Root rot of wheat

M. MERGOUM [1], A. LYAMANI [2], N. NSARELLAH [1]

SUMMARY

The expansion of cereal to marginal and stressed environments in order to satisfy the increasing food demand of population is common to many countries. Dryland root rot desease of wheat is an other challenge that faces the agronomist in general to improve productivity in these environments. This paper review the major research works conducted in many parts of the world on root rot disease of cereals. Major emphasis is made-whenever it is possible-on most of the research accomplished on root rot on Morocco since 1984. This review paper includes most references on root rot and might be useful for any person involved in root rot research.

Key words: Root rot, cereals, Morocco

RESUME

Titre: pourritures racinaires du blé

L'extension de la culture des céréales aux zones marginales et stressées afin de combler le déficit croissant en produits céréaliers est un phénomène très commun à plusieurs pays. Les maladies causant les pourritures racinaires très fréquentes dans ce type d'environnements, reste un défit crucial à soulever par les chercheurs pour augmenter la production céréalière dans ces zones. Cet article est une revue bibliographique des principaux travaux de recherches menés sur les pourritures racinaires à travers le monde. Les études menées par les chercheurs au Maroc sur cet aspect sont aussi incluses dans ce manuscrit. Nous estimons que cet article englobe les principaux résultats et références sur les pourritures racinaires des blés utiles à tout chercheur qui veut entamer des recherches liées à ce sujet.

Mots Clés: Pourritures racinaires, céréales, Maroc

[1] Centre Aridoculture, INRA, Settat, Maroc
[2] INRA, CRRA-Gharb, El Menzeh, Kénitra, Maroc

ملخص

العنوان: التعفنات الجدرية في القمح

إعداد: م. مرجوم[1]، أ. اليماني[2] و ن. نصر الله[1]

1: المركز الجهوي للبحث الزراعي، سطات، المغرب
2: المركز الجهوي للبحث الزراعي، القنيطرة، المغرب

بدأت زراعة الحبوب، التي تعتبر من أهم المنتوجات الفلاحية عبر العالم تغطي مساحات شاسعة من المناطق الجافة وشبه الجافة وهذا راجع للنقص المتزايد في منتوجات الحبوب. ويعتبر التعفن الجدري من بين الأمراض التي تحد من منتوجية القمح في هذه المناطق. يلخص هذا التقرير أهم الأبحاث التي أجريت عبر العالم حول التعفنات الجدرية للحبوب. كما يحتوي على أهم النتائج والأبحاث التي أجريت في المغرب على هذه الأمراض. ويشتمل على أهم المراجع والنتائج التي يحتاجها كل باحث مهتم بالبحوث في مجال أمراض التعفنات الجدرية .

الكلمات المفتاحية: التعفنات الجدرية، الحبوب، المغرب

INTRODUCTION

Common root rot, foot rot, crown rot, pink rot, culm rot, and stalk rot are descriptive terms used to designate a group of wheat diseases caused by one or more organisms, alone or in association (Burgess *et al.* 1975). Common root rot has been reported from most cereal growing areas of the world. However, the occurrence and frequency of causal agents vary regionally and from year to year (Fernandez *et al.* 1985; Lyamani 1988).

Cochliobolus sativus and several species of *Fusarium* including *F. graminearum* Schwabe, *F. culmorum* (W.G. Smith) Sacc., and *F. avenaceum* (Fr.) Sacc. are considered the primary causal agents of root rot of wheat (Burgess *et al.* 1975; Specht and Rush 1988; Lyamani 1988).

Root rot is a persistent and inconspicuous disease that reduces seedling vigor and impairs functioning of roots and crowns resulting in loss of stands, reduced yield and lower grain quality (Fenster *et al.* 1972; Mergoum 1991; Mergoum *et al.* 1994). The damage from root rot pathogens varies from year to year and from field to field depending upon the amount of inoculum present as well as soil and climatic factors (Statler and Darlington 1972; Lyamani 1988; Tinline and

Ledingham 1979). In addition to the environmental factors, certain cultural practices may play an important role in the expression of this disease (Tinline 1986; Broscious and Frank 1986; Wildermuth and McNamara 1991; Mergoum 1991; Houmairi 1993).

This paper reviews works on root rot disease of wheat conducted in many parts of the world with emphasis on those realized in Morocco. It includes sections on economic importance, causal agents, source of inoculum, virulence and competition, control, inoculation technics and selection for root rot tolerance or resistance. For the purpose of consistency, and to avoid confusion in this report, all symptoms previously indicated will be referred to as "root rot".

ECONOMIC IMPORTANCE

Root rot was described as an "insidious, presistent and inconspicuous disease" that reduces yields to some degree each year (Fenster *et al.* 1972). In the USA, root rot disease is considered the third greatest cause of yield reduction of wheat after the rusts and smuts (Merrill 1977). In the northwestern region of the USA, yield reduction of wheat by *F. culmorum* was estimated to be at least 10% (Cook 1968b) and reached 50% (Cook 1968a) in some infected fields. Under favorable conditions, yield reductions of up to 50 and 70% in wheat and barley, respectively, were attributed to common root rot in some areas of Nebraska (U.S. Department of Agriculture 1979) and North Dakota (Stack 1982). Overall stand reductions caused by *Cochliobolus sativus* ranged from 11 to 29% and from 27 to 62% in wheat and barley, respectively (Frank 1985). Similar stand reductions were reported in areas of Colorado and Wyoming (Hill and Fernandez 1983), Montana (Grey *et al.* 1991), and Tennessee (Reed 1952). Average yield losses due to root rot in North America were estimated to 3 to 4% (Weise 1977).

Loss surveys in the Canadian regions have shown that root rot is a widespread and important disease of wheat and barley (Ledingham *et al.* 1973; Piening *et al.* 1976; Verma *et al.* 1976a; Tinline and Ledingham 1979). These studies showed that average yield losses in wheat ranged from 5 to 12% over the period of 1939 to 1973. In barley, Canadian researchers estimated an average 10,3% yield loss caused by root rot from 1970 to 1972 (Piening *et al.* 1976). Grain loss of "Manitou" wheat ranged from 22.5 to 34.9% depending on disease severity and cropping systems (Verma *et al.* 1976b). In the Canadian prairie provinces, estimated yield loss caused by root rot of wheat was 5.7% from 1969 to 1971 (Ledingham *et al.* 1973). Yields of barley were reduced by 16% and 40% on fallow land and stubble, respectively (Piening *et al.* 1983).

In Australia, reduction of 26.6% in average yield was reported (Purss 1966). Up to 20% dead heads and 100% infection by *F. graminearum* were recorded (Wearing and Burgess 1977).

In brazil, reports indicate losses caused primarily by *C. sativus* (Luz 1984) of 14 and 19%, respectively, in the wheat cultivars "Nobre" and "CNT 10".

In Morocco, field studies conducted in 1985-86 and 1986-87 in the West Central regions showed average yield losses of 4 and 6%, respectively (Lyamani 1988). Under artificial inoculation by root rot pathogens *Helminthosporium sativum* and *Fusarium culmorum*, yield losses as high as 60% were recorded on durum cultivar Marzak in 1989-90 cropping season (Mergoum 1991).

