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Management of Turcicum leaf blight [*Exserohilum turcicum* (Pass.) Leonard & Suggs] of maize (*Zea mays* L.) through integration of host resistance and fungicide at Bako, Western Ethiopia

Megersa Debela[1]*, Mashilla Dejene[1] and Wende Abera[2]

[1]School of Plant Sciences, Haramaya University, Ethiopia.
[2]International Institute of Tropical Agriculture (IITA), Nigeria.

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Turcicum leaf blight (TLB) (*Exserohilum turcicum*) is a major disease affecting maize production in western Ethiopia. The objectives of this study were to determine the effect of maize varieties integrated with fungicides on epidemics of turcicum leaf blight; to determine the effect of turcicum leaf blight severity on yield and yield components of maize; and to assess the cost and benefit of using fungicides. The field experiment was conducted at Bako Agricultural Research Center in 2014 main cropping season using six maize varieties (BH-540, BH-543, BH-546, BH-660, BH-661 and AMHQ-760) integrated with foliar sprays of the systemic fungicide propiconazole (Tilt) at the rate of 350 ml ha^{-1}and the contact fungicide mancozeb (Dithane M-45) at 2.6 kg ha^{-1}. The experiment was arranged in 3 × 6 factorial combinations in split plot design with three replications. A pinch of ground maize leaf infected by *E. turcicum* was inoculated at third-fifth leaves. Unsprayed plots were left as control or check for each variety. Disease severity was scored using 1 to 5 scale on 12 randomly-tagged plants in the central rows. Integration effects of varieties with fungicides significantly affected the grain yield and thousand kernel weight (TKW) of maize varieties. The highest (11383 kg ha^{-1}) grain yield was obtained from propiconazole-treated hybrid maize variety BH-546. Turcicum leaf blight resulted in grain yield losses of up to 40.7% on the unsprayed plots of the susceptible variety BH-543. Percent severity index, AUDPC, incidence and disease progress rates were negatively correlated with yield components regardless of grain yield loss. The highest marginal benefit (ETB 48,801.28 ha^{-1}) and marginal rate of return (ETB 6.33) were obtained from propiconazole-treated varieties BH-543 and BH-546, respectively. This study contributes to integrated TLB management options, and to make a valid recommendation for TLB management strategy, the study should be repeated over years and locations where TLB of maize is of major economic importance.

Key words: *Exserohilum turcicum*, fungicides, percent severity indices, maize-varieties, yield.

INTRODUCTION

Maize (*Zea mays* L.) is one of the widely grown crops in the world, ranking third next to wheat and rice (FAOSTAT, 2012). It is a staple food for several million people in the developing world where they derive their protein and calorie requirements from it (Randjelovic et al., 2011). In Ethiopia, maize is one of the most important cereal crops grown. The total annual production and productivity (72, 248,481 and 00 kg) exceeds all other cereal crops except *teff* [*Eragrostis tef* (Zucc.) Trotter] in area coverage (Mosisa et al., 2012; CSA, 2014). Considering its importance, wide adaptation, total production and productivity, maize is regarded as one of the high priority food security crops in Ethiopia, the second-most populous country in the sub-Saharan Africa after Nigeria (CSA, 2011).

The mid-altitude sub-humid agro-ecology is considered to be the major maize-growing zone in Ethiopia (Legesse et al., 2012). However, maize production has remained low, with the estimated national average yield of 3.4 t ha^{-1} (CSA, 2014) compared to the world average yield estimated at 5 t ha^{-1} (FAOSTAT, 2012) due to several major constraints, including foliar diseases.

In western Ethiopia, turcicum leaf blight, TLB [*Exserohilum turcicum* (Pass.) Leonard & Suggs] and gray leaf spot, GLS (*Cercospora zeae-maydis* Tehon & Daniela and *Cercospora sorghi* var. *maydis* Ell. & Ev.) are the most important reported maize diseases. Farmers in the study area (46.7%) indicated TLB as the major leaf disease on maize. GLS is ranked as the second most important leaf disease in the area, as reported by 17.9% of the respondents (Wende et al., 2013).

Turcicum leaf blight incidence ranges from 95 to 100% in areas with constant moisture and high humidity and the yield loss can reach up to 70%. Turcicum leaf blight is reported to cause devastating damage on most commercial varieties of maize released in the country (Tewabech et al., 2012). According to Wende et al. (2013) turcicum leaf blight is ranked as the number one problem and is considered a high research priority of maize in Ethiopia.

