Table of Contents

Contents

Temporal progress and development of common rust of maize (*Puccinia sorghi* Schw.) and its effect on yield and yield components of hybrid maize varieties in eastern Ethiopia

*Zelalem Bekeko,*School of Plant Sciences, Haramaya University P.O. Box 138, Dire Dawa, Ethiopia*

Abstract

Under favorable environmental conditions, common rust of maize is the most devastating foliar disease of maize. West Hararghe middle lands, Eastern Ethiopia are hot spot areas for the development of the disease. Field experiments were conducted to determine the temporal development of common rust and its effect on grain yield and yield components on hybrid maize varieties at Haramaya University, Chiro Campus, during the 2013 and 2014 cropping seasons. The experiment was arranged in split plot design with three replications under natural epidemics. A contact fungicide Mancozeb (75%WP) at different rates (control, 1.5, 3.0, 4.5 and 6.0 kg ha^{-1}) was applied five times at every seven days during the experimental period. Data on agronomic and disease parameters were recorded from the middle two rows. From the combined analysis of variance, maize varieties showed significant differences with reaction to common rust of maize, indicating the existence of genetic variability among the selected varieties. Up to 65% and 52% common rust severity levels were recorded on the varieties BH-140 and Shone, respectively. There was also a significant difference in the overall mean of common rust severity, incidence and Area under Disease Progress Curve(AUDPC) values among the varieties and spray intervals. On BH-140 and Shone common rust was progressing at rate of 0.0850 and 0.0352 units per day, respectively. Critical point model was found to be better than multiple point model and AUDPC values in estimating the relationships between common rust severity and yield as well as most of the yield components(R^2=96). The disease resulted in grain yield loss of up to 45%, 42% and 10% on BH-140, Shone and BH-660, respectively. Maximum yield reduction of 45% and severity of 65% were recorded from the unsprayed plots. In conclusion, application of Mancozeb at a rate of (4.5 and 6.0 kg ha^{-1}) contributed in the reduction of the effect of the disease and its temporal development on maize varieties in sprayed plots. Therefore, an integrated disease management strategy (fungicide and host resistance) should be employed in managing this disease in the study area.

Keywords: maize; Puccinia sorghi; epidemics; fungicide; disease progress rate; models; AUDPC; yield

Introduction

Common maize rust (*Puccinia sorghi* Schw.) is one of the major and most important foliar diseases of maize in most parts of the major maize-producing areas of the world including Ethiopia. It is a widely spread disease mostly recorded from 1500-2000 m.a.s.l. It reaches devastating severity in some years, while being mild in others. The disease has been repeatedly reported from east Africa, Asia, Australia, Canada, Latin America, Mexico and USA (Schieber, 1965a). Distribution and pathogenesis of *P. sorghi* on maize in Africa is a greater importance in Ethiopia in particular and East Africa in general than the aggressive tropical rust (*P. polysora)*. In the highlands of Ethiopia and Kenya, *P. sorghi* severely attacks local maize varieties starting from the first leaf stage (Schieber, 1965b; Nestsanet, 2005).

Maize is the major host of *Puccinia sorghi*. The alternate host of this pathogen is *Oxalis corniculata* (Dey *et al.*, 2012). The uredial stage, which is responsible for repeated cycles of infection, is adapted from cool to moderate temperature conditions wherever early morning dews predominate. As a result, the disease is serious in areas where cool to moderate temperatures and high relative humidity prevail. It is reported that the maximum and minimum mean temperatures of 13 and 24 ^{o}C are within the optimum range for common maize rust development and spore germination during the main season (Fininsa, 2001). The optimum temperature for common maize rust infection ranges from 16 to 23^{o}C (Fininsa, 2001). In the tropics, common maize rust tends to cycle endemically on higher altitudes.

Puccinia sorghi is macrocyclic, heteroecious rust. The most important spore stage is the uredospore, which is the repeating stage of the fungus. The pathogen has high variability for virulence, as numerous virulence phenotypes (races) identified on differential lines are known to exist. It is considered to be obligate parasite, i.e., it survives on living maize plants or the alternate hosts only (Agrios, 2005). Since the spores are windblown, transmission may occur over long distances, leading to rapid spread of the disease.

Several methods (cultural, chemical and host resistance) are available to manage common maize rust, but none has been totally satisfactory. Attempts have been made to manage common maize rust through cleaning up of alternate hosts, cultural practices, and use of chemicals (Assefa *et al.*, 2012). Breeding for disease resistance has been done in U.S.A. Although breeders have followed different approaches to achieve greater efficiency and higher yield, no common rust of maize resistance breeding program was executed in Ethiopia. However, materials exhibiting best yields were evaluated for disease resistance (Tewabech, 1992; Dagne *et al*., 2008; Asfaw *et al.,* 2012).

