DISEASE CYCLE AND CONTROL OF PEPPERMINT
RUST CAUSED BY *PUCCINIA MENTHAE* PERS.

by

CHESTER ELLSWORTH HORNER

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1954

APPROVED:

Professor of Botany and Chairman of Department of
Botany

In Charge of Major

Chairman of School Graduate Committee

Dean of Graduate School

Date thesis is presented   May 5, 1954

Typed by Ruth Brown

ACKNOWLEDGEMENT

TABLE OF CONTENTS

Page

TABLES

Page

TABLES (continued)

FIGURES

DISEASE CYCLE AND CONTROL OF PEPPERMINT
RUST CAUSED BY <u>PUCCINIA</u> <u>MENTHAE</u> PERS.

INTRODUCTION

Culture of peppermint (<u>Mentha</u> <u>piperita</u> L. var. Mitcham) for its essential oil has been carried on in Oregon since about 1909. The industry grew slowly at first, then expanded rapidly since 1940. Peppermint is grown in Oregon chiefly on the rich, river bottom soils of the Willamette River and its main tributaries. It is grown to a lesser extent on peat and mineral soils along the lower Columbia River.

Mint rust (<u>Puccinia</u> <u>menthae</u> Pers.) was first found in Oregon in commercial mint plantings of the lower Columbia River area in 1948. In the summer of 1949 economic losses occurred in certain fields in Columbia county and by November every mint field was infested with rust (26). Mint rust appeared in Willamette Valley mint fields in the spring and summer of 1950 and by November every mint field examined in Western Oregon was infested (26).

Rust on common spearmint (<u>Mentha</u> <u>spicata</u> L.) and Scotch spearmint (<u>M</u>. <u>cardiaca</u> L.) has been a seasonally important disease in the Midwest for many years (23, p. 17) but rust was not reported on peppermint in that area until 1952 (17). The races of the mint rust fungus attacking common spearmint and peppermint are distinctly different

in pathogenicity and not cross-infective on these two mint
species (4). Mint rust has been known on both spearmint
and peppermint in Europe and parts of Russia for many
years (6) and (27). Control measures for mint rust devel-
oped by European and Russian investigators are not gener-
ally applicable in the United States because of wide
differences in cultural practices.

The disease cycle of peppermint rust in the field has
not previously been investigated in this country. When
mint rust became epiphytotic in the Northwest in 1949, re-
search on the disease cycle and control of this disease
was undertaken and is reported in this thesis.

REVIEW OF LITERATURE

The Crop

According to Nelson (16, p. 30) the peppermint indus-
try began in Oregon in 1909 with planting stock from
Michigan. Nelson (16, pp. 1-30) ascribes the origin of the
present commercial variety of peppermint (Mentha piperita
L. var. Mitcham) to the natural hybrids (M. sylvestris x
M. rotundifolia) x M. aquatica and traces its culture from
England to the United States.

Commercial peppermint is male sterile (16, pp. 192-
196) and is propagated mainly by rhizomes which are pro-
duced abundantly. Peppermint production in Oregon has
increased rapidly since 1940. The average total acreage in
Oregon from 1936 to 1945 was 3,620 acres (23, p. 3). In
1946 acreage was increased to 9,000 (23, p. 3) and by 1952
had reached 15,000 acres.*

The Fungus

The mint rust fungus, (Puccinia menthae), first de-
scribed by Persoon in 1801 (21, p. 227) on Mentha aquatica,
has been recorded on many genera and species of the family
Labiatae from all over the world. In 1934 Arthur (2, pp.

*Records from a private source.

327-329) recorded mint rust on 48 species and 9 genera of
the family Labiatae in the United States and Canada.

Puccinia menthae is an autoecious full-cycle rust be-
longing to the family Pucciniaceae in the order Uredinales.
It is composed of numerous pathogenic races which can be
differentiated by their reaction on suitable genera, spe-
cies and varieties of the Labiatae. In 1906 Cruchet (6)
differentiated 8 pathogenic races in Europe. Recently
Baxter and Cummins (4) have demonstrated the presence of
15 races in North America.

The Disease

Vergovsky (27) studied the life cycle of mint rust in
the Crimea. He demonstrated that rust mycelium was not
systemic in the peppermint plant, and that overwintering
of teliospores was necessary for new infections to be
initiated the following spring. Rust caused losses of 20
to 50 per cent of the yield of oil depending on meteor-
logical conditions, and further, the menthol content of
oil from rust infected leaves was less than from healthy
leaves. He listed the time lapse from basidiospore infec-
tion to aeciospore production on peppermint as 10-12 days;
from aeciospore infection to urediospore production 12-15
days; and from urediospore infection to urediospore pro-
duction 18-20 days. Only young, tender stem or leaf

tissues could be infected by basidiospores, mature plant tissues were not infected.

Mint rust has caused serious losses on peppermint, Mentha piperita L. (14), 26) and 27); spearmint, M. spicata L. (23, p. 17), and M. cardiaca L. var Scotch (4); and on Japanese field mint M. arvensis L. var piperascens (9). These mints are grown as field crops for their essential oil which is removed by steam distillation of the hay. Spearmint is also grown in the winter as a forced greenhouse crop near many large cities where the leafy shoots are sold as a flavoring for foods and drinks. In 1945 Niederhauser (18) published the results of a comprehensive study of the rust disease of greenhouse-grown spearmint and its control. His work on the life cycle of mint rust agreed with that done earlier by Vergovsky (27). Hot water treatment of rhizomes before planting them in the greenhouse was an effective method of control.

Muhle (14) in Germany has recently substantiated the earlier work of Vergovsky on the disease cycle of the peppermint rust fungus.

Rust on commercially grown peppermint was first reported in the United States by Steenland (26) in Oregon where it became epiphytotic in 1949. Later Baxter (3) reported its occurrence in Western Ontario, Canada in 1951

and Nelson (17) in Michigan in 1952.

Control

Vergovsky (27) demonstrated that plowing the mint
stubble under in the fall to a depth of at least 5 cm.
was effective in greatly reducing the amount of spring
infection. Sulfuric acid used to kill the regrowth in
the fall also greatly reduced spring infections by pre-
venting the production of overwintering teliospores on
the foliage. Copper sulfate and Bordeaux sprays were
not effective in protecting the foliage from severe in-
fection. Sulfur, while more effective against rust re-
duced the accumulation of oil in the plants. Vergovsky
recommended early cutting as a means of avoiding excessive
leaf drop due to heavy rust infection. Dusting with
sulfur or spraying with Bordeaux has been recommended for
rust control on spearmint in the Midwest (23, p. 17) but
is not generally practiced.

Muhle (14) has suggested that some control can be
obtained by such cultural practices as avoiding heavy
nitrogen fertilization, harvesting before rust is severe
and crop rotation. Cuttings taken in the fall, submerged
in formalin, copper sulfate, Germisan, Ceresan and Aretan
solutions of 0.4 to 2 per cent for varying lengths of time

were rust free the following spring. Injury of the cuttings was noted at the higher concentrations and longer durations.

GENERAL METHODS

Certain general laboratory and field methods were
followed throughout the course of this investigation and
will be described in this section. Special methods were
applied to individual experiments and will be described
in later sections.

Laboratory and Greenhouse Methods

Spore germination

Teliospore germination tests were made frequently
during the course of studies on overwintering, time of
germination and infection, and length of viability in the
field. Telia bearing leaves were collected, the spores
removed with a scalpel and floated on 2 per cent sucrose
solution. For maximum germination teliospores floating on
2 per cent sucrose solution in Petri plates were held at
15° C. in controlled temperature cabinets.

Aeciospore and urediospore germination tests were
made in conjunction with experiments on overwintering,
effects of temperature, length of viability and inhibition
of germination by chemicals. Spore suspensions were made
by washing leaves or shoots with sporulating sori in
flasks of distilled water. Drops of the spore suspension

were pipetted onto solidified 1.7 per cent water agar in
Petri plates. For maximum germination the agar plates
were held at 20° C. for 24 to 48 hours.

Pathological histology

Rust infected tissues were studied by histological
methods. Sections of diseased leaves and stems were kill-
ed in F.A.A. and dehydrated with tertiary butyl alcohol.
The tissues were then infiltrated and embedded with paraf-
fin and sectioned on a rotary microtome. The most satis-
factory stain used was iron hematoxylin and eosin.

Inoculation

Inoculations of disease free plants with teliospores,
aeciospores and urediospores were made frequently during
the course of this investigation. Spores were suspended
in water and sprayed on leaves, stems and buds with a De
Vilbiss No. 15 atomizer. When uniform spore suspensions
were used the number of spores per ml. was determined with
a Neubauer haemacytometer and the spore suspension adjusted
to the desired level by the addition of water. After in-
oculation plants were placed in moist chambers for 24 to
48 hours, then removed to the greenhouse bench.

Inoculation of young shoots and buds with teliospores

consisted of placing teliospores on the leaves of buds or on the young shoots with a camel's hair brush. The inoculated plants were then placed under bell jars or plastic covers for 48 hours.

Greenhouse cultural methods

Several phases of this investigation were carried out in the greenhouse under uniform methods of soil preparation and culture. Soil consisted of a mixture of sandy loam, sand and peat moss to which a 16-20-0 commercial fertilizer was added. All soil was thoroughly mixed and screened.

Test plants were grown from rhizomes and cuttings. When test plants of uniform size were desired these were selected from cuttings rooted for 2 to 3 weeks in sand.

During the period from October to March supplementary light was used to simulate a 14 to 18 hour day length.

Field Methods

The experimental design used in most field tests was a randomized block. The number of replications was varied to meet the needs of the individual experiments.

Mass inoculation of field plots was made by spraying a suspension of urediospores in water onto the foliage

from a 3 gallon Hudson knapsack sprayer. A variable
direction nozzle was used to direct the spray on the
undersides of the leaves. Following inoculation the
plots were watered with an overhead sprinkler irrigation
system for 12 hours.

FIELD DISEASE CYCLE AND FACTORS AFFECTING IT

Method of Overwintering

The mint rust fungus overwinters as teliospores on
fallen leaves, mint stubble, rhizomes and the soil surface.
Vergovsky (27) established that the fungus did not over-
winter as perennial mycelium. This has been substantiated
by Niederhauser (18) and Muhle (14).

Teliospores are produced from May to December on mint
plants in the field under Oregon conditions. They have
been observed occasionally in May, June, July and August
on mint plants which were subject to unfavorable environ-
mental conditions. Low temperature, low light intensity
and nutrient deficiency are factors closely associated
with teliospore production during the spring and summer
months. Teliospores have not been observed before July 25
on plants growing under favorable environmental condi-
tions.

Teliospores may be produced on leaves, stems and
rhizomes. Figure 1 shows mixed telial and uredial sori
on mint stems collected from the field August 27, 1952.

The greatest source of overwintering teliospores is
on the regrowth which becomes heavily infected after har-
vest. In Oregon the shift from production of urediospores

13

Figure 1. Mixed uredial and telial sori on peppermint
stems collected from the field.

to teliospores takes place during October.

Teliospores of _Puccinia menthae_ require a short
period of dormancy before they are capable of germination.
Niederhauser (18, p. 14) found a minimum dormancy period
in the greenhouse of 12 days after the telium broke
through the epidermis until the spores germinated. The
dormancy period in the field cannot be assumed to be the
same because of greater extremes of moisture and tempera-
ture which are known to affect dormancy of teliospores of
other rust species (1, pp. 209-225).

During the middle of October, 1951, conditions were
favorable for rust infection. Urediospore infections that
took place during that time produced almost 100 per cent
telial sori which began to sporulate by November 1. To
determine the time of maximum germination of teliospores
that were subject to field conditions, several mint plants
were examined November 10 and selected leaves on the mint
regrowth bearing newly erupted telial sori were marked. At
approximately 20 day intervals collections of teliospores
were made from 5 of the marked leaves and brought into the
laboratory for germination tests. The spores were floated
on 2 per cent sucrose solution in Petri plates and the
plates incubated for 48 hours at 15° C. Each plate con-
tained spores from one leaf and 50 spores were counted in

each plate and the number germinated recorded (Table 1).

Table 1. Germination of teliospores collected
from the field at different dates.

Date collected	Number of spores in 50 germinated from leaf number					Total no. germinated	Per cent germination
	1	2	3	4	5		
Nov. 10, 1951	8	11	6	9	7	41	16.4
Nov. 19, 1951	11	14	9	17	15	66	26.4
Dec. 7, 1951	17	14	21	19	23	94	37.6
Dec. 23, 1951	19	20	17	29	31	116	46.4
Jan. 13, 1952	33	24	21	33	30	141	56.4
Jan. 24, 1952	19	11	14	9	10	63	25.2
Feb. 15, 1952	11	14	16	9	11	52	20.8
Feb. 25, 1952	9	6	11	4	8	38	15.4

Teliospore germination occurred over the entire
period of 108 days included in this test and maximum
germination occurred with spores collected in December and
January.

Infection by Basidiospores

Niederhauser (18, pp. 14-21) described the phenomena
associated with basidiospore infection and subsequent

development of spermogonia in spearmint rust. Vergovsky
(27) found the period of time necessary from basidiospore
infection to production of aeciospores was 10-12 days under
laboratory conditions. Figure 2 shows cross sections of a
peppermint stem with spermogonia and aecia.

Field observation in Oregon suggested that infection
by basidiospores takes place in December and January, but
mature aecia have not been recorded before February 9. A
test was made to determine when basidiospore infection
takes place in the field and the time lapse between
basidiospore infection and aeciospore production under
field conditions.

An unplowed field with heavy teliospore production on
the regrowth and rhizomes was selected in November 1952.
Beginning December 1, 25 young shoots from 1 to 2 inches
long were collected at approximately 2-week intervals
until March, 1953, when the field was plowed. The young
shoots were placed in plastic bags containing moist paper
towels and brought to the laboratory.

