

Yield reduction of spring wheat in relation to disease development caused by *Septoria nodorum*

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Abstract. Effects of *Septoria nodorum* on the grain yields and yield components of three spring wheat cultivars were studied in Finland using artificial field inoculation over three years.

At low infection level, in 1986, grain yield was reduced in all cultivars by 2–10 %, but statistically insignificantly. In 1984 severe infection reduced the grain yields of cultivars Kadett and Tähti by 27 % and 32 %, respectively, while in 1985 the yield of Tähti was reduced by 16 % and that of Kadett by 18 %.

Grain weights were reduced under low disease stress by 3–5 %, while under severe disease stress the reductions were 7–20 %.

Disease strongly reduced the green-leaf area duration compared with fungicide-treated plots. Examination of single tillers showed that all yield components were significantly reduced. The disease amount on second leaves correlated best with grain weight loss.

Implications of these results for controlling the damage caused by *S. nodorum* in spring wheat are discussed.

Index words: *Septoria nodorum*, yield loss, spring wheat

Introduction

Septoria nodorum Berk., the cause of glume blotch disease of wheat, has become one of the most important cereal diseases in northern Europe and many other parts of the world in recent decades (EYAL 1981, KING et al. 1983 a). Increasing *Septoria* severity is likely to be related to changes in cultivars and husbandry practices, which have provided new opportunities for disease outbreaks in many areas. Crop losses caused by *S. nodorum* vary

from 5 % to 70 % (reviewed by KING et al. 1983 a, KARJALAINEN 1985), and in Finland previous studies (KARJALAINEN et al. 1983, KARJALAINEN 1985) have shown yield losses of 10–35 % depending on the year and the cultivar. Yield reduction might be related to the reduction in photosynthetic rate as well as to the reduction in overall photosynthesis, which is mainly due to disease-induced speeding up of senescence (SCHAREN and KRUPINSKY 1969,

SPIERZ 1973, KARJALAINEN and SALOVAARA 1988).

Septoria has been a major wheat pathogen in Finland for a long time (MÄKELÄ 1973), and our climate together with field characteristics favour its epidemic development. In most years summers are cool and there are frequent rains. In addition, wheat fields are often small and surrounded by lakes or forests which provide the humidity in wheat canopy necessary for disease development. In recent years farmers in southern Finland, in particular, have increasingly started to use growth regulators and extra nitrogen as well as in some cases zero tillage, which all may have a disease speeding effect. However, these farmers have found it necessary to regularly use fungicides to control leaf diseases. *Septoria* epidemics can be sporadic, and careful disease monitoring may allow to forecast the risk of *Septoria* occurrence and at the same time help to avoid unnecessary treatments while providing information on the accurate spray timing for fungicide application (ROYLE et al. 1986).

The purpose of this study was to provide more information on how *Septoria* affects some yield characteristics of spring wheat cultivars under severe and mild epidemic conditions.

Materials and methods

Yield reduction in spring wheat caused by *Septoria nodorum* was studied in the years 1984—1986. Three cultivars, susceptible Tähti and Hankkija's Tapio, and moderately resistant Kadett, were used in field tests carried out at the University Farm of Viikki of the University of Helsinki. Experiments were carried out in a randomized block design with 6—8 replications, half of which were inoculated with *S. nodorum*. All inoculated plots were surrounded by guard plots to prevent inoculum spread into control plots. Standard fertilization and herbicide treatments were used. In 1986, 0.5 l/ha of Tilt was applied on some plots of Tähti and Tapio just before flag leaf

emergence in order to evaluate the effect of a fungicide to control *Septoria*.

Inoculation was done by spraying *S. nodorum* spore suspension onto test plots. Mixtures of three fungal isolates collected from southern Finland were used. The fungus was cultured on oatmeal agar in petri dishes under NUV light for 7—10 days. The dishes were then flooded with sterile water and spores were released by gently rubbing the agar surface with a spatula. Spore suspensions of about 10^6 spores/ml with some 'Tween 20' were used for inoculation.

In 1984 and 1985 test plots were inoculated twice, at the third leaf stage and one week after that. In 1986, three inoculations were done, starting at the third leaf stage. Inoculations were done late in the evening, using 50 ml of spore suspension per plot.