Currently, cultural methods depend largely on the use of early planting and intercropping of maize with other crops. Delayed planting may increase the disease pressure on maize as the late-planted hybrids are still in the susceptible whorl stages in the later part of the season. Consequently, late planted fields may develop heavy epidemic (Daniel *et al*., 2008). However, onset of rainy season, which dictates planting time, is not the same every year in Ethiopia. Hence, changing date of planting may or may not be helpful in controlling the disease. In intercropping systems, common maize rust spreads slowly from the infected to healthy plants (Fininsa, 2001). Experimental results from Bako research site showed that intercropping of maize with haricot bean resulted in low common maize rust severity as well as better economic return from the crops (Tewabech *et al.,* 2012). Assefa and Tewabech (1993) also reported that maize intercropped with sweet potato showed reduced levels of common maize rust intensity when both crops were planted at the same time. Integrating early planting with reduced maize density in intercropping and educating the users about the scheme may offer an option to manage common maize rust. In addition, diversity in the cultivars grown can provide substantial benefits to farmers (Tewabech *et al*., 2012).

The use of fungicides for management of common maize rust has been studied for many years and certain chemicals have been found to be effective. These fungicides include the C- 14 demethylation inhibitors, isomerase and reductase inhibitors, succinate dehydrogenase inhibitors and complex III inhibitors, which are being used for managing rusts caused by *Puccinia* spp. in different crops. According to Assefa et. al. (1997), a combined application of mancozeb and propiconazole at the rate of 2 kg a.i (active ingredient) per ha each (2 to 3 applications at ten-day interval) effectively controlled common rust. Earlier Zineb and Maneb were recommended for the management of common rust and spraying these fungicides against common rust gave 28 g increase in thousand-kernel weight (Teclemariam, 1985; Heller *et al*., 1990 and Reuveni, *et al.,* 1994). Experimental evidence indicated that older, mature tissue is resistant; however, younger tissue or tissue with delayed maturation is more susceptible. In susceptible varieties, the fungus grows extensively, sporulates abundantly and the lesions increase in size and this is usually accompanied by the development of a yellow halo. In most resistant reactions, the fungus causes only chlorosis, but occasionally small pustules may also develop. In some resistant genotypes, rapid cell necrosis or hypersensitivity occurs and very limited fungal growth is seen (Van Dyke and Hooker, 1969a).

In Hararghe areas, the prevailing weather conditions are conducive for common rust of maize development. The recently introduced hybrid maize varieties are more susceptible to rust under Hararghe conditions than the locally adapted ones. This can affect the livelihood of maize consumers in the highlands of Hararghe (Bekeko, 2013; Abate *et al*., 2016). This might be due to the fact that the hybrid varieties may not have resistance gene(s) against prevailing *P. sorghi* races in the area or the conditions are more favorable to development of common rust of maize. Although the race composition of *P. sorghi* is not known from this region, variability in virulence and pathogenicity cannot be ruled out (Fininsa, 2001). Integration of fungicides and host resistance helps in managing foliar diseases of maize such as the common rust. No matter how this disease is the most economically important foliar disease of maize in the eastern parts of Ethiopia, integration of varietal resistance and fungicides in managing the disease and its effect on the temporal development, empirical yield loss and effects of the disease on morpho-agronomic parameters of the hybrid maize varieties deployed for production into the eastern part of the country is not systematically investigated. Therefore, the objectives of this investigation were to determine the temporal progress and development of common rust of maize and its effect on yield and yield components of hybrid maize varieties at West Hararghe Zone, Eastern Ethiopia.

Materials and Methods

Description of Study Areas

West Hararghe is located between 7° 55'N to 9° 33'N latitude and 40° 10'E to 41°39'E longitude. The major crops grown in the study area are sorghum, maize, chat, coffee, field beans, potato and tef. The area is characterized by the Charcher Highlands having undulating slopes and mountainous in topography. The mean annual rainfall ranges from 850 to 1200 mm/year with minimum and maximum temperatures of 12 and 27°C, respectively.

Description of Experimental Materials

Twelve treatment combinations consisting of six varieties and one fungicide were used. The six maize varieties used were BH-140, BH-660, Shone, BH-540, Raare and Melkasa-4. BH-660 and BH-140 grow at an altitude of 1600-2200 m.a.s.l. and their potential yields are 9000-12000 and 9500-12000 kg ha^{-1}, respectively, and BH-540, BH-140 and Raare grow at an altitude of 1800-2200 m.a.s.l. and their potential yields are 8000-9000, 8500-11000 and 8500-11500 kg ha^{-1},respectively, under good management conditions at research station.

Treatments and Experimental Design

The fungicide Mancozeb was sprayed five times at seven-day interval or unsprayed based on the following treatment combinations:

1) BH-660+Unsprayed
2) BH-540+Unsprayed
3) Raare+Unsprayed
4) BH-140+Unsprayed
5) Shone+Unsprayed
6) Melkassa-4+Unsprayed
7) BH-660+ Mancozeb sprayed
8) BH-540+ Mancozeb sprayed
9) Raare+ Mancozeb sprayed
10) BH-140+ Mancozeb sprayed
11) Shone+ Mancozeb sprayed
12) Melkassa-4+ Mancozeb sprayed

Experimental Procedures

Treatments were arranged in a factorial experiment using split plot design (varieties were assigned to subplots and the fungicide as main plots to control drift problem while spraying) with three replications. Each plot consisted of four rows of 5.1 m long spaced at 75 cm apart. The distance between adjacent hills was 30 cm. At planting, two seeds were placed per hill and were thinned to one plant after ensuring good establishment. A 100 kg ha^{-1} nitrogen fertilizer was applied in two splits; half at planting and the rest at 37 days after emergence. Urea and diammonium phosphate were used as sources of nitrogen and phosphorus fertilizers, respectively. All the trial management practices were based on the recommendation for the location. Cultural weed control (including hoeing) practices and slashing were performed for all plots as deemed necessary (Daniel *et al*., 2008).

