2	11.3	16.3	27.6	9.3	17.7	0.0	15.7
41	11 Oct	21.4	12.0	16.7	28.6	11.6	18.3	0.0	12.8
42	12 Oct	17.1	14.2	15.7	19.0	14.7	15.1	0.0	15.0
43	13 Oct	20.6	14.2	17.4	27.1	15.2	19.5	0.0	11.1
44	14 Oct	22.1	13.3	17.7	28.4	13.1	19.8	0.0	15.2
45	15 Oct	19.5	14.3	16.9	26.7	15.1	18.9	0.0	19.2
46	16 Oct	19.0	11.1	15.1	23.3	8.3	13.7	0.0	7.3
47	17 Oct	17.6	8.5	13.1	21.5	4.2	12.0	0.0	13.8

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
48	18 Oct	18.7	11.3	15.0	23.2	9.8	16.6	0.0	14.1
49	19 Oct	20.0	11.1	15.6	28.3	9.1	17.1	0.0	15.2
50	20 Oct	19.7	13.5	16.6	26.7	11.6	18.9	1.3	19.8
51	21 Oct	13.5	11.0	12.3	12.2	9.4	7.9	1.6	24.0
52	22 Oct	14.6	11.4	13.0	16.4	11.9	12.4	0.2	16.5
53	23 Oct	15.0	12.8	13.9	18.0	14.4	13.3	0.1	19.8
54	24 Oct	17.1	14.1	15.6	21.3	17.1	16.5	0.3	17.5
55	25 Oct	17.7	10.9	14.3	23.3	7.2	13.1	0.0	11.9
56	26 Oct	15.0	8.1	11.6	19.9	2.5	10.9	0.0	14.3
57	27 Oct	14.9	8.6	11.8	21.1	4.4	11.6	0.0	14.8
58	28 Oct	16.7	9.7	13.2	22.1	8.3	13.9	0.0	8.4
59	29 Oct	12.2	7.3	9.8	13.5	3.8	7.9	0.0	0.0
60	30 Oct	10.0	7.9	9.1	10.1	6.0	6.2	0.1	5.0
61	31 Oct	12.2	9.2	10.7	13.4	9.7	10.1	0.0	20.2
62	1 Nov	13.6	10.5	12.1	16.5	12.3	11.9	1.0	23.7
63	2 Nov	12.9	10.9	11.9	15.7	11.7	10.5	0.4	19.6
64	3 Nov	11.9	10.3	11.1	14.8	11.7	10.1	2.4	24.0
65	4 Nov	12.2	7.9	10.1	17.4	6.6	8.5	14.2	23.1
66	5 Nov	8.1	6.2	7.2	10.1	6.1	5.3	0.4	7.4