The shoots were washed, trimmed of roots, placed be-
tween rectangular pieces of potato tuber and sectioned at
30 microns on a sliding microtome. The sections were
floated in water, placed in a water suction apparatus to
evacuate air bubbles in the intercellular spaces, stained
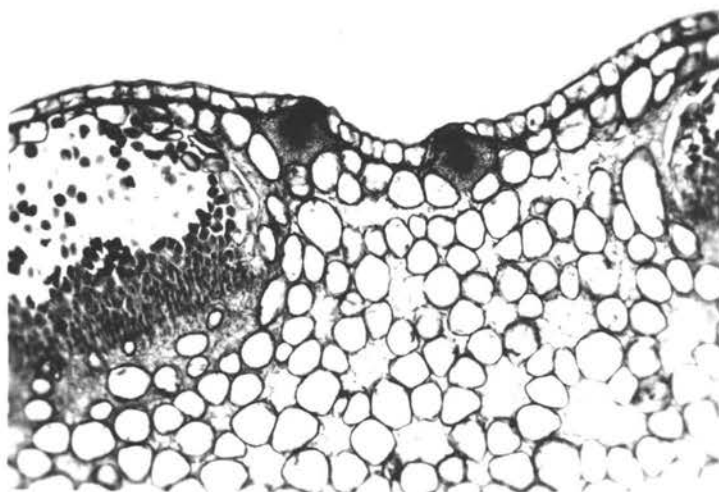
A
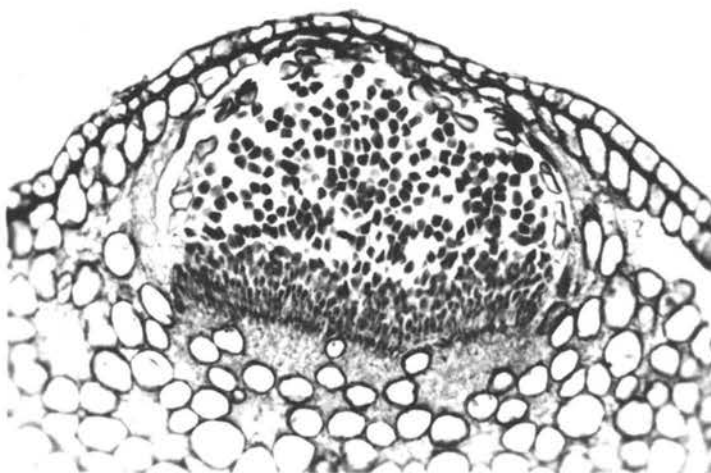
B

Figure 2. Cross sections of a peppermint stem with
spermogonia and aecia (A) and an aecium (B).

with 0.5 per cent methylene blue in lactophenol, mounted
on microscope slides and examined under a microscope for
evidence of infection, spermogonia, and aecia formation.

Visible external symptoms of infection were first ob-
served on shoots collected December 30, however, internal
intercellular rust mycelium and characteristic intra-
cellular haustoria were observed microscopically in sec-
tions from shoots collected December 13 (Table 2).
Spermogonia formation was first observed December 30, but
aeciospores were not produced until February 17, 65 days
later. Thus, under field conditions from December to
February a much longer time is required for basidiospore
infections to ultimately result in aeciospore production
than 10 to 12 days as reported by Vergovsky (27) for
laboratory conditions.

The first external symptoms of infection on stems,
petioles and leaf veins consist of pink or red, slightly
raised blisters 1 to 3 millimeters in diameter. These
blisters gradually enlarge and may attain a length of 3
centimeters on large, vigorous shoots. It is possible to
recognize infections caused by basidiospores very early
in their development by the small red blisters they cause,
therefore, the effect of temperature on the development
of spermogonia and aecia was tested.

Table 2. Time of basidiospore infection and
spermogonia and aecia formation on
young mint shoots under field con-
dition in Oregon in 1952-'53.

Date shoots collected	Number of 25 shoots showing:			
	Basidiospore infection	Spermogonia formation	Aecia formation	Aecia sporulation
Dec. 1, 1952	0	0	0	0
Dec. 13, 1952	3	0	0	0
Dec. 30, 1952	11	3	0	0
Jan. 11, 1953	10	4	2	0
Jan. 15, 1953	14	6	2	0
Feb. 1, 1953	19	11	9	0
Feb. 17, 1953	22	19	14	3
Mar. 4, 1953	21	16	14	9
Mar. 14, 1953	24	20	20	17

Twenty young shoots with the first visible symptoms
of basidiospore infections were selected and washed sev-
eral times in sterile distilled water, then placed in
quartz sand saturated with Hoagland's nutrient solution
in 20 centimeter test tubes. Five tubes containing the
test plants were placed in each of 4 controlled tempera-
ture cabinets at 5, 10, 15 and 20° C. Observations were
made daily on the development of spermogonia and aecia by

checking the infected area on a dissecting microscope without removing the plants from the test tubes. Records were made (Table 3) of the date of the first appearance of spermogonial exudate indicating the presence of mature spermogonia, and of the first rupture of the epidermis by the aecia indicating the presence of mature aecia.

Development of both spermogonia and aecia was most rapid at 20° C. At 5° C. development was greatly retarded and only 1 of 5 plants had mature aecia after a period of 40 days. Although infection by basidiospores may take place in the field during December and January, the developopment of spermogonia and aecia is greatly retarded by the low temperatures generally prevailing then. This explains why mature aecia have not been observed before February 9, although basidiospore infections were found as early as December 13. Peltier (20, pp. 32-40) found a similar situation of retarded development to exist in the urediospore cycle of wheat stem rust subjected to low temperatures.

Aeciospore Cycle

Aeciospore production on spearmint in the field was observed in Indiana from April 15 to the first week in July by Baxter and Cummins (4). In Oregon viable aeciospores produced in the field have been collected from

Table 3. Influence of temperature on the
development of spermogonia and
aecia of mint rust.

Temperature	Plant number	Number of days until appearance of mature:	
		Spermogonia	Aecia
5° C.	1	33	--
	2	29	38
	3	--	--
	4	34	--
	5	30	--
10° C.	1	14	26
	2	19	30
	3	19	29
	4	16	26
	5	14	24
15° C.	1	7	14
	2	7	15
	3	9	16
	4	6	14
	5	10	16
20° C.	1	5	12
	2	5	11
	3	3	9
	4	4	9
	5	4	10

February 9 to June 27. Aeciospore production is heaviest
during March and April. Although abundant aeciospores are
produced in the field during late February and March, the
earliest date recorded for the appearance of urediospores
is April 22. The appearance of mature aecia on shoots
collected in the field may be seen in Figure 3.

Vergovsky (27) stated that the incubation period from
aeciospore infection to urediospores production was 12 to
15 days on peppermint. Niederhauser (18, p. 23) found an
incubation period of 14 to 17 days for the production of
urediospores from aeciospore inoculum on spearmint in the
greenhouse.

To determine if aeciospores produced during February
and March were capable of infecting peppermint under field
conditions and under greenhouse conditions favorable for
infection, field collections of aeciospores were made
February 22, March 15 and 29 and April 22, 1952, and test-
ed for percentage of viable spores by plating droplets of
a spore suspension on 1.7 per cent water agar then counting
the number of spores in 200 germinating after 24 hours in-
cubation at 20° C. Peppermint plants about 6 inches high
were inoculated by spraying with the spore suspensions,
then placed in a moist chamber in the greenhouse at ap-
proximately 20° C. for 48 hours. Plants were removed from

Figure 3. Mature aecia on young peppermint shoots.
Some shoots with multiple infections. Note
hypertrophy, twisting and distortion,
especially lower right.

the moist chamber and one lot of 5 plants was placed out-
side the greenhouse on the ground to simulate field condi-
tions. A second lot of 5 plants was placed in the green-
house at a mean temperature of 20° C. The plants were
examined frequently and the incubation period necessary for
the production of urediospores recorded. The incubation
period under field conditions was greatly extended for
aeciospore infections of February 22 and March 15 (Table
4), however, under greenhouse conditions favorable for
infection and development of the mycelium, the incubation
period was within the range previously reported by
Vergovsky (27) and Niederhauser (18, p. 23).

Table 4. Comparison of the length of the in-
cubation period for the production
of mint rust urediospores under field
and greenhouse conditions during
February, March and April.

Date of spore collection	Per cent spore germination	Number of days incubation required before urediospores produced under:	
		Field conditions	Greenhouse conditions
Feb. 22	58.0	30*	15
Mar. 15	68.0	44	14
Mar. 29	72.0	20	15
Apr. 22	86.5	17	15

*Plants in this test were lost after 30 days.

Peltier (20, p. 49) found the incubation period for the production of wheat rust urediospore to be a minimum of 8 weeks at a temperature of 0 to 5° C. Temperature seems to be the most important factor determining length of incubation but Raines (22) found a small increase in rust incubation time coincident with a decrease in host vigor.

The influence of temperature and storage time on aeciospore viability was studied. Young mint shoots bearing sporulating aecia were collected from the field during April 1952. Twenty shoots were placed in Petri dishes at each of 9 different temperatures. A temperature of minus 15° C. was maintained in a Philco deep freeze; minus 5° and 0° were maintained in freezing compartments of refrigerators and plus 5° to plus 30° C. were maintained in constant temperature cabinets. A variation in temperature of plus or minus 1.5° C. was the maximum variation recorded in any of the storage apparatus. At periodic intervals 4 shoots were selected from each storage temperature and the aeciospores removed by washing in 20 mls. of water to make a spore suspension. Droplets of the spore suspension were pipetted onto 1.7 per cent water agar in Petri plates and germinated at 20° C. The percentage germination of two hundred spores counted for each temperature is

recorded in Table 5.

Table 5.   Effect of temperature and storage
time on aeciospore viability.

Storage time in days	Percentage germination at temperatures* of:								
	-15	-5	0	+5	+10	+15	+20	+25	+30
1	0.0	0.0	1.0	46.5	43.5	59.5	65.5	32.0	40.5
2	0.0	0.0	0.0	54.0	61.5	81.5	86.0	30.0	1.5
4	-	-	-	52.0	44.5	53.5	83.0	25.5	0.5
7	-	-	-	63.5	85.0	13.5	41.5	0.5	0.0
14	-	-	-	45.5	46.5	2.0	11.0	2.0	0.0
28	-	-	-	16.5	9.0	2.0	0.0	0.0	0.0

*plus or minus 1.5° C.

None of the aeciospores were viable after 1 day at
-15 and -5° C., and only 1 per cent were viable at 0° C.
Viability was lost rapidly at 25 and 30° C. but aecio-
spores held at 5, 10 and 15° C. were still viable after
28 days when the test was terminated.

Under field conditions environmental factors greatly
influence aeciospore production, survival and infection.
Several days of freezing weather beginning March 2, 1951
reduced aeciospore viability from 76 to 6 per cent.   In
exposed places rust mycelium and host cells associated

with it were killed by freezing weather during the first week of March, 1951 resulting in necrotic areas being formed at the point of aecial infection.

Beginning April 1, 1951, 27 consecutive days of clear, dry weather prevailed. Although abundant aeciospore inoculum was present no uredia were found until May 10, 13 days after a general rain. By May 17, uredial sori were abundant wherever sporulating aecia had been present on April 27.

The initial spread of mint rust by aeciospores has repeatedly been observed to be limited to a few feet. In 1953 Baxter and Cummins (4) reported no first-generation uredia at distances greater than 18 inches from the source of aeciospores.

Tests were conducted to determine the distance and general pattern of initial spread of mint rust by aeciospores and subsequent urediospores. On April 11, 1951, a mint field that had been fall-plowed was found to have a few widely scattered aecial sori. Six sporulating aecia were selected and marked. A careful examination of all mint shoots within a twelve-foot radius was made and no other aecial or uredial sori were found. These isolated aeciospore sources were carefully checked at about two-week intervals and the spread of rust from these sources

was charted. Fourteen days was considered as the minimum
time necessary from infection to sporulation. Spread was
determined by examination of all mint shoots within 12
feet of the original aeciospore source at 14 to 17 day in-
tervals. The experiment was terminated June 28. Figure 4
is a representative chart showing distance and direction
of spread. Initial spread by aeciospores was consistently
less than 4 feet. Direction of spread consistently con-
formed to the general wind pattern in the test area.

Urediospore Cycle

Viable urediospores have been collected in the field
from April 22 till December 13. Urediospores appearing in
April and May have consistently been traced back to sporu-
lating aecia in close proximity. Urediospores collected
during December were not viable with the exception of
those collected from foliage protected from weather ex-
tremes.