Fungicide Applications

Mancozeb 75% WP (Dithane M-45) @ 3 g/lt at 2.6 kg ha^{-1} was applied using knapsack sprayer of 15 litres capacity. Control plots were sprayed with water only in the same manner with that of fungicide sprayed plots to prevent the differences among plots because of moisture. The fungicide was applied five times at 7 days interval starting from the time lesions were visible on the three to five basal leaves of the susceptible variety, i.e. with about 2-3% rust incidence. The number of times of application of the fungicide varied according to the length of the period between the initiation of infection and crop physiological maturity (Ward *et al*., 1997a).

Data Collection

Disease parameters

Disease incidence

Appearance of the disease in the experimental plots was inspected at seven-day interval. Initial scoring for disease incidence was conducted when lesions were visible on the three to five basal leaves of the plants. The number of plants infected in each plot was recorded four times every seven days and their means were converted into percentage as the total plant observation (Wilkinson, 1969).

Disease severity

Severity was recorded on ten randomly tagged plants per plot. It was assessed using the 1-5 standard disease scoring scale recommended by Roan *et al*. (1974) (1 for very slightly infected, one or two restricted lesion on lower leaves or trace; 2 for slightly to moderate infection on lower leaves, a few scatter lesions on lower leaves; 3 for abundant lesions on lower leaves, a few on middle leaves; 4 for abundant lesions on lower and middle leaves extending to upper leaves; and 5 for abundant lesions on all leaves, plant may be prematurely killed by blight). The rating was made at seven-day interval starting at about 2-3% infection on the lower leaves of the susceptible variety (BH-140). Then, the severity grades were converted into percentage severity index (PSI) for analysis using the formula developd by Wheeler (1969) as follows:

$$\text{PSI} = \frac{\text{Numerical rating } \times 100}{\text{Total no of plants observed } \times \text{maximum rating}}$$

Area under the disease progress curve (AUDPC)

The disease severity scores were used to calculate infection rate and AUDPC for each treatment. AUDPC was calculated with the formula suggested by Shaner and Finney (1977):

$$AUDPC = \sum_{i=1}^{n-1} 0.5(x_{i+1} + x_i)(t_{i+1} - t_i)$$

Where, x_i is the cumulative disease severity expressed as a proportion at the i^{th} observation, t_i is the time (days after sowing) at the i^{th} observation and n is total number of observations. Since common rust severity was expressed in percent and time (t) in days, AUDPC values were expressed in %-days (Wilcoxson *et al*., 1975). AUDPC values were then used in analysis of variance (ANOVA) to compare amounts of disease among plots with different treatments. Logistic equation, ln [(Y/1-Y)], (Van der Plank, 1963; Madden *et al*., 2007) was used for estimation of infection rate from each treatment.

Agronomic data

Days to 50% tasseling: This was recorded as the number of days after emergence to the time when 50% of the plants emerged protruded tassels.

Days to maturity: This was recorded as the number of days after sowing to when 90% of the plants in a plot form black layer at the point of attachment of the kernel with the cob.

Ear height: Heights of ten pre-tagged plants in the central rows of each plot were measured in centimetre as height between the bases of a plant to the insertion of the top ear of the same plant.

Plant height: Heights of ten pre-tagged plants in the central rows of each plot were measured in centimetre as height between the bases of a plant to the position of the anthesis point.

Number of ears per plant: Number of ears per plant of ten tagged plants was counted from each plot.

Ear length: Ear length of ten pre-tagged plants was measured from base of ear to tip of ear from each plot.

Stand count at harvest: The stand count was determined by counting from the central four rows of each plot just at the time of harvesting. Total stand count per net plot area was converted into total stand count per hectare.

Thousand kernel weight: Kernels were drawn randomly from each plot, counted using Jap-144066/02 seed counter machine, and weighed in grams using sensitive balance.

Yield per plot and per hectare: Total grain yield from the four middle rows was determined and adjusted to 12.5% moisture content.

Data Analysis

Analysis of variance

Data on common rust of maize incidence and severity from each assessment date, yield and yield components, AUDPC and all agronomic data were subjected to analysis of variance (ANOVA) using SAS. Mean separation was made based on the LSD at the 5% probability level.

