An Empirical Model for Forecasting Alternaria Leaf Spot in Apple

CHOONG-HOE KIM[1], WON-DAE CHO[1], AND SEUNG-CHUL KIM[2]

김충회 • 조원대 • 김승철 : 사과 점무늬낙엽병(斑點落葉病)예찰을 위한 한 경험적 모델

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ABSTRACT An empirical model to predict initial disease occurrence and subsequent progress of Alternaria leaf spot was constructed based on the modified degree day temperature and frequency of rainfall in three years field experiments. Climatic factors were analized 10-day bases, beginning April 20 to the end of August, and were used as variables for model construction. Cumulative degree portion (CDP) that is over 10°C in the daily average temperature was used as a parameter to determine the relationship between temperature and initial disease occurrence. Around one hundred and sixty of CDP was needed to initiate disease incidence. This value was considered as temperature threshhold. After reaching 160 CDP, time of initial occurrence was determined by frequency of rainfall. At least four times of rainfall were necessary to be accumulated for initial occurrence of the disease after passing temperature threshhold. Disease progress after initial incidence generally followed the pattern of frequency of rainfall accumulated in those periods. Apparent infection rate (r) in the general differential equation $dx/dt = xr(1-x)$ for individual epidemics when x is disease proportion and t is time, was a linear function of accumulation rate of rainfall frequency (Rc) and was able to be directly estimated based on the equation $r=1.06Rc-0.11$ ($R^2=0.993$).

Disease severity (x) after t time could be predicted using exponential equation $[x/(1-x)]=[x_0/(1-x)]e^{(b_0+b_1R_c)t}$ derived from the differential equation, when x_0 is initial disease, b_0 and b_1 are constants. There was a significant linear relationship between disease progress and cumulative number of air-borne conidia of *Alternaria mali*. When the cumulative number of air-borne conidia was used as an independent variable to predict disease severity, accuracy of prediction was poor with $R^2=0.3328$.

INTRODUCTION

Alternaria leaf spot caused by *Alternaria mali* Roberts was first reported in U.S.A. (5) and has been a major concern on apple cultivation in Korea(3). Seriousness of this disease has also been reported in Japan since 1956(6). In Korea, according to Lee and Lee (3), the disease was first found in Kyongbuk province around 1960s. The fungus produces lesions mainly on leaves of apple tree causing early falling, but also attacks fruits and twigs.

Infections occur from the flowering time throughout the season by conidia of *A. mali* that were dispersed into air from the infected plant materials.

Control of this disease is rather difficult due to long infectious period and nature of massive inoculum production of *A. mali*. Control program of this disease is heavily dependent on fungicide application. In many cases, two third of fungicide sprays being applied during the season are aimed to control this disease.

Due to frequent fungicide application, development of fungicide tolerant strain of *A. mali* brought about another difficulty to control this

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[1] Department of Plant Pathology, Agricultural Sciences Institute, Suwon 170 Korea (농업기술연구소 병리과, 수원 170)

[2] Technical Extension Department, Han-Nong Corporation (주식회사 한농 보급부)

disease (2,3).

The management of this disease depends upon the ability to anticipate epidemic outbreaks to schedule appropriate actions for disease control. Unnecessary fungicide sprays may be eliminated by forecasting epidemic outbreak. Although the association of specific weather condition, especially temperature and rainfall, with outbreak of this disease has been recognized, systems to forecast this disease have not been attempted yet.

The objectives of this study were to examine the relationships between specific weather condition and epidemic outbreak of Alternaria leaf spot and to develop a model for forecasting this disease based on specific climatic factors.

MATERIALS AND METHODS

Model construction. The model is based on an empirical relationship between disease incidence and climatic condition to determine the periods when environmental conditions were favorable for Alternaria leaf spots. The model was derived from 3 years field researches and uses a combination of two main environmental factors, temperature and rainfall, to describe the observed relationship between development of the disease and it's environment.

Cumulative degree portion (CDP) was used as a parameter for temperature. This is a summation of degree portions that are over 10°C in daily average temperature and CDP was obtained by subtracting 10°C from daily average temperature and by accumulating that value when daily average temperature exceeds 10°C. Daily average temperature less than 10°C was disregarded for CDP calculation. The calculation of CDP started April 20 until time of initial disease occurrence. The CDP can be designated as $\sum(T_d-10)$ when T_d is daily average temperature (°C) from the period of April 20.