Disease development was monitored by counting and labelling 60 plants per plot and estimating the percentage of diseased leaf area on three upper leaves. Green-leaf area duration was monitored by visually estimating non-green leaf area, which was more accurate to estimate than green-leaf area.

Before harvest, the 60 labelled tillers per plot were collected and their yield components were analyzed. Grain yields and thousand grain weights were analyzed from larger data.

Single-tiller analysis was also carried out by labelling 60 tillers in a large commercial field of cultivar Tapio. Before harvest the labelled tillers were taken for yield component analysis.

Correlation, regression, and variance analyses were computed from yield data.

Results

Disease development

Patterns of disease development of *Septoria nodorum* on three spring wheat cultivars are presented from two years, 1984 and 1986, when conditions for infection varied greatly. In 1984 the weather was very suitable for rapid disease development because of frequent

rains, and even the first leaves were rapidly covered by diseased lesions. In this year (Fig. 1) the late but susceptible cultivar Tähti was slowly infected at the beginning of the growing period, but after ear emergence infection advanced quickly. A similar pattern of disease development was noticed for all three cultivars so that Kadett was consistently the most resistant and Tähti the most susceptible one, while Tapio was intermediate.

In 1986 the weather was unsuitable for rapid disease development because there was a long rainless period in the growing season. Disease development on two upper leaves was monitored on Tähti and Kadett. In general, infection started slowly despite several inoculations to induce disease build-up so that only about 30 % of the first leaves of susceptible Tähti was destroyed at the end of July, while the first leaves were totally destroyed at that time in 1984. In 1986, the first leaves of Kadett were only slightly infected (Fig. 2), and Kadett was again clearly more resistant than Tähti throughout the growing period.

A separate experiment was also carried out in 1986 to test the effectiveness of fungicide treatments (Tilt) to reduce disease development. Treatments before flag leaf emergence efficiently prevented disease build-up on both Tähti and Tapio (Fig. 3).

Development of leaf area (cm²) on cultivars Kadett and Tähti was monitored over a three-week period under severe disease stress in 1984. At the beginning, leaf area was larger on susceptible and larger-leaved Tähti than on Kadett, but the leaf area of Tähti rapidly reduced toward the end of the period compared with that of resistant Kadett (Fig. 4).

In 1986, the effect of disease on reducing green-leaf area was monitored by visually estimating the non-green leaf area on flag leaves. Reduction in green-leaf area appeared to follow a similar pattern on both Kadett and Tähti (Fig. 5), and more resistant Kadett appeared to prolong upper leaf green area duration slightly longer than susceptible Tähti. However, at the end of the period there was

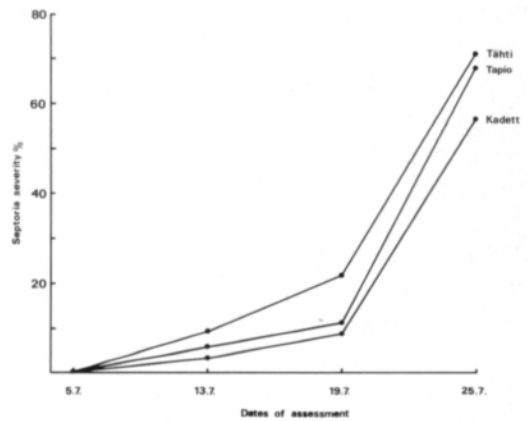


Fig. 1. Disease progress of *Septoria nodorum* on the flag leaves of spring wheat cultivars Tähti, Tapio, and Kadett in 1984.

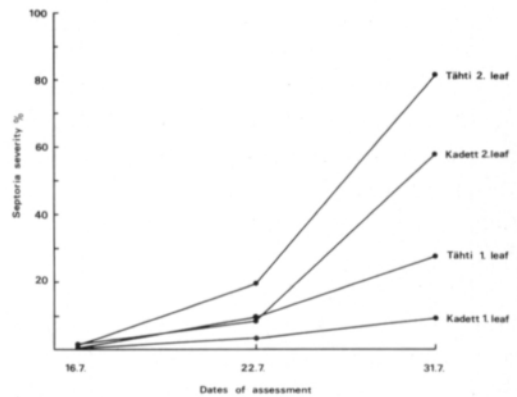


Fig. 2. Disease progress of *S. nodorum* on the flag and second leaves of spring wheat cultivars Tähti and Kadett in 1985.

