African Crop Science Journal
African Crop Science Society
ISSN: 1021-9730 EISSN: 2072-6589
Vol. 10, Num. 1, 2002, pp. 67-79

African Crop Science Journal, Vol. 10. No. 1, 2002, pp. 67-79

EFFECT OF STUBBLE MANAGEMENT, TILLAGE AND CROPPING SEQUENCE ON THE SEVERITY OF TAKE-ALL AND EYESPOT DISEASES OF WHEAT

ASEFA TAA, D.G. TANNER[1] and A.T.P. BENNIE[2]

Kulumsa Research Center, Ethiopian Agricultural Research Organization (EARO), P.O. Box 489, Asella, Ethiopia
[1]CIMMYT/CIDA Eastern Africa Cereals Program, P.O. Box 5689, Addis Ababa, Ethiopia
[2]Department of Soil Science, University of the Orange Free State, P.O. Box 339, Bloemfontein 9300, Republic of South Africa

(Received 2 May, 2001; accepted 8 September, 2001)

Code Number: cs02007

ABSTRACT

Bread wheat (*Triticum aestivum* L. em Thell) is affected by several soil- and stubble-borne diseases in Ethiopia, including take-all and eyespot, which often necessitate instituting control. In this study, the efect of stubble management, tillage and cropping sequence on the severity of these diseases was investigated. Four multi-factor crop management trials were initiated in 1992 at two research sites in the south-eastern highlands of Ethiopia. Two trials were established at each site: one based on tractor and the other on ox-plough tillage. A three year rotation, consisting of two consecutive crops of wheat following one crop of faba bean, reduced the severity of take-all, but had little effect on eyespot severity. Conservation tillage decreased take-all severity relative to conventional tillage, but had no effect on eyespot severity. Stubble burning did not exhibit a consistent effect on the severity of either disease. However, full stubble retention relative to partial removal increased eyespot severity. The interactions among the three crop management factors were seldom significant for either disease. Rotation of wheat with faba bean should be recommended as a means of minimising take-all severity. The adoption of conservation tillage practices for wheat production in Ethiopia should not be hindered for fear of spreading these specific trash-borne diseases, although, full stubble retention could increase the severity of eyespot.

Key Words: Conservation tillage, *Pseudocercosporella herpotrichoides* (Fron) Dei., *Triticum aestivum*

RÉSUMÉ

Le blé des pains (*Triticum aestivum* L. em Thell) est affecté par plusieurs maladies due à la couverture de chaume en Ethiopie. Elles incluent le 'take-all' et l'ocelle nécéssitant un contrôle établit. Dans cette étude, les effets de la gestion de la couverture de chaume, labourage et la séquence des cultures sur la sévérité de ces maladies étaient examinés. Quatre essais à facteurs multiples de gestion des plantes étaient initiés en 1992 dans deux sites des recherches dans le sud-est de la région montagneuse d'Ethiopie. Deux essais étaient établis à chaque site, l'un basé sur le labourage par tracteur et l'autre le labourage à boeufs. Une rotation éffectuée après trois ans sur deux cultures consecutives de blé suivie par une culture d'haricots faba, a réduit la sévérité du 'take-all', mais a eu peu d'effets sur l'ocelle. Le labourage destiné à la conservation a diminué la sévérité relative du 'take all' par rapport au labourage conventionel, mais sans produire des effets sur l'ocelle. La brulure du chaume n'a pas exhibé des effets consistants en sévérité et 'take-all' et de l'ocelle. Cependant, la retention relative à l'enlèvement partiel l'ocelle a augmenté sa sévérité. Les interactions parmi les trois facteurs de gestion de plantes étaient rarement significatives pour l'une ou l'autre maladie. La rotation entre le blé et l'haricot faba devrait être recommende comme un moyen de minimiser la sévérité du 'take-all'. L'adoption des pratiques du labourage conservatif pour la production du blé en Ethiopie ne devrait pas être entravée par peur de l'éparpillement de ces maladies, même si une complète rétention de l'ocelle pourrait augmenter la sévérité de cette dernière.