Results and Discussions

Temporal progress and development of common rust of maize

From the combined analysis of variance, maize genotypes showed significant differences with reaction to common rust of maize, indicating the existence of genetic variability among the selected varieties (Table 1). The analysis of variance also indicated the existence of significant differences among the fungicide treatments and the hybrids on the temporal development of the common rust epidemics in the study area (Table 1). Smaller water-soaked spots were first observed on the lower leaves of the susceptible variety (Melkassa -4). Early lesions on leaves are small, circular to elongate, and often occur in clusters. Even if the symptoms of CRM (common rust of maize) were observed a week after disease onset, they were not easily distinguishable from lesions caused by other foliar pathogens on maize. The pustules quickly rupture to several masses of rusty-red to brown spores and these on maturity turn blackish-brown because of replacement of uredospores by teliospores (Agrios, 2005). However, symptoms vary depending on the susceptibility of the variety, age of the host, part of the plant infected and spore stage of the rust. Similarly Dey *et al*. (2012) reported that symptoms started appearing as slightly oval, water soaked, small elliptical yellowish green colored spots on the leaves in the initial stage. But in due course, such spots extended along the length of the leaf becoming enlarged.

As lesions mature, the fungus erupts through the leaf surface (epidermis) and the lesions become more elongated. At this stage, a prominent yellow halo is usually evident. Brownish-red oblong pustules are the characteristic symptom on leaves; uredinospores that rub off on fingers are what impart the color to the lesion. Disease symptoms vary by hybrid susceptibility. Hybrids with resistance to CRM such as BH-660 and BH-540 typically produced fewer and smaller lesions and fewer fungal spores. On hybrids with race-specific resistance, lesions are smaller and yellow and produce no spores.

Table 1: Mean values of the effects of fungicide application and hybrid maize varieties on temporal development of Common Rust of Maize at Chiro using critical point model in 2013 and 2014 main cropping season (May to November).

Factor	**Initial incidence (%)**[1]	**Final incidence (%)**[1]
Fungicides		
Unsprayed	13.50a	95.00a
Mancozeb	10.25a	65.80b
CV%(a)	**17.50**	**2.05**
LSD (5%)	**4.20**	**15.75**
Varieties		
BH-140	50.50b	88.50b
Raare	55.70a	91.65a
BH-540	15.55b	55.25bc
BH-660	12.70b	40.25bc
Shone	55.85b	88.75c
Melkassa-4	48.35a	95.60a
CV%(b)	**10.55**	**12.25**
LSD (1%)	**18.90**	**17.85**

Disease severity

Severity of all maize varieties showed a significant ($p \leq 0.01$) difference at all assessment dates, where the susceptible variety Melkassa-4 exceeded all other varieties starting from first date of disease assessment. At first date of disease assessment (initial disease development), the severity on Melkassa -4 was the highest (36.75%) score and the lowest (20.55%) severity was that of the moderately resistant variety BH-660 (Table 2). In most resistant reactions, the fungus causes only chlorosis, but occasionally small pustules may also develop. In some resistant genotypes, rapid cell necrosis or hypersensitivity occurs and very limited fungal growth is seen (Van Dyke and Hooker, 1969a and Kim *et al*., 1976).

The severity of main plot effects (due to fungicides) showed significant differences at the 69 DAP, 76 DAP, 83 DAP and last assessment dates. At 69 DAP assessment date, the CRM percent severity (45.65%) on the untreated plot was significantly ($p \leq 0.05$) different from that of the Mancozeb (22.52%) treated plots (Table 2). At 76 DAP, 83 DAP and last assessment dates, the main plot effects showed highly significant ($p \leq 0.01$) difference in severity scores, in which the untreated plot exceeded the all other treated plots. In the final severity, there were significant differences among fungicide, varieties and two-way interaction effects of fungicide by varieties. The main plot severity (65%) of untreated plot was higher than that of Mancozeb (24.5%) treated-plots.

The varietal effects (sub-plot treatment means averaged over all main plot treatments) of the last severity scoring were highly significant ($p \leq 0.01$). The severity value (67.40%) on the variety Melkassa-4 exceeded the severity levels of all other maize varieties and the lowest (14.25%) severity was recorded on the variety BH-660 (Table 2), indicating the resistant reaction of the popular hybrid BH-660. This finding is also in line with the previous finding showing Melkassa-4 is the most susceptible and it is currently out of production due to its susceptibility to common rust of maize and other foliar diseases. The differences amongst the hybrids for grain yield and resistance to common rust of maize diseases indicated the potential inherent genetic variability in the hybrids, which can be exploited by breeders in their future breeding activities.

Hybrids which were tolerant to common rust of maize had fewer numbers of lesions on their foliage despite being subjected to the same disease pressure as the susceptible hybrids. The present study indicated the presence of significant differences between early maturing and late maturing maize hybrids on the level of common rust disease severity. In resistant maize hybrids, the severity of the disease was slightly increasing with time, as opposed to the susceptible ones, where the disease severity increases remarkably at higher rate as time elapses (Table 1 and 2).Similarly in varietal analysis (sub-plot treatment means at the same main-plot treatment), there was a significant difference in severity levels among varieties treated alike. However, significant differences ($p \leq 0.001$) occurred among untreated- and Mancozeb-treated sub-plots (varieties). Varieties Melkassa-4 and BH-660 had the highest and lowest severity values for untreated and Mancozeb treated plots (Table 2). Two-way interaction effects of foliar fungicide by maize varieties showed significant ($P \leq 0.05$) differences at 76 DAP, 83 DAP and last assessment dates. This finding is in line with the reports of Dey *et al.* (2012) who indicated the effects of the fungicides in influencing the temporal development of the diseases on different maize varieties.