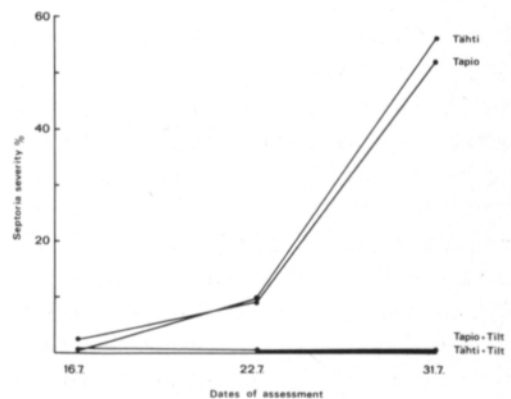


Fig. 3. Effects of Tilt-treatment on disease progress of *S. nodorum* on the second leaves of spring wheat cultivars Tapio and Tähti.

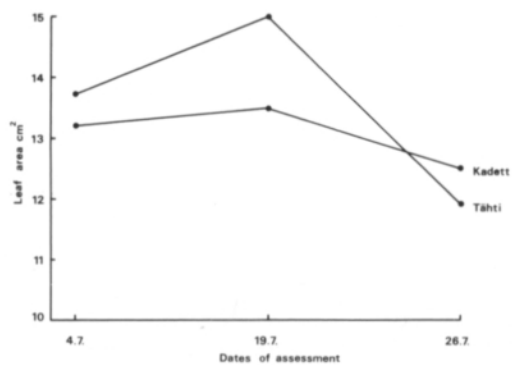


Fig. 4. Development of flag leaf area under disease stress conditions in 1984 on the cultivars Tähti and Kadett.

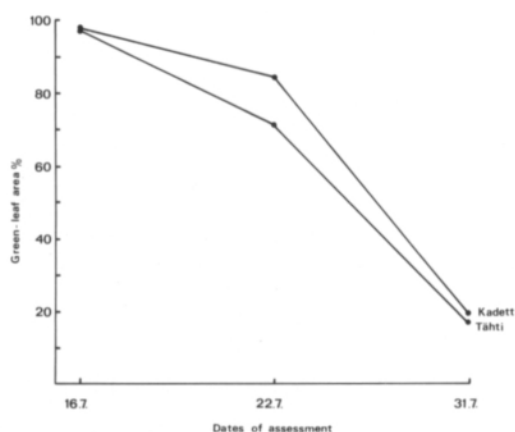


Fig. 5. Reduction in green-leaf area of the flag leaves of cultivars Tähti and Kadett under disease stress in 1986.

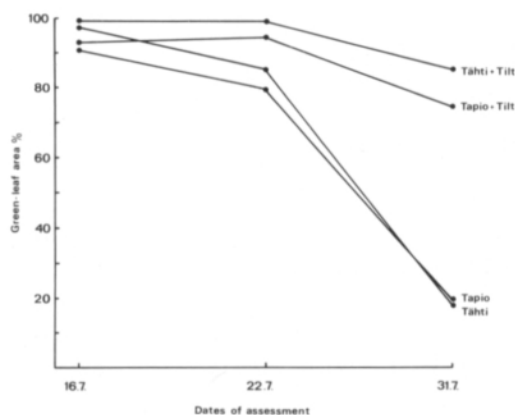


Fig. 6. Effects of Tilt-treatment on the green-leaf area development of the flag leaves of cultivars Tähti and Tapio in 1986.

hardly any difference between these two cultivars. Fungicide treatments (Tilt) effectively prolonged green-leaf area duration of both Tähti and Tapio (Fig. 6), suggesting that a fungicide treatment may help preserve more green-leaf area for photosynthesis, which in turn produces an increased supply of assimilates to be translocated into the grain compared to untreated control.

Effects of disease on grain yield and yield components

In 1984 and 1985 the weather was suitable for disease development, and the yield data

Table 1. Effect of *Septoria* infection on grain yield and grain weight of spring wheat cultivar Tähti in 1984—1985.