Mots Clés: Labourage conservatif, *Pseudocercosporella herpotrichoides* (fron) Dei., *Triticum aestivum*

INTRODUCTION

Take-all (*Gaeumannomyces graminis* var. *tritici* Walker) and eyespot (*Pseudocercosporella herpotrichoides* (Fron) Dei.) are economically important diseases of small grain cereals in many regions of the world. However, bread wheat (*Triticum aestivum* L. em Thell.) is regarded as the most susceptible host for both diseases (Wiese, 1977; Zogg, 1980).

Wheat plants infected by take-all disease exhibit bleached spikes, uneven plant height, and irregular maturity (Wiese, 1977; Zogg, 1980). A black-brown dry rot extends to the crown and basal portion of the culm, while a superficial, dark, shiny mycelial plate beneath the lowest leaf sheath is diagnostic. When roots and crowns are damaged by take-all to the extent that symptoms such as "white heads" are obvious, grain yields are often reduced by 50% or more (Bockus, 1983). Wheat plants infected by eyespot exhibit elliptical or "eye" shaped lesions on the basal portion of the stem, and a greyish, cottony mycelium inside the internode is diagnostic (Wiese, 1977). Yield reduction often occurs when half of the circumference of the stem is girdled by an eyespot lesion (Scott and Hollins, 1974).

Although both diseases appear to be prevalent in wheat fields, few studies of potential control measures have been conducted in Ethiopia: one study reported wheat yield losses of up to 29% due to eyespot infection, which was exacerbated due to carryover of inoculum on infected stubble (Eshetu and Yitbarek, 1983). Since the pathogens are soil- and trash-borne, crop residue is an important inoculum carrier (Jenkyn and Plumb, 1981). Thus, stubble management practices can dramatically alter the severity of disease caused by soil- and trash-borne pathogens (Jenkyn and Plumb, 1981).

Conservation tillage (CT) commonly involves the retention of crop stubble on the soil surface, as a result of reduced tillage operations. As a general principle, CT combined with stubble retention, reduces the risk of soil erosion and increases water infiltration and storage in the soil profile (Harte and Armstrong, 1983). However, the retention of stubble residues on the soil surface has frequently been associated with an increased incidence of crop pests and diseases (Moore and Cook, 1984; Throckmorton, 1986; de Boer *et al*., 1993).

Rotation and cropping sequence experiments in wheat-based cropping systems improves wheat yield and sustains productivity in Ethiopia (Tanner *et al*., 1999). The interruption of weed, disease and insect life cycles is one of the important benefits generally cited as an advantage accruing from crop rotation (Herrman and Wiese, 1985).

The effects of stubble management (SM), tillage, and cropping sequence (CS) practices on stubble- and soil-borne diseases of wheat have not been adequately addressed in Ethiopia. Thus, a study was undertaken to examine the effects of the above agronomic practices on the severity of take-all and eyespot diseases of wheat in Ethiopia.

MATERIALS AND METHODS

Experimental sites. Four crop management trials were initiated during 1992 at the Kulumsa (8°02' N, 39°10' E) and Asasa (7°08' N, 39°13' E) research sites, located in the south-eastern highlands of Ethiopia at altitudes of 2200 and 2360 m above sea level, respectively. Both sites are located in the M2 agro-ecological zone of Ethiopia: tepid to cool, moist highland. The long-term mean monthly minimum and maximum temperatures during the main cropping season (June-November) are 10.6 and 22.1°C at Kulumsa, and 6.7 and 22.7°C at Asasa. Mean precipitation during the main season is 504 mm at Kulumsa and 472 mm at Asasa. The soil type at Kulumsa is clay loam (an intergrade between an eutric Nitisol and a luvic Phaoezem), whereas the Asasa soil is sandy loam (calcic Chernozem).

Trial design. Two trials were located at each site: one mechanised and the other ox-ploughed. The mechanised trial consisted of 12 treatments in a complete factorial combination of: (a) three levels of post-harvest SM-stubble burning, partial stubble removal (50%), and complete retention of stubble; (b) two levels of tillage, namely, zero (ZT) and conventional tillage at Kulumsa, and minimum tillage (MT) and conventional tillage at Asasa, and; (c) two levels of CS: continuous wheat and one year of faba bean (*Vicia faba*) followed by two years of wheat.