Table 2: Mean values of the effects of fungicide application and maize varieties on Common Rust of Maize severity on maize hybrids at Chiro using multiple point models during 2013 and 2014 main cropping seasons

Factor	**Initial severity (%)**[l]	**2nd severity (%)**[l]	**3rd severity (%)**	**4th severity (%)**[l]
Fungicides				
Unsprayed	15.80a	35.35b	45.65a	65.00a
Mancozeb	10.25b	15.85ab	22.52b	24.50b
CV%(a)	**3.25**	3.95	4.90	8.58
LSD (5%)	**Ns**	2.84	3.25	4.8 5
Varieties				
BH-140	25.86b	35.35b	42.55bc	47.35bc
Raare	35.57a	37.25a	43.10a	45.45a
BH-540	15.75c	21.00b	27.10b	55.60b
BH-660	10.55d	12.35b	13.53c	14.25c
Shone	35.65a	41.57b	53.65c	64.60c
Melkassa-4	36.75a	43.51a	54.25a	67.40a
CV%(b)	3.56	8.67	9.25	9.28
LSD (1%)	2.51	3.45	4.50	4.55

Values in the column with the different letter represent significant variation; CV = coefficient of variation [1] Initial severity assessment at 48 DAP; [2] 5th severity assessment at 76DAP. [3] 6th severity assessments at 90 DAP, CRM common rust of maize.

Area under disease progress curve (AUDPC)

Area under the disease progress curve **(**AUDPC) showed significant (p≤0.01) difference among the main plot effects of maize varieties and fungicide treatments. Similarly, two-way interaction effects of fungicide treatment by variety showed significant (p≤0.05) difference within treatment combinations. The analysis of variance (ANOVA) indicated that the highest AUDPC (1874.35%-days) was recorded on the untreated and the lowest AUDPC (554.75%-days) in Mancozeb-treated plots (Table 3).

Higher areas under disease progress curves were recorded on the susceptible maize varieties than the resistant hybrid ones (Table 3). This study also indicated that susceptible varieties had the highest area under disease progress curves than the resistant ones. No significant difference was also observed between the average scores of the susceptible varieties: having the highest (1874.35%-days) AUDPC for BH-540, followed by the AUDPC (1684.31%-days.) for the maize variety BH-660. The AUDPC values for Melkassa-4 and BH-660 were significantly (p≤0.01) different from the other varieties. The AUDPC values for the variety BH-660 were lower by 1320% - and 731% -days than the values for Melkassa -4 and BH-540, respectively (Table 3).). Previous works at Bako by Daniel *et al.* (2008) indicates varieties considered as susceptible such as Abobako, BH-540 and Local-M had AUDPC values more than resistant variety Shone and BH-660 varieties.

The two-way interaction effects of fungicide application by maize variety showed significant (p≤0.05) difference among different treatment combinations (Table 3). The highest (1874.35%-days) AUDPC was calculated with the data from the susceptible variety Melkassa -4 grown under un-treated condition, followed by AUDPC (1785.25%-days) from the variety BH=140 grown under the same condition compared to all treatment combinations.

Table 3: Mean values of the effect of fungicide application and varieties on CRM severity and AUDPC on maize hybrids at Chiro during 2013 and 2014 main cropping seasons.

Factor	Final severity (%)[1]	AUDPC
Fungicides		
Unsprayed	65.25a	1425.20a
Mancozeb	25.50b	922.80b
CV%(a)	**7.59**	3.48
LSD (5%)	**2.85**	140.50
Varieties		
BH-140	65.24bc	1785.25b
Raare	59.47a	1745.82a
BH-540	42.35b	1285.00b
BH-660	26.65d	554.75b
Shone	67.90cd	1768.72b
Melkassa-4	65.58a	1874.35a
CV%(b)	7.55	7.58
LSD (1%)	5.50	135.20

Values in the column with the different letters represent significant variation; CV = coefficient of variation LSD=Least significant difference; AUDPC=Area under disease progress curve. [1] severity assessed at 90DAP

Disease progress rate of CRM on hybrid maize varieties

Disease progress rates calculated from the data taken seven days after the disease symptoms showed significant ($p \leq 0.01$) difference on the hybrid maize varieties. Disease progress rate of varieties BH-140, Raare, BH-540, BH-660, and Melkassa -4 were 0.01468, 0.04520, 0.00256, 0.01350, 0.03782 and 0.05430units-days, respectively (Table 4). These results indicated that the disease has progressed at a faster rate on Melkassa -4(susceptible) and Raare, which were 4 times faster than the variety BH-660. Disease progress rates of the resistant varieties, namely BH-540 and BH-660 showed little increase in rate starting from the time of disease onset onwards, while the susceptible varieties Raare, BH-140, BH-540 and Melkassa -4 showed variability in temporal epidemic progression of the disease (Table 4).Analyses of the main effects of fungicide application revealed significant difference (P≤0.05) starting from 69 DAP. Untreated and mancozeb-sprayed maize plots increased in infection rate.