Frequency of rainfall was used as another prediction parameter in combination with CDP for initial disease incidence and subsequent progress of the disease. Cumulative number of rainfalls from the period over temperature threshhold was plotted against time to examine the pattern of rainfall frequency in each epidemic year and a simple linear regression was generated from the plot. Accumulation rate of rainfall frequency (Rc), that is slope of the regression, was correlated to apparent infection rate (r) of each epidemic obtained from a general differential equation model for disease progress (7) $dx/dt=xr\,(1-x)$, when x is disease proportion and t is time. Apparent infection rates of the each year's epidemic were calculated for the period from the initial incidence of the disease to the point of disease proportion reaching 0.9. This was obtained from the logistic equation:

$$\ln\left(\frac{x}{1-x}\right)=rt+\ln\left(\frac{x_0}{1-x_0}\right)$$

derived from the above differential equation, when x_0 and x are sequential disease proportions and t is time in days.

A correlation analysis was performed to examine the relationship between r and Rc and an appropriate equation accounting for the relationship was generated.

Cultural condition. The experiments were carried out at the Kumgok orchard near Suwon city during the seasons of 1980, 1981 and 1982. The apple variety Red-delicious was chosen throughout the study because this variety is susceptible to Alternaria leaf spot. The Kumgok orchard was selected because this orchard was managed by one of the authors and because severe incidence of Alternaria leaf spot disease had been observed in this orchard for several years. Six-year-old Red-delicious trees were grown over hilly area of the orchard and were isolated each other 3×4m distance.

Five trees were randomly selected from this area and were marked with garden stakes. These trees were protected from any pesticide application throughout the seasons using specially made a polyethylene sheet curtain.

Monitoring the climatic condition. Ambient air temperature, relative humidity, and amounts and frequency of rainfall were continuously monitored during the periods of April 20 to the end of August in 1980, 1981 and 1982 using a hygrothermograph (Model H-311, manufactured by Weather Measure Corporation, Sacramento, CA. 9584 U.S.A.) and a tipping bucket rain gage (Model B-011, manufactured by Nakaaea Instruments Co. Ltd., Japan). The hygrothermograph was placed in a wooden instrument shelter. The shelter was located 1.3m above ground in the center of experimental area. The hygrothermograph was calibrated in the laboratory by following the operator's manual. The rain gage was installed adjacent to the instrument shelter.

Monitoring air-borne conidia. Number of airborne conidia of *Alternaria mali* was continuously monitored in the orchard during the seasons of 1980, 1981 and 1982 using a Rotary Spore Trap (manufactured by Ikeda Ind. Ltd., Japan). The spore trap was installed under the roof of an instrument shelter that was located between the Red-delicious trees in the northeast side of the experimental area. The spore trap vertically holds two microscopic glass slides one in each side arm. Prior to mounting, one side of the slides was coated with glycelin jelly. The microscopic slide was approximately 1.5m above the ground. The spore trap was operated for one hour daily from 24:00 to 01:00 a.m. at the rate of 1600 rpm starting April 10 to the end of July. The microscopic slide was collected daily from the spore trap at 10:00 a.m.. A coverglass area (18×18mm^2) was selected from the center of the microscopic slide. Number of conidia of *A. mali* on that area was counted under the microscope. Number of conidia from both microscopic slides was added together to determine the daily number of air-borne conidia.

Disease assessment. Development of Alternaria leaf spot on the premarked five Red-delicious trees was examined at 10-11 day intervals from April 10 to the end of August in 1980, 1981 and 1982. In each tree number of infected leaves having at least one lesion was counted based on 200 leaves randomly selected, one hundred each, from two directions of the tree and was converted into the percentage of infected leaves.

RESULTS

Disease progress. Initial incidence of Alternaria leaf spot was observed in early June in 1980, mid-June in 1981 and mid-May in 1982, respectively (Fig. 1A). Disease development after initial incidence differed greatly with seasons (Fig. 1A and 1C). In 1980, disease progressed most rapidly among three seasons and reached 90% within 40 days after initial incidence. In 1981, disease development was somewhat similar to that of 1980 and it took 50 days to reach 90% disease severity. Disease progress was most slow in 1982 and took 80 days to reach 90% disease, although initial incidence was 20 to 30 days earlier compared to the other two years. Apparent infection rate (r) calculated from the logistic disease progress model $\ln\left(\frac{x}{1-x}\right)=rt+\ln\left(\frac{x_0}{1-x_0}\right)$ clearly showed this difference (Fig. 1C). Apparent infection rates of 1980, 1981 and 1982's epidemics were 0.29, 0.20 and 0.06 respectively.