The ox-plough trial consisted of: (a) two levels of post-harvest (SM - stubble burning and partial removal (50%); (b) two levels of tillage (MT and conventional tillage), and; (c) two levels of CS (continuous wheat and one year of faba bean) followed by two years of wheat.

For each trial, all treatments were laid out in a split-split-plot arrangement, in a randomised completed block design, with three replicates. The SM treatments were allocated to main plots of 20 m x 20 m, tillage to sub-plots of 10 m x 20 m, and CS to sub-sub-plots of 5 m x 20 m in 1992.

Crop management practices. In the mechanised trials, conventional tillage consisted of one pass with a tractor-drawn disc plough, followed by two passes with a disc harrow during the "short rains" fallow period, in order to maximise weed control. At Kulumsa, a tractor-drawn "Aitchison Seedmatic 3000" zero-till drill was used to sow seed plus basal fertiliser for the conventional tillage and ZT treatments. However, in the mechanised trial at Asasa, one pass with a disk harrow was used to incorporate broadcast seed and fertiliser for the MT and conventional tillage treatments.

In the ox-plough trials, conventional tillage consisted of four ploughings prior to sowing similar to farmers' practice, while for MT, one pass was done to incorporate the broadcast seed and fertiliser.

For the MT and ZT treatments, chemical fallow was practised during the "short rains" period each year: glyphosate was applied at 720 g active ingredient (a.i.) ha^{-1} as required during the "short rains" season to prevent weeds from attaining a height of 20 cm with a maximum of two applications per season.

Partial stubble removal simulated grazing by removing 50% of post-harvest crop stubble. Thus, approximately 500 kg ha^{-1} of stubble remained on the soil surface at sowing time. Straw burning was done during late January each year before the "short rains". Plots with complete stubble retention were left undisturbed until spraying or tillage operations began; more than 2 t ha^{-1} of stubble remained on the soil surface at sowing time.

Zone-specific recommended cultural practices for the non-experimental crop management factors were adopted for bread wheat and faba bean during the trial period. Over the trial period (1992 - 1999), sowing dates ranged from June 11 to 19 at Asasa and from June 26 to July 7 at Kulumsa. As per the initial trial plan, the best recommended crop cultivars were utilised each season. This was particularly important for bread wheat since some cultivars succumbed to new races of foliar rust (*Puccinia* spp.) pathogens during the course of the trial. Thus, over the trial duration, the bread wheat cultivars Enkoy (1992-93), Mitike (1994), and Qubsa (1995-99) were sown at a seed rate of 150 kg ha^{-1}. From 1992-94, bread wheat received a basal N application of 41 kg ha^{-1} at Kulumsa and 18 kg ha^{-1} at Asasa. From 1995-99, newly-recommended fertiliser rates were implemented, and bread wheat received a basal N application of 82 kg ha^{-1} at Kulumsa and 41 kg ha^{-1} at Asasa.

During 1992, 1995, and 1998, faba bean cultivar CS20DK was sown at a seed rate of 200 kg ha^{-1}; for faba bean, basal N was applied at a rate of 18 kg ha^{-1} at both Kulumsa and Asasa. Both crops received a basal application of 20 kg P ha^{-1} each year. Due to the risk of damage by spray drift, hand-weeding was used during 1992, 1995, and 1998 when both wheat and faba bean were sown. During 1993, 1994, 1996, 1997 and 1999, when all plots were sown to wheat, weed control strategies consisted of a post-emergence herbicide spray application of a tank mix of fenoxaprop-P-ethyl + fluroxypyr + MCPA at 0.069 + 0.175 + 1.0 kg a.i. ha^{-1}, respectively.

Disease assessment. The severity of take-all and eyespot was estimated in the 1994, 1996, 1997 and 1999 cropping seasons for each plot in each trial. Samples of main stems and tillers were collected for disease assessment immediately after harvest. Random samples were collected by traversing a "W" pattern across each sub-sub-plot. After washing and drying the samples, a minimum of 80 crowns from each sub-sub-plot were assessed for disease symptoms.