To determine if urediospores could overwinter on in-
fected leaves under field conditions, heavily infected
plants were collected during September, 1951 and air dried
in a barn until October 18, then exposed to field condi-
tions throughout the fall and winter. On October 20 a
germination test showed 29.5 per cent viability of 400
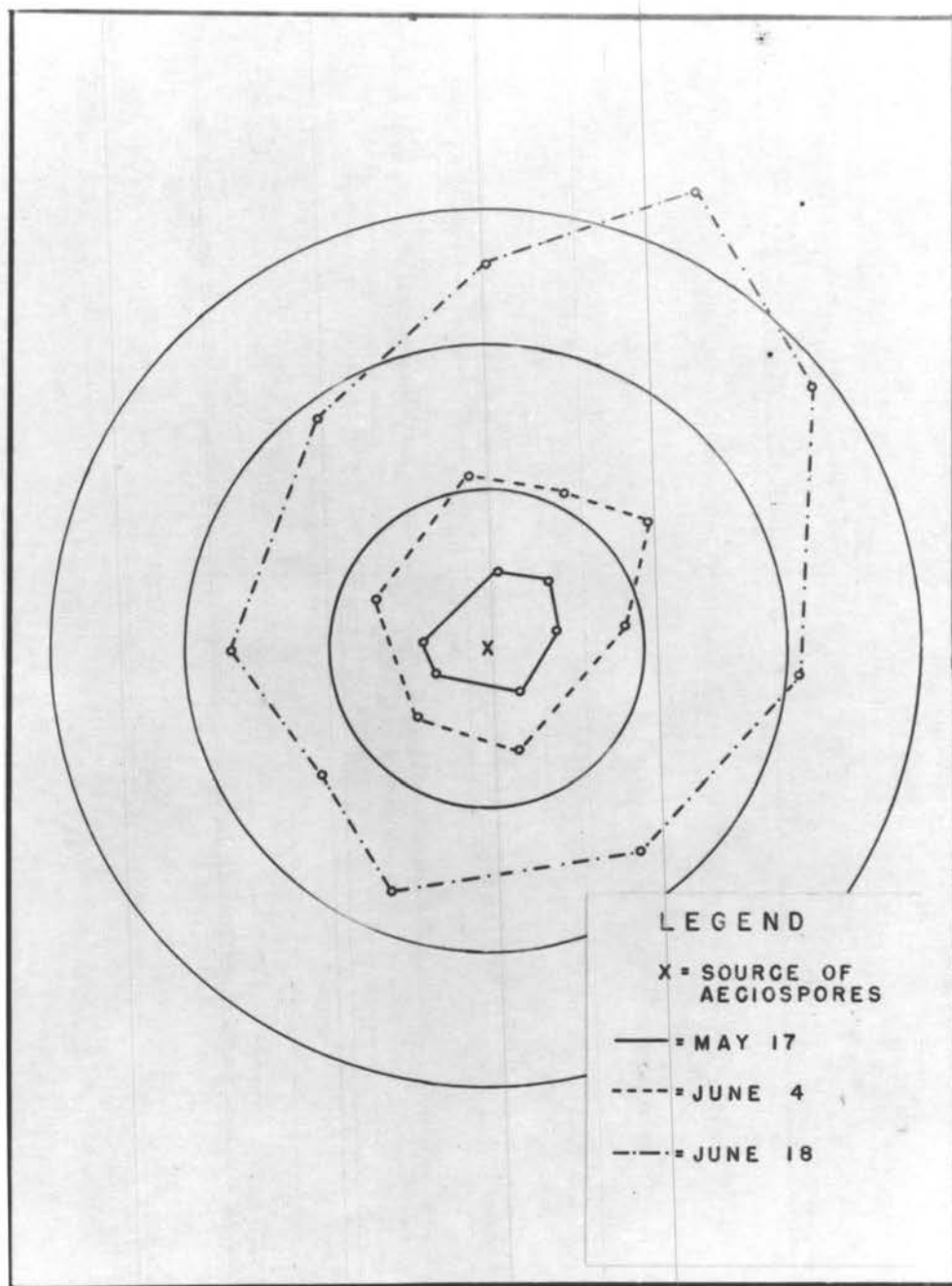
Figure 4. Rate and direction of spread of mint rust from a
single aeciospore source. Each concentric
circle represents 4 feet.

counted spores. Foliage of the heavily infected plants
was placed in $\frac{1}{4}$-inch mesh wire baskets and the baskets
placed in a mint field. Leaves were collected from the
baskets on different dates from October 20, 1951 to
January 24, 1952. The leaf samples were washed in water
which was then strained through cheese cloth to remove the
larger particles of plant debris. The spore suspension
was pipetted onto 1.7 per cent water agar in Petri plates,
the plates held at 20° C. for 24 hours, then spore counts
were made and germination percentage recorded (Table 6).

Table 6. Viability of urediospores taken at
different dates from mint foliage
exposed to field conditions.

Date spores collected	Number of spores counted	Number of spores germinated	Per cent germination
Oct. 20, 1951	400	117	29.5
Nov. 19, 1951	200	34	17.0
Dec. 13, 1951	200	18	9.0
Dec. 23, 1951	200	9	4.5
Jan. 8, 1952	37	4	11.8
Jan. 23, 1952	86	0	0.

The time interval between the last viable urediospores found and their appearance on plants the succeeding season is 105 days. There is no evidence that urediospores over-winter in the field under Oregon conditions.

Increase and dissemination of the urediospore stage of mint rust is dependent on favorable climatic conditions. Vergovsky (27) found intense fructification followed 19 to 20 days after ideal meteorological conditions for infection. Field observations in Oregon have verified Vergovsky's observations. New "crops" of urediospores consistently appeared in large numbers 14 to 20 days after conditions favorable for infection. During July and August mint rust frequently increases so rapidly that an entire field with moderate rust infection may be 50 per cent defoliated 3 weeks after favorable conditions for infection.

Moisture has been observed to be the most important factor contributing to rapid increase of the urediospore stage of mint rust. Vergovsky (27) found that infection by urediospores did not take place in the absence of rain or dew.

It was repeatedly observed in the field that heavy, dense foliage favored infection of the lower leaves. The relative humidity under dense foliage was checked

periodically during July 1953 on a clear day and night. A
hand aspirator psychrometer was used to measure relative
humidity in these tests. Relative humidities were measur-
ed at or near the ground level, and at 6 and 12 inches
above the ground level, both under dense foliage and in
the open. Results are shown graphically in Figure 5.

In conjunction with the experiment on relative humid-
ity in the field another experiment was conducted in the
greenhouse to determine the relative humidity necessary
for infection by urediospores. A humidity chamber was
constructed as described by Hopp (10, pp. 25-44). It con-
sisted of a glass chamber into which air was forced by a
pump designed for aerating aquariums. Before entering the
chamber the air was bubbled through distilled water or
saturated salt solutions to acquire the desired relative
humidity. Peppermint plants growing in 3-inch clay pots
were inoculated by dusting rust urediospores on the
leaves. The plants were placed in the humidity chamber
for 48 hours then removed to the greenhouse bench and
checked after 2 and 3 weeks for the presence of uredial
sori. Since the relative humidity over salt solutions
varies with the temperature (10, pp. 25-44), an attempt to
keep a constant temperature of 20° C. was made by placing
the test apparatus close to the greenhouse thermostat
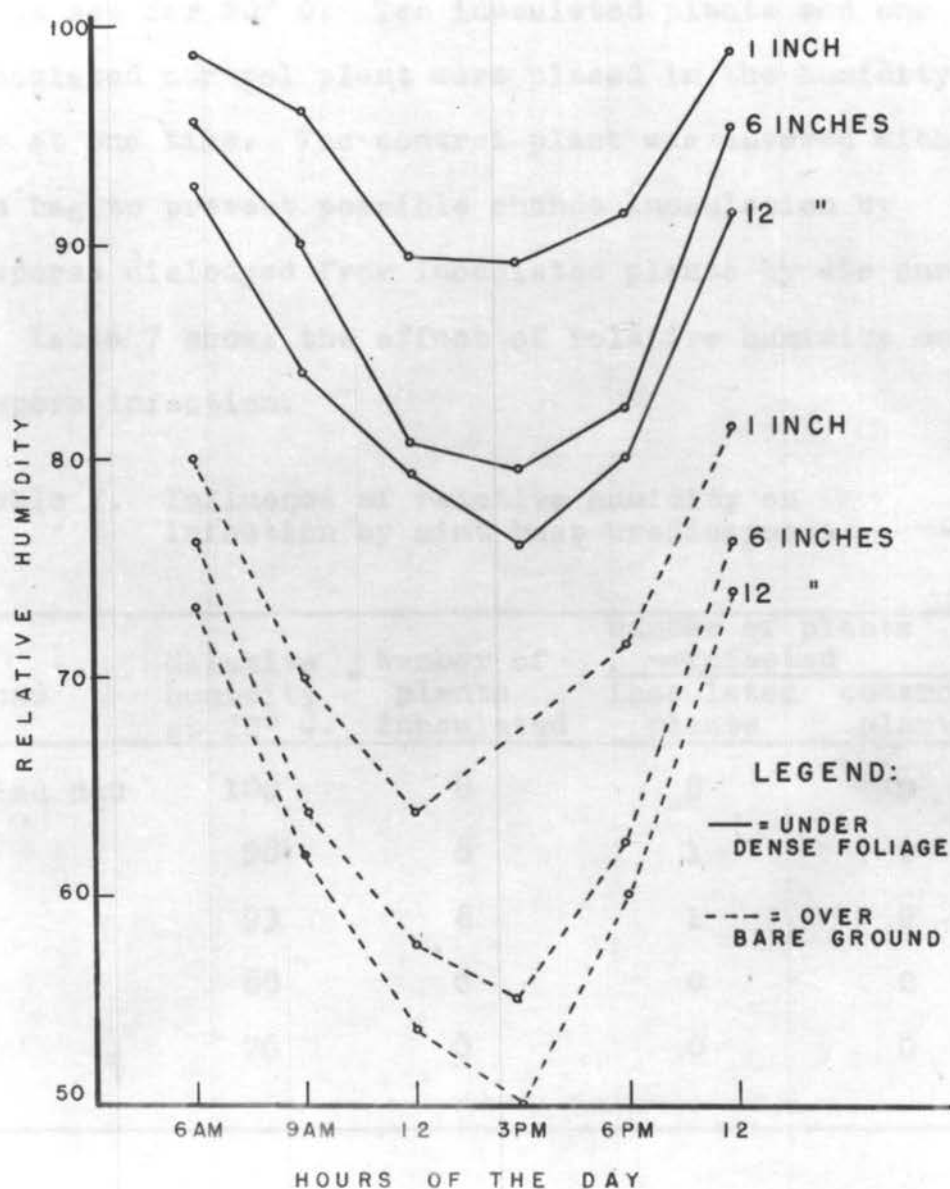
Figure 5. Comparison of relative humidity in the open and under dense mint foliage at different heights above-ground and at different hours of the day.

which was set for 20° C. Two inoculated plants and one non-inoculated control plant were placed in the humidity chamber at one time. The control plant was covered with a plastic bag to prevent possible chance inoculation by urediospores dislodged from inoculated plants by air currents. Table 7 shows the effect of relative humidity on urediospore infection.

Table 7. Influence of relative humidity on infection by mint rust urediospores.

Solutions used	Relative humidity at 20° C.	Number of plants inoculated	Number of plants infected	
			inoculated plants	control plants
Distilled H_2O	100	8	8	0
K_2SO_4	98	8	1	0
KNO_3	93	8	1	0
K_2CrO_4	88	6	0	0
NaCl	76	6	0	0

At 100 per cent relative humidity for 48 hours all inoculated test plants became infected and developed abundant uredial sori. Only 1 of 8 test plants was infected at 98 per cent relative humidity for 48 hours. The one test plant infected at 93 per cent relative humidity developed only 4 uredial sori while the test plant infected

at 98 per cent relative humidity had 12 sori. Because of
the difficulty of maintaining an exact relative humidity
on a transpiring leaf surface, it is probable that the in-
fections at 98 and 93 per cent were the result of relative
humidities higher than 98 per cent due to the proximity of
stomata. Nevertheless, the data show that humidity near
the saturation point is required for a high degree of in-
fection by mint rust urediospores. As shown in Figure 5,
the relative humidity under dense foliage during a clear
day may be 98 per cent or more for as long as 6 hours. The
absence of free air movement under dense mint foliage fa-
vors a high humidity for longer periods of time than in
sparse mint cover. Conditions favorable for rust infec-
tion are thus more favorable in dense stands than in
sparse stands. Field observations have demonstrated that
the urediospore stage of mint rust starts sooner, in-
creases more rapidly and is more severe in dense stands of
mint than in sparse stands.

Radiation by direct sunlight, and associated dessica-
tion and high temperatures affect urediospore viability.
Vergovsky (27) observed that urediospores collected from
sun-dried peppermint leaves were not viable while uredio-
spores collected from leaves dried in the shade remained
viable.

To determine the effect of direct sunlight in the field on urediospore viability, a vigorous plant with heavy infection was selected and two of the lateral branches tied to stakes to expose the undersides of the leaves bearing numerous sporulating sori to direct radiation from the sun. Two other lateral branches were tied to a stake to expose only the upper leaf surfaces to direct sun radiation. The experiment was started on a clear day in July. Spores for germination tests were collected from exposed leaves after 2, 4 and 8 days of continuous clear weather. Spore suspensions were pipetted onto water agar in Petri plates, and after 24 hours incubation at 20° C. the percentage of viable spores was determined by counting 400 spores from each treatment.

The data in Table 8 shows spore germination reduced 42 per cent after 2 days, 65.7 per cent after 4 days, and 79.8 per cent after 8 days exposure to direct solar radiation. The viability of spores protected from direct solar radiation by the leaf was not affected. While solar radiation greatly reduces viability of urediospores from sori directly exposed to the sun, it is not an important factor in reducing urediospore viability in the field because nearly all sori are produced on the undersides of the leaves where they are not exposed to long durations of

direct sunlight.

Table 8. Comparison of the percentage of
viable urediospores collected
from sori exposed to and protected
from direct solar radiation.

Duration of exposure	Per cent germination of 400 urediospores from sori:	
	Directly exposed to solar radiation	Protected from direct solar radiation
2 days	36.5	62.7
4 days	23.5	67.5
8 days	12.7	63.0

During periods of high temperature and light intensity
rust mycelium and associated host cells are often killed
resulting in small necrotic spots being formed on the
leaves. Death of fungus and host tissue may take place
either before or after rust sporulation. Figure 6 (A)
shows 2 mint leaves with numerous necrotic spots collected
in the field several days after the beginning of a hot,
dry period during July. Although death of rust mycelium
and associated host tissue may occur on plants growing
under high soil moisture conditions, it occurs more often
and to a greater degree on plants growing under moderate
or low soil moisture conditions.