The two-way interaction analyses of fungicide application by varieties showed significant difference from 76 DAP onwards. The last calculated disease progress rates were significantly different from each other regardless of the Mancozeb-treated variety BH-660 and variety BH-540 as well as the untreated variety BH-660 and the Mancozeb-treated variety BH-540, which showed significant difference in temporal epidemic progression of the disease indicating the importance of the fungicide in limiting the rapid progress of the disease (Tables 4)

Table 4: Effects of fungicide application and varieties on the last progress rate (unit-day^{-1}) of CRM on maize hybrids at Chiro in the 2013 and 2014 main cropping seasons.

Factors	**Final CRM progress rate**	**SE of (r)^a**	**(R^2%)^b**
Fungicides			
Unsprayed	0.032561a	0.0013	88.45
Mancozeb	0.028327b	0.0013	96.00
CV (%)(a)	**16.50**		
LSD (5%)	**0.003520**		
Varieties			
BH-140	0.035265c	0.0020	85.55
Raare	0.031480a	0.0020	84.60
BH-540	0.026408b	0.0020	88.55
BH-660	0.017214d	0.0020	90.25
Shone	0.036250cd	0.0020	87.55
Melkassa-4	0.037423ab	0.0020	85.90
CV (%)(b)	**13.56**		
LSD (0.01)	**0.004862**		

Values in the column with the different letters represent significant variation; CV = coefficient of variation ^{a}= standard error of main factor ^{b} = Coefficient of determination or proportion explained by the model, P = Significant probability level of rates when regressed over time

Effects of fungicide, variety and their interactions on some agronomic parameters

Days to 50% tasselling, silking and 90% physiological maturity

The main effects of fungicide application showed non-significant ($p \leq 0.05$) difference on days to 50% tasselling, silking and 90% physiological maturity of hybrid maize varieties (Table 5). However, varietal effect showed significant ($p \leq 0.05$) difference on the days to 50% tasselling, silking and 90% physiological maturity. The mean days to 90% physiological maturity of BH-140, Raare, BH-540, BH-660 and Shone were 153, 152.8, 153.7, 162.5, 147 and 134.5 days after planting, respectively (Table 5). This was because of the variation in inherent genetic makeup of the hybrid maize varieties. The two-way interaction effect of fungicide with variety showed no significant difference on days to 50% tasseling and silking and days to 90% physiological maturity.

Plant height, ear height and stand count

Plant height, ear height, stand count and number of ears per plant were significantly ($p \leq 0.05$) affected by the hybrid maize variety included in this experiment. Significantly higher values of plant heights, 262.4 and 260.45 cm and ear heights of 130.7 and 125.52 cm were obtained from the hybrid maize varieties BH-660 and Shone than the other hybrid maize varieties. The highest (37357) stand count on hectare basis (Table 5) and the highest (1.10) number of ears per plant (Table 5) were obtained from the hybrid maize variety BH-660, which was significantly different from other hybrid maize varieties. The analysis of the main effects of fungicides and their interactions did not show any significant difference in stand count.

Table 5: Mean values of the effects of fungicide and hybrid maize varieties on days to 50% tasselling and silking, and days to 90% physiological maturity at Chiro in the 2013 and 2014 main cropping seasons.

Factor	Days to		
	50% anthesis	**50% silking**	**90% physiological maturity**
Fungicides			
Unsprayed	78.52a	90.50a	148a
Mancozeb	77.76a	98.45b	132.6b
CV (%) (a)	**2.88**	**4.78**	**1.87**
LSD (0.05)	**NS**	**NS**	**NS**
Varieties			
BH-140	80.5b	91.7bc	153.0c
Raare	80.5b	90.8c	152.8b
BH-540	80.5b	91.7bc	153.7b
BH-660	80.0a	96.9a	162.5a
Shone	83.4a	96.60ab	147a
Melkassa-4	70.7b	88.25ab	134.5b
CV (%)(b)	**3.52**	**5. 45**	**2.35**
LSD (0.01)	**2.70**	**4.58**	**1.63**

Grain yield

The yield produced showed significant difference for main effect and integration effects of varieties with fungicides. The main effects of fungicide application showed highly significant ($p \leq 0.01$) difference in hybrid maize grain yield. The highest (7680 kg ha^{-1}) maize yield was obtained from Mancozeb-sprayed plots and the lowest (6475 kg ha^{-1}) was obtained from the unsprayed hybrid maize plot. From field experiment conducted at Haramaya, Netsanet (2005) reported the effectiveness of fungicides in limiting the effect of common rust on maize yield which is in agreement with the present finding.

The analysis of variance (ANOVA) for grain yield showed significant ($p \leq 0.01$) difference among the hybrid maize varieties. The variation in mean grain yield between the tested hybrid maize varieties was attributed to their genetic potential for yield and disease resistance.

Accordingly, the variety BH-540 gave the highest (9331. kg ha^{-1}) mean grain yield, followed by the variety BH-660 (7476 kg ha^{-1}) that was significantly different from the other hybrid maize varieties. The analysis of mean grain yields of other maize varieties showed non-significant ($p>0.05$) differences among themselves (Table 6). This might be due to the fact that BH-540 was released for mid altitude areas than BH-660 which was released for higher altitude areas in which the growing conditions of the Hararghe area favored the yield genes of the BH-540 than the other hybrids used in this experiment.