Eyespot severity was assessed using a 0-3 rating scale (Scott and Hollins, 1974) where 0 = crowns with no infection, 1 = slight infection (1-10% of crowns infected), 2 = moderate infection (11-40% of crowns infected), and 3 = severe infection (>41% of crowns infected). If eyespot lesions were not clearly visible, the internodes were split and checked for internal growth of a typical greyish, cottony mycelium. The number of crowns in each severity class was recorded, and a weighted percent severity score for eyespot was calculated for each sub-sub-plot using the following formula: (100 x S([number of crowns in each severity class] x [the severity class rating])) ÷ ([total number of crowns scored] x 3).

Take-all severity was assessed on the same sampled crowns using a 0-5 rating scale (Scott, 1969). By this scale, 0 = crowns with no infection, 1 = trace infection (1-5% of crowns infected), 3 = moderate infection (11-30% of crowns infected), and 5 = severe infection (61-100% of crowns infected). A weighted percent severity score for take-all was calculated following the formula: (100 x S([number of crowns in each severity class] x [the severity class rating])) ÷ ([total number of crowns scored] x 5).

Statistical analysis. Disease severity scores were subjected to statistical analysis after square root transformation (weighted percent severity score + 0.5). Transformation was necessary to achieve homogeneity of variance among treatments.

For both diseases, analyses of variance were calculated separately for each trial and year as well as combining the data for each trial across four years. For significant factor interactions, interaction means were separated using the least significant difference (LSD) test at $P \leq 0.05$ level, unless otherwise specified.

For each of the 16 data sets included in the study (i.e., four trials by four years), simple pair-wise correlations were calculated among grain yields, and take-all and eyespot severity on a sub-sub-plot basis. Data were analysed using MStatc computer package.

RESULTS

Take-all severity. The results of the combined analyses of variance for take-all severity (Tables 1 and 2) revealed that the year effect accounted for a high proportion of total variability, reflecting both a pronounced environmental effect on the severity of the disease and changes in the wheat cultivar sown over the trial duration. However, no consistent trends were apparent: take-all severity was highest during the 1999 season for three trials, but was highest in 1994 for the Asasa mechanised trial (Table 2). Mean take-all severity was similar across locations included in this study (Table 2).

Stubble management practice had no significant effect on take-all severity in any of the four trials, and SM by year interaction was also not significantly influenced by location (Table 1).

Tillage practice exerted a significant effect on take-all severity in three of the trials (Table 1), and, in each case, tillage by year interaction was not significant. Conventional tillage (CT) significantly reduced the severity of take-all in the mechanised trials at both locations, but the reduction was more pronounced at Asasa [MT] than at Kulumsa [ZT] (Table 2). In the ox-plough trials, MT reduced the severity of take-all at Kulumsa but not at Asasa.

Cropping sequence affected take-all severity in the ox-plough trial at Kulumsa; the main effect of CS was highly significant, while CS by year interaction was not significant (Table 1). Take-all severity was reduced in wheat following a faba bean precursor crop, including both the first and second consecutive wheat crops following faba bean, relative to the disease level recorded in continuous wheat (Table 2).

The main effect of CS was obscured in both mechanised trials by the significant interaction of CS with year (Table 1). Take-all severity was lower in wheat following faba bean during 1994 at Asasa and during 1996 at Kulumsa, but were higher during 1999 at Kulumsa (Table 3). No significant effect of CS on take-all severity was apparent for the remaining five site-season combinations.

The two-way interaction effects among SM, tillage and CS were non-significant in all four trials (Table 1); however, the three-way interaction effect, SM by tillage by CS , was significant in the two trials at Kulumsa. The 12 three-way interaction means for take-all in the mechanised trial at Kulumsa (Table 4) revealed that stubble burning, combined with conventional tillage, markedly increased take-all severity in wheat grown in rotation with faba bean. Nonetheless, the main effect of tillage was apparent in the 12 interaction means; the three lowest levels of take-all were associated with CT. The inconsistency of the effect of cropping sequence effects were also apparent within this set of interaction means. In contrast, the eight interaction means for the ox-plough trial at Kulumsa more clearly demonstrated the disease-reducing effects of CT and of rotation with faba bean.