Climatic condition. Cumulative degree

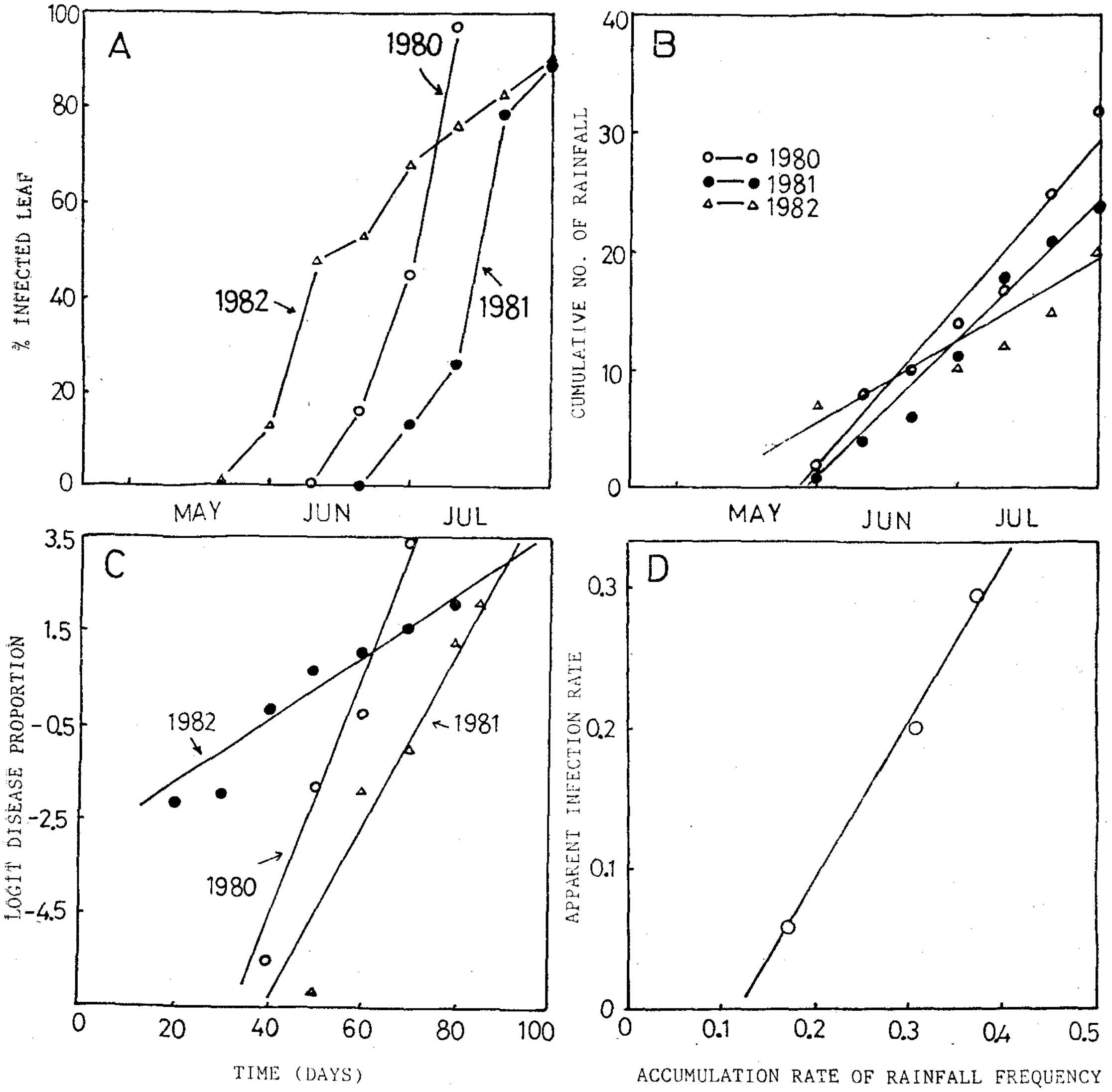

Fig. 1. (A) Disease progress curves of Alternaria leaf spot on apple at the Kumkok orchard in Suwon in 1981, 1982 and 1983. (B) Cumulative number of rainfalls from the time after 160 accumulation of degree portion that is over 10°C in the daily average temperature. (C) Linear regression of logit transformed disease proportions against time in days in 1980's, 1981's and 1982's epidemics. (D) Relationship between apparent infection rate and accumulation rate of rainfall frequency in the three epidemic seasons.