Yield losses due to common root rot of wheat and barley resulted from a reduction in emergence (Verma *et al.* 1976 a; Grey *et al.* 1991; Mergoum 1991; Mergoum *et al.* 1988; 1994), tiller number (Verma *et al.* 1976a; Grey *et al.* 1991; Mergoum,1991; Mergoum *et al.* 1994), number of spikes per plant (Piening 1973; Ledingham *et al.* 1973; Piening *et al.* 1976), spike size (Verma *et al.* 1976a; Weise 1977), number of kernels per spike (Sims *et al.* 1961; Lidingham *et al.* 1973; Verma *et al.* 1976a; Weise 1977; Mergoum 1991; Mergoum *et al.* 994), kernel weight (Sims *et al.* 1961; Lidingham *et al.* 1973; Verma *et al.* 1976; Weise 1977; Mergoum 1991; Mergoum *et al.* 1988), and kernel size (Sims *et al.* 1961). However, the number of tillers per plant and number of kernels per spike appear to be the yield components most affected by root rot in wheat (Verma *et al.* 1973). Wheat kernel protein levels seem to be only slightly affected by root rot (Ismaïl and Michalik 1980). Plants can recover from initial stunting due to early infection by root rot pathogens if favorable environmental conditions occur during the late growth stages (Sallans 1959). Recovery from *F. culmorum* infection was less marked than from *C. sativus* infections and is variable among wheat cultivars. Simultaneous infection of environmental conditions occur during the late growth stages (Sallans 1959). Recovery from *F. culmorum* infection was less marked than from *C. sativus* infections and is variable among wheat cultivars. Simultaneaous infection of wheat seedling with both *F. culmorum* and *C. sativus* caused more initial stunting followed by a greater recovery than with either pathogen alone (Sallans 1965). When severe damage occurs in the crowns, however, the plants will not recover even though under optimum environmental conditions. Recovery depends on the amount of damage caused to crown tissue (Fenster *et al.* 1972).

CAUSAL ORGANISMS

The root rot disease complex of cereals can be caused by one or several organisms, alone or in combination (Statler and drlington 1972). *Cochliobolus sativus* (Ito & Kuribayashi) Drechsler ex Dstur, (conidial stage = *Helminthosporium sativum* Pammel, King and Bakke, Syn. *Bipolaris sorokinianum* (Sacc. in Sorokin Shoemaker), has long been known as an important component of the root rot complex (Verma *et al.* 1974; 1976a; Frank 1985; Specht and Rush 1988).

In addition to *C. sativus*, several species of *Fusarium* including *F. culmorum* (W. G. Smith) Sacc., *F. graminearum* Schwabe; and F. avenaceum (Fr.) Sacc. which are considered the most virulent species, can cause root rot disease alone (Cook 1968a, 1980; 1981; Couture 1982; 1983); or in association with *C.*

sativus (Watking and Kerr, 1980; Scardaci, and Webster 1982; Diehl *et al.* 1982; Hill and Fernandez 1983; Saari and Wilcoxson, 1974). In Morocco, Although, most studies demonstrated that root rot of wheat is caused mainly by *Helminthosporium sativum* and *Fusarium culmorum* (Baye 1988; Lyamani 1988; Mergoum 1991; Houmairi 1993), many prevalent fungi including *F. equiseti*, *F. oxysporum*, *F. solani* and *F. graminearum* were associated with root rot (Lyamani 1988; Houmairi 1993).

SYMPTOMS

Root rot symptoms on cereals may consist of discoloration, necrosis or rotting of roots, subcrown internode, crown, and/or the stem base (Sallans 1965; Watkins and Kerr 1980; stack 1982). Under severe root rot conditions, symptoms such as stunting, late death of tillers, and premature ripening and bleaching of the spikes commonly known as "white heads" or "dead heads" may occur (Walkins and Kerr 1980; Scardaci and Webster 1982; Stack 1982; Lyamani 1988; Mergoum 1991; Mergoum *et al.* 1994). Early infection may result in preemergence and postemergence seedling blight (Butler 1961; Watkins and Kerr 1980).

DISTRIBUTION

Root rot surveys have been extensively conducted in the USA (Fenster *et al.* 1972; Frank 1985; Hill and Fernandez 1983; Grey and Mathre 1984), Canada (Ledingham 1961; 1973; Verma *et al.* 1974; 1976b; Duczeck *et al.* 1985), Australia (McNight and Hart 1966; Wearing and Burgess 1977), Brazil (Diehl *et al.* 1982; Luz 1984), India (Neima and Joshi 1973), England (Snyder and Nash 1968), Italy (Piglionica *et al.* 1975), Hungary (Mesterhazy 1974), France (Cassini 1967), Morocco (Baye 1984; Lyamani 1988), and Poland (Manka *et al.* 1985).

In Colorado and Wyoming (Hill and Fernandez 1983) and in Texas, USA (Specht and Rush 1988), root rot of winter wheat is caused primarily by the association of *C. sativus* and *Fusarium acuminatum*. *F. acuminatum* is more prevalent in the spring and summer (Hill and Fernandez 1983), while *C. sativus* usually infects winter wheat during the fall or early spring.

In Morocco, several species of *Fusarium* are associated with root rot symptoms in addition to *C. sativus* (Lyamani 1988). The most prevalent *Fusarium* species are *F. equiseti*, *F. culmorum*, *F. oxysporum*, and *F. solani*. *C. sativus* and *F. culmorum* are considered the major pathogens causing root rot of spring wheats and barley in Morocco (Baye 1984; Lyamani 1988).

SOURCE OF INOCULUM

The relative importance of seed and soil as sources of inoculum for root rot organisms has been intensively investigated in the cereal growing areas throughout the world. Seed loss surveys conducted in Australia (Chambers 1962), Canada (Ledingham 1961; 1970), England (Hewett 1967), Morocco (Lyamani 1975; 1988), Finland (Ylimaki 1970; Uoti and Ylimaki 1974) andFrance (Cassini 1970) showed that seed infection by root rot pathogens was generally low.

The primary inoculum of *Fusarium* spp. is soil born chlamydospores in plant debris which is localized mainly in the upper 10 cm of the soil. *F. culmorum* exists in the soil as single, double and clumps of chlamydospores free or embedded in organic matter (Cook 1980). *F. graminearum* chlamydospores are more likley to lose viability under high soil temperatures and rapid desiccation than are those of *F. culmorum*. Therefore, mycelium in crop residue appears to be the main form of viable inoculum of *F. graminearum* (wearing and Burgess 1977; Sitton and Cook 1981).

Conidia and/or mycelium in plant debris in or on the soil are the primary survival structures of *C. sativus* (Ledingham *et al.* 1960; Chinn 1976a; 1976b; Weise 1977). *C. sativus* conidia can remain viable in the soil for many years (Ledingham 1970) and therefore, soil born inoculum has a major role in infection (Verma *et al.* 1976b).

SURVIVAL

The thick-walled chlamydospores produced by *F. culmorum* in the soil can survive there for years (Cassini 1970; Sitton and Cook 1981; Williams and Schimitthenner 1962; Inglis and Cook 1986). These spores tend to remain inactive unless hosts are available. This pathogen can also survive as mycelium on plant debris. Both *F. culmorum* and *F. nivale* can infect hosts other than cereals and this may contribute to their prolonged survival in certain fields (Jamalainen 1959).