The turcicum leaf blight injures or kills the leaf tissues and thereby reduces the area of green chlorophyll which manufactures food for the plant. If considerable leaf area is killed the vigour and yields are reduced. If much of the green area is killed, starch formation is restricted and the kernels become chaffy. The blighted leaves are not even suitable for fodder because of the lowered nutritional value (Pant et al., 2001). While turcicum leaf blight is known to be present under field environments little is known about the reaction of several maize varieties and effects of fungicides to the disease. Moreover, integration of varieties with fungicides to manage the TLB is not documented in the study area. Therefore, effort must be directed towards searching for turcicum leaf blight resistant varieties and effective management option(s) to reduce or manage the effect of TLB on yield and yield components of this crop. Therefore, this research was undertaken with the following specific objectives to:

1. Determine the effect of maize varieties integrated with fungicides on epidemics of turcicum leaf blight;
2. Determine the effect of turcicum leaf blight severity on yield and yield components of maize; and
3. Assess the cost/benefit of using fungicides against turcicum blight.

MATERIALS AND METHODS

Description of the experimental area

This experiment was conducted at Bako Agricultural Research Center (BARC). BARC lies between 9°6' N latitude and 37°09' E longitude with an altitude of 1650 m.a.s.l. The mean annual rainfall of the last 54 years is 1238.4 mm and it has unimodal pattern of distribution. The rainy period goes from April to October. Maximum rainfall is received in the three months (June, July and August). BARC has a warm, humid climate with mean minimum, mean maximum and average temperatures of the last 54 years was 13.32, 28 and 20.6°C, respectively. Average relative humidity of BARC is 63.55%. The majority (60%) of the soil (1,400 ha) of BARC is reddish brown, clay and loam in texture (Wakene, 2000). According to USDA soil classification, the soil is Alfisols developed from basalt parent materials and is deeply weathered and slightly acidic in reaction (Wakene, 2000).

Description of experimental materials

Eighteen treatment combinations consisting of six varieties, two types of fungicides were used. The six maize varieties used were BH-540, BH-543, BH-546, AMHQ-760, BH-660 and BH-661. BH-660, BH-661 and AMHQ-760 grow at an altitude of 1600 to 2200 m.a.s.l. and their potential yields are 9000-12000, 9500-12000 and 8000-10000 kg ha^{-1}, respectively, and BH-540, BH-543 and BH-546 grow at an altitude of 1000-2000 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 (Source Bako National Maize Research Center (BNMRC).

Management of the experiment

Treatments were arranged in a factorial experiment using split plot design (varieties were assigned to subplots and fungicides as main plots to control drift problem while fungicide spraying) with three replications. Each plot consisted of six rows of 5.1 m long spaced at 75 cm apart and the distance between adjacent hills was 30 cm. At planting, two seeds were placed per hill and were thinned to one after establishment. A 100 kg ha^{-1} nitrogen fertilizer (46 kg N ha^{-1} from urea) was applied in two splits; half at planting and the rest at 37 days after emergence. All the trial management practices were based on the recommendation for the location. For weed control, hoeing, slashing and hand weeding were performed for all plots when necessary.

Inoculation and disease establishment

To ensure uniform disease infection, artificial inoculation was

*Corresponding author. E-mail: megedebela@gmail.com. Tel: 0928644852.

conducted according to procedures described by Reid and Zhu (2005) as follows: Maize leaves infected by TLB were identified by its classical symptoms and collected from a field in the previous year. The collected leaves were sun-dried and stored in the paper bag till the next cropping season. The presence of spores and mycelium of TLB were observed under microscope from stored maize leaves and then chopped and ground. A pinch (tea spoonful) of ground leaves were added into the whorl of maize plant at the fifth leaf growth stage.

Fungicide application

Mancozeb 75% WP (Dithane M-45) at rate of 2.6 kg ha^{-1} and propiconazole (Tilt) 25% EC at 350 ml ha^{-1} were applied using knapsack sprayer of a 15-L capacity. Control plots were sprayed with water only in the same manner with that of fungicide sprayed plots to minimize difference due to moisture. The area of sprayed main plot was bordered by plastic sheet at the time of fungicide spraying to minimize the risk of fungicide drift to the adjacent main plots. The fungicide was applied three times at 10-day-interval starting from the time lesions were visible on the three to five basal leaves of the susceptible variety.

Data collection

Disease severity

Disease severity was recorded on twelve randomly-tagged plants per plot. It was assessed using the 1-5 standard disease scoring scale recommended by CIMMYT (www.cimmyt.org), where:

1 = very slightly infected, one or two restricted lesions on lower leaves or trace.
2 = slight to moderate infection on lower leaves, a few scatter lesions on lower leaves.
3 = abundant lesions on lower leaves, a few on middle leaves.
4 = abundant lesions on lower and middle leaves extending to upper leaves.
5 = abundant lesions on all leaves, plant may be prematurely killed by blight.