67	6 Nov	10.9	6.9	8.9	14.4	4.7	7.3	0.0	5.4
68	7 Nov	11.1	5.4	8.3	16.5	0.82	7.1	0.0	9.5
69	8 Nov	10.5	4.6	7.6	14.8	2.2	6.6	0.0	4.7
70	9 Nov	10.7	3.2	7.1	18.4	-1.2	7.1	0.0	13.3
71	10 Nov	12.6	5.6	9.1	22.5	4.1	11.2	0.0	15.3
72	11 Nov	14.0	7.2	10.6	24.5	6.5	14.2	0.0	15.7
73	12 Nov	13.7	9.3	11.5	20.9	9.9	14.1	0.0	17.4
74	13 Nov	14.9	10.2	12.6	24.1	11.9	15.6	0.0	14.5
75	14 Nov	15.7	11.3	13.5	24.2	13.8	16.9	0.0	14.3
76	15 Nov	16.7	11.9	14.3	23.4	11.9	16.9	0.0	7.0
77	16 Nov	11.9	9.4	10.7	11.9	7.1	7.2	0.5	18.1
78	17 Nov	13.8	9.2	11.5	21.8	9.6	13.9	0.0	8.5
79	18 Nov	14.5	9.4	12.1	21.9	8.9	13.7	0.0	16.1
80	19 Nov	16.1	10.8	13.5	23.8	11.3	15.3	0.0	16.8
81	20 Nov	16.4	11.1	13.8	26.1	12.9	16.9	0.0	17.1
82	21 Nov	12.2	8.0	10.1	13.3	5.1	6.8	1.1	24.0
83	22 Nov	9.3	6.5	7.9	12.2	4.2	5.5	1.8	19.6
84	23 Nov	10.5	4.5	7.5	16.1	1.6	9.3	0.0	14.9
85	24 Nov	10.6	4.2	7.4	13.2	1.3	5.3	0.0	14.5
86	25 Nov	11.5	6.0	8.8	14.6	4.5	8.2	0.0	13.9
87	26 Nov	13.2	6.5	9.9	20.9	5.5	10.9	0.1	16.6
88	27 Nov	14.4	11.7	13.1	19.8	16.1	15.0	0.6	20.8
89	28 Nov	15.3	11.3	13.3	22.4	14.6	16.6	1.2	20.6
90	29 Nov	13.3	8.6	11.1	16.5	8.2	10.1	0.6	21.0
91	30 Nov	9.9	8.1	9.0	11.2	8.1	6.6	0.1	24.0
92	1 Dec	10.5	8.3	9.4	13.4	9.6	7.7	0.1	24.0
93	2 Dec	8.9	-0.79	4.1	11.9	-6.4	0.03	0.0	3.9
94	3 Dec	0.04	-1.5	-0.73	1.6	-7.4	-4.6	0.0	4.9
95	4 Dec	1.5	-1.4	0.05	7.7	-8.2	-1.5	0.0	10.6