Death of rust mycelium and associated host cells has
been experimentally induced by heat resulting in a

A
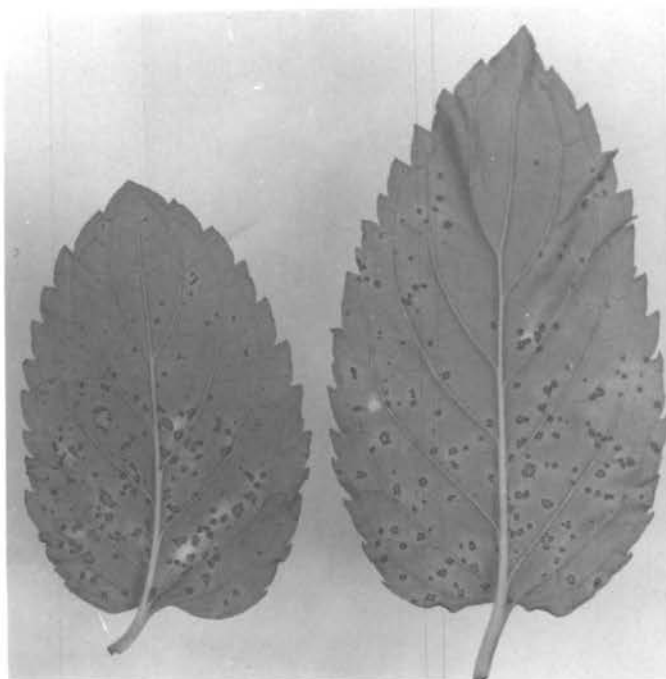
B

Figure 6.   Death of rust infected tissue caused by high
temperature. Leaves collected from the field
(A); and leaves given 100° F. treatment for
4 hours 8 days after inoculation (B).

condition identical to that observed in the field after a period of hot, dry weather. A chamber designed and described by Owen (19, pp. 9-12) to maintain a minimum relative humidity of 40 per cent and a temperature from 80 to 150° F. was used. Test plants were inoculated with urediospores, placed in moist chambers for 48 hours then removed to the greenhouse bench. At periods of 4, 8 and 16 days after inoculation plants were placed in the heat chamber for varying lengths of time. Thermocouples and a Brown portable potentiometer were used to measure temperatures at the lower leaf surface. Thermocouples were made of number 36 copper and constantine wire joined with solder. A temperature variation of plus or minus 2° F. was consistently maintained by adjusting the distance of a Westinghouse infra-red lamp used as a heat source. The criterion used to determine whether rust mycelium and associated host tissue was killed consisted of the production of necrotic spots within 10 days after treatment. Figure 6 (B) shows the effect of 100° F. for 4 hours on leaves from a plant inoculated 8 days prior to heat treatment.

The data in Table 9 show that no death occurred at temperatures below 100° F. except in plants tested 16 days

Table 9. Effect of temperature, length of
exposure and incubation time on
death of rust mycelium and
infected leaf cells.

Time after inoculation in days	Temperature in degrees Farenheit	Production of necrotic lesions indicating death after exposure for:		
		1 hr.	2 hrs.	4 hrs.
	80	-	-	-
	90	-	-	-
4	100	-	-	+
	110	-	-	+
	120	+	+	+
	80	-	-	-
	90	-	-	-
8	100	-	-	+
	110	-	+	+
	120	+	+	+
	80	-	-	-
	90	-	-	+
16	100	+	+	+
	110	+	+	+
	120	+	+	+

after inoculation and heated for 4 hours. Plants tested

16 days after inoculation had numerous sori that had

broken through the leaf epidermis within the last 2 days.

Death occurred at lower temperatures as the time after

inoculation was increased. High temperatures for extended

periods would effectively reduce rust severity in the

field.

CROP LOSS CAUSED BY PEPPERMINT RUST

All spore stages of _Puccinia_ _menthae_ cause some crop loss in peppermint either by direct parasitic action or indirectly by providing suitable infection courts for facultative parasites.

Losses Caused by Basidiospore Infection, Spermogonia and Aecia

Some mint shoots which become infected on the stem by basidiospores do not survive to produce aeciospores. Freezing weather may kill the infected area providing an entrance point for such facultative parasites as the _Rhizoctonia_ stage of _Pellicularia_ _filamentosa_ (Pat.) Rogers, _Fusarium_ spp., _Phoma_ sp. and _Pythium_ spp. The parasitic nature of the above fungi to peppermint has been established by wound inoculation and subsequent reisolation (11).

Mint shoots which become infected after plowing and have large aecial lesions on their stems rarely survive to maturity. Vergovsky (27) reported that young shoots with aecia died from desiccation of the infected area when growing under low soil moisture conditions. Under high soil moisture, hypertrophy was induced thus preventing desiccation.

Under field conditions in Oregon, shoots with aecial infections rarely die from desiccation. More frequently death is the result of invasion of the sporulating aecial pustule by facultative parasites. In addition to the fungi previously mentioned, slugs frequently eat the entire infected area on stems and leaves.

On April 14, 1952 four unplowed mint fields were examined and found to have 72, 84, 91 and 95 per cent respectively of the new shoots infected with the aecial stage of mint rust. Two hundred shoots were examined in each field in determining the above percentages. An analysis of the number of shoots killed by the aeciospore stage in these fields was made by critically examining an area of one square yard in each field and recording the total number of shoots counted and the number killed (Table 10). The test was not continued to determine how many shoots would eventually be killed because the fields were plowed soon after the first counts were made.

Isolations were made from 5 recently killed shoots from each of the four fields and from several live shoots bearing aecial lesions that appeared to be invaded by secondary organisms. Fungi belonging to the genera Fusarium and Phoma were the predominant organisms isolated. Both these genera are known to contain species that are

facultative parasites.

Table 10. The percentage of peppermint shoots
killed in four different fields
from invasion of the aecial lesions
by secondary organisms.

Field number	Number of shoots examined	Number of shoots killed	Per cent killed
1	286	29	10.1
2	344	46	13.4
3	186	22	11.8
4	294	40	13.6

Peppermint in fields with 90 per cent or more of the
shoots bearing aecial lesions showed only a slight reduc-
tion in stand after plowing when compared to peppermint
with 20 per cent of the shoots bearing aecial lesions.
Twenty infected shoots produced a stand of 17 plants,
while 20 healthy shoots produced a stand of 20 plants when
planted four inches deep in field soil in flats in the
greenhouse. The infected shoots readily rooted above the
point of infection and produced healthy plants except in 3
cases in which the infected shoots failed to survive.

Losses Caused by the Urediospore Stage

The most apparent loss caused by urediospores is leaf drop. Actual reduction in yield from other, less apparent causes may equal or exceed losses from leaf drop. In 1951 field tests were conducted that demonstrated yield could be reduced nearly 30 per cent by the urediospore stage without leaf drop.

During the summer of 1951 rust increase was cyclic according to periods of weather conditions favorable for infection. Heavily infested areas appeared in fields near the points of initial infection by aeciospores. It was thus possible to take yield data from severely and adjacent lightly or non-infested areas in the same field.

In a preliminary experiment comparative leaf drop was determined on heavily and lightly infected mint. Two areas 20 feet square with uniformly heavy and light rust infestation, respectively, were staked. Each area was further subdivided into 25 plots 4 feet square. One plant from each small plot was selected by entering the plot and cutting a plant at the soil level. The number of pairs of leaves that had dropped from the main stem was recorded for each plant. A comparison of the number of pairs of leaves lost on heavily and lightly infected plants is given in Table 11.

Table 11. Comparison of leaf drop from
heavily and lightly rust
infected peppermint plants.

Plant number	Number of pairs of leaves dropped from the main stem of plants with:	
	Heavy rust infection	Light rust infection
1	8.5	6.0
2	7.0	4.0
3	8.5	5.5
4	5.0	6.5
5	6.0	3.0
6	5.5	5.0
7	7.5	4.5
8	7.5	4.0
9	8.0	3.5
10	6.5	5.5
11	9.0	4.0
12	6.0	3.5
13	6.5	7.0
14	8.5	3.5
15	7.5	4.5
16	7.0	5.0
17	5.5	4.0
18	8.0	4.5
19	8.5	6.5
20	7.0	3.0
21	9.0	4.5
22	6.5	4.0
23	6.0	5.0
24	8.0	3.5
25	6.0	4.0
total	179.0	total 114.0
mean	7.2	mean 4.6

The same plots used for leaf drop comparisons were
cut, the green hay weighed, a sample removed for dry
weight determination and the remaining hay distilled to
determine yield of oil. After determining the dry weight
of the hay the percentage of oil of the dry weight was

calculated. These data are presented in Table 12.

Table 12. Comparison of oil yield from
heavily and lightly rust
infected peppermint.

Rust rating	Green wt. of hay in pounds	Dry wt. of hay in pounds	Oil yield in grams	Per cent oil of the dry wt.
Heavy	116	24.8	106	0.94
Light	110	23.5	136	1.27

The oil yield from heavily rust infected plants was
26 per cent less than from lightly infected plants when
calculated on the basis of percentage of oil of the dry
hay. It is hardly possible that the small difference in
leaf drop shown in Table 11 could account for 26 per cent
reduction in oil yield.

In another test an attempt was made to determine how
much reduction in yield might be attributed to rust on the
leaves exclusive of leaf drop. Peppermint from adjacent
heavily and lightly rusted plots in three different fields
was cut 8 inches above the soil level to eliminate the
leaf drop zone. Green weight, dry weight, oil yield and
percentage of oil of the dry weight were determined as
previously described, and are given in Table 13.

Table 13. Comparison of oil yield from
heavily and lightly rust
infected peppermint from
3 different fields.

Rust infection and field no.	Green wt. of hay in pounds	Dry wt. of hay in pounds	Oil yield in grams	Per cent oil of the dry wt.
1	75	16.05	64	0.88
Heavy 2	85	18.19	68	0.82
3	70	14.98	64	0.94
1	79	16.90	96	1.25
Light 2	65	13.91	73	1.15
3	83	17.76	94	1.17

The per cent reduction in yield of heavily rust infected compared with lightly rust infected mint was 29.6, 28.7 and 19.7 for the three fields respectively, when calculated on a basis of percentage of oil of the dry weight.

Heavy urediospore infection inhibits lateral stem development, especially when heavy infection occurs early in plant development. Figure 7 shows a comparison of lateral stem development on rust free (left) and heavily infected (right) plants grown under similar stand density and environmental conditions.
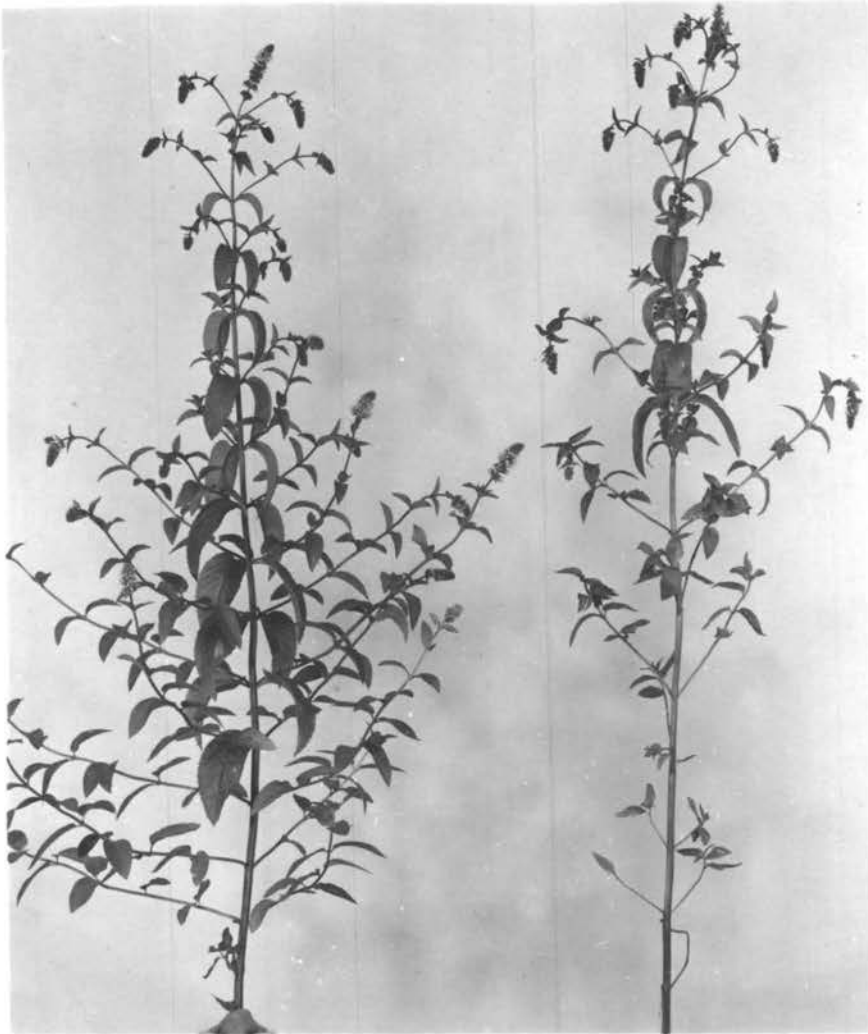
Figure 7.   Comparison of leaf drop and lateral stem
            development on healthy (left) and severely
            rust infected (right) peppermint plants.

Heavy urediospore infection reduces the production of
rhizomes and those produced are weaker and more suscepti-
ble to root and rhizome rots (11). To ascertain how much
rhizome production might be reduced, two greenhouse beds
were filled with similar soil and planted with 10 plants
each. The plants used in this test were rooted cuttings
of uniform size and vigor from the same clone and were
grown under similar environmental conditions. Plants in
one bed were inoculated with rust on June 1 and thereafter
at 2 week intervals. Plants in the other bed were main-
tained rust free. The mint in both beds was cut when the
first bloom appeared. The regrowth from the rust infected
plants was again heavily inoculated with rust. Plants
from both beds were dug in September and the rhizomes com-
pared by number, size, and weight per plant. These data
are given in Table 14.

A statistical analysis was made to determine if the
difference between the observed means was significant at
the 5 per cent level. The hypothesis that the population
mean of the differences is equal to zero was tested by the
t-test for each quantitative character measured. There
was no significant difference in the number of rhizomes
produced by rust infected and rust free plants. The mean
values of diameter, length and weight of rhizomes produced

by rust free plants were significantly greater than the
mean values from rhizomes produced by rust infected plants.

Table 14. Comparison of number, size and
weight of rhizomes produced by
heavily rust infected and rust
free peppermint plants.