The rating was made at seven-day interval starting at about 2 to 3% infection on the lower leaves of the susceptible variety, BH-543. Then the severity scales were converted into percentage severity index (PSI) for analysis using the formula of 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 percent severity index (PSI) scores were used to calculate disease infection rate and Area under the disease progress curve (AUDPC) for each treatment. AUDPC was calculated with the formula suggested by Campbell and Madden (1990):

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

Where, x_i = is the cumulative percent severity index expressed as a proportion at the ith observation, ti = is the time (days after sowing) at the ith observation, and n = is total number of observations.

Since TLB percent severity index was expressed in percent and time (t) in days, AUDPC values was 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 (Gomez and Gomez, 1984). Logistic equation, ln [(Y/1-Y)], (Van der Plank, 1963), was used for estimation of infection rate from each treatment. Treatment means were separated using the least significant difference (LSD) at 5% probability level.

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 50% silking

This was recorded as the number of days after emergence to the time when 50% of the plants emerged protruded silk.

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.

Thousand kernel weights (g)

Kernels were drawn randomly from each plot, counted manually and weighed in grams using sensitive balance.

Yield per plot and per hectare

Total grain yield harvested from the four middle rows was determined and adjusted to 12.5% moisture content as follows:

$$\text{Adjusted yield per plot} = \frac{(FW(100 - AMC) \times 0.8)}{RDW}$$

Where: FW = Field weight harvested from four central rows of each plot; AMC = Actual moisture content; RDW = Recommended dry weight (Given) = 87.5; 0.8 = Shelling % (Given). Then the yield per plot was converted into yield per hectare (tonnes ha^{-1}).

Relative yield loss

Losses in grain yield were calculated as the difference between mean yield of protected plots and unprotected plots of the respective variety. Losses were calculated separately for each of the treatments using the formula developed by Robert and James (1991):

$$RYL\ (\%) = \frac{(Y_1 - Y_2)}{Y_1} \times 100$$

Where, RYL = Relative yield loss; Y_1 = mean yield of protected plots (plot with maximum protection). Y_2 = Mean yield of unprotected plots (unsprayed plots).

Data analysis

Analysis of variance (ANOVA)

Data on turcicum leaf blight incidence and severity from each assessment date, yield and yield components, AUDPC, lesion size and all agronomic data were subjected to analysis of variance (ANOVA) using SAS software (SAS 2009 version). Mean separation was done based on the LSD at the 5% probability level and interaction effects were separated by SAS extension software *PLGLM800* (P=0.05).

Correlation analysis

Correlation analysis was performed using SAS PROC CORR (SAS system windows 9) to determine relationship among disease assessment parameters, such as disease incidence, percent severity index, lesion size and area under disease progress curve (AUDPC) with yield and yield components.

Regression analysis was undertaken to determine the response of relationship between AUDPC and percent severity index score on yield of six maize varieties under different fungicide types. The goodness of fit for regression equation models was determined by evaluating the indictors; coefficient of multiple determinations (r) that explains proportion of the total variation of the dependent variable (yield) associated with independent variable, F-statistics that test the over all- significance of the regression equation at defined probability level.

Cost and benefit analysis

Prices of maize grain (Birr ton^{-1}) were obtained from local markets and total sale from one hectare was computed. Price of seeds of each variety was collected from local market and farmers union in the localities. Price of mancozeb and propiconazole per kilogram and liters was assessed and the total price incurred to spray one hectare of maize was also calculated. Labor to spray those chemicals was computed.

The cost/benefit analysis for integrated TLB management options was performed using partial budget analysis or marginal rate of returns (CIMMYT, 1988).

The formula is as follows:

$$MRR = \frac{DNI}{DIC}$$

Where, MRR = is marginal rate of returns, DNI = difference in net income compared with control, and
DIC = difference in input cost compared with control.

The following points were considered during cost/benefit analysis using partial budget.

1. Since the experiment was based on a research field; yields produced were adjusted to 10% lower than values from research field, assuming the farmers farming condition.
2. Costs for all agronomic practices were uniform for all varieties and treatments within the site;
3. Costs of labor and spray equipment was taken based on the price in the locality; and cost return and benefit were calculated per hectare basis.

RESULTS AND DISCUSSION

Percentage severity index

Maize varieties showed a highly significant ($p \leq 0.01$) difference in TLB percentage severity index at all assessment dates. At the first date of disease assessment, the percent severity index of TLB on BH-543 was the highest (27.84%) score; and the lowest (26.56%) percent severity index of TLB was that of the moderately resistant varieties BH-661 and BH-546 (Table 1).