	Grain yield kg/ha	Ratio	1000-grain weight, g	Ratio
<i>1984</i>				
Control	4617	100	39.3	100
<i>Septoria</i> -inoculated	3156	68	31.6	80
Significance	***		*	
L.S.D. _{.5} %	623		1.6	
<i>1985</i>				
Control	2540	100	33.3	100
<i>Septoria</i> -inoculated	2140	84	28.8	86
Significance	*		*	
L.S.D. _{.5} %	290		3.1	

Table 2. Effect of *Septoria* infection on grain yield and grain weight of spring wheat cultivar Kadett in 1984—1985.

	Grain yield kg/ha	Ratio	1000-grain weight, g	Ratio
<i>1984</i>				
Control	6287	100	41.5	100
<i>Septoria</i> -inoculated	4603	73	33.1	80
Significance	**		*	
L.S.D. _{.5} %	850		1.2	
<i>1985</i>				
Control	3305	100	38.0	100
<i>Septoria</i> -inoculated	2723	82	35.5	93
Significance	*		N.S.	
L.S.D. _{.5} %	450		2.9	

N.S. = non-significant

show (Tables 1 & 2) that *S. nodorum* is capable of causing significant yield reductions to wheat crops. In 1984, the disease reduced the grain yields of susceptible Tähti and more resistant Kadett by 32 % and 27 %, respectively (Table 1). The grain weights of both cultivars were significantly reduced, by 20 %. In 1985 the yields of all test cultivars were generally very low, and the yield of Tähti was reduced by 16 % and that of Kadett by 18 %. The grain weight of Tähti was again significantly reduced (Table 2).

In 1986 there was a long dry period during the experiment, and *S. nodorum* was unable to grow rapidly into the upper parts of the wheat canopy. Thus grain yields were only slightly reduced. Disease-induced yield reductions for all three cultivars, Tähti, Kadett, and Tapio, were statistically insignificant (Table 3), although the yield of Tähti was reduced by over 400 kg/ha. The yields of Kadett and Tapio were less affected by the disease. Table 4 summarizes the yield data from Tähti and Kadett over three years showing that only the yield of more susceptible Tähti was significantly affected by the disease, while a more stable trait, grain weight, indicates significant reductions for both cultivars.

Yield component data were also obtained from a single-tiller assessment experiment from cultivar Tähti. Results indicated (Table 5) that all yield components were significantly reduced by the infection. As results from previous studies (e.g. KARJALAINEN 1985) had suggested that grain weight is a stable component of grain yield, which characterizes yield reduction in a reliable way, single-tiller assessments were carried out on a commercial plot of Tapio in order to assess the amount of disease on two upper leaves and to find out which leaf, leaf 1 or leaf 2, correlates best with grain weight reduction. Fig. 7 indicates that in general the amount of disease on either leaf correlates well with grain weight reduction, but the second leaf appears to be an even better indicator of grain weight loss than the first one.

Table 3. Effect of *Septoria* infection on grain yields and grain weights of spring wheat cultivars Tähti, Kadett, and Tapio in 1986.

Cultivars	Grain yield kg/ha	Ratio	1000-grain weight, g	Ratio
<i>Tähti</i>				
Control	4280	100	40.9	100
<i>Septoria</i> -inoculated	3847	90	39.3	96
Significance	N.S.		N.S.	
L.S.D. _{.5 %}	637		4.4	
<i>Kadett</i>				
Control	5127	100	44.9	100
<i>Septoria</i> -inoculated	5019	98	42.6	95
Significance	N.S.		N.S.	
L.S.D. _{.5 %}	1385		5.6	
<i>Tapio</i>				
Control	4986	100	43.7	100
<i>Septoria</i> -inoculated	4710	94	42.3	97
Significance	N.S.		N.S.	
L.S.D. _{.5 %}	491		9.3	

N.S. = non-significant

Table 4. Combined data over three years of the effects of *Septoria* on grain yields and 1000-grain weights of cultivars Tähti and Kadett in 1984—1986.