Rust class and plant number	Number of rhizomes produced	Average diameter of rhizomes in millimeters	Average length of rhizomes in inches	Dry weight of rhizomes in grams
1	6	3.5	21	7.2
2	4	4.0	23	6.4
3	4	4.5	17	6.1
Rust 4	6	4.0	26	8.2
infected 5	6	3.5	23	7.1
plants 6	5	3.5	18	4.9
7	4	5.0	20	6.5
8	7	3.0	23	8.3
9	5	3.5	21	6.3
10	5	3.5	20	6.0
Sum 52	Sum 38.0	Sum 212	Sum 67
Mean 5.2	Mean 3.8	Mean 21.2	Mean 6.7
1	5	5.5	30	11.2
2	4	5.0	27	9.2
3	5	5.0	24	9.0
Rust 4	6	6.0	26	10.3
free 5	6	5.0	29	9.2
plants 6	6	6.0	30	12.4
7	5	6.5	32	12.6
8	6	5.5	29	11.8
9	8	4.5	24	10.0
10	6	5.5	28	11.0
Sum 57	Sum 54.5	Sum 279	Sum 106.7
Mean 5.7	Mean 5.5	Mean 27.9	Mean 10.7

Losses Caused by the Teliospore Cycle

Telial sori on rhizomes function as points of entry for facultative parasites that cause root and rhizome rots. Rhizome rots caused by Rhizoctonia solani, Fusarium spp. Pythium sp. and Phoma sp. (11) have repeatedly been observed to start from rust pustules on the rhizomes. Serious reductions in stand have been observed in fields where rhizome rots were severe.

METHODS OF EVALUATING RUST SEVERITY AND CONTROL DATA

Evaluation of Rust Severity

Taking accurate yield data from large numbers of
plots is difficult and time consuming. For example, an
experiment testing the relative rust control of 10 fungi-
cides at 3 different times of application with 4 replica-
tions would involve the separate cutting, weighing and
distillation of more than 100 plots. The average distill-
ation time for each plot is 45 minutes to 1 hour. During
the interval of 10 or more days required to complete dis-
tillation such factors as rust increase and maturity could
greatly influence yield thus making comparisons of yield
from plots harvested at the beginning and end unreliable.
In order to circumvent this situation a criterion was
needed that would be both rapid and directly correlated
with yield.

Leaf drop and recording the amount of rust on the
plants were both considered. Since leaf drop had previous-
ly been shown to account for a lesser amount of the reduc-
tion in yield than had rust on the leaves, the latter was
chosen for further evaluation.

Bullis et al (5, p. 10) state that approximately 99
per cent of the oil bearing glands of Mentha piperita are

on the leaves. More than 95 per cent of uredial sori are
also on the leaf surfaces. When uredial sori erupt they
break the host epidermis and destroy the oil glands
situated on that part of the epidermis (Figure 8). Later,
desiccation of the infected area around the sori results
in further reduction of oil gland numbers.

It was conceivable that disease classes based on the
percentage of oil glands destroyed on the leaves would be
a reliable criterion of yield losses. The reliability of
using disease classes to compute an "infection" or "dis-
ease index" has been well established by McKinney (15) and
applied with good results to other leaf diseases (12).

Horsfall and Heuberger (12) further extended the
application of the McKinney infection-index formula.
Marsh et al (13) found that the method was open to statis-
tical analysis.

The method as applied by Horsfall and Heuberger (12)
consists of having classes of disease representative of
different percentages of infection. The mean disease in-
dex for a plot can be computed by the following formula:

$$\text{Disease index} = \frac{\text{sum of class numbers}}{NT}$$

The value T is the total number of plants or leaves
rated and N is the number of the highest disease class.
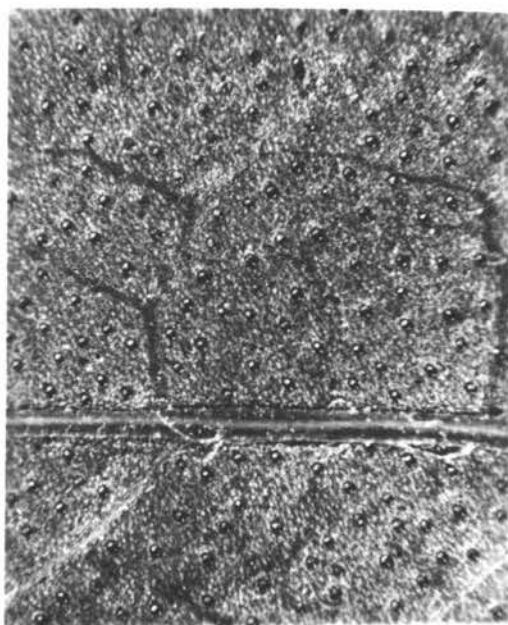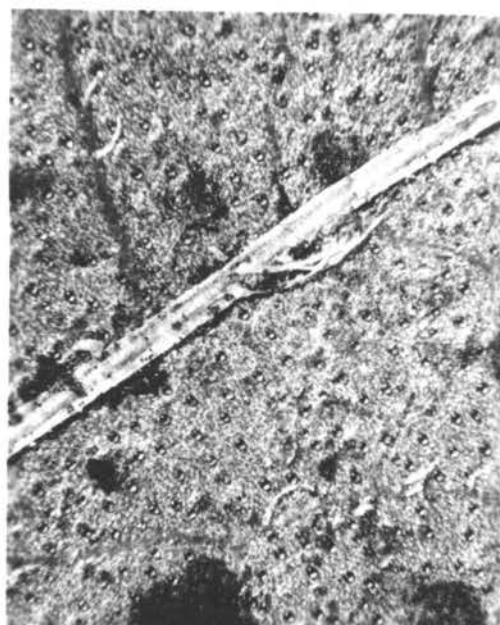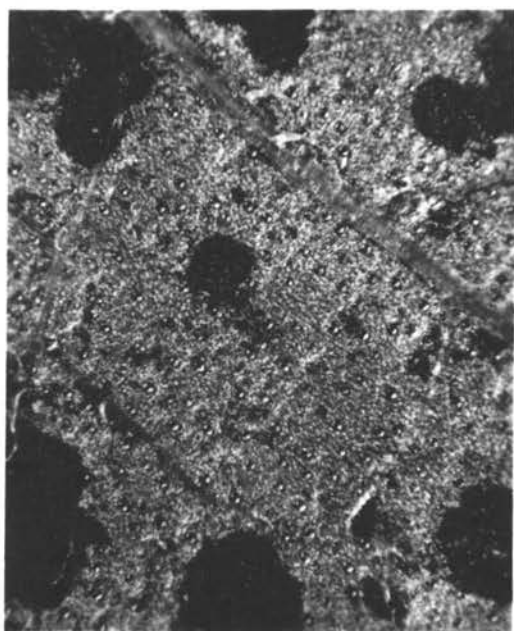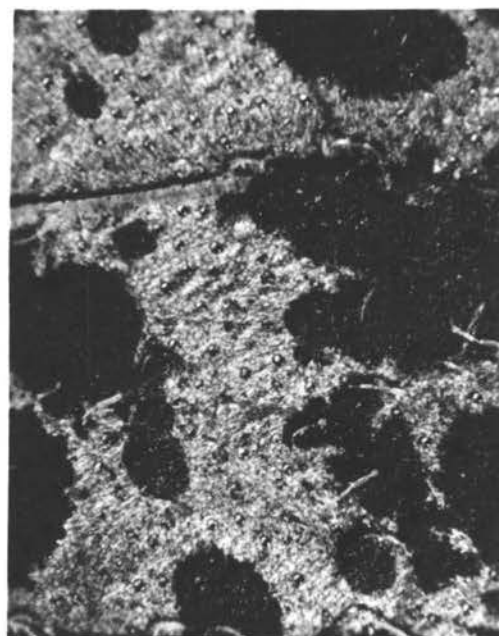
Figure 8.   Destruction of oil glands on leaf surfaces by
            different degrees of rust. A, none; B, light;
            C, moderate; D, severe rust infection.

The disease index is the mean infection index for plants
or leaves. In peppermint, a disease index based on per-
centage of oil glands destroyed should be a reliable
criterion of yield.

To determine the percentage of oil glands destroyed by
erupting rust sori fifteen peppermint plants were grown
from uniform rooted cutting in 6 inch clay pots. When the
plants were 16 to 18 inches high one leaf of each pair on
the main stem was covered with folded paper squares held
in place with paper clips. The 15 plants were then divided
into 3 lots of 5 plants each. The uncovered leaves of each
plant were sprayed with urediospore suspensions of differ-
ent concentrations of spores. Plants in the 3 lots received
an inoculum of 50,000, 10,000 and 1,000 urediospores per
ml. of suspension respectively. After the plants were dry
the paper squares were removed and the plants were placed
in a moist chamber for 72 hours, then returned to the green-
house bench. Three weeks after inoculation, paired leaves
from the base, middle and upper parts of the stem were
separately collected, pressed and dried. Forty-five pairs
of leaves were thus available for analyses. However, con-
siderable variation in the amount of infection on leaves
sprayed with the same spore suspension occurred. Because
of this variation, leaves representing light, moderate and

heavy rust infection with their rust free counterparts
were arbitrarily chosen for analysis of leaf gland numbers.

Oil glands were counted with a compound microscope
fitted with a 5 x objective and a 10 x ocular containing a
counting grid. Five counts were made at random on the
underside of the leaf blade and the number of oil glands
in each microscopic field was recorded (Table 15).

The percentage reduction in oil gland numbers for
the different disease classes was computed and is given
in Table 15. Rust infection classes 1, 2 and 3 reduced
oil gland numbers from 2.46 to 4.66, 16.74 to 22.13, and
39.91 to 48.14 per cent respectively.

Disease classes of 0, 1, 2 and 3 could be representa-
tive of 0, 0-5, 6-25 and 26-50 per cent reduction in oil
gland number respectively. Then by application of the
formula:

Per cent reduction in oil glands =

$$\frac{(X\,0) + (X\,1) + (X\,2) + (X\,3)}{3\,T} \times 50 = \text{disease index}$$

where X 0 = the number of leaves in rust class 0
X 1 =   "   "   "   "   "   "   "   1
X 2 =   "   "   "   "   "   "   "   2
X 3 =   "   "   "   "   "   "   "   3

3 = numerical value of the highest rust class.

T = total number of leaves counted.

The value 50 rather than 100 is used to transform the

Table 15. Number of oil glands per unit area on peppermint
leaves with four classes of rust infection and
from three positions on the plant.

| Position on plant | Rust classes | Number of oil glands per microscope field | | | | | Totals of fields by disease classes | Means of fields by disease classes* | Per cent reduction in glands by disease classes |
		1	2	3	4	5			
Base	0	63	66	71	58	64	322	64.4	0.0
	1	58	61	66	57	65	307	61.4	4.66
	2	53	51	49	47	52	252	50.4	21.74
	3	33	35	38	32	29	167	33.4	48.14
Middle	0	73	74	68	77	74	366	73.2	0.0
	1	66	71	70	73	77	357	71.4	2.46
	2	55	59	57	54	60	285	57.0	22.13
	3	48	42	44	39	40	213	42.6	41.80
Top	0	99	92	89	92	94	466	93.2	0.0
	1	88	82	91	90	96	447	89.4	4.08
	2	76	80	82	73	77	388	77.6	16.74
	3	58	63	52	51	56	280	56.0	39.91

*L.S.D. at .05 for means of disease classes 1, 2 and 3 = 5.20, 6.51 and 8.13
for base, middle and top respectively. L.S.D. for position means of rust
class 0 = 8.17.

data to a percentage basis because in no case have leaves
been observed with more than 50 per cent of the oil glands
destroyed by rust.

If a disease rating method were a reliable criterion
of yield much of the labor and experimental error of taking
yield data could be circumvented. An experiment was de-
signed to test the reliability of using the disease rating
described above rather taking yield data. Leaves with
rust ratings 0, 1, 2 and 3 from each of 3 positions on the
main stem of mint plants were mounted under a transparent
plastic cover to use as a standard for comparison in se-
lecting leaves in the field. Figure 9 shows the standard
used. A large sample of leaves was collected for each
rust rating from the lowest pair of leaves on the main stem,
the fifth pair above the lowest, and the tenth pair above
the lowest pair. The samples were air dried for two
weeks then 100 gram samples were distilled in the labora-
tory using standard taper flasks and condensers. The dis-
tillate was collected in a titration burrette and oil
yield read directly from the burrette to the nearest .1
and estimated to the nearest .05 milliliters. The oil
yield from each sample is given in Table 16.