Thousand kernel weight (TKW)

The analysis of variance (ANOVA) of the main and interaction effects showed significant ($p\leq0.05$) difference among the treatments in thousand kernel weight (TKW) regardless of the main effects of fungicide applications (Table 6). The result showed highly significant ($p\leq0.01$) difference in TKW between BH-660 and Melkassa-4 and also both of these varieties significantly differed ($p\leq0.01$) from all other hybrid maize varieties. The hybrid maize variety BH-540 significantly ($p\leq0.01$) differed in TKW from Shone and BH-540 maize hybrids (Table 6). However, there was no significant difference between the maize varieties BH-140, Raare and Melkassa-4.

Table 6: Mean values of the effect of maize variety and fungicide on mean grain yields TKW and yield loss of maize hybrids at Chiro in the 2013 and 2014 main cropping seasons.

Factor	Grain yield (KG/ha)	TKW(g)	YL (%)
Fungicides			
Unsprayed	6475c	337.56b	45.30
Mancozeb	7680b	345.48b	28.50
CV (%) (a)	**18.51**	**22.45**	
LSD (0.05)	**12.85**	**88.50**	
Varieties			
BH-140	6810.8c	357.78b	22.52
Raare	7071c	347.78bc	28.95
BH-540	9331a	296d	15.60
BH-660	7476c	390.1a	12.00
Shone	8375a	343.3bc	27.80
Melkassa-4	7225c	328.89c	33.54
CV (%) (b)	**11.50**	**8.75**	
LSD (0.05)	**11.54**	**23.63**	

Means with the same letter within the column are not significantly different from each other. Ns= Non significant and LSD = Least significant difference at α = 0.05 probability level

Conclusions and Recommendations

Common rust of maize is the most devastating disease of maize under favorable environmental conditions. A West Hararghe middle land is a hot spot area for the development of common rust. This study indicated the potential of the disease in limiting maize productivity in eastern parts of Ethiopia. It was also revealed that maize varieties (*Shone*, BH-140, *Raare* and BH-540) introduced to Hararghe highlands were highly susceptible to the disease. The maximum yield was obtained from plots treated with 4.5 and 6.0 kg ha^{-1}Mancozeb where the temporal epidemic progression of the disease was limited (R^2=96). It was found that temporal epidemic development of the disease was influenced by the type of hybrids used, rates of the fungicide and the prevailing weather condition. Critical point model was found to be better than multiple point and AUDPC models in estimating the relationships between common rust severity and yield as well as most of the yield components. The disease resulted in grain yield loss of up to 45, 42 and 10% on BH-140, Shone and BH-660, respectively. Maximum yield reduction of 45% and severity of 65% were recorded from the unsprayed plots. Therefore, an integrated disease management strategy is recommended to manage this disease in the study area. Economic analyses are required to identify the best treatment combinations that would give the highest net return. Finally, it is recommended that an integrated disease management (IDM) strategy (fungicide, cultural practices and host resistance) has to be adopted in managing the disease and sustain the livelihood of maize consumers in the Hararghe highlands, eastern part Ethiopia.

Acknowledgements

This research was financed through Haramaya University Research Grant for Academic staffs (2012 to 2014). The author thanks Professor Chemeda Fininsa for his technical comments at the experimental site (Chiro Campus) and the Office of the vice President for Research Affairs of the Haramaya University for smooth facilitation of research activities, the farmers of East and West Hararghe Zone and development agents in East and West Hararghe Zones for their collaboration during the field experiment and surveys and for their assistance in transportation facilities and data collection.

References

Abate T, Shiferaw B, Menkir A, Wegary D, Kebede Y, Tesfaye K, Kassie M, Bogale G,Tadesse B, Keno T. (2015). Factors that transformed Maize productivity in Ethiopia. *Food Security*, 1;7(5):965-81.

Agrios, G. N. (2005). *Plant Pathology, 5th Edition*. Elsevier Academic Press, London, UK.

Asfaw, N., Yeshi, C., Kassahun, S., and Aleligne, K. (1992). Importance, production practice, constraints and research need of Maize under small holders in Ethiopia, pp. 43-51. *In* T. Benti and J.K. Ransom (eds.). Proceedings of the First National Maize Workshop of Ethiopia, 5-7 May, IAR, Addis Ababa.

Assefa, T. and Tewabech T. (1993). Review of Maize disease research in Ethiopia. pp. 43-51. *In*: Benti, T. and Ransom, J.K. (ed.) Proceedings of the First National Maize Workshop of Ethiopia, May 5-7, 1992, IAR/CIMMYT, Addis Ababa.

Assefa, T. (1997). Management of two major diseases of Maize in Ethiopia. *African Crop Science Conference Proceedings* 3: 913-920.

Assefa, T. (1999). Survey of Maize diseases in Western and North-Western Ethiopia. pp. 121-124. *In*: Maize Production Technology for the Future: Challenges and Opportunities: Proceedings of the 6th Eastern and Southern Africa Regional Maize Conference. CIMMYT/EARO. Addis Ababa.

Asfaw, S., Shiferaw, B., Simtowe, F., and Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy*, 37: 283–295.