F. graminearum can also produce chlamydospores under appropriate temperature conditions. Chlamydospores were developed in non-autoclaved soil stored at 21 to 30°C but not at 5 to 11°C (Nyval 1970; Sitton and Cook 1981). However, this fungus survives primarily as mycelium in plant debris (Wearing and Burgess 1977). *F. culmorum* and *F. graminearum* are not good competitors against antagonistic soil fungi. Both colonize plant tissue mainly through the parasitic process (Cook and Bruehl 1968; Cook 1970; Warren and Kommedahl 1973; Wearing and burgess 1977).

C. sativus survives mainly as conidia or as a mycelium in host plant debris. Conidia can survive several years in the soil (Ledingham *et al.* 1960; Ledingham

1970; Weise 1977). *C. sativus* may also be carried through storage on seeds especially under wet conditions during harvest (Williams *et al.* 1980).

VIRULENCE AND COMPETITION

Variability in virulence among isolates of *C. sativus* and *Fusarium* species is well known and was described as a type of physiologic specialization which is common among many fungi. Most isolates of *C. sativus* tested for their pathogenicity to cereal seedlings showed moderate to weak virulence. No differences among these isolates were observed when tested on barley (Kidambi *et al.* 1985).

Studies made on the pathogenicity of *Fusarium* pathogens showed considerable variability in virulence among and within pathogenic *Fusarium* species. *F. culmorum* and *F. graminearum* are strongly virulent and *F. avenaceum* is a weakly virulent, while the remaining *Fusarium* species are non-pathogenic to weakly virulent (Osmald 1949; chambers 1972; Colhoun *et al.* 1968; Uoti 1976a; Mesterhasy 1978; Lyamani 1988). Virulence of *F. culmorum* isolates to both seedling and adult plant under field conditions was greater than that found under greenhouse conditions.

Competition between *Fusarium* species and *C. sativus* in the wheat subcrown internodes has been reported (Tinline 1977). *C. sativus* infection of already colonized subcrowns by *F. culmorum* and *F. acuminatum* is inhibited. *Fusarium*, however, is able to infect and colonize internodes already infected by *C. sativus* (Tinline 1977). Wheat seedlings inoculated with both *F. culmorum* and *F. acuminatum* were shown to enhance the effects of *C. sativus* (Fernandez *et al.* 1958). In some cases however, infection with several fungi was less damaging than single infections.

EPIDEMIOLOGY

Climatic factors

There is a general agreement among workers that soil moisture and temperature are critical factors in root rot desease development.

In the Pacific Northwest region of the USA, root and foot rot of wheat caused by *F. culmorum* is most severe in the 200 to 350 mm annual precipitation, stubble mulched, wheat-fallow areas (Cook 1968 b). Other investigations (Cook and Christen 1967) in the same regions showed that *F. graminearum* and *F. culmorum* both cause foot and root rot of wheat in warm, dry soil. However, *F. graminearum* is associated with slightly warmer and drier soil than *F. culmorum*. The occurrence of severe *Fusarium* crown and root rot of wheat in this region is probably the result of water potentials harmfully low to host physiology but nearly ideal for the pathogen (Cook 1973).

Several reports (Sasi 1980; Sasi *et al.* 1981; Hill 1984) demonstrated the existence of differences in lesion size due to *F. culmorum* among cultivars when wheat seedlings were grown under water stress conditions. Under Moroccan conditions of high root rot incidence and severity, high yield losses were detected during the 1986-87 dry season compared to the wetter 1985-86 season (Lyamani 1988). Similarly, root rot development under water stressed conditions was significantly superior to that scored under irrigated trials in the Moroccan West Central region during 1988-1991 period. White heads scores reached 65% for Durum wheat cultivar Marzak at Tessaout Station (Mergoum 1991; Mergoum *et al.* 1994). Positive correlations have been established between the onset of water stress, foot rot severity, and yield reduction (Papendick *et al.* 1971; Grey *et al.* 1991).

Fungal responses to water potential vary with temperatures (Bruehl and Cunfer 1971; Manandhar and Bruehl 1973). Isolates of *F. culmorum* from different areas exhibit optimum growth at -0,8 to -1,4 Mega Pascal (MPa) at 20 to 30°C and -2,8 MPa at 35°C, (Cook and Christen 1976). Prolonged moisture stress coupled with relatively high soil temperature in the fall are important factors which enhance early development of root rot on the underground plant parts (Fenster *et al.* 1972). Soil temperatures at planting time and subsequent root and crown intensity were strongly correlated. It was concluded that a soil temperature of 65°F at planting time was optimum (Fenster *et al.* 1972). Higher temperatures which usually coincided with early plantings, caused yield losses due to severe root rot. Low temperatures, however, caused less plant development (Fenster *et al.* 1972) and freezing temperatures may predispose wheat plant to damage by fungi normally considered weak such as *F. roseum* types and *C. sativus* (Fernandez *et al.* 1985).

Agronomic factors

Development of plant and soil microflora including root rot pathogens are affected by soil fertilization. There is a general agreement that inadequately nourished wheat and barley seedlings are more disposed to disease attack (Papendick and Cook 1974; Verma *et al.* 1975). On the other hand preliminary studies on the effects of nitrogen on root rot incidence conducted in the Gharb region of Morocco showed that high levels of nitrogen enhanced disease development on wheat (Baye 1984); these results however, conflicted with those obtained in the West Central regions of Morocco (Mergoum 1991). It is believed that excess of nitrogen in cereals enhances root rot severity (Smiley *et al.* 1972) as a result of promoted growth and increased transpiration of plants which rapidly deplete the soil moisture (Garrett 1976; Cook 1980; Patly 1981). Seedling blight caused by *Fusarium* spp. averaged 11 to 14% in the presence of fertilizer (N, P, K) and residues and 1 to 2% when both were absent.

The form of nitrogen fertilizer may influence the severity of many diseases specially of those caused by facultative parasites (Smiley *et al.* 1972). Studies on *Fusarium* root rot (Rowaished 1981) showed that infection and disease severity

was higher in plants supplied with ammonium nitrogen (NH_4) than in those receiving nitrate nitrogen (NO_3). The influence of phosphate fertilizer has also been investigated and results were variable. High soil phosphate levels resulted in limited root rot infection compared to low phosphate levels (Piening *et al.* 1969; Verma *et al.* 1975).

Potassium effects on root rot pathogens are not well defined. While nitrogen and phosphate seemed to decrease disease incidence in early stage of crop growth, potassium tends to enhance it. At later stages however, the roles are reserved, i.e. nitrogen and phosphate tend to increase disease development (Onuorah 1969).

Several investigators have studied the relationship between date of planting and root or crown disease intensity and severity (Fenster *et al.* 1972; Willams *et al.* 1980; Mergoum 1991). In the USA, root and crown rot intensity was the greatest in early planted seeding and progressively diminished with late planting of wheat (Fenster *et al.* 1973; Mergoum 1991). Early planting is related to high soil temperatures. High correlations between soil temperature at planting time and subsequent root and crown rot incidence were established (Willams *et al.* 1980). Early planting results in a depletion of soil moisture because of heavy fall plant growth, thus enhancing root and crown rot disease because of drought stress (Watkinsand and Kerr 1980; Fenster *et al.* 1972; Mergoum 1991).