Although the data in Table 16 are not subject to sta-
tistical analysis because of the absence of replications
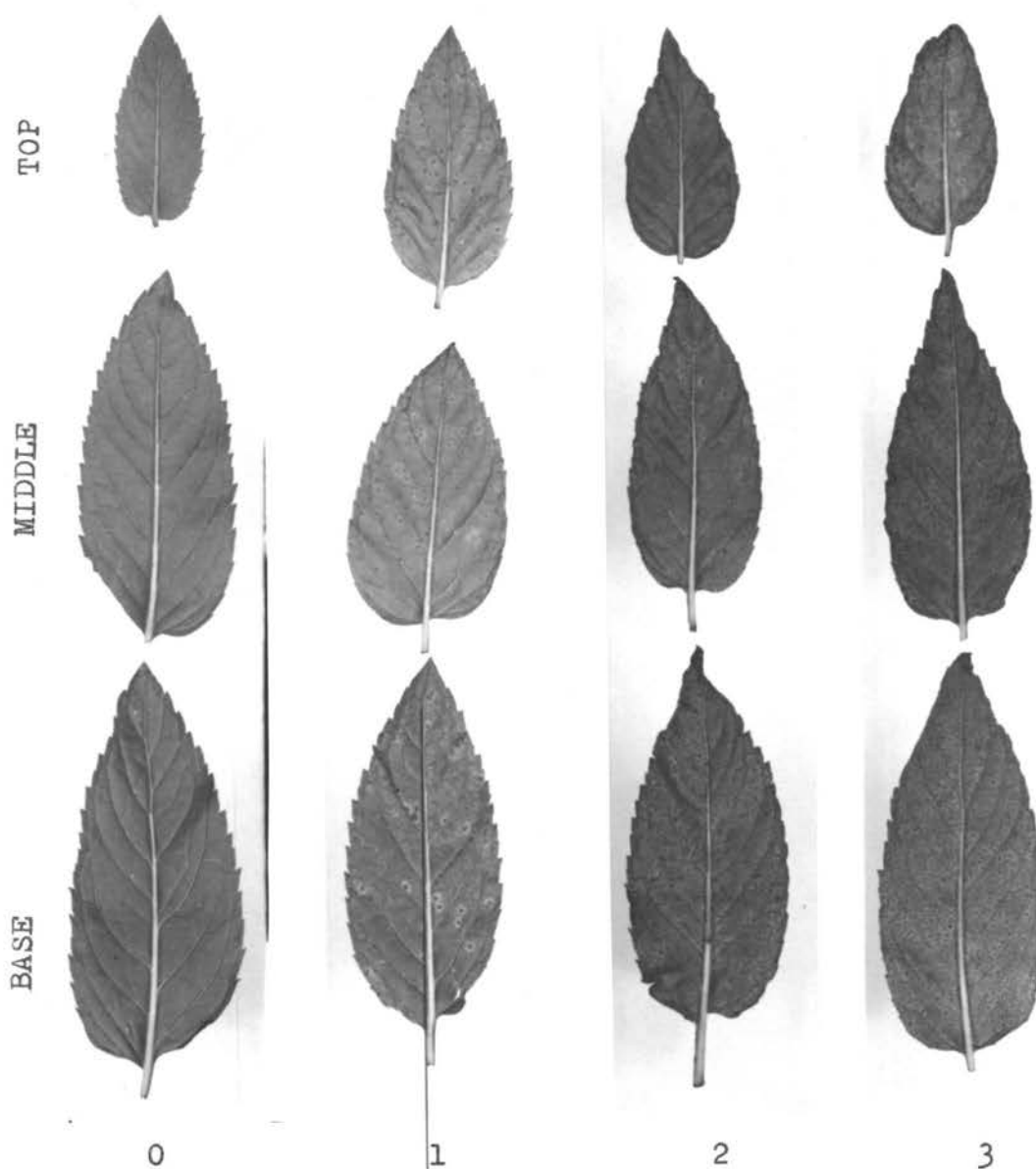
Figure 9. Rust rating standard used to evaluate rust severity and control data. Rust classes 0, 1, 2 and 3 represent 0, 0-5, 6-25 and 26-50 per cent reduction in oil gland numbers respectively.

certain trends are apparent. The oil yield consistently
decreased as rust severity increased. The percentage re-
duction in yield for the rust severity classes in each
case is within the arbitrary values of 0, 0-5, 6-25 and
26-50 per cent for classes 0, 1, 2 and 3 respectively.
The oil yield consistently increased in leaves taken from
base to top (Table 16) as did oil gland numbers (Table
15).

Table 16. Yield of oil from peppermint leaves
with four degrees of rust infection
collected from 3 positions on the
plants.

Position on plant	Rust classes	Oil yield in mls. from 100 grams of leaves	Per cent reduction in yield
Base	0	2.25	0.0
	1	2.15	4.4
	2	2.00	11.1
	3	1.55	31.1
Middle	0	3.05	0.0
	1	*	---
	2	2.50	18.0
	3	1.85	39.3
Top	0	3.35	0.0
	1	3.30	1.5
	2	3.00	10.4
	3	2.15	35.8

*Yield was lost by an accident.

Evaluation of Control

The reliability of using a disease index as a crite-
rion of rust severity and yield in evaluating the relative
effectiveness of different fungicides was tested in the
field. The details of this experiment are given in the
section on control pp. 77 to 82. Table 27, p. 82 shows a
comparison of disease index and yield from plots treated
with 10 different fungicides. The correlation coefficient
(r) of disease index x yield data from 10 fungicide treat-
ments was calculated and is shown in Table 17. It can be
seen from the data in Table 27 that as disease index in-
creases, yield decreases which is to be expected since
disease index measures the amount of oil glands destroyed
by erupting rust sori.

Table 17. Statistical analysis of the correla-
tion of disease index and yield from
10 fungicide treatments.

Source of variation	SS SS x y	$\sqrt{\text{SS SS} \atop x\ y}$	r	De-grees free-dom of r	r at t .05
Replication	75,458.2105	274.6966	.6031	3	.8783
Treatment	2,884,474.0359	1,698.3739	-.9417	9	.6021
Error	1,286,602.3598	1,134.2850	-.2776	39	.3044
Total	9,995,259.3018	3,161.5280	-.5531	53	-----

CONTROL OF PEPPERMINT RUST

The control of rust diseases of field crops has been best achieved by breeding and selection of resistant varieties, and, in the case of heteroecious rusts, by eradication of alternate hosts. _Puccinia menthae_ is an autoecious rust, and the development of resistant varieties by breeding or selection usually takes several years. Because of the immediate need other methods of control were investigated.

Cultural Practices

Vergovsky (27) established that _Puccinia menthae_ was not systemic in peppermint. He found that infected shoots and rhizomes would produce healthy plants if covered with 5 cm. or more of soil. Infected shoots covered with less than 4 cm. of soil produced infected plants because the sporulating infected area was carried above the soil surface by shoot elongation. Vergovsky's results have been verified for Oregon conditions by repeated field observations. Vergovsky suggested deep fall plowing as a means of control.

In 1951 Steenland (26) and Dietz et al. (7) reported

that the incidence of the aecial stage of mint rust was
much higher on back-furrows, dead-furrows and head-lands
where old stubble carrying teliospore inoculum was not
covered by plowing. Clean fall plowing was suggested for
control (26), (7). In 1953 Baxter and Cummins (4) re-
iterated the value of deep fall plowing and elimination
of plant debris along back-furrows and dead-furrows al-
though no experimental data were given.

A comparison was made of the incidence of the aecial
stage on unplowed, poorly-plowed and thoroughly plowed
portions of the same mint field. The experiment was con-
ducted as part of a demonstration for growers. Table 18
shows a comparison of the incidence of the aecial stage
from 3 plowing practices.

The data show that thorough coverage of plant debris
during plowing greatly reduces the incidence of the aecial
stage, but may not completely eliminate it. The data bear
out field observations that most rust starting in the
field originates on poorly-plowed areas such as dead-
furrows, back-furrows and head-lands.

After plowing the incidence of functional aecia can
be reduced still more by cultivation. Mint shoots with
aecia are very brittle at the point of infection and are
readily broken. Cultivation with a finger or rotary hoe

Table 18. Effect of different plowing
practices on the incidence of
the aecial stage of mint rust.

Plot number	Per cent of 500 shoots bearing aecial pustules on mint that was:		
	Not plowed	Poorly-plowed*	Thoroughly plowed**
1	91.0	6.0	0.8
2	72.0	3.4	0.0
3	84.0	4.4	0.0

* Poorly-plowed indicates that considerable plant debris
from the previous seasons growth remained uncovered af-
ter plowing.

**Thoroughly plowed indicates that most all plant debris
was covered by plowing.

type weeders breaks off many of the infected shoots. When

the infected shoots are broken before the aecial pustules

have released spores, the broken shoots normally die back

to the first node below the break and the aecial pustule

may not become functional.

A comparison was made of the effect of cultivation in

reducing the number of infected shoots bearing aecia.

Twenty mint shoots with aecia which had not yet released

spores were marked in each of three plots. A finger type

weeder was drawn over the plots and the number of infected

shoots that were broken off was recorded. Ten days later

the plots were checked again and the number of shoots that
had survived to produce aeciospores was recorded. These
data are given in Table 19.

Table 19. Effect of cultivation on the
survival of aecial infected
peppermint shoots.

| | Number of aecial infected shoots: | | |
Plot number	Present before cultivation	Broken off by cultivation	Functional 10 days after cultivation
1	20	11	13
2	20	9	12
3	20	8	9

The data in Table 19 show that approximately half the
infected shoots were broken off by cultivation, of which
only 6 out of 28 survived to produce aeciospores. The
data show that cultivation reduces the number of aecial in-
fections that could become functional in rust spread.

Since most of the mint grown in Oregon is irrigated
by overhead sprinkler systems frequent irrigation might
provide moisture conditions favorable for rust infection
and result in rapid increase of the disease to destructive
proportions. However, observations made in the field in
1951 indicated that although rust might be more abundant

on irrigated mint, losses from rust were greater on non-irrigated mint. In 1952 a field experiment was conducted to test the effect of irrigation on rust severity and leaf drop.

A series of paired plots were established by removing every other pair of sprinklers on an irrigation line. The plots were 10 feet square and located in the central part of either the irrigated or non-irrigated sections. The amount of leaf drop on the main stem and a computed disease index were used as criteria of rust severity. Plots were sampled by cutting 10 plants at random in each plot. The leaf drop and disease rating of each plant was recorded. Leaf drop and disease index values in replication are recorded in Table 20.

A statistical analysis of the data was made by the method of paired observations. The computed t-value for leaf drop was 12.86 with 4 degrees of freedom. The critical t-value at the 1 per cent level of significance is 4.60, therefore one may conclude that irrigation reduces leaf drop significantly. The computed t-value for disease index was 0.35187 with 4 degrees freedom and the critical t-value is 4.60 at the 1 per cent level. Therefore, irrigation did not significantly increase disease severity.

Table 20. Effect of irrigation on rust
severity and leaf drop.

Replication number	Irrigated		Not irrigated	
	Leaf drop*	Disease index*	Leaf drop*	Disease index*
1	6.4	1.50	9.9	1.37
2	6.0	1.53	10.3	1.27
3	6.1	1.57	10.1	1.40
4	5.8	1.37	10.0	1.43
5	6.0	1.73	9.0	1.67

*Each value is the mean of 10 observations.

Dimock and Baker (8) have demonstrated that rust on
snapdragons resulted in more host damage under semiarid
conditions than under humid conditions because of excessive
desiccation of host tissue brought about by low humidity.
A similar situation exists on irrigated and non-irrigated
mint in Oregon, where low soil moisture appears to be one
of the most significant factor associated with desiccation
of rust infected mint leaves.

Eradication of Wild and Escaped Mint

Several species of the family Labiatae that are hosts
for Puccinia menthae grow wild in Oregon. Wild species of
the Labiatae that have been demonstrated to be hosts for

the race of rust attacking commercial peppermint in Oregon are *Mentha* *canadensis* L., *M*. *piperita* L. var. American and *Satureja* *douglasii* (Benth) Brig. Two of the above species, *M*. *piperita* var. American and *M*. *canadensis*, have been observed to act as sources of rust inoculum for adjacent peppermint fields. It is not likely that *S*. *douglasii* is an important source of rust inoculum since it has rarely been found near peppermint fields and most specimens collected were not infected with rust.

Peppermint which has escaped from cultivation has been observed to be an important source of rust inoculum for adjacent commercial plantings. Escaped mint is common along field edges, creeks, sloughs and ditchbanks in the mint growing areas. Such escaped mint is nearly 100 per cent infected with the aecial stage of mint rust in the spring and functions as an important source of inoculum for commercial plantings.

Trials were undertaken to determine the most feasible and economical methods of preventing spread of rust from wild and escaped mints to commercial plantings. Eradication of rust infected wild and escaped mints, to be effective in preventing rust spread, must be accomplished before or during aeciospore discharge in the spring. Attempts by growers to kill rust infected, escaped mint

with 2,4-D (2,4-Dimethylamine) indicated that the infected
plants were killed too slowly to prevent rust spread. It
seemed desirable to test chemicals that would cause an
initial quick kill of the infected plant parts to prevent
initial rust spread followed by systemic herbicides such
as 2,4-D for complete eradication.

In 1951 8 materials and combinations were used in a
replicated field test to determine their effectiveness for
killing the above-ground parts of rust infected plants be-
fore aeciospore discharge. Table 21 gives the materials,
rates and relative effectiveness in killing plant parts
before spore discharge. The materials were rated as ex-
cellent, good, fair and poor. All materials were applied
as a spray and the test plots received the equivalent of
100 gallons per acre.

The most consistent results were obtained with the
dinitro weed-killers in diesel oil or in diesel oil and
water. Later tests and widespread usage by growers have
further substantiated the effectiveness of dinitro weed-
killers in diesel oil. 2,4-D alone and 2,4-D plus 2,4,5-T
were not effective in killing the mint plants before in-
fected plants had discharged viable spores. However the
contact weed-killers, such as dinitro, are not effective
in eradicating the wild and escaped mint. Good regrowth

Table 21. Relative effectiveness of different
herbicides for killing rust infected
mint plants before aeciospore dis-
charge.

Materials	Rates per acre	Effectiveness rating
Sodium cyanate 80%	20 lbs. in 100 gal. water	Good
Potassium cyanate 91%	20 lbs. in 100 gal. water	Good
Dinitro ortho secondary butyl Phenol 55%	1½ quarts in 100 gal. water	Fair
Dinitro-o-sec. butyl phenol Plus diesel oil	1½ quarts and 30 gal. in 70 gal. water	Good
Dinitro-o-sec. butyl phenol Plus diesel oil	1½ quarts in 100 gal. diesel oil	Excellent
Diesel oil	100 gal.	Good
2,4-Dimethylamine	1 lb. parent acid in 100 gal. water	Poor
2,4-Dimethylamine plus 2,4,5-Triethylamine	1 lb. parent acid each in 100 gal. water	Fair

nearly always appears after infected plants have been
burned back by dinitro and diesel oil, but this regrowth
is not infected with rust. A spray mixture of equal parts
of 2,4-D and 2,4,5-T usually results in complete eradica-
tion of the regrowth when applied during warm days in July.

In some cases 2 sprays of the mixture have been necessary
for a complete kill.

Eradication of the Aecial Stage by Chemicals

The aecial stage of mint rust is present in Oregon
mint fields from March to May wherever plowing did not
completely cover the previous season's stubble and
rhizomes. If the aecial stage could be eradicated from
infected shoots in the field and from adjacent wild and
escaped mint, the field should remain rust free until
infected by wind-borne inoculum from adjacent infected
areas. Heavy infection from wind-borne urediospores takes
place late in the growing season and usually does not re-
sult in severe losses. Several trials were conducted in
1951 to determine if eradication of the aecial stage could
be accomplished before spore dissemination.