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
96	5 Dec	5.6	1.3	3.5	8.3	1.9	4.8	0.1	13.8
97	6 Dec	3.1	0.61	1.9	3.5	-0.60	-0.58	0.0	4.4
98	7 Dec	5.7	-0.18	2.8	8.4	-2.9	1.1	0.0	11.6
99	8 Dec	6.7	0.71	3.7	12.9	-0.73	4.2	0.0	13.5
100	9 Dec	7.4	2.0	4.7	11.8	1.2	4.7	0.0	16.7
101	10 Dec	8.8	1.2	5.0	17.3	-1.3	6.5	0.0	17.0
102	11 Dec	8.9	1.9	5.4	16.1	-0.18	6.5	0.1	15.2
103	12 Dec	11.3	8.4	9.9	15.2	11.2	11.2	0.4	16.0
104	13 Dec	8.6	2.3	5.5	11.2	1.7	3.9	0.7	18.7
105	14 Dec	2.3	-1.8	0.25	1.7	-8.7	-6.1	0.0	0.0
106	15 Dec	-0.93	-2.4	-1.7	5.7	-9.6	-3.7	0.0	0.0
107	16 Dec	0.2	-1.7	-0.75	5.5	-3.1	-0.39	0.0	5.3
108	17 Dec	1.0	-1.3	-0.15	9.0	-2.2	1.9	0.0	3.2
109	18 Dec	-0.34	-2.5	-1.4	4.2	-9.6	-4.8	0.0	0.13
110	19 Dec	-1.2	-3.3	-2.3	3.3	-12.6	-5.8	0.0	8.4
111	20 Dec	-1.3	-3.1	-2.2	-2.5	-9.1	-5.8	0.0	18.3
112	21 Dec	-1.4	-2.5	-2.1	-5.4	-11.2	-10.4	0.0	5.6
113	22 Dec	-1.3	-2.8	-2.1	2.3	-13.9	-7.6	0.0	11.7
114	23 Dec	-0.71	-1.7	-1.2	9.5	-1.2	3.2	0.0	18.6
115	24 Dec	0.88	-1.1	-0.11	9.7	-0.87	3.2	0.3	15.1
116	25 Dec	-0.85	-5.2	-3.0	-0.84	-14.3	-9.5	0.0	0.0
117	26 Dec	-2.2	-6.3	-4.3	-3.9	-14.8	-11.0	0.0	0.0
118	27 Dec	-1.1	-3.3	-2.2	6.5	-3.9	0.67	0.0	4.3
119	28 Dec	-1.1	-2.6	-1.9	5.1	-2.9	-0.84	0.0	2.1
120	29 Dec	-1.1	-3.9	-2.5	5.9	-8.6	-2.9	0.0	9.5
121	30 Dec	-1.1	-4.1	-2.6	5.8	-6.0	-1.1	0.0	3.9
122	31 Dec	-0.94	-3.4	-2.2	7.7	-6.6	0.66	0.1	21.4
	1986								
123	1 Jan	-0.95	-2.2	-1.6	6.9	-4.7	-0.23	0.0	5.9
124	2 Jan	-0.61	-3.4	-2.0	12.1	-6.9	1.6	0.0	8.3
125	3 Jan	0.75	-1.1	-0.18	11.6	1.5	5.2	0.0	5.1
126	4 Jan	-0.25	-1.2	-0.73	7.2	-2.2	1.6	0.0	11.0
127	5 Jan	-1.0	-2.5	-1.8	2.6	-4.7	-3.1	0.0	6.5
128	6 Jan	-1.1	-2.8	-2.1	6.6	-5.3	-0.90	0.0	1.2
129	7 Jan	-1.1	-3.4	-2.3	1.5	-10.7	-5.3	0.0	4.4
130	8 Jan	-1.3	-4.7	-3.0	-0.19	-13.2	-7.3	0.0	12.9
131	9 Jan	-0.96	-4.7	-2.8	10.8	-12.5	-2.2	0.0	10.1
132	10 Jan	-0.78	-3.4	-2.1	11.2	-5.2	1.4	0.0	4.1
133	11 Jan	-0.93	-1.8	-1.4	4.9	-1.7	-1.5	0.0	14.5
134	12 Jan	0.31	-2.6	-1.1	14.6	-3.4	4.1	0.0	8.6
135	13 Jan	-1.2	-3.4	-2.3	-0.38	-8.0	-4.9	0.0	0.60
136	14 Jan	-0.93	-3.8	-2.4	5.1	-8.1	-1.7	0.0	0.51
137	15 Jan	-0.53	-3.3	-1.9	6.7	-8.5	-1.3	0.0	4.3
138	16 Jan	0.67	-3.2	-1.3	16.1	-7.0	3.7	0.0	9.6
139	17 Jan	-0.03	-2.1	-1.1	10.2	-3.6	1.5	0.0	14.9
140	18 Jan	2.5	-1.1	0.7	15.7	1.5	7.7	0.0	14.8
141	19 Jan	4.2	-0.26	1.7	12.0	1.6	4.3	1.7	19.7
142	20 Jan	-0.26	-0.81	-0.54	1.8	-1.4	-1.9	0.0	0.0