Eyespot severity. The results of the combined analyses of variance for eyespot severity (Table 5) revealed that year effect is the major component of total variability, reflecting environmental influences on pathogenicity and cultivar differences in susceptibility. As was the case for take-all severity, there was no apparent trend over time for eyespot severity (Table 6); although eyespot severity was highest in 1999 for all four trials, two trials exhibited similar disease levels in 1994, while another trial exhibited a similar high disease level in 1997.

Stubble management main effects on eyespot severity were not significant in three trials, while in the Kulumsa mechanised trial the SM effect was obscured by the significant year by SM interaction (Table 5). In the Kulumsa mechanised trial, full retention of crop stubble increased eyespot severity relative to partial removal in 1996 and 1999, and increased disease severity relative to stubble burning in 1996 and 1997 (Table 7). In 1994, SM effects on eyespot severity were not significant. In the ox-plough trial at Asasa, SM effects were inconsistent: the SM effect was not significant in 1996 and 1997; in 1994, eyespot severity was higher under partial removal relative to stubble burning; a reverse response to burning was observed in 1999 (Table 7).

Tillage main effect and tillage by year interaction were not significant in most cases (Table 5): the exceptions, and then only at the 10% level of significance, were tillage in the Kulumsa ox-plough trial and tillage by location interaction in the Kulumsa mechanised trial. In the Kulumsa ox-plough trial, MT modestly reduced the severity of take-all. In the Kulumsa mechanised trial, ZT increased the severity of eyespot in 1997, while in the other three years there was no significant effect of tillage.

The SM by tillage effect was the only significant two-way interaction affecting eyespot severity (Table 5); SM by tillage interaction was highly significant in the Kulumsa mechanised trial and, to a lesser extent, in the Asasa ox-plough trial. Although the highest levels of eyespot in the Kulumsa mechanised trial occurred under complete stubble retention (Table 8), the disease severity under complete retention did not differ from stubble burning with conventional tillage or partial removal of stubble with ZT. In the Asasa ox-plough trial, conventional tillage with stubble burning resulted in the lowest eyespot severity, but was not significantly different from MT with partial removal of stubble.

The cropping sequence main effect and CS by year interaction were not significant for both ox-plough trials. For the mechanised trials, however, significance was observed for the CS by year interaction (Table 5). Essentially, these significant interaction effects were attributed to the Asasa trial in 1996 and the Kulumsa trial in 1999. In both trials, however, eyespot severity was increased in wheat in rotation with faba bean and the effect of CS was not significant for the other six site-season combinations (Table 9).

The three-way interaction effect - SM by tillage by CS - was only significant in the Kulumsa ox-plough trial (Table 5). The eight three-way interaction means for eyespot severity in the Kulumsa ox-plough trial (Table 10) revealed that straw burning combined with conventional tillage in wheat, in rotation with faba bean, resulted in the lowest absolute level of eyespot; however, this level of eyespot did not differ significantly from the disease severity in the four treatments involving CT.

Simple correlations. The simple correlations (Table 11), calculated for individual plot disease scores and grain yields within each site-season combination, revealed that the severity of take-all and eyespot increased concurrently. The two diseases exhibited significant positive associations in ten site-season combinations vs. a negative association in only one site-season. In general, take-all severity was negatively related with wheat grain yield; significant negative correlations were observed in five site-seasons but no positive associations occurred. Conversely, eyespot severity was not strongly correlated with wheat grain yield; however, the association was positive in three site-seasons, suggesting that factors conducive to grain yield also enhanced eyespot severity.