The trials consisted of applying contact plant-killer
chemicals to the mint when the new shoots were 3 to 5
inches high thus killing back all above ground growth. In
a preliminary trial to determine the most effective of
several materials 8 different materials or mixtures were
applied as sprays or dusts to unreplicated field plots 30
feet wide and 340 feet long. As many aecial infected
shoots as could be found were marked in each plot before

treatment. Ten days after treatment the marked shoots
were examined and the number still having functional aecia
recorded. About 10 days before harvest plants in the
plots were rated as lightly, moderately or severely rust
infected. The data from this preliminary trial are re-
corded in Table 22.

On the basis of effective eradication of the aecial
stage and minimum permanent damage to the stand, the mix-
ture of dinitro plus cyanate in water and the mixture of
dinitro and diesel oil in water were chosen for further
trials. Although dinitro in diesel oil alone resulted in
complete eradication of infected shoots, it also resulted
in a severe reduction in stand. All other treated plots
had stands judged equal to the check plot at harvest-time.

The two materials selected as the best in the 1951
trial were further tested in 1952. A randomized block de-
sign consisting of 3 replications was employed. Criteria
were: (1) eradication within 10 days after treatment,
(2) leaf drop from the main stem at harvest time, (3) a
computed disease index at harvest time, and (4) stand
density 6 weeks after treatment. Leaf drop, disease index
and stand density are subject to statistical analysis.
Table 23 gives the data on eradication, leaf drop and dis-
ease index. Table 24 shows a comparison of stand counts
on treated and untreated plots 6 weeks after treatment.

Table 22. Effectiveness of 8 treatments for
the eradication of the aecial
stage of mint rust.

| Treatment | Rate per acre | Number of infected shoots: | | Rust rating 10 days before harvest |
		Before treatment	After treatment	
Potassium cyanate (91%) spray	15 lbs. in 100 gal. water	11	4	Moderate
Sodium cyanate (40%) spray	40 lbs. in 100 gal. water	15	2	Moderate
Potassium cyanate (91%) plus dinitro spray	15 lbs. and 1½ qts. in 100 gal. water	16	0	Light
Dinitro plus diesel oil spray	1½ qts. in 50 gal. diesel	11	0	Light
Dinitro plus diesel oil spray	1½ qts. and 20 gal. in 100 gal. water	19	0	Light
Sodium cyanamid dust	100 lbs.	42	29	Severe
Calcium cyanamid dust	200 lbs.	15	13	Severe
Sodium-calcium cyanamid dust	100 lbs. each	6	6	Severe
Check		14	14	Severe

Table 23. Comparison of the effectiveness
of two chemical treatments for
eradication of the aecial stage
of mint rust and their effect on
subsequent rust control.

Treatment	Rate per acre	Repli- cation	Number shoots infected:		Pairs of leaves dropped* and means ($\bar{x}$)	Disease index* and means ($\bar{x}$)
			Before treat- ment	10 days after treat- ment		
Potassium cyanate plus dinitro	10 lbs. plus 1½ qts. in 100 gal. water	1	8	0	5.50	16.67
		2	5	0	5.00	16.67
		3	13	1	5.30	20.00
					$\bar{x} = 5.27$	$\bar{x} = 17.85$
Dinitro plus diesel oil	1½ qts. plus 20 gal. in 100 gal. water	1	13	3	4.35	18.33
		2	11	0	5.15	21.67
		3	7	0	4.85	17.78
					$\bar{x} = 4.78$	$\bar{x} = 19.26$
Untreated control		1	12	12	8.10	23.89
		2	5	5	9.15	28.33
		3	14	13	9.05	25.00
					$\bar{x} = 8.77$	$\bar{x} = 25.74$

*Least significant difference at .05 for leaf drop
means = 1.39; for disease index means = 4.66.

Table 24. Effect of chemical burn back on
the number of mint shoots per
square yard six weeks after
treatment.

Treatment	Number of shoots per square yard in replication:			Mean no. shoots per sq. yard
	1	2	3	
Potassium cyanate plus dinitro in water	186	114	134	145
Dinitro plus diesel oil in water	158	131	161	150
Untreated control	108	93	88	96

An analysis of variance of leaf drop demonstrated
that both treatments were significantly different from the
controls at the 5 per cent level, but not different from
each other. Similarly, the disease indexes of both treat-
ments were significantly different from the controls, but
not from each other.

The number of shoots per unit area (Table 24) appear-
ed to be larger on the treated than on the control plots.
However, the apparent increase in number of shoots is not
significant at the 5 per cent level of probability. The
fact that as many shoots were present on the treated as on
the untreated plots can be explained on the following

basis. After "burning back" with chemicals, new shoots
grow from buds in the leaf axils near the soil surface.
In mints the leaves are opposite, hence, in some cases 2
new shoots grew in place of the one which was "burned
back". In other cases shoots were killed by the treat-
ments.

<div align="center">Protectant Fungicides</div>

Fungicide screening trials

During the growing season of 1951 an experiment was
conducted to test the effectiveness of several widely used
fungicides for the control of the urediospore stage of
mint rust. A randomized block design with 5 replications
and plots 10 feet square was employed. All applications
were made with a hand sprayer except in the one case
where Ferbam dust was used, it was applied with a hand
duster. Four applications were made at 10 to 14 day in-
tervals from the appearance of the first urediospores
until three weeks before harvest. Rates of application
were those recommended by the manufacturer for control of
various other diseases.

Plots were individually cut, weighed and distilled.
Each plot was sampled by cutting 12 plants selected at
random, and rating the leaves at 3 positions on the main

stem for rust severity. The 3 positions at which leaves
were numerically rated into rust classes were at the base,
middle and top of the plant. The exact pair of leaves to
be rated was determined by rating the first pair of basal
leaves; counting 4 nodes and then rating the fifth pair of
leaves, counting 4 more nodes and rating the tenth pair of
leaves or the pair immediately below the terminal flower
spike, whichever occurred first. A disease index for each
plot was computed by applying a variation of the McKinney
infection-index formula described on p. 57.

The treatments, rates of application and disease in-
dex in replication are given in Table 25. An analysis of
variance of the disease index data in Table 25 resulted in
a significant F-value for treatments. Further statistical
tests (L.S.D. and extreme mean) revealed that Phygon re-
duced disease severity. All other treatments were not
effective in reducing disease severity.

Yields of oil from each plot are given in Table 26.
Statistical treatment of oil yield data resulted in a
significant F-value for treatments. L.S.D. and extreme
mean tests revealed that Phygon increased oil yields. None
of the other treatments increased oil yields significantly.

The yield data in Table 26 were used to test the re-
liability of the disease index as previously described on

Table 25. Effectiveness of 10 materials for rust control as shown
by a computed disease index.

Materials and rates	Disease index in replication:					Mean disease index*
	1	2	3	4	5	
Phygon 2,3-dichloro- 1,4-napthouinone (50%) 1 lb. per 100 gal.	6.02	7.87	9.26	16.20	12.50	10.37**
Cop-o-zinc basic copper (42%) and zinc (11%) sulfates 4 lbs. per 100 gal.	16.20	18.33	15.74	31.94	25.00	21.44
Cuprocide cuprous oxide (90%) 1½ lbs. per 100 gal.	25.54	16.20	28.70	21.76	23.15	22.87
Captan n-trichloromethylthiotetra- hydrophthalimide (50%) 2 lbs. per 100 gal.	19.44	26.85	21.76	24.54	37.50	26.02
Copper-A tetra copper calcium oxychloride (45%) 4 lbs. per 100 gal.	26.39	25.92	30.55	28.70	26.39	27.59
Ferbamspray ferricdimethyldithiocarbamate (76%) 2 lbs. per 100 gal.	28.70	27.31	25.00	24.07	33.80	27.78

Table 25. (continued).

| Materials and rates | Disease index in replication: | | | | | Mean disease index |
	1	2	3	4	5	
Crag 341-C glyoxalidine acetates (50%) 1 pint per 100 gal.	25.00	22.68	32.01	24.07	37.96	28.15
Orthorix calcium polysulfides (26%) polyethylene glycol monoiso octylphenyl ether (10%) 2 qts. per 100 gal.	18.98	32.41	34.72	30.09	30.09	29.26
Lime sulfur calcium polysulfides (29%) 2 qts. per 100 gal.	21.30	29.63	40.74	26.85	34.72	30.65
Ferbam dust ferricdimethyldithiocarbamate (10%) 55 lbs. per acre	27.78	33.80	37.96	30.09	25.92	31.11
None (control	19.44	36.11	35.65	37.50	41.20	33.98

* Least significant difference at .01 = 8.71
** Significantly different from check at .01

Table 26. Effectiveness of 10 materials for
rust control as shown by yield of
oil.

Material	Grams of oil in replication:					Mean oil yield in grams*
	1	2	3	4	5	
Phygon	64	67	76	59	67	66.6**
Captan	53	57	55	46	57	53.6
Cop-o-zinc	61	49	52	48	57	53.4
Cuprocide	50	58	44	49	64	53.0
Copper-A	55	46	58	51	53	52.6
Ferbam (spray)	47	49	60	52	47	51.0
Crag 341-C	50	46	53	55	44	49.6
Lime sulfur	45	43	52	51	51	48.4
Orthorix	47	53	42	39	60	48.2
Ferbam (dust)	44	41	50	53	48	47.2
None (control)	51	47	44	50	54	49.2

* Lease significant difference at .01 = 9.52.
**Significant by L.S.D. at .01.

p. 62. Table 27 shows a comparison of yield and disease
index for the various treatments. The data in Table 27
show that yield decreased as disease index increased; and
both yield and disease index data show Phygon to be the
fungicide exhibiting the best rust control possibilities.

Table 27. Comparison of disease index and
oil yield means from peppermint
plots treated with 10 fungicides.

Fungicides used	Mean disease index	Mean oil yield in grams
Phygon	10.37	66.6
Cop-o-zinc	21.44	53.4
Cuprocide	22.87	53.0
Captan	26.02	53.6
Copper-A	27.59	52.6
Ferbam (spray)	27.78	51.0
Crag 341-C	28.15	49.6
Orthorix	29.26	48.2
Lime sulfur	30.65	48.4
Ferbam (dust)	31.11	47.2
None (control)	33.98	49.2

Flavor evaluation of peppermint oil from plots treated with fungicides

In 1949 Steenland (26) conducted trials with ferbam
(ferricdimethyldithiocarbamate) for mint rust control and
found that the resulting oil after distillation contained
up to 400 parts per million of carbon disulfide. Further
tests were conducted which established that oil from mint
treated with dithiocarbamates contained carbon disulfide

in quantities sufficient to make the oil undesirable.

Other fungicides used on mint might also cause unde-
sirable residues or flavors in the oil. Samples of oil
from plots treated with the fungicides listed in Table 25
were submitted to the Beech-Nut Packing Company for flavor
analyses. Dr. L. G. Cox of the Beech-Nut Packing Company
stated that on the basis of their organoleptic panel tests
the oil from the various treatments were placed in the
following order of preference:

1.	Phygon	Captan)	
2.	Crag 341-C	Lime Sulfur)	
3.	Copper-A	Ferbam spray)	undesirable
4.	Cuprocide	Ferbam dust)	
5.	Orthorix		
6.	Cop-o-zinc		

Fungicidal sprays and dusts

Since Phygon was the only fungicide that gave good
rust control and was also selected as the best material by
oil flavor evaluation, it was the only fungicide chosen for
further rust control trials.

During the summer of 1953, field trials were conducted
to determine: 1) whether Phygon sprays or dusts were most
effective for rust control; 2) what concentrations of
Phygon dusts or sprays were most effective; 3) how many
spray or dust applications were necessary for rust control;

and 4) whether mint treated with Phygon sprays or dusts on a field scale would have an undesirable flavor when distilled by standard commercial methods. The experimental design consisted of a randomized block with 4 replications of ½ acre plots.

Dusting equipment consisted of a trailer-mounted, tapered-boom duster made by the Tufts Company, Alhambra, California. The duster in operation is shown in Figure 10. Spray equipment consisted of a tractor-mounted spray boom fitted with cone-type spray nozzles. A push-bar parallel with and ahead of the spray boom was employed to tip the mint plants forward ahead of the spray pattern, thus exposing more of the undersides of the leaves to the spray. The spray equipment in operation is shown in Figure 11.

Dust and spray applications were made at 13 to 17 day intervals beginning May 29. Either 3 or 5 applications were made. Sprays were applied at Phygon concentrations of ¼, ½ and 1 pound per 100 gallons and approximately 100 gallons per acre. Phygon dust applications were 1¼, 2½ and 5 per cent dusts at 40 pounds per acre.

Just prior to harvest all plots were sampled by selecting 10 plants at random and rating them for rust severity by the method previously described. From the rust

Figure 10. Duster used in fungicidal control trials.

Figure 11.   Sprayer used in fungicidal control trials.

severity ratings a disease index was computed for each plot. Plots in each treatment were distilled separately and oil samples collected for flavor evaluation.

The mean disease index from both dust and spray plots is given in Table 28. Analysis of variance of spray treatments revealed no significance for treatments, therefore, sprays were not effective in reducing rust severity. Analysis of variance of dust treatments revealed a significant F-value for treatments. L.S.D. tests among dust treatment means revealed that both $2\frac{1}{2}$ and 5% dusts with 5 applications reduced rust severity at the one per cent level of probability. Three dust applications did not reduce rust severity at any of the rates used.

Oil samples representing all treatments were submitted to the A. M. Todd Company, Kalamazoo, Mich.; the Beech-Nut Packing Company, Canajoharie, New York; and the Wm. Wrigley Jr. Company, Chicago, Ill. for flavor evaluation. All three companies found no consistent differences in flavor of oil from treated and untreated plots. Oil from treated plots was judged as good as oil from untreated control plots.