portion(CDP), average rainfall amounts and rainfall frequency in 10-day period from April 20 to the end of July in 1980, 1981 and 1982 are shown in Table 1. Relative humidity was not listed in the table since it was not used as a parameter for model construction. Average relative humidity for 10-day periods was correlated with rainfall frequency ($r=0.5769$) that was used as a predictor in the model. Ambient air temperature during the season was generally lower in 1980 than those of 1981 and 1982. This was particularly true for the germination and flowering periods that are mid-April to early May in the growing

Table 1. Density of air-borne conidia of *Alternaria mali* and climatic conditions in terms of cumulative degree portions that is over 10°C in the daily average temperature (CDP) and frequency and amount of rainfall during the seasons of 1980, 1981 and 1982 at the Kumgok orchard in Suwon

Period	Number of air-borne conidia[a]			CDP[b]			Rainfall frequency[c] (Avr. amount mm)		
	1980	1981	1982	1980	1981	1982	1980	1981	1982
April 10~20	0	0	0	—	—	—	—	—	—
April 21~30	0	11	4	4.9	30.1	46.9	1(23.4)	3(8.3)	1(0.2)
May 1~10	0	90	28	33.9	55.4	47.9	2(2.6)	3(11.0)	3(6.7)
May 11~20	0	40	262	49.6	28.4	68.1	3(14.0)	4(5.6)	4(27.7)
May 21~31	0	36	1476	89.7	87.9	110.7	2(17.0)	1(7.0)	3(11.5)
June 1~10	61	259	3700	96.9	87.4	90.6	6(6.7)	2(3.2)	1(2.8)
June 11~20	258	970	1290	116.7	119.8	113.9	2(40.7)	2(3.1)	2(1.2)
June 21~30	17	521	4640	110.3	124.6	124.8	4(17.8)	5(10.5)	0(0)
July 1~10	804	159	1325	113.1	131.9	144.2	3(3.6)	7(27.3)	2(1.4)
July 11~20	1094	171	1529	130.1	153.2	141.1	8(17.2)	3(11.7)	3(11.1)
July 21~30	—	186	13376	138.1	180.7	147.7	7(7.7)	3(7.6)	5(46.2)

[a] Values are total number of daily air-borne conidia of *A. mali* detected by the spore trap for the period. The spore trap was operated daily for one hour from 24:00 to 1:00 am with 1600 rpm.

[b] CDP can be designated as $\sum(T_d-10)$, when T_d is daily average temperature over 10°C.

[c] Trace of rainfall (e.g. few drops of rain) was ignored in rainfall frequency.

season. In 1982, air-temperature was appreciably high particularly in the early and mid-season when compared to the other two years. Temperature in 1981 season was generally intermediate ranging between 1980 and 1982. Frequency of rainfall also varied greatly with year(Table 1). During the stages of germination, flowering, and initial fruit formation from late April to mid-May, rainfall was most frequent in 1981 followed by 1982 and 1980 seasons. Thereafter, rainfall became most frequent in the season of 1980. The mid- and late growing season of 1982 was extremely dry compared to other two years, until rainy season began at the later part of July. Rainfall in 1981 season was generally intermediate between those of 1980 and 1982.

Relationships between disease development and climatic conditions. In 1982, initial disease occurrence was observed in mid-May when 163 of CDP was accumulated with 4 times of rainfall. In 1980 and 1981, CDP reached above 160 in late May with 2 and 1 time of rainfall, respectively. Nevertheless, disease incidence was not observed untl early June and mid-June when cumulative frequency of rainfall reached more than three. From these 3 year's observations, least climatic conditions in terms of CDP and rainfall frequency satisfying initial incidence could be designated as $\sum(T_d-10)\geqq 160$ with $R_f\geqq 4$, when T_d is daily average temperature from the date of April 20 and R_f is rainfall frequency accumulated from the period reaching 160 CDP.