DISCUSSION

The traditional tillage practice of peasant farmers in Ethiopia involves multiple passes with an ox-plough over the three to four month period prior to sowing (Tanner *et al*., 1999). Heavy rainfall may occur during this period, leading to serious erosion. In recent years, a growing awareness of the importance of sustaining soil productivity has increased interest in soil and water conservation *via* CT-based crop production systems (Lal, 1989). However, Scott (1969) reported that cultivation significantly reduces the number of white heads caused by take-all in wheat, and concluded that this was probably due to enhanced microbial activity in the well-aerated mixture of soil and stubble. Moore and Cook (1984) reported that the best control of take-all in wheat is by thorough tillage. They also suggested that early loosening of ploughed soil hastened the decline of the take-all fungus relative to more compact soil under zero tillage. In addition, the inoculum may be concentrated in the crown zone in ZT soil, whereas the inoculum in tilled soil is more diffusely distributed throughout the tillage zone. Cook and Waldher (1977) reported equal eyespot severity for both an uncultivated mulch and mould-board ploughed soil. Herrman and Wiese (1985) showed that eyespot severity was highest in ploughed plots, intermediate in MT plots, and least common in ZT plots. In the current study, CT clearly reduced the severity of take-all, but had little or no effect on the level of eyespot disease. Thus, the adoption of CT for wheat production in Ethiopia is not expected to adversely affect the incidence of these two trash-borne diseases of wheat.

The effects of either retaining or burning crop stubble on the severity of take-all and eyespot vary widely in literature. In Australia, burning stubble prior to sowing did not affect the severity of take-all in continuously-cropped ZT wheat (de Boer *et al*., 1992), but reduced the level of take-all in wheat sown after lupins (Murray *et al*., 1991). In the UK, burning stubble prior to cultivation did not affect the severity of take-all compared with ploughing under stubble (Slope *et al*., 1970). In Australia, Kollmorgen *et al*. (1987) reported that stubble mulching effectively reduced the survival of take-all in buried straw. Eyespot was reported to be more prevalent where residues were either retained on the surface or incorporated in the soil (Murray *et al*., 1991), but was also reported to have been unaffected by burning prior to ploughing (Slope *et al*., 1970). de Boer *et al*. (1993) reported the highest severity of eyespot associated with stubble retention in continuously-cropped ZT wheat. Burning of wheat stubble, on the other hand, reduced the severity of the disease in the uncultivated plots to negligible levels; burning substantially reduced the severity of affected plants, but did not eliminate the disease (de Boer *et al*., 1993). They also showed that conventional tillage, combined with stubble burning, resulted in high eyespot levels comparably to levels of direct sowing into stubble, presumably because cultivation brought previously-buried, infected crop debris to the surface. In the current study, SM had no apparent effect on the severity of take-all; however, full stubble retention increased eyespot severity relative to partial removal of stubble. Thus, wheat production with full stubble retention, particularly under CT practices, may have an adverse effect on the level of eyespot disease of wheat in Ethiopia.

Cropping sequences may influence the inoculum density of residue-borne pathogens (Sutton and Vyn, 1990). Production of wheat in a sequence with non-host crops may suppress wheat pathogens by: allowing more time for the organisms to decline in residues, modifying the residue microclimate, or through other effects (Sutton and Vyn, 1990). de Boer *et al.* (1993) reported that rotation of wheat with leguminous crops reduces the level of inocula of take-all and eyespot relative to continuously cropped wheat. In the current study, CS had no consistent effect on the severity of eyespot; however, inclusion of faba bean in the wheat-based rotation dramatically reduced the severity of take-all relative to continuous wheat. Thus, rotation with faba bean can be promoted as one component of an integrated approach to control take-all disease of wheat in Ethiopia.

ACKNOWLEDGMENTS

This study was financially supported by the Ethiopian Agricultural Research Organization (EARO), in co-operation with the CIMMYT/CIDA Eastern Africa Cereals Programme. The authors are grateful to Dr. Amanuel Gorfu, Messrs. Kefyalew Girma, Shambel Maru, Mekonnen Kassaye, Tamirat Belay and Workiye Tilahun for assistance in conducting the experiment and data collection.

REFERENCES

- Bockus, W.W. 1983. Effects of fall infection by *Gaeumannomyces graminis* var. *tritici* and triadimenol seed treatment of take-all in winter wheat. *Phytopathology* 73:540-543.