Day	Date	Soil Max	Soil Min	Soil Avg	Air Max	Air Min	Air Avg	Rain	Lfw
143	21 Jan	4.8	−0.96	1.9	15.4	−3.5	4.4	0.0	3.3
144	22 Jan	6.5	−0.81	2.8	15.9	−1.9	5.4	0.0	9.3
145	23 Jan	5.9	−0.74	2.6	11.1	−2.9	3.3	0.0	4.1
146	24 Jan	1.1	−1.3	−0.1	5.5	−7.1	−1.8	0.0	1.5
147	25 Jan	−0.14	−1.1	−0.62	3.3	−2.5	−0.35	0.0	5.1
148	26 Jan	−0.05	−0.71	−0.38	3.2	−4.5	0.30	0.1	14.5
149	27 Jan	−0.67	−1.7	−1.2	−4.6	−15.9	−12.3	0.0	0.0
150	28 Jan	−1.7	−2.5	−2.1	−8.6	−18.2	14.6	0.0	0.0
151	29 Jan	−1.2	−1.9	−1.6	2.8	−10.8	−6.3	0.3	12.1
152	30 Jan	−1.1	−1.4	−1.3	−1.3	−4.8	−3.2	0.0	0.0
153	31 Jan	−0.94	−1.3	−1.1	9.5	−4.0	7.1	0.2	0.0
154	1 Feb	−0.81	−1.1	−0.96	12.8	1.7	8.6	0.0	0.88
155	2 Feb	1.7	1.3	1.5	13.0	9.1	8.6	0.0	1.7
156	3 Feb	5.1	1.3	3.2	11.3	5.3	5.7	1.5	23.9
157	4 Feb	8.7	2.1	5.4	13.4	4.8	8.0	0.0	16.1
158	5 Feb	10.6	2.8	6.7	18.4	6.5	10.2	0.1	20.4
159	6 Feb	8.0	1.8	4.9	13.4	3.6	5.7	1.1	21.6
160	7 Feb	8.3	1.5	4.9	13.1	2.2	6.2	0.1	10.4
161	8 Feb	8.1	0.09	4.1	11.4	1.4	6.0	0.0	3.5
162	9 Feb	7.0	3.1	5.1	9.5	−1.1	4.2	0.0	15.3
163	10 Feb	4.9	3.9	4.4	13.3	−0.63	1.3	0.2	24.0
164	11 Feb	4.2	2.4	3.3	−0.36	−7.7	−4.0	0.56	24.0
165	12 Feb	−0.89	−3.2	−2.0	−2.2	−7.6	6.2	0.0	6.3
166	13 Feb	−1.1	−4.7	−2.9	−3.0	−10.9	8.1	0.0	0.0
167	14 Feb	−1.4	−3.9	−2.7	−3.4	−10.4	8.1	0.0	11.5
168	15 Feb	−1.1	−1.5	−1.3	0.19	−4.7	4.8	0.0	4.1
169	16 Feb	−0.42	−1.7	−1.1	13.5	−7.2	1.9	0.4	1.8
170	17 Feb	0.42	−1.0	−0.29	11.4	2.3	6.8	0.4	10.6
171	18 Feb	9.8	0.02	4.9	16.4	5.8	9.4	0.2	16.5
172	19 Feb	9.6	2.6	6.1	16.3	5.2	8.1	0.1	20.6
173	20 Feb	14.3	2.3	8.3	21.4	5.4	12.2	0.0	16.3
174	21 Feb	14.3	3.6	9.1	22.2	3.5	11.8	0.0	8.4
175	22 Feb	4.1	1.9	3.0	3.9	0.97	−0.13	0.5	23.1
176	23 Feb	8.4	0.01	4.2	7.7	−0.79	2.1	0.0	2.3
177	24 Feb	3.4	0.01	1.7	2.8	0.14	0.07	0.2	12.6
178	25 Feb	4.8	−0.88	2.1	1.3	−3.6	−2.1	0.0	11.6
179	26 Feb	−0.85	−1.7	−1.3	−0.03	−6.1	−4.8	0.0	11.7
180	27 Feb	−0.53	−0.96	−0.75	3.5	−2.4	−1.9	0.3	7.2
181	28 Feb	2.8	−0.98	−0.91	1.9	−5.1	−2.7	0.0	0.0

Appendix G. Soil Nutrient Analysis for Experimental Site Located at the Agronomy Farm, VPI&SU, Blacksburg, Virginia.

Analysis of soil samples was performed by the Soil Testing and Plant Analysis Laboratory, VPI & SU, Blacksburg, Virginia on 28 May 84.

Nutrient	Concentration in ppm
Phosphorus (P)	53.0
Potassium (K)	191.0
Calcium (Ca)	940.0
Magnesium (Mg)	99.0
Manganese (Mn)	16.1
Zinc (Zn)	6.1
Soil pH	6.0

The vita has been removed from the scanned document