The pattern of disease progress after initial incidence was similar to the pattern of accumulation of rainfall frequency (Fig. 1B). When cumulative number of rainfall frequency was plotted against time in days, accumulation rate of rainfall frequency (*Rc*) in 1980, 1981 and 1982 was 0.37, 0.31 and 0.16 respectively (Fig. 1B).

Apparent infection rates of the 3 year's epidemics were a linear function of *Rc*. Their relationship could be designated as $r=1.06\,Rc-0.1146$ with $R^2=0.9931$ (Fig. 1D). From this equation, apparent infection rate can be predicted when *Rc* is used as a predictor of *r*.

Disease proportion x after t time could be estimated with *Rc* from the general differential equation:

$$dx/dt=xr(1-x) \quad \cdots\cdots\cdots\cdots (1)$$

r in this equation is a linear function of Rc as described below

$$r=b_0+b_1\ Rc \quad \cdots\cdots\cdots\cdots (2)$$

Here, b_0 and b_1 are constants.

Replace r in (1) with (2)

$$dx/dt=x\ (b_0+b_1\ Rc)\ (1-x) \cdots\cdots\cdots\cdots (3)$$

In this equation, unit change of disease per time was written with accumulation rate of rainfall frequency (*Rc*). Integrate (3):

$$x=x_0e^{(b_0+b_1Rc)t} \cdots\cdots\cdots\cdots (4)$$

Here x_0 is initial disease proportion and x is disease proportion after t time. In equation (4), replace x and x_0 with correction factor for multiple infection:

$$\left(\frac{x}{1-x}\right)=\left(\frac{x_0}{1-x_0}\right)e^{(b_0+b_1Rc)t} \cdots\cdots\cdots\cdots (5)$$

Take natural logarithm in (5)

$$\ln\left(\frac{x}{1-x}\right)=(b_0+b_1Rc)t+\ln\left(\frac{x_0}{1-x_0}\right) \cdots\cdots\cdots\cdots (6)$$

In this study $b_0=-0.1146$ and $b_1=1.06$. From the equation (6), disease proportion x after t time can be predicted from the accumulation rate of rainfall frequency *Rc*.

Relationship between disease development and number ofair-borne conidia. Conidia of *A. mali* in the air were first detected by spore trap at the early June in 1980, and late April in 1981 and 1982 (Table 1). Density of air-borne conidia was markedly greater in 1982 than in 1980 and 1981. In 1980 time of first detection of the conidia in the air coincided with time of initial occurrence of the disease. In 1981 and 1982, initial incidence of the disease was observed 50 and 20 days later from the first detection of air-borne conidia, respectively. There was a significant linear relationship between logit transformed disease severity and cumulative daily number of air-borne conidia (Fig. 2). This relationship was designated as $y=-8.47+2.45x$ when y is logit transformed disease severity, $\left(\ln\frac{y}{1-y}\right)$ and x is log transformed cumulative daily number of air-borne conidia. When cumulative daily number of air-borne conidia was used as an independent variable to predict disease severity, the accuracy of the prediction was low with $R^2=0.3328$.

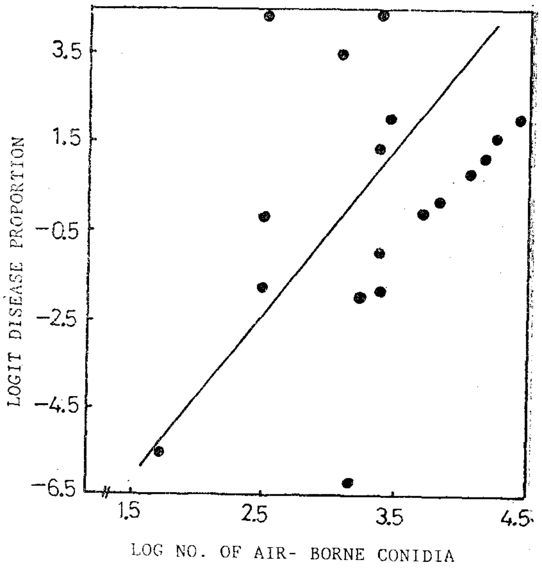

Fig. 2. A correlation between logit transformed disease proportion of *Alternaria mali* on apple and log transformed number of air-borne conidia collected from the orchard during 1980, 1981 and 1982 seasons.