Cultivars	Grain yield kg/ha	Ratio	1000-grain weight, g	Ratio
<i>Tähti</i>				
Control	3999	100	38.7	100
<i>Septoria</i> -inoculated	3277	82	33.8	87
Significance	*		***	
L.S.D. _{.5 %}	545		2.5	
<i>Kadett</i>				
Control	4775	100	41.4	100
<i>Septoria</i> -inoculated	4117	86	37.7	91
Significance	N.S.		*	
L.S.D. _{.5 %}	1091		3.6	

N.S. = non-significant

Table 5. Effect of *S. nodorum* on yield components of spring wheat cultivar Tähti in 1986.

	Number of grains per ear	Ear weight g	1000-grain weight, g
Control	22.4	0.84	37.4
<i>Septoria</i> -inoculated	18.7	0.62	32.6
Significance	***	***	***
L.S.D. _{.5 %}	1.7	0.08	1.3

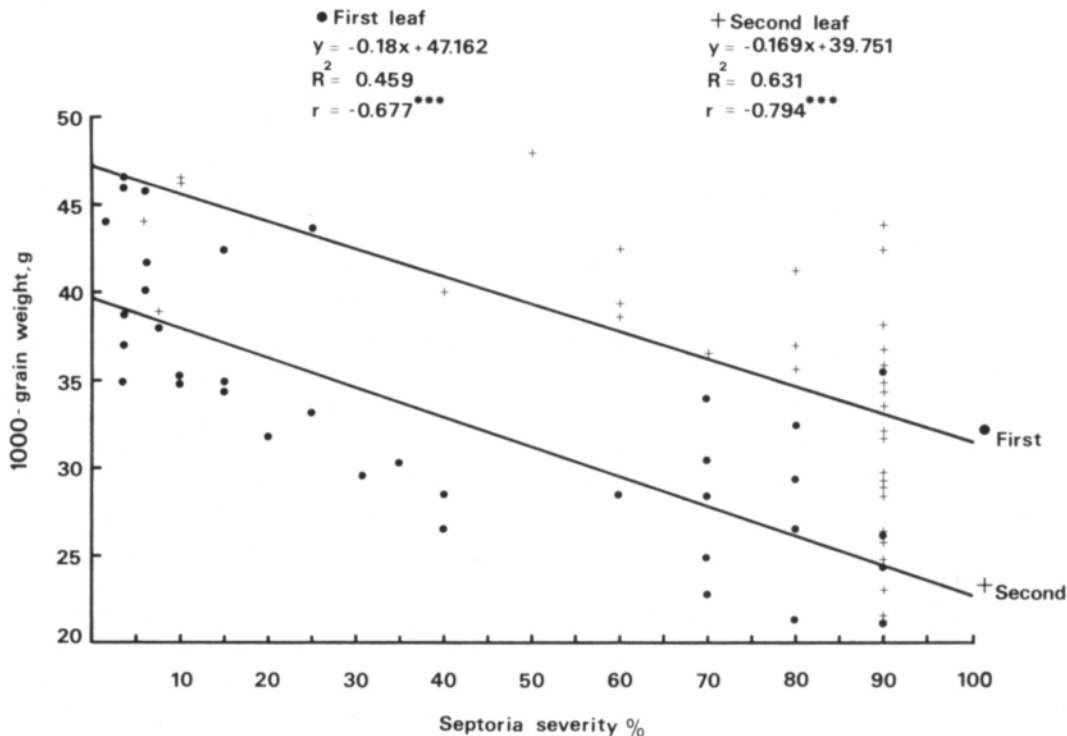


Fig. 7. Correlation between *S. nodorum* severity and grain weight on the first and second leaves of cultivar Tapio.

Discussion

Our results suggest that under humid conditions favourable for disease development, *S. nodorum* can cause yield losses as high as 20–32%. In the past ten years there have been several rainy summers (e.g. 1981, 1984, 1985, 1987) and severe occurrences of *S. nodorum*.

There are two types of epidemic development of *S. nodorum*, sudden outbreaks and gradual epidemics (ROYLE et al. 1986). In a sudden outbreak disease lesions appear simultaneously on all upper leaves, usually early in crop growth. These outbreaks are related with a single heavy rain that moves the basal inoculum 50–60 cm upwards within the crop. Inoculum transport also depends on the size of the raindrops because large drops produce large splash droplets (BRENNAN et al. 1985).