Seeding rate reported to significantly affect root rot disease developement (Papendick and Cook 1974). Disease severity increased with increased seeding rates. However, no correlation could be detected between disease severity and seeding rate by other workers (Tinline 1986; Broscious and Frank 1986; Mergoum 1991). Similar results were obtained for the effects of spacing and interplanting barley plants on root rot (Piening 1983; Broscious and Frank 1986).

Rotation of crops resulted in more diverse soil microflora including *Fusarium* species (Nash and Snyder 1965; Windel and Kommedahl 1971) compared to monocropping the same crop (Ledingham 1961; Willams and Schmitthenner 1962). Rotations with crops other than wheat, barley, corn, or western ryegrass will reduce the level of root rot in succeeding wheat or barley crops (Cassini 1967; Cook 1968a; Stack 1982; Wildermuth and McNamara 1991).

CONTROL

Chemical

Seed treatments with available chemicals have a limited value for the control of cereal root rot since the pathogens are in the soil and infection can take place after the protective period of the fungicide treatment is over (Colhoum 1972; Watkins and Kerr 1980; Stack 1982; Mergoum 1991). However, seed treatment with an appropriate fungicide may be used to reduce preemergence and

postemergence "damping off" of seedlings (Fenster *et al.* 1972; Watkins and Kerr 1980). Several chemicals have been evaluated for root rot control and have yielded variable results (Burrage and Tinline 1960; Mergoum 1991). Seed treatments with systemic fungicides such as Thiabendazote (Cassini 1967; 1970) and Benomyl + Thiram (Diehl *et al.* 1983) are the most effective fungicides to control *Fusarium* infection. Other fungicides such as Nuarimol and Fenapronil were reported to be effective against *C.sativus* (Dieht *et al.* 1983). Promising results were obtained in controlling root rot in spring wheat by using Triadimenol, Imazalil and Nuarimol (Verma *et al.* 1986). However, Imazalil was effective to reduce significantly root rot winter wheat under Colorado, USA conditions (Mergoum 1991).

Population of *F. culmorum* and saprophytic *Fusarium* were reduced within retention zone following injection of anhydrous ammonia (NH3) into the soil in the field (Smiley *et al.* 1972). Further studies, however, showed small or no reduction of *Fusarium* propagules in the tillage layer when anhydrous ammonia was applied to the soil. This was attributed primarily to insufficient distribution of anhydrous ammonia throughout the tillage layer (Smiley *et al.* 1972).

Biological

Early work (Anwar 1949) on biological control of root rot demonstrated a depressive effect of natural soil microflora on cereal rotting pathogens. *Trichoderma harzianum* was reported to have excellent inhibiting action against both *F. culmorum* and *C. sativus* (Dymovych 1960; Uoti 1976b). However, this microorganism was not effective against root and foot rot pathogens of winter wheat in Colorado, USA (Mergoum 1991). Other organisms including *Pyyronema confluens*, *Penicillium* spp., *Chaetomium cochhoides*, and *Chaetomium globosum* have also shown some degree of biological control of cereal root rot pathogens (Uoti 1976 b).

Cultural practices

The most effective means to control cereal root and crown rot is by good crop management practices which reduce environmental stress, particularly water stress. Crop rotation is an important tool for the farmer to reduce root rot effects (Stack 1982). Rotation to any crop resistant to the causal agent of the disease to allow an appropriate time between successive wheat or barley crops probably will reduce the pathogen populations to a low level (Stack 1982; Baye 1984; Wildermuth and McNamara 1991).

Planting seedbed, tillage which permits the incorporation of the straw residues deep into the soil, the use of large and heavy seeds which produce vigorous plants, and seed treatment with appropriate chemicals may reduce root rot damage (Fenster *et al.* 1972; Williams *et al.* 1980; Watkins and Kerr 1980).

Adequate levels of nitrogen (Ledingham 1970; Smiley *et al.* 1972; Papendick and Cook 1974; Cook 1980) and potassium (Stack, 1982) can contribute to a significant reduction in the root rot severity.

While early planting gives good plant stands, it generally coincides with high soil temperatures and may result in the depletion of soil moisture which enhances disease development. Late planting conserves soil water reserves but may results in poor plant growth which increases the chances of winter injury and "blow out" of plants (Fenster *et al.* 1972; Williams *et al.* 1980; Mergoum 1991).

Genetic resistance

The key to the practical control of root rot appears to lie in the development of resistant cultivars (Sallans and Tinline 1965). Lack of suitable techniques for consistently distinguishing differences in resistance among cultivars and the absence of sources of immunity or resistance are the main obstacles in identifying varieties (Butler 1961; Mergoum 1991). However differences between wheat cultivars was obtained under field conditions with the greatest differences occurring when inoculum was spread alongside the growing plants (Dodman and Wildermuth 1985). Differences in varietal reaction in the field have been demonstrated (Dodman and Wildermuth 1987; Purss 1965; Mergoum 1991; Mergoum *et al.* 1994), but none of the cultivars tested showed evidence of high resistance (Hanson *et al.* 1950; Purss 1965; Mergoum 1991). Selection for yield has undoubtedly eliminated the most susceptible lines, but it has not been successful in improving cultivar resistance enough to prevent yield losses.

Comparisons of the reaction to root rot caused by *C. sativus* and *Fusarium* spp. of 14 lines *Triticum* species revealed the resistance of lines of the diploids *T. aegilopoides* and *T. monococcum* and the susceptibility of lines of the hexaploid *T. compactum*. *T. timopheevi* lines appeared more resistant than those of the other tetraploid species (Harding 1972). Test of 10 cultivars of durum wheat and 10 cultivars of bread wheat demonstrated that although significant differences existed between cultivars, in general durum wheat were the most susceptible (Mergoum 1991; Mergoum *et al.* 1994). However, screening 1130 accessions of durum wheat from the world collection showed the existence of excellent sources of tolerance to root rot in Morocco. Unfortunately, these accessions are in general agronomicaly undesirable and therefore need many genetic improvements (Mergoum *et al.* 1994). Test of the chromosome substitution for the D genome in winter wheat by chromosome 1 to 7 of *Aegilops squarrosa* L. and *Agropyton* species demonstrated that substitution had no consistent effects on root rot severity caused by *C. sativus* (Conner *et al.* 1989). In general, common wheat appears to be more resistant than durum wheat (Cassini 1967; Statler and Darlington 1972; Baye 1984; Mergoum 1991; Mergoum *et al.* 1994).

When both *C. sativus* and *Furarium* root rot pathogens were used as inoculum, there was no high resistance exhibited by any tested wheat genotype (Hanson et al., 1950; Sims *et al.* 1961) although some cultivars showed significant

differences in reaction (Statler and Darlington 1972; Lyamani 1988; Mergoum 1991; Mergoum *et al.* 1988; 1994).

The seedling stage of wheat appeared to be more susceptible than later stages (McNight and Hart 1966; Statler and Darlington 1972; Mergoum 1991). However, some cultivars were severely damaged by *F. roseum* alone or in combination with *C. sativus* at the seedling stage as well as at the adult stage (Statler and Darlington 1972). Other findings confirmed that the degree of resistance to *F. graminearum* infection depends upon cultivars and maturity stage (Schroeder and Christensen 1963).