The percentage severity indices of TLB from the main plot effects (due to fungicides) were significantly different at the 69, 76, 83 and 90 DAP assessment dates. At 69 DAP assessment date, the TLB percent severity index (34.63%) on the untreated plot was significantly ($p \leq 0.05$) different from the indices due to mancozeb (33.68%) and propiconazole (32.57%) treated plots (Table 1). At 76 DAP, 83 DAP and last assessment date (90 DAP), the main plot effects showed highly significant ($p \leq 0.01$) difference in percent severity indices, in which the untreated plot exceeded the treated ones (Tables 1 and 2).

At the 90 DAP, there were significant differences in percent severity indices among fungicides, varieties and their interactions. The percent severity index (48.28%) of the untreated plot was higher than the ones treated with mancozeb (43.53%) and propiconazole (35.25%). This finding is consistent with the findings of Veerabhadraswamy et al. (2014) who reported lower percent severity index on propiconazole-treated (25.7%) and mancozeb-treated plots (38.9%) than the average of untreated plots (94.3%). Similarly, a previous study by Shachin (2009) indicated that fungicides resulted in significant differences in their efficacies to inhibit the growth of *Exserohilum turcicum*. Further, Rajeshwar et al. (2013) reported lowest percent of TLB severity index due to application of mancozeb (18.3%) and propiconazole (25.5%).

The varietal effects of the last percent severity index were highly significant ($p \leq 0.01$). The highest percent severity index (49.43%) on the variety BH-543 exceeded the severity levels on all other maize varieties and the lowest (36.86%) percent severity index was recorded on the variety BH-660 (Table 2), indicating the resistant reaction of the popular hybrid BH-660 and also this finding is in line with the previous finding showing BH-543 is the most susceptible and it is currently out of production due to its susceptibility to TLB.

The differences amongst the hybrids for grain yield and resistance to TLB diseases indicated the potential inherent genetic resistance in the hybrids, which can be exploited by breeders in their future breeding activities. Similarly, Daniel (2006) reported that TLB tolerant hybrids had few lesions on their foliage despite being subjected to the same disease pressure as the susceptible hybrids. Further, the mean value of the disease assessment for

Table 1. Effects of fungicides and maize varieties on TLB percent severity index assessed at different dates after planting (DAP) at Bako during 2014 main cropping season.

Factor	48 DAP	69 DAP	76 DAP	83 DAP
Fungicides				
Unsprayed	26.826^{a}	34.63^{b}	41.26^{a}	44.13^{a}
Mancozeb	27.12^{a}	33.68^{ab}	37.89^{b}	39.9^{b}
Propiconazole	26.826^{a}	32.57^{a}	33.08^{c}	32.96^{c}
CV (%) (a)	2.12	3.91	3.97	6.48
LSD (5%)	Ns	1.21 LSD (1%)	2.22	3.88
Varieties				
BH-540	26.826^{ab}	32.83^{b}	35.45^{bc}	37.43^{bc}
BH-543	27.847^{a}	37.42^{a}	43.61^{a}	45.48^{a}
BH-546	26.565^{b}	31.90^{b}	37.12^{b}	38.86^{b}
BH-660	26.696^{ab}	30.93^{b}	33.03^{c}	34.29^{c}
BH-661	26.565^{b}	31.77^{b}	33.96^{c}	34.68^{c}
AMHQ-760	26.826^{ab}	36.91^{a}	41.32^{a}	43.24^{a}
CV (%) (b)	2.96	6.77	7.62	7.69
LSD (1%)	1.21	2.95	3.69	3.89

Mean values with the same letter within a column are not significantly different at described probability level; CV = Coefficient of variation; LSD = Least significant difference at 5% and 1% probability level.

Table 2. Main effects of fungicide and varieties on last (90 DAP) assessment date of TLB percent severity index and AUDPC on maize hybrids at Bako during 2014 main cropping season.

Factor	Terminal PSI[1]	AUDPC
Fungicides		
Unsprayed	48.28^{c}	1650.17^{c}
Mancozeb	43.5^{b}	1543.31^{b}
Propiconazole	35.25^{a}	1369.16^{a}
CV (%) (a)	6.99	4.28
LSD (1%)	4.54	60.2
Varieties		
BH-540	40.552^{bc}	1466.07^{b}
BH-543	49.427^{a}	1735.22^{a}
BH-546	42.237^{b}	1484.22^{b}
BH-660	36.861^{d}	1366.78^{b}
BH-661	37.719^{cd}	1388.67^{b}
AMHQ-760	47.278^{a}	1684.31^{a}
CV (%) (b)	8.6	6.46
LSD (1%)	4.72	127.32

Mean values with the same letter within a column are not significantly different at described probability level; CV = coefficient of variation; LSD = Least significant difference; AUDPC = Area under disease progress curve; [1] PSI = Percent severity index assessed at 90 DAP.

turcicum leaf blight varied considerably among locations due to environment and varieties, and the disease reached maximum percent severity index of 94.44% on susceptible varieties (Daniel, 2006).