Bekeko, Z., (2013). Improving and sustaining soil fertility by use of enriched farmyard manure and inorganic fertilizers for hybrid Maize (BH-140) production at West Hararghe zone, Oromia, Eastern Ethiopia. *African Journal of Agricultural Research,* 8(14): 1218-1224.

Dagne, W., Habtamu, Z. Demissew, A. Temam, H. and Harjit S. (2008). The Combining ability of Maize Inbred lines for grain yield and reaction to Gray leaf spot disease. *East African Journal of Sciences,* 2(2): 135-145.

Daniel A, Narong S, Somsiri S, Ed S. (2008). Evaluation of Maize varieties for resistance to Northern leaf blight under field conditions in Ethiopia. *Kasetsart Journal of Natural Sciences*, 42:1-10.

Dey U, Harlapur SI, Dhutraj DN, Suryawanshi AP, Badgujar SL, Jagtap GP, Kuldhar DP. (2012). Spatiotemporal yield loss assessment in corn due to common rust caused by *Puccinia sorghi* Schw. *African Journal of Agricultural Research*, 7(37): 5265-5269.

EARO. (1999). Research strategy for Maize. Ethiopian Agricultural Research organization (EARO), Addis Ababa, Ethiopia.

Fininsa, C. (2001). Epidemiology of bean common bacterial blight and Maize rust in intercropping. Doctoral thesis. Swedish Univ. Agri. Science Uppsala, Sweden.

Fininsa, C. and Yuen, J., (2001). Association of Maize rust and leaf blight epidemics with cropping systems in Hararghe Highlands, Eastern Ethiopia. *Crop Protection,* 20: 669-678.

Groth, J.V., Zeyen, R.L., Davis, D.W. and Christ, B. J. (1983). Yield and quality losses caused by common rust in sweet corn hybrids. *Crop Protection*, 2: 105-111.

Heller A, Grossmann F, Frenzel B, Hippe S. (1990). A cytological study of the development of *Erysiphe graminis* in its host barley, as influenced by the two fungicides ethirimol and propiconazole. *Canadian Journal of Botany*, 68:2618-2628.

Kim, S.K. and Brewbaker, J.L. (1976). Effects of *Puccinia sorghi* rust on yield and several agronomic traits of Maize in Hawaii. *Crop Science,* 16: 874-877.

Netsanet B. (2005). Management of common leaf rust of Maize (*Puccinia sorghi* Schw.) in Eastern Ethiopia. *M.Sc. Thesis* Submitted to the Department of Plant Sciences, Haramaya University, Ethiopia.

Raymundo, A.D. and Hooker, A.L. (1981). Measuring the relationship between Northern leaf blight and yield losses. *Plant Disease,* 65: 325-327

Reuveni, R., Agapov, V. and Reuveni, M. (1994). Foliar spray of phosphates induces growth increase and systemic resistance to *Puccinia sorghi* in Maize. *Plant Pathology,* 43: 245-250.

Schieber, E. (1965b). Comparative studies of the reaction of *Pucciniasorghi*on different corn races of Guatemala. *Phytopathology,* 55: 126 (Abstract).

Schieber, E. (1965a). Distribution of *Puccinia sorghi* and *P. polysora* in Africa and pathogenecity of these species on corn lines with Latin American germplasm. *Phytopathology,* 55: 1074 (Abstract).

Shaner, E. and Finney, R. E. (1977). The effect of Nitrogen fertilization on the experassion of slow-mildewing resistance in Konex wheat. *Phytopathology*, 67: 1051-1056.

Madden, L. V., Hughes, G., & van den Bosch, F. (2007). *The study of plant disease epidemics.* St Paul: APS.

Teclemariam, W. (1985). A review of research on Maize and Sorghum diseases in Ethiopia. pp. 25-29. *In*: Tsedeke, A. (ed.) *Proceedings of the First Symposium on Crop Protection Research in Ethiopia* 4-7 Feb. 1985. Addis Ababa, Ethiopia.

Tewabech T. (1990). Maize diseases in Ethiopia. pp. 35-39 *In* :Yaynu Hizkias and Seid Ahmed 12(eds) Proceedings of the 15the Annual Meeting of the Ethiopian Phytopathological Committee 13-14 March ,1990, Addis Ababa, Ethiopia.

Tewabech, T., Getachew, A., Fekede, A. and Dagne, W. (2012). Maize pathology research in Ethiopia: A review. *In:* Mandefro, N., Tanner, D. and Twumasi-Afriyie, S. (eds.), Enhancing the Contribution of Maize to Food Security in Ethiopia. *Proceedings of the 2nd National Maize Workshop of Ethiopia.*

Van der Plank, J.E., (1963). Epidemiology of plant disease. New York and London Academic publishers. 206p.

Wheeler, J.B.E.J. (1969). *An Introduction to Plant Diseases*. Wiley, London, 347pp.

Wilcoxson, R.D., Skovmand, B. and Atif, A.H. (1975). Evaluation of Maize cultivars ability to retard development of major diseases. *Annals of Applied Biology*, 80: 275-2181.

Wilkinson, D.R. and Hooker, A.L. (1969). Genetics of reaction to *Pucinia sorghi* n ten corn inbreds from Africa and Europe. *Phytopathology,* 58: 605-608.