Studies on the inheritance of varietal reaction to root and crown rot yielded variable results. Evidence of segregation to the disease in the F3 (Hanson *et al.* 1950) and other segregating generation progenies (Sallans and Tinline 1965) was obtained. Reports on the inheritance of root rot resistance in various crosses showed that the reaction was governed by a single gene pair (Arny 1948; 1951; Larson and Atkinson 1981; 1982), or many gene pairs (polygenic) (Cohen *et al.* 1969).

INOCULATION AND SELECTION TECHNIQUES

Selection of resistant cultivars to root pathogens has been hindered by inadequate, inconsistent inoculation methods, and lack of accurate and suitable techniques for measurement of the disease response. Several inoculation techniques have been tried including natural infection (Tinline and Ledingham 1979), incorporation of the inoculum onto or into the soil (Dodman and Wildermuth 1987; 1985; Fernandez *et al.* 1985; Cook 1980), seed inoculation (Grey *et al.* 1991; Dodman and Wildermuth 1987; 1985; Harding 1971, Ismaïl and Michalik 1980; Mergoum 1991; Mergoum *et al.* 1994), spraying the plants with a suspension of conidia (Dodman and Wildermuth 1987), and taping infested wheat straw to the plant subcrown internodes (Tinline 1977). An inoculation method using an agar disc containing conidia of the pathogen was used on roots (Armitage 1984; Hill et al., 1987; Mergoum 1991; Mergoum *et al.* 1988), on leaves (Hill 1984), and on cut stems (Sasi *et al.* 1981).

The incidence and severity of lesioning and discoloration of the subcrown internodes have been used for disease assessment since the above ground symptoms are seldom observed (Ledingham *et al.* 1973; Mergoum 1991). Plants are classified into 4 groups: severe, moderate, slight, and clean depending upon the extent of discoloration of the subcrown internodes.

Disease rating classes from 1 to 4 based on disease severity and percent of diseased plants were elaborated and have been used in several studies to assess yield loss due to root rot (Verma *et al.* 1976b; Tinline and Ledingham 1979; Mergoum 1991). Premature ripening and bleaching of the spikes commonly known as "white heads" or "dead heads" percentages were successfully used in

order to discriminate between reactions of wheat genotypes (Mergoum 1991; Mergoum *et al.* 1994).

Other disease scoring techniques have been used including the percent of diseased plants or tillers (Dodman and Wildermuth 1985; 1987; Lyamani 1988), the ease in pulling plants from the soil (Kommedahl and Patel 1960), seedling reactions (Harding 1971; Hill *et al.* 1987; Mergoum 1991; Mergoum *et al.* 1988), percentage of recovery of disease seedlings (Armitage 1984), changes in amino acids, total protein content, and production of toxic substances which inhibit seedling growth (Ismaïl and Michalik 1980; Rabie *et al.* 1986). All of these techniques have yielded variable and inconsistent results and have not been effective in differentiating small quantitative differences in disease resistance among genotypes.

REFERENCES

Anwar, A.A. (1949). Factors affecting the survival of *Helminthosprium sativus* and *Fusarium lini* in soil. *Phytopath.* **39**, 1005-19.

Armitage, C.R. (1984). Quantitative assessment of wheat seedling root infection by *Fusarium acuminatum*. M. S. thesis. Colorado State University. Fort Collins.

Arny, D.C. (1984). Inheritance of resistance to spot blotch of barley. (Abstr) *Phytopath.* **38**, 1.

Arny, D.C. (1948.) Inheritance of resistance to spot blotch of barley seedlings. *Phytopath.* **41**, 691-8.

Baye, Y. (1984). Les pourritures racinaires des céréales: comportement variétal, influence de la fertilisation azotée. Mémoire de troisième cycle. Institut Agronomique et Vétérinaire Hassan II, Rabat, Maroc.

Broscious, S.C., and Frank, J.A. (1986). Effects of crop management practices on common root rot of winter wheat. *Plant Dsease* **70**, 857-9.

Bruehl, G.W., and Cunfer, B. (1971). Physiologic and environmental factors that affect the severity of snow mold of wheat. *Phytopath.* **61**, 792-9.

Burgess, L.W., Wearing, A.H., and Toussoun, T.A. (1975). Survey of *Fusaria* associated wih crown rot of wheat in eastern Australia. *Aust. J. Agric. Res.* **26**, 791-9.

Butler, F.C. (1961). Root and foot rot diseases of wheat. *Sci. Bull. Dep. Agric. N. S. W.* **77**,98 pp.

Cassini, R. (1967). A propos des dégats provoqués par *Fusarium roseum* (Link) Sn. et H. dans les cultures de céréales du bassin Parisien. Académie d'Agriculture de France. Extrait du Procès Verbal de la séance du 21 Juin 1967.

Cassini, R. (1970). Sur l'importance de la contamination des semences dans l'apparition et le développement de la maladie du pied des céréales dûe au *Fusarium roseum* (Link) Sm. et H. Ann. Acad. Sci. Fenn. A, In *Biologica* **168**, 28-30.

Chambers, S.C. (1962). Root diseases in wheat on clover leaf. Factors under investigation. 1. The role of oats after hay. *Journal of the Department Of Agriculture, Western Asustralia* **3**, 299.

Chambers, S.C. (1972). *Fusarium* species associated with wheat in Victoria. *Australian Journal of Experimental Agriculture and Animal Husbandry* **12**, 433-6.

Chinn, S.H.F. (1976a). Influence of rape in a rotation on prevalence of *Cochliobolus sativus* conidia and common root rot of wheat. *Can. J. Plant Sci.* **56**, 199-201.

Chinn, S.H.F. (1976b). *Cochliobolus sativus* conidia population in soils following various cereals crops. *Phytopath.* **66**, 1082-4.

Cohen, E., Helgason, S.B., and Donald, M.C. (1969). A study of factors influencing the genetics of the reaction of barley to root rot caused by *Helminthosporium sativum*. *Can. J. Bot.* **47**, 429-443.

Colhoum. J. (1972). Control of *Fusarium* diseases of cereals. *Ann. Agri. Fenn.* **11**, 292-7.

Colhoum, J., Taylor, G.S., and Tomlinson, R. (1986). Fusarium disease of cereals. II. Infection of seedlings by *F. culmorum* and *F. avenaceum* in relation to environmental factors. *Trans. Trans. Br. Mycol. Soc.* 51 (3 and 4), 397-404.

Conner, R.L., Whelan, E.D.P., and MacDonald, M.D. (1989). Identification of sources of resistance to common root rot in wheat - alien amphiploid and chromosome substitution lines. *Crop Sc.* **29**, 916-9.

Cook, R.J. (1968a). Influence of oats on soil-borne populations of *Fusarium* roseum f. sp. cerealis "*culmorum*". *Phytopath.* **58**, 957-60.

Cook, R.J. (1968b). *Fusarium* root and foot rot of cereals in the Pacific Northwest. *Pystopath.* 58, 127-31.

Cook, R.J. (1970). Factors affecting saprophytic colonization of wheat straw by *Fusarium roseum* f.s.P. *cerealis "culmorum"*. *Phytopath.* **6**, 1672-6.