DISCUSSION

Systems of disease forecasting based on weather analysis in relation to the likelyhood of disease development have been developed with several crop disease (4, 8). In those systems some key environmental data funtioned as predictors of epidemics. Methodology of empirical model construction was discussed elsewhere by one of the author (1). In this study temperature and rainfall frequency were used as parameters to predict initial incidence and subsequent progress. Air temperature at the germination period may affect both host growth and development of inoculum. The condition of high temperature in this period may expedite emergence and expansions of leaves and also promote production of conidia on overwintered diseased plant parts, resulting early incidence of disease. Actually, temperature in the germination period was much higher in 1982 than in 1980. Dispersal of air-borne conidia and initial incidence of the disease was 40 days earlier in 1982.

Another important climatic factor for disease development appeared to be frequent rainfall. This condition may be essential in conidia production as inoculum sources and in colonization process at infection court. In 1980 and 1981, initial incidence of the disease was delayed 10 to 20 days from the period when air temperature reached the same level of 1982 for initial incidence. Disease was first observed after four times rainfall accumulated from that period in 1980 and 1982. Air temperature after initial incidence of the disease may not be so important as rainfall for disease development, because the rate of disease progress differed greatly under the similar temperature conditions being observed in 1980 and 1982. Frequency of rainfall seemed to be more important factor than rainfall amount for disease severity although they were correlated each other ($r=0.6285$). In actual application for disease forecasting, frequency of rainfall would be more convenient since it is simpler to measure.

Although density of air-borne conidia was significantly correlated with disease progress, the degree of correlation was quite low. This indicates presence of significant variation that could not be explained by inoculum density. Environmental factor such as rainfall and temperature might be more important for disease progress than inoculum density.

The model described in this study could be used in current control program of the disease. Prediction of time of initial incidence and susequent progress should help fungicide spraying schedule. Unnecessary application of fungicide can be eliminated and efficacy of fungicide application could be maximized by this forecasting scheme. The model in the present study was constructed based on the 3 year's field experiment data. The model needs to be verified and improved with more field observations under diverse environmental conditions. Prediction ability of current model could be greatly improved by forecasting rainfall frequency through long term weather map analysis.

The variables associated with host plant such as level of resistance can also be incorporated into the model. Future research in this area could make the model dependable, locally useful, and a widely applicable scheme for predicting epidemics of Alternaria leaf spot and scheduling fungicides.

摘 要

사과 점무늬낙엽병(斑點落葉病)의 初發과 초발후의 병진전을 예찰하기 위하여 기상요인중에서 적산온도(積算)와 강우빈도를 사용하여 예찰할 수 있는 경험적 모델이 3년간의 포장시험으로 작성되었다. 사과의 생육기간중 4월 20일부터 7월말까지 기상요인을 측정, 분석하였고 이들 기상요인들이 모델작성의 變量으로써 사용되었다. 하루의 평균온도에서 10°C를 뺀 온도가 적산되어(CDP) 대기온도와 점무늬낙엽병초발과의 관계를 알기위한 한 母數로서 사용되었다. 병의 초발에 필요한 CDP는 약 160으로서 이 수치는 초발에 필요한 CDP의 下限온도로 사용되었다. 160 CDP가 도달된 후에는 강우 빈도가 초발을 결정하는 요인이었으며 적어도 4번의 강우가 초발에 필요하였다. 초발후의 병진전은 대체로 강우 빈도가 누적되는 모양과 유사하였다. 병진전의 일반 微分방정식모델 $dx/dt=$

$xr\ (1-x)$에서 산출된 3개년의 병진전 직선의 명백한 감염속도(r)는 강우빈도의 누적율(Rc)과 1차(직선)기능으로서 직선방정식 $r=1.06Rc-0.11$ ($R^2=0.993$)에서 직접 추정이 가능하였다. 일정시간(t)후의 발병정도 (x)는 미분방정식 모델에서 유도된 指數방정식 $[x/(1-x)]=[x_0/(1-x_0)]e^{(b_0+b_1Rc)t}$에서 예측될 수 있는데 이때의 x_0는 초발시발병정도 b_0와 b_1은 강우빈도 누적률 Rc의 母數이다. *Alternaria mali* 분생포자의 공기중밀도의 매일의 누적치와 병진전과는 통계상 유의적인 1차관계(linear relationship)가 있었는데 공기중 분생포자 밀도의 누적치를 독립변량으로 사용하여 병진전을 예측하였을때 예측의 정확도는 $R^2=0.3328$로서 비교적 낮았다.

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