In gradual epidemics the disease arises on successive leaf layers as they appear during the sustained weather period suitable for inocu-

lum travel and infection. In Finland, gradual epidemics are probably more common than sudden outbreaks, and infection in the field often appears to follow this pattern.

A severe *Septoria* infection seems to have complex reasons. A previous rainy season probably affects next year's epidemic conditions by providing abundant infected plant debris on the soil because in Finland the fall is often wet, which makes ploughing difficult. If the first part of the growing season is cool and wet, inoculum can be transported to new wheat crops early, and if there are several rainy days between mid-June and late July, the disease can gradually progress from lower to upper canopy.

Our results in 1986 showed that even under unsuitable dry conditions *S. nodorum* can reduce wheat yield by 5–10%. Even in a rainless period, *Septoria* may survive and develop in the canopy because in late season dew provides humidity for several hours. However, practical experience suggests that hot and

dry weather for several weeks (e.g. in 1983 and 1986) effectively retards *Septoria* development.

In this paper we have shown that *Septoria*-infection speeds up senescence and shortens green-leaf area duration. This in turn reduces overall photosynthesis and decreases the supply of assimilates that can be translocated to the grain. It was thus logical that the grain weight was strongly affected in this experiment. Our results also showed that fungicide treatment effectively reduced disease development and particularly prolonged flag leaf period thus also lengthening grain-filling time. This is in accordance with earlier data (SPIERZ 1973) indicating that a fungicide treatment given at the right time can effectively reduce disease and increase grain yield. In our experiments fungicide treatments increased the grain yields of spring wheat by 5–30 % compared with untreated controls. Although infection seems to reduce green-leaf area and overall photosynthesis so drastically, it may have only a small effect on the pattern of assimilate distribution (WAFFORD and WHITBREAD 1976).

In our experiments all yield components were strongly affected by infection as revealed by the single-tiller experiment, which is in line with earlier data (JONES and ROWLING 1976, WAFFORD and WHITBREAD 1978, KARJALAINEN et al. 1983). In general, early infection appears to reduce yield less than a late one (JONES and ROWLING 1976, VERREET et al. 1987), and single-ear yields in particular are strongly affected by late infection. Field data (BRÖNNIMANN 1968, SPIERZ 1973, NELSON et al. 1976, SCOTT and BENEDIKZ 1977, WAFFORD and WHITBREAD 1978, KARJALAINEN et al. 1983, VERREET et al. 1987) show quite consistently that wheat is sensitive to *S. nodorum* at a later stage of development, and greatest losses occur after late infection. Sometimes losses caused by early infection are compensated by other yield components if the infection is weak or moderate (JONES and ROWLING 1976, WAFFORD and WHITBREAD 1978), but compensation is probably not effective

enough to prevent yield losses after severe infection. In Finland, wheat is most often infected in late season, and as the amount of rain increases towards the end of the growing season, *Septoria* infection frequently speeds up at the same time. Yield losses in Finnish wheat crops thus seem to be mainly due to late *Septoria* attacks.

These data indicate yield losses of 20–30 % under severe and 5–10 % under mild disease conditions. Previously we reported a 10 % reduction in one cultivar and one year (KARJALAINEN et al. 1983). In the rainy years of 1981, 1984, 1985, and 1987, there was often as much *Septoria* in many farmers' fields as in our experimental fields. However, disease distribution even in a single field varies. Estimates of national losses caused by *S. nodorum* in Finland are not available, but annual yield losses of up to 8 % have been recorded in Great Britain. KING et al. (1983 b) have provided a linear regression equation between disease severity and yield loss. It indicated a yield loss of 1.011 % for each 1 % increment in severity on the flag leaf and a loss of 0.551 % for each 1 % increment on the second leaf. Our single-tiller analysis done in a commercial field of cultivar Tapio suggested that the amount of disease on the second leaf correlates best with grain yield loss. Under northern growing conditions the second leaf may be a better crop loss estimate than the flag leaf because in the field it is often more reliable to estimate the amount of disease (without inoculation) on the second than on the flag leaf.