Cook, R.J. (1973). Influence of low plant and soil water potentials on disease caused by soil borne fungi. *Phytopath.* **63**, 451-8.

Cook, R.J. (1980). *Fusarium* foot rot of wheat and its control in the Pacific Northwest. *Plant Dis.* **64**, 1061-6.

Cook, R.J. (1981). *Fusarium* diseases of wheat and other small grains in North America. In " *Fusarium*: Diseases, Biology, and Taxonomy ". (P.E. Nelson, T.A. Toussoun, and R.J. Cook, eds). Pages 39-55. Pennsylvania State Univ. Press, Univ. Park.

Cook, R.J., and Bruehl, G.W. (1968). Relative significance of parasitism *versus* saprophytism in colonization of wheat straw by *Fusarium roseum* "*culmorum*" in the field. *Phytopath.* **58**, 306-8.

Cook, R.J., and Christen, A.A. (1976). Growth of cereal foot-rot fungi as affected by temperature - water potential interactions. *Phytopath.* **66**, 193-7.

Couture, L. (1982). Receptivité des cultivars de céréales de printemps à la contamination des graines sur inflorescence par les *Fusarium* spp. *Can. J. Plant Sci.* **62**, 29-34.

Couture, L. (1983). Rendement en grains de parcelles de céréales de printemps originant de semences contaminées par des *Fusarium* spp. *Can. J. Plant Sci.* **63**, 617-21.

Diehl, J.A., Tinline, R.D., Kochhann, R.A., Shipton, R.J., and Rovira, A.D. (1982). The effect of fallow periods on common root rot wheat in Rio Grande do Sul, Brazil. *Phytopath.* **72**, 1297-130.

Diehl, J.A., Picinnini, E.C., Sartari, J.F., and Ferandes, J.M.C. (1983). Influence of seed treatment with fungicides on the control of common root rot of wheat. *Fitopatologia Brasileira* **8**, 06.

Dodman, R.L., and Wildermuth, G.B. (1985). Field resistance of wheat cultivars to crown rot (*Fusarium graminearum* Group 1). *In* "Ecology and management of soilborne pathogens". (Eds C.A. Parker, A.D. Rovira, K.J. Moore, and P.T.W. Wong) pp. 172-3 (Am. Phytopathol. Soc.: Minnesota, USA).

Dodman, R.L., and Wildermuth, G.B. (1987). Inoculation methods for assessing resistance in wheat to crown rot caused by *Fusarium graminearum* Group 1. *Aust. J. Agric. Res.* **38**, 473-86.

Duczek, L.J., Verma, P.R., and Spurr, D.T. (1985). effect of inoculum density of *Cochliobolus sativus* on common root rot of wheat and barley. *Can. J. Plant Pathol.* **7**,382-6.

Dymovych, V.O. (1960). The effect of volatile antibiotics of cultures of various species of *Trichoderma* on phytopathogenic bacteria and fungi. [In Ukranian]. Mikrobiol. Zhur. A Kad. Nank Ukrain. R. S. R. 22, 32-8; *Biol. Abst.* **39**, 249. 1962.

Fenster, C.R., Boosalis, M. G., and Weihing, J.L. (1972). Date of planting studies of winter wheat and winter barley in relation to root and crown rot, grain yields and quality. *Neber. Agric. Exp. Res. Bull.* **250**.

Fernandez, J.A., Wofford, D.S., and Horton, J.L. (1985). Interactive effects of freezing and common root rot fungi on winter wheat. *Phytopath.* **75**, 845-7.

Frank, J.A. (1985). Influence of root rot on winter survival and yiedls of winter barley and winter wheat. *Phytopath.* **75**, 1039-41.

Garrett, S. D. (1976). Influence of nitrogen on cellulolysis rate and sporophytic survival in soil of some cereal root rot fungi. *Soil Biol. Biochem.* **8**, 229-34.

Grey, W.E., and Mathre, D.E. (1984). Reaction of spring barleys to common root rot and its effect on yield components. *Can. J. Plant Sci.* **64**, 245-53.

Grey, W.E., Engel, R.E., and Mathre, D.E. (1991). Reaction of spring barleys to common root rot under several moisture regimes: Effect on yield components, plant stand, and disease severity. *Can. J. Plant Sc.* **71**, 461-72.

Hanson, E.W., Ausemus, E.R., and Stakman, E.C. (1950). Varietal resistance of spring wheats to fusarial head blight. *Phytopath.* **40**, 902-14.

Harding, H. (1971). Effect of *Bioolaris sorokiniana* on germination and seedling survival of varieties or lines of 14 *Triticum* species. *Can. J. Bot.* **49**, 281-7.

Harding, H. (1972). Reaction to common root rot of 14 *Triticum* species and the incidence of *Bioolaris sorokiniana* and *Fusarium* spp. in subcrown internode tissue. *Can. J. Bot.* **50**, 1805-10.

Hewett, P.D. (1967). A survey of seed borne fungi of wheat. II. The incidence of common species of *Fusarium*. *Trans. Br. Mycol. Soc.* **50** (2), 175-82.

Hill, J. P., 1984. Quantitative disease assessment of wheat seedling leaves inoculated with *Fusarium roseum "culmorum"*. Phytopath. 74: 665-667.

Hill, J.P., and Fernandez, J.A. (1983). Fungi associated with common root rot of winder wheat in Colorado and Wyoming. *Plant Dis.* **67**, 795-6.

Hill, J. P., Armitage, C.R., Autzman-Eades, D., and Hanchey, P. (1987). Surface disinfestation of wheat seed and inoculation of seedling roots with single macroconidia of *Fusarium acuminatum*. *Plant Dis.* **71**, 130-1.

Houmairi, H. (1993). Contribution à l'étude des pourritures racinaires des céréales: comportement variétal; rotation et pratiques culturales, étude de la pathogénie de *Fusarium esuiseti*. Thèse de DES de troisième cycle. Université Cadi Ayyad, Faculté des Sciences Semlalia, Marrakech.

Inglis, D.A., and Cook, R.J. (1986). Persistence of chlamydospores of *Fusarium culmorum* in wheat fields of Eastern Washington. *Phytopath.* **76**, 1205-08.

Ismaïl, L. M. K., and Michalick, I. (1980). Proteins and amino acids in shoots and roots of some wheat cultivars before and after infection with *Heminthosporium sativus*, Pam., King et Bakke. *Egypt. J. Bot.* **23 (3)**, 145-60.

Jamalainen, E.A. (1959). Overwintering of Graminea plants and parasitic fungi; III. Isolations of *Fusarium nivale* from gramineous plants in Finland. *Maatal. tiet. Aikak.* **31**, 282-4.

Kiddambi, R.D., Lutz, A.L., and Van Alfen, N.K. (1985). Disease progress and epidemiology of crown rot of spring in Utah. *Can. J. Plant Pathol.* **7**, 233-7.

Kommedahl, T., and Patel, K.P. (1966). A method of rating wheat varieties in the field for resistance to common root rot. *Plant Dis. Res.* **50 (1)**, 26-7.

Large, E.C. (1954). Growth stages in cereals, illustration of the Feekes scale. *Plant Path.* **3**, 128-9.