Resistant Varieties

Breeding and selection of resistant varieties is one of the most successful methods of controlling rust

Table 28. Effectiveness of Phygon sprays
and dusts at different rates and
times of application for mint
rust control as shown by a
computed disease index.

Treatment and rate	No. of applications	Mean disease index
¼ lb.	3 5	34.62 35.60
spray ½ lb.	3 5	36.11 34.44
1 lb.	3 5	33.33 31.50
None	-	35.55
1¼%	3 5	32.36 30.55
Dust 2½%	3 5	25.69 19.78**
5%	3 5	26.25 20.11**
None	-	33.33

**L.S.D. at .01 for dust treatment means = 7.68

diseases of plants. Plant breeding programs for the
development of peppermint and spearmint varieties resis-
tant to the destructive Verticillium wilt disease are now
being conducted by the United States Department of Agri-
culture in cooperation with Purdue University, by Michigan

State College and by the A. M. Todd Company, Kalamazoo, Michigan. Breeding of rust resistant spearmint varieties is also being conducted by Michigan State College and the A. M. Todd Company.

Mentha crispa L. has been used as the wilt resistant parent in crosses with M. piperita by Nelson (16) and by E. C. Stevenson and C. A. Thomas* of the U. S. Department of Agriculture. Since 1951 hybrids of Mentha crispa x Mentha piperita have been made available to the author through the courtesy of Dr. C. A. Thomas. These hybrids have been tested in the greenhouse for resistance to the race of Puccinia menthae attacking peppermint in Oregon.

Test plants were grown either from rhizomes or rooted cuttings in 6-inch clay pots and inoculated by spraying a urediospore suspension onto the undersides of the leaves. At least three replications of each variety were employed for each test. After inoculation high humidity was maintained around the plants for 48 hours by frequently spraying water on a heavy muslin cover placed over the greenhouse bench. Three weeks after inoculation and again one week later all plants were examined and rated for rust resistance.

*Personal communication with Dr. C. A. Thomas

Five different types of reaction to rust were con-
sistently observed among the hybrids tested. The differ-
ent uredial reactions were assigned numerical values
characterized as follows:

    0 = no evidence of infection.

    1 = infection followed by the appearance of small
        necrotic spots; no sporulation.

    2 = infection followed by necrotic spots; sporulating
        sori minute.

    3 = infection followed by necrosis or chlorosis;
        sporulating sori small.

    4 = infection followed by abundant, large,
        sporulating sori.

Ninety-one hybrids and 6 species of Mentha have been
tested for their reaction to the race of Puccinia menthae
designated as race 2 by Baxter and Cummins (4). The
uredial reactions of the six mint species listed in Table
29 agree with those found by Baxter and Cummins for race 2.
Each of 91 M. crispa x M. piperita hybrids were tested and
4 were found to be immune, 31 highly resistant, 14 moderate-
ly resistant, 16 moderately susceptible and 26 susceptible
to race 2 of P. menthae. Other races of P. menthae capable
of attacking the immune and resistant hybrids may exist in
Oregon.

Hybrids with different uredial reactions to race 2
could be used as differential hosts to detect other races

Table 29. Resistance of 5 species and 91
hybrids of Mentha to race 2 of
Puccinia menthae.

Species or hybrid	Number of plants tested	Number of plants showing rust reaction:				
		0	1	2	3	4
Mentha crispa L.	3	3				
" piperita L.	3					3
" spicata L.	3	3				
" cardiaca L.(Scotch)	3				3	
" pulegium L.	3	3				
" canadensis L.	3					3
91 hybrids of Mentha crispa x M. piperita	273[a]	12[b]	93[c]	42[d]	48[e]	78[f]

[a] 3 plants of each hybrid were tested
[b] 3 plants each of 4 hybrids
[c] 3   "   "   " 31   "
[d] 3   "   "   " 14   "
[e] 3   "   "   " 16   "
[f] 3   "   "   " 26   "

of Puccinia menthae which might be present in Oregon.
Collections of mint rust aeciospores were made from 3 mint
species in 12 different localities in the state. Aecio-
spores rather than urediospores were used to detect races
because Stakman and Loegering (24) and 25) demonstrated
that different races of wheat stem rust were 4 to 20 times
more prevalent in aeciospore collections.

Mentha piperita, Mentha spicata and five M. crispa x
M. piperita hybrids showing rust reactions of 0, 1, 2, 3
and 4 respectively, were inoculated with each of 12

collections of aeciospores. Rust reactions were determined 4 weeks after inoculation and compared with the known reaction of the test plants to race 2. Table 30 shows that two races of rust were differentiated by the reactions of the test plants. In this test one race always originated from either M. piperita or M. canadensis and caused a reaction identical with race 2 on all test plants. The other race always originated from M. spicata and was not infective to any of the test plants except M. spicata. It appears that only one race of Puccinia menthae capable of attacking peppermint is prevalent in Oregon at the present time.

Table 30. Rust reaction produced on 2
species and 5 hybrids of Mentha
by aeciospores collected from
3 mint species in 12 localities.

Locality number	Rust reaction on:		Hybrids with reaction to race 2 of:				
	M. piperita	M. spicata	0	1	2	3	4
1 Mentha piperita	4	0	0	1	2	3	4
2 " "	4	0	0	1	2	3	4
3 " "	4	0	0	1	2	3	4
4 " "	4	0	0	1	2	3	4
5 " "	4	0	0	1	2	3	4
6 Mentha canadensis	4	0	0	1	2	3	4
7 " "	4	0	0	1	2	3	4
8 Mentha spicata	0	4	0	0	0	0	0
9 " "	0	4	0	0	0	0	0
10 " "	0	4	0	0	0	0	0
11 Mentha piperita	4	0	0	1	2	3	4
12 " "	4	0	0	1	2	3	4

SUMMARY AND CONCLUSIONS

Peppermint rust caused by <u>Puccinia</u> <u>menthae</u> overwinters
as teliospores on fallen leaves, mint stubble and rhizomes,
and on the soil surface. Teliospores are produced from May
to December, but heaviest production occurs during October
and November. Maximum germination of teliospores produced
in November occurred during December and January, but
spores were still germinating in February, 108 days after
being produced.

Infection of young mint shoots by basidiospores be-
gins as early as December and continues through March.
Low temperature retards the development of spermogonia and
aecia. An average of 10 days were required for mature
aecia to develop from basidiospore infections at 20° C.,
whereas, 27 days were required at 10° C.

Aeciospores are produced from February to June, but
development of urediospores from aeciospore infections
during February and March is greatly retarded by low tem-
peratures. Infections during February and early March
required an incubation period of approximately 6 weeks
under field conditions, while under greenhouse conditions
favorable for rust development the incubation period was 2
weeks. Aeciospores rapidly lost their viability at tem-
peratures below 0° C. and above 30° C., while viability

was retained longest at 5° C.

Initial spread of rust by aeciospores is limited to a few feet.

No evidence was found that urediospores overwinter in the field under Oregon conditions. The time interval between the last viable urediospores found in the fall and their appearance the succeeding season was 105 days.

Rust mycelium and infected host cells were killed before rust sporulation at a temperature of 100° C. for four hours while after rust sporulation they were killed at 90° C. for four hours. Urediospores produced in sori exposed to direct solar radiation lost their viability much more rapidly than urediospores protected from direct solar radiation.

Crop losses caused by <u>Puccinia</u> <u>menthae</u> occur during all stages of development of the parasite. Most losses caused by basidiospore infection, spermogonia and aecia come about from invasion of the infected area by secondary organisms and subsequent death of the infected shoot or rhizome.

Crop losses caused by urediospore infections include leaf drop, inhibition of lateral shoot development and destruction of oil glands by erupting sori.

Plants with heavy urediospore infection produce rhizomes smaller in diameter, length and weight than healthy

plants.

A method of evaluating rust severity and control data based on percentage destruction of oil glands on the leaves proved to be a valuable tool for evaluating the effectiveness of fungicides.

Control measures of thorough plowing to cover all old stubble and plant debris, eradication of wild and escaped mint near commercial plantings, eradication of mint infected with the aecial stage within plantings by contact plant-killer chemicals and properly timed irrigation all effectively reduced rust losses.

Of 9 protectant fungicides tested only Phygon controlled rust effectively.

Phygon dusts were more effective than sprays; and $2\frac{1}{2}\%$ dust was more effective than $1\frac{1}{4}\%$ dust, and equally as effective as 5% dust.

Two races of Puccinia menthae were found in Oregon. One of these races attacks Mentha piperita, M. canadensis, and certain M. crispa x M. piperita hybrids, while the other race attacks M. spicata. The two races are not cross infective on any of the hosts mentioned above.

Of 91 hybrids of M. crispa x M. piperita tested for rust resistance, 4 were immune, 31 highly resistant, 14

moderately resistant, 16 moderately susceptible and 26 susceptible to the race of _Puccinia menthae_ attacking commercial peppermint.

BIBLIOGRAPHY

1. Arthur, Joseph C. The plant rusts. New York, Wiley, 1929. 446p.

2. _____ Manual of the rusts in United States and Canada. Lafayette, Indiana, Purdue research foundation, 1934. 438p.

3. Baxter, John W. The occurrence of rust on peppermint in Western Ontario. U. S. Dept. of Agriculture, Plant Disease Reporter 35:418. 1951.

4. _____ and George B. Cummins. Physiologic specialization in Puccinia menthae Pers. and notes on epiphytology. Phytopathology 43:178-180. 1953.

5. Bullis, D. E., F. E. Price and Dale E. Kirk. Relationship of maturing and weathering to yield and quality of peppermint oil. Corvallis, Oregon state college, 1948. 15p. (Oregon. Agricultural experiment station. Bulletin 458)

6. Cruchet, Paul. Contributions a l'etude biologique de quelques Puccinies sur Labiees. Centralblatt fur bacteriologie, parasitenkunde und infektion-skrankheiten 17:212-224. 1907.

7. Dietz, S. M., A. P. Steenland and C. E. Horner. Mint rust (Puccinia menthae) epiphytotic in the Northwest. Phytopathology 41:938. 1951.

8. Dimock, A. W. and Kenneth F. Baker. Effect of climate on disease development, injuriousness, and fungicidal control as exemplified by snapdragon rust. Phytopathology 41:536-552. 1951.

9. Drummond-Goncalves, R. A. Ferrugem da hortela pimenta. Biologico 9:383-386. 1943.

10. Hopp, Henry. Control of atmospheric humidity in culture studies. Botanical gazette 98:25-44. 1936.

11. Horner, Chester E. Root and rhizome rot of peppermint. Phytopathology 42:514-515. 1952.

12. Horsfall, J. G. and J. W. Heuberger. Measuring magni-
    tude of a defoliation disease of tomatoes.
    Phytopathology 32:226-232. 1942.

13. Marsh, R. W., H. Martin and R. G. Munson. Studies
    upon the copper fungicides. 3. The distribution
    of fungicidal properties among certain copper
    compounds. Annals of applied biology 24:853-866.
    1937.

14. Muhle, E. Zur biologie und bekampfung des pfefferminz-
    rostes, Puccinia menthae Pers. Die Pharmazie
    10:541-546. 1951.

15. McKinney, H. H. Influence of soil temperature and
    moisture on infection of wheat seedlings by
    Helminthosporium sativum. Journal of agri-
    cultural research 26:195-218. 1923.

16. Nelson, Ray. Verticillium wilt of peppermint. East
    Lansing, Michigan state college, 1950. 259p.
    (Michigan. Agricultural experiment station.
    Technical bulletin 221)

17. _____ Mint rust and its control. Michigan
    state college agricultural experiment station
    quarterly bulletin 34:436-455. 1952.

18. Niederhauser, J. S. The rust of greenhouse-grown
    spearmint and its control. Ithaca, Cornell
    University, 1945. 30p. (Cornell university.
    Agricultural experiment station. Memoir 263)

19. Owen, Herbert Elmer Jr. Certain factors affecting the
    establishment of the douglas fir (Pseudotsuga
    taxifolia (Lamb.) Britt.) seedlings. Master's
    thesis. Corvallis, Oregon state college, 1953.
    71 numb. leaves.

20. Peltier, George L. A study of the environmental con-
    ditions influencing the development of stem rust
    in the absence of an alternate host. Lincoln,
    Nebraska, University of Nebraska, College of
    agriculture, 1923. 52p. (Nebraska. Agricultural
    experiment station. Research bulletin 25)

21. Persoon, Christiaan Hendrik. Puccinia menthae.
    Synopsis methodica fungorum p227. 1801.

22. Raines, M. A. Vegetative vigor of the host as a fac-
         tor influencing susceptibility and resistance to
         certain rust diseases of the higher plants.
         American journal of botany 9:183-203. 1922.

23. Sievers, A. F. and E. C. Stevenson. Mint farming.
         Washington, U. S. Government printing office,
         1948. 30p. (U. S. Dept. of agriculture.
         Farmers bulletin no. 1988)

24. Stakman, E. C. and W. Q. Loegering. Physiologic races
         of Puccinia graminis in the United States in 1950.
         Washington, D. C., U. S. Dept. agriculture,
         bureau of plant industry, soils, and agricultural
         engineering, 1951. 16p. (Unnumbered publications
         issued July, 1951. Mimeographed)

25. _____ Physiologic races of Puccinia
         graminis in the United States 1945-1949.
         Washington D. C., U. S. Dept. agriculture, bureau
         of plant industry, soils, and agricultural
         engineering, 1950, 19p. (Unnumbered publications
         issued November, 1950. Mimeographed)

26. Steenland, A. P. The peppermint rust situation in
         Oregon. Proceedings of the Oregon essential oil
         growers league, second annual meeting, 1951.
         Corvallis, Oregon state college, 1951. 37p.
         (Mimeographed)

27. Vergovsky, V. I. Mint rust and methods of its control.
         Simferpol (Crimea) All union scientific research
         institute for medicinal and medicinal-technical
         plants. Bulletin 3:5-54. 1935. (Translation
         from the Russian by John S. Niederhauser, 1943,
         deposited in Cornell University plant pathology
         library)