- Cook, R.J. and Waldher, J.T. 1977. Influence of stubble mulch residue management on *Cercosporella* foot rot and yield of winter wheat. *Plant Disease Reporter* 61:96-100.
- de Boer, R.F., Steed, G.R. and MacAuley, B.G. 1992. Effects of stubble and sowing treatments on take-all of wheat in north eastern Victoria. *Australian Journal of Experimental Agriculture* 32:641-644.
- de Boer, R.F., Steed, G.R., Kollmorgen, J.F. and MacAuley, B.G. 1993. Effects of rotation, stubble retention and cultivation on take-all and eyespot of wheat in northern Victoria, Australia. *Soil and Tillage Research* 25:263-280.
- Eshetu Bekele and Yitbarek Semeane. 1983. Occurrence of eyespot and preliminary loss assessment study in wheat and barley around Holetta, Ethiopia. *Ethiopian Journal of Agricultural Science* 5:97-107.
- Harte, A.J. and Armstrong, J.L. 1983. Stubble management for soil conservation in northern New South Wales. *Journal of Soil Conservation in New South Wales* 39:134-141.
- Herrman, J. and Wiese, M.V. 1985. Influence of cultural practices on incidence of foot rot in winter wheat. *Plant Disease* 69:948-950.
- Jenkyn, J.F. and Plumb, R.T. 1981. *Strategies for the Control of Cereal Disease.* Federation of British Plant Pathologists, London, England.
- Kollmorgen, J.F., Ridge, J. and de Boer, R.F. 1987. Effects of tillage and straw mulches on take-all of wheat in northern Wimmera of Victoria. *Australian Journal of Experimental Agriculture* 27:419-423.
- Lal, R. 1989. Conservation tillage for sustainable agriculture: Tropical versus temperate environments. *Advances in Agronomy* 42:85-197.
- Moore, K.J. and Cook, R.J. 1984. Increased take-all of wheat with direct drilling in the Pacific Northwest. *Phytopathology* 74:1044-1049.
- Murray, G.M.M., Heenan, D.P. and Taylor, A.C. 1991. The effect of rainfall and crop management on take-all and eyespot of wheat in the field. *Australian Journal of Experimental Agriculture* 31:645-651.
- Scott, P.R. 1969. Control of *Ophiobolus graminis* between consecutive crops of winter wheat. *Annals of Applied Biology* 63:47-53.
- Scott, P.R. and Hollins, T.W. 1974. Effect of eyespot on the yield of winter wheat. *Annals of Applied Biology* 78:269-279.
- Slope, D.B., Etheridge, J. and Callwood, J.E. 1970. The effect of flame cultivation on eyespot disease of winter wheat. *Plant Pathology* 19:167-168.
- Sutton, J.C. and Vyn, T.J. 1990. Crop sequences and tillage practices in relation to diseases of winter wheat in Ontario. *Canadian Journal of Plant Pathology* 12:358-368.
- Tanner, D.G., Verkuijl, H., Asefa Taa and Regassa Ensermu. 1999. An agronomic and economic analysis of a long-term wheat-based crop rotation trial in Ethiopia. In: *The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa.* pp. 213-248. CIMMYT, Addis Ababa, Ethiopia.
- Throckmorton, R.I. 1986. Tillage and planting equipment for reduced tillage. In: *No-tillage and surface tillage agriculture.* Sprague, M.A. and Triplett, J.A. (Eds.), pp. 19-55. John Wiley and Sons, New York.
- Wiese, M.V. 1977. *Compendium of Wheat Diseases.* American Phytopathological Society, St. Paul, Minnesota, USA.
- Zogg, H. 1980. Seedling blights, root and foot rots of wheat. In: *Wheat.* Häfliger, E. (Ed.), pp. 56-58. Ciba-Geigy Ltd., Basle, Switzerland.

THE FOLLOWING IMAGES RELATED TO THIS DOCUMENT ARE AVAILABLE:

PHOTO IMAGES

[cs02007t10.jpg] [cs02007t9.jpg] [cs02007t4.jpg] [cs02007t3.jpg] [cs02007t8.jpg] [cs02007t11.jpg] [cs02007t2.jpg] [cs02007t7.jpg] [cs02007t1.jpg] [cs02007t6.jpg] [cs02007t5.jpg]