Larson. R., and Atkinson, T.G. (1981). Reaction of wheat to common root rot: identification of a major gene, crr, on chromosome 5B. *Can. J. of genet. and Cytol.* **3**, 173-82.

Larson. R., and Atkinson, T.G. (1982). Reaction of wheat to common root rot: Linkage of a major gene, crr, with the centromere of chromosome 5B. *Can. J. of genet. and Cytol.* **24**, 19-25.

Ledingham, R.J. (1961). Crop rotation and common root rot in wheat. *Can. J. Plant Sci.* **41**, 479-86.

Ledingham, R.J. (1970). Effects of straw and nitrogen on common root rot of wheat. *Can. J. Plant Sci.* **50**, 175-9.

Ledingham, R.J. (1973). Wheat losses due to common root rot in the prairie provinces of Canada, 1969-71. *Can. Plant Dis. Survey* **53**, 113-22.

Ledingham, R. J., Sallans, B.J., and Wenhardt, A. (1960). Influence of cultural practices on incidence of common root rot in wheat in Saskatchewan. *Can. J. Plant Sci.* **40**, 310-6.

Ledingham, R.J., Atkinson, T.G., Horricks, J.S., Mills, J.T., Piening, L.J., and Tinline, R.D. (1973). Wheat losses due to common root rot in the prairie provinces of Canada, 1969-71. *Can. Plant Dis. Surv.* **53**, 113-22.

Luz, W.C. (1984). Yield losses caused by fungal foliar wheat pathogens in Brazil. *Phytopath.* **74 (12)**, 1403-7.

Lyamani, A. (1975). Etude de la mycoflore associée aux semences de blé et orge au Maroc. Mémoire de troisième cycle. Instiut Agronomique et Vétérinaire Hassan II. Maroc.

Lyamani, A. (1988). Wheat root rot in West Central Morocco and effects of *Fusarium culmorum* and *Hesminthosporium sativum* seed and soil-borne inoculum on root rot developement, plant emergence and crop yield. Ph. D. Thesis. Iowa state University. Ames.

Manka, M., Visconti, A., Chelkowski, J., and Bottalicer, A. (1985). Pathogenicity of *Fusarium* isolates from wheat, rye, and triticale toward seedlings and their ability to produce trichothecenes and Zearalenone. *Phytopathol. Z.* **113**, 24-9.

Manandhar, J.B., and Bruehl, G.W. (1973). In vitro interactions of *Fusarium* and *Verticilium* wilt fungi with water, pH, and temperature. *Phytopath.* **63**, 413-9.

McKnight, J.B., and Hart, J. (1966). Some field observations on crown rot disease of wheat caused by *Fusarium graminearum*. Queensl. **J. Agric. Anim. Sci. 23**, 373-8.

Mergoum, M. (1991). Effects of *Fusarium Acuminatum, Fusarium Culmorum*, or *Cholchliobolus Sativus* on Wheat. Ph. D. Dissertation. Colorado State University. 146 pp.

Mergoum, M., and Quick, J.S. (1988). Adult Plant Response to Infection of Winter Wheat Seedling Roots by *Fusarium acuminatum*. p. 89. In Agronomy Abstracts. ASA, Anaheim, CA. USA.

Mergoum M., Hill, J.P., and Quick, J.S. (1988). Quantitative Adult Plant Response to Infection of Winter Wheat Seedling Roots by Single Macroconidia of *Fusarium acuminatum*. p. 495. In Phytopathology Abstracts. APS, CA. USA.

Mergoum M., Quick, J.S., and Nsarellah, N. (1994). Root rot of Wheat: Inoculation techniques and Effects on Yield and its Components under Varying Water and Nitrogen Levels in Morocco. *Al Awamia* (In press).

Mergoum, M., Nsarellah, N., and Nachit, M. (1994). Screening Durum Wheat for Root Rot Diseases (*Cochliobolus sativus*and *Fusarium culmorum*) in Moroccan Dryland. In Agronomy Abstracts, ASA, Sealte, WA, USA.

Merrill, W. (1977). Theory and concepts of plant pathology. Pennsylvania State University Press, The Penn. State Universoty, University Park, PA.

Mesterhazy, A. (1974). *Fusarium* diseases of wheat and triticale in South East Hungary. *Cereal Res. Comm.* **2**, 167-73.

Mesterhazy, A. (1978). Comparative analysis of artificial inoculation methods with *Fusarium* spp. on winter wheat varieties. *Phytopath. Z.* **93**, 12-25.

Nash, M.S., and Snyder, W.C. (1965). Quantitative and qualitative comparisons of *Fusarium* populations in cultivated fields and non-cultivated parent soils. *Can. J. Bot.* **43**, 939-45.

Neima, K.G., and Joshi, I. (1973). Spot blotch disease of wheat in relation to hostage temperature and moisture. *Indian Phytopath.* **26**, 41-8.

Nyvall, R.F. (1970). Chlamydospores of *Fusarium roseum "graminearum"* as survival structures. *Phytopath.* **60**, 1175-7.

Onourah, P.E. (1969). Effect of mineral nutrition on the *Fusarium* brown foot rot of wheat. *Plant and soil* **30**, 99-104.

Oswakd, J.W. (1949). Cultural practices and infections crop diseases. Springerverlag. Berlin. 249 p.

Papendick, R.I., and Cook, R.J. (1974). Plant water stress and development of *Fusarium* foot rot in wheat subjected to different cultural practices. *Phytopath.* **64**, 358-63.

Papendick, R.I.,Cook, R.J., and Shipton, P.J. (1971). Plant water stress and the development of *Fusarium* foot rot in wheat. *Phytopath.* **61**, 905.

Piening, L.J. (1973). Differential yield response of 10 barley cultivars to common root rot. *Can. J. Plant Sci.* **53**, 763-4.

Piening, L.J. (1983). Effects of seed spacing on common root rot of some barley cultivars. *Can. J. Plant Sci.* **63**, 611-6.

Piening, L. J., Edwards, R., and Walker, D. (1969). Effects of some cultural practices on root rot of barley in Central Alberta. *Can Plant Dis. Surv.* **49**, 95-7.

Piening, L.J., Walkuz, D.R., and Dagenais, M. (1983). Effect of fertilizer on root rot of barley on stubble and follow land. *Can. J. Plant Pathol.* **5**, 136-9.

Piening, L.J., Atkinson, T.G., Horricks, J.S., Lendingham, R.J. Mills, J.T., and Tinline, R.D. (1976). Barley losses due to common root rot in the prairie provinces of Canada, 1970-72. *Can. J. Plant Dis.* Surv. **56**, 41-5.

Piglionica, V., Gigante, F. and Frisullo, S. (1975). Cereal diseases in Southern Italy. II. *Fusarium roseum* f. sp. *cerealis* on *durum wheat. Phytopathol. Mediterr/* **14**, 60-8.

Purss, G.S. (1965). Studies of varietal resistance to crown rot of wheat caused by *Fusarium graminearum* schw. Queens. *J. Agric. Anim. Sci.* **23**, 475-97.

Purss, G.S. (1970). Resistance to common root rot (*Cochliobolus sativus*) in wheat in Queensland. *Aust. J. Exp. Agric. and Anim. Husb.* **10**, 497-501.