The use of fungicides to control wheat diseases has increased in the past few years. In some areas in southern Finland winter wheat is sprayed first at the stem extension phase mainly to control mildew and again later to control *Septoria*. In Finland *Septoria* seems to cause greatest crop losses rather late in crop growth, and one spraying with optimal timing would probably be sufficient. In this experiment, one application immediately after flag leaf emergence drastically reduced

Septoria development and lengthened green-leaf area duration. Similar results have been reported by SPIERZ (1973) and OBST (1985).

The use of simple forecasting rules (TYLDESLEY and THOMPSON 1980, OBST 1985) and information of the previous year's weather

and ploughing conditions will be an important step towards the rational planning of chemical control of the *Septoria* disease in Finland.

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Septoria-taudin vaikutus kevätvehnän satoon

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Tutkimuksessa selvitettiin *Septoria*-taudin vaikutusta kolmen kevätvehnälajikkeen, Tähten, Hankkijan Tapion ja Kadettin, satoon ja eräisiin satokomponentteihin vuosina 1984—1986. Kokeet tehtiin Helsingin yliopiston Viikin koetilalla saastuttamalla koeruudut laboratoriossa kasvatetusta *Septoria nodorum* -sienestä tehdyllä itiöseoksella. Osa Tähti- ja Tapio-ruuduista käsiteltiin Tiltillä juuri ennen lippulehden puhkeamista.

Taudin kehitystä kasvustossa seurattiin arvioimalla tietyn välein tautilaikkujen määrä kahdella ylimmällä lehdellä. Samanaikaisesti määritettiin ylälehtien kuihtumisasaste. Sadonkorjuun jälkeen laskettiin jyväsato ja 1000-jyvän paino ja määritettiin satokomponentit yksilöpuiduista Tapion ja Tähten tähkistä.

Sää vaikuttaa ratkaisevasti *Septoria*-taudin leviämiseen. Vuodet 1984 ja 1985 olivat sateisia ja viileitä, jolloin tauti levisi nopeasti kasvuston alaosista ylälehtiin ja tähkiin asti. Vuosi 1986 oli kuuma ja kuiva, taudille epäsuotuisa. Kaikissa kokeissa *Septoriaa* vastaan kestävin oli Kadett ja alttein Tähti, Tapio sijoittui näiden väliin.

Vuonna 1984 Kadettin jyväsato oli 27 % ja Tähten 32 % pienempi kuin saastuttamattoman verranteen. Kummankin 1000-jyvän paino aleni 20 %. Vuonna 1985 sadot olivat yleensä alhaisia, ja Tähten sadonalennus oli

16 % ja Kadettin 18 %. 1000-jyvän painot alenivat vastaavasti 14 % ja 7 %. Vuonna 1986 *Septoriaa* oli niin vähän, että sadonalennukset olivat tilastollisesti merkityksettä.

Tauti alensi huomattavasti kaikkia Tähten satokomponentteja. Tapio-viljelykseltä otettu näyte osoitti, että taudin määrä sekä lippulehdellä että erityisesti toiseksi ylimmällä lehdellä korreloi selvästi 1000-jyvän painon alenemiseen, mikä satokomponentti yleensä kuvaa luotettavasti *Septoria*-taudin vaikutusta.

Vihreän lehtialan seuranta osoitti, että *Septoria*-infektio nopeuttaa kasvin kuihtumista, jolloin yhteyttävä lehtiala pienenee ja yhteyttämisaika lyhenee, minkä seurauksena jyväkoko pienenee. Tiltin vaikutus lieneekin perustunut osin siihen, että se paitsi vähensi taudin kehitystä myös vaikutti lehtialan säilymiseen vihreänä pidempään. Tulokset viittaavat siihen, että Suomessa torjuntakäsittely on paikallaan sateisina kesinä. Torjunnan paras ajoitus näyttää olevan lippulehden puhkeamisen ja tähkälletulon välillä, jolloin käsittely estää tehokkaasti patogeenipopulaation etenemisen kasvustossa ja lehtien ennenaikaisen kuihtumisen. Viileänä kasvukautena torjunta pidentää myöhäisten lajikkeiden kasvuaikaa entisestään.