Rabie, C.J., Sydenham, E.W., Thiel, P.G., Lubben, A., and Marasas, W.F.O. (1986). T-2 toxin production by *Fusarium acuminatum* isolated from oats and barley. *Appl. Env Microbiol.* **52**, 594-6.

Reed, H.E. (1952). Cereal root-rot studies in Tennesse. *Phytopath.* **42**, 287.

Rowaished, A.K. (1981). The influence of different forms of nitrogen on *Fusarium* root rot desease of winter wheat seedlings. *Phytopath. Z.* **100**, 331-9.

Saari, E.E., and Wilcoxson, R.D. (1974). Plant disease situation of High-yielding dwarf wheats in Asia and Africa. *Ann. Rev. Phytopathol.* **12**, 343-51.

Saalns, B.J., (1959). Recovery in Wheat from early infections by *Helminthosporium sativus* and *Fusarium culmorum. Can. J. Plant Sci.* **39**, 187-93.

Sallans, B.J. (1965). Root rots of cereals 3. *The Botanical Review* **31 (4)**, 505-35.

Sallans, B.J., and Tinline, R.D. (1965). Resistance in wheat to *Cochliobolus sativus*, a cause of common root rot. *Can. J. plant Sci.* **45**, 343-51.

Sasi., G.M. (1980). Fusarium foot rot of wheat varietal responses. M.S. thesis. Colorado State University, Fort Collins.

Sasi, G., Hill, J.P., and Baker, R. (1981). Effect of soil matric potential on infection of wheat by two *Fusarium roseum* cultivars. *Phytopath.* **71**, 253.

Scardaci, S.C., and Webster, R.K. (1982). Common root rot of cereals in California. *Plant Dis.* **66**, 31-4.

Schrœder, H.W., and christensen, J.J. (1963). Factors affecting resistance of wheat to scab caused by *Gibberella Zea. Phytopath.* **53**, 831-8.

Sims, H.J. Meagher, J.W., and Millikan, C.R. (1961). Dead heads in wheat field studies in Victoria. *Australian Journal of Experimental Agriculture and Animal Husbandry* **1**, 99-108.

Sitton, J.W., and Cook, R.J. (1981). Comparative morphology and survival ability of Clamydospores of *Fusarium roseum culmorum* and *graminearum. Phytopath.* **71**, 98-100.

Smiley, R.W., Cook, R.J., and Papendick, R.I. (1972). Fusarium foot rot of wheat and peas as influenced by soil application of anhydrous ammonia and ammonia-potassium azide solutions. *Phytopath.* **62**, 86-91.

Snyder, W.C., and Nash, S.M. (1968). Relative incidence of *Fusarium* pathogens of cereal in rotation plots at Rothamsted. *Trans. Br. Mycol. Soc.* **51**, 317-425.

Specht, L.D., and Rush, C.M. (1988). Fungi associated with root and foot rot of winter wheat and populations of *Bioolaris sorokiniana* in the Texas panhandle. *Plant Dis.* **72**, 959-63.

Stack, R.W. (1982). Root and crown rots of small grains. Cooperative Extension Service, Ext. Circular PP-785, North Dakota state University.

Statler, G.D., and Darlington, L.C. (1972). Resistance of hard red spring wheat and durum wheat to seedling blight and crown rot. *Plant Dis. Res.* **56** (**9**), 788-92.

Tinline, R.D. (1986). Agronomic practices and common root rot in spring wheat: Effect of depth and density of seedling disease. *Can. J. Plant Pathol.* **8**, 429-35.

Tinline, R.D. (1977). Multiple infections of subcrown internodes of wheat (*Triticum aestivum*) by common root rot fungi. *Can. j. Bot.* **55**, 30-4.

Tinline, R.D., and Ledingham, R.J. (1979). Yield losses in wheat and barley cultivars from common root rot in field tests. *Can. J. Plant. Sci.* **59**, 313-20.

Uoti, J. (1976a). Pathogenicity studies with *Fusarium culmorum* (W. G. S. M) Sacc. *Ann. Agric. Fenn.* **15**, 267-71.

Uoti, J. (1976b). The effect of five *Fusarium* species on the growth and development of spring wheat and barley. Ann. Agri. Fenn. 15: 254-262. US. Department of Agriculture. 1979. Cooperative Plant Pest report. 4 (13).

Verma, P.R., Morall, R.A.A., and Tinline, R.D. (1973). Epidemiology of common root rot of wheat. Proc. 2nd Int Congr. Plant Pathol. Minneapolis. MN. (Abstr No 177).

Verma, P. R., Morall, R.A.A., and R. D. Tinline. (1974). The epidemiology of common root rot in Manitou wheat. Disease progression during the growing season. *Can. j. Bot.* **52**, 1757-64.

Verma, P.R.,Tinline, R.D. and Morall, R.A.A. (1975). The epidemiology of common root rot in Manitou wheat. II. Effects of treatments, particularly phosphate fertilizer, on incidence and intensity of disease. *Can. J. Bot.* **53**, 1230-8.

Verma, P.R., and Morall, R.A.A., and Tinline, R.D. (1976a). The effect of common root rot on components of grain yield in Manitou wheat. *Can. J. Bot.* **54**, 2888-92.

Verma, P.R., Morall, R.A.A., and Tinline, R.D. (1976a). The epidemiology of common root rot in Manitou wheat. IV. Appraisal of biomass and grain yield in naturally infected crops. *Can. j. Bot.* **54**, 1656-65.

Verma, P. R., Spurr, D.T., and Sedum, F.S. (1986). Effect of triadimenol, imazalil and nuarimal seed treatment on subcrown internode length, coleoptile-node-tillering and common root rot in spring wheat. *Plant and soil* **91**, 133-8.

Warren, H.L., and Kommedahl, T. (1973). Fertilization and wheat refuse effects on *Fusarium* species associated with wheat roots in Minnesota. *Phytopath.* **63**, 103-8.

Watking, J.E., and Kerr, E.D. (1980). Root and crown rot of winter wheat. Neb Guide G80-483.

Wearing, A.H., and Burgess, L.W. (1977). Distribution of *Fusarium roseum* graminearum" group 1 and its mode of survival in eastern Australian wheat belt soils. *Trans. Br. Mycol. Soc.* **69** (**3**), 423-42.

Wiese, M.V. (1977). Compendium of wheat diseases. A. P. S., St. Paul, MN. 112 pp.

Wildermuth, G.B., and McNamara, R.B. (1991). effects of cropping history on soil populations of *Bioolaris sorokiniana* and common root rot of wheat. *Aust. J. Agric. Res.* **41**, 1-10.

Williams, L.E., and Schmitthenner, A.F. (1962). Effect of crop rotation on soil fungus populations. *Phytopath.* **52**, 241-6.

Williams, Jr. E., Singleton, L.L., and Russell, C.C. (1980.) Wheat root rots, O. S. U., Extension No. 7622.

Windels, C.F., and Kommedahl, T. (1971). Comparisons of *Fusarium* spp and populations in cultivated and non cultivated soils. (Abstr). *Phytopath.* **61**: 1026.

Wlimaki, A. (1970). The microflora of cereal seeds in Finland. *Ann. Agri. Fenn.* **9**, 293-5.