The current finding revealed that there were significant differences between early maturing and late maturing maize hybrids in the level of disease severity. Assefa (1994) reported that blight resistance appeared to be associated with late maturity perhaps bound up with physiological changes within the plant. Percent severity index of TLB on resistant hybrid maize varieties was slightly increasing with time, as opposed to the susceptible ones, where the disease severity increase was remarkably high as time elapsed.

The effects of foliar fungicides by maize varieties interaction showed highly significant ($p \leq 0.01$) difference at 76 and 83 DAP. At the 76 and 83 DAP assessments, the untreated variety BH-543 showed the highest percent severity indices of 49.15 and 52.09%, respectively. The lowest percent severity indices at 76 DAP (30.07%) and 83 DAP (29.55%) were noted on propiconazole-treated varieties BH-546 and BH-661, respectively (Table 3).

Analyses of variance (ANOVA) of two-way interaction effects of TLB percent severity index at the 90 DAP showed a significant ($p \leq 0.05$) difference for fungicide by variety treatment combinations. The highest (58.83%) TLB percent severity index was recorded in the untreated plots of BH-543 variety treatment combinations, which was not significantly different from the untreated plots by AMHQ-760 variety. However, the lowest severities

Table 3. Two-way interaction effects of fungicide application by variety on TLB percent severity index on hybrid maize varieties at Bako in 2014 cropping season.

Fungicides	Variety	PSI at 76 DAP	PSI at 83 DAP
Unsprayed	BH-540	38.55^{cd}	41.14^{cde}
	BH-543	49.15^{a}	52.09^{a}
	BH-546	43.08^{b}	45.32^{bc}
	BH-660	36.9d^{e}	38.23^{efg}
	BH-661	34.54^{defg}	36.93^{efgh}
	AMHQ-760	45.3^{ab}	51.1^{a}
Mancozeb	BH-540	33.19^{efg}	35.9^{fghi}
	BH-543	46.59^{ab}	49.18^{ab}
	BH-546	37.5^{de}	40.18^{efg}
	BH-660	30.72^{g}	32.83^{hij}
	BH-661	35.88^{def}	37.56^{efgh}
	AMHQ-760	43.40^{bc}	43.7^{cd}
Propiconazole	BH-540	34.56^{defg}	35.23^{ghi}
	BH-543	35.07^{defg}	35.17^{ghi}
	BH-546	30.7^{g}	31.06^{ij}
	BH-660	31.43f^{g}	31.8^{ij}
	BH-661	31.44f^{g}	29.55^{j}
	AMHQ-760	35.25^{def}	34.915g^{hi}
CV (%)		**7.6**	**7.7**
LSD (1%)		**4.437**	**4.852**

Mean values in the same letter within a column are not significantly different at 5% probability level; Ns = Non-significant and DAP = Days after planting.

(32.48, 32.54 and 34.10%) were recorded on propiconazole- treated BH-661, BH-660, and BH-546 varieties, respectively (Table 4). The result of integration of fungicides by variety disease management options had the outstanding result for management of TLB disease.

Area Under Disease Progress Curve (AUDPC)

Area under the Disease Progress Curve (AUDPC) showed highly significant ($p \leq 0.01$) difference among the main effects of maize varieties and fungicide treatments. Similarly, two-way interaction effects of fungicide treatment by variety showed significant ($p \leq 0.05$) difference within treatment combinations.

The highest AUDPC (1650.17%-days) was recorded on the untreated and the lowest AUDPC (1369.16%-days) in propiconazole-treated plots (Table 2). The Highest areas under disease progress curve was recorded on BH-543 (1735.22%-days), followed by the AUDPC (1684.31%-days.) for the maize variety AMHQ-760 (Table 2).

Previous works at Bako by Daniel et al. (2008) indicated that varieties considered as susceptible to TLB, such as Abobako, BH-540 and Local-M had AUDPC values higher than the resistant varieties Kuleni and BH-660. This finding is in agreement with the present finding. The AUDPC values for BH-543 and AMHQ-760 were highly and significantly ($p \leq 0.01$) different from the AUDPC values from other varieties. The AUDPC values for the variety BH-660 were lower by 368.44 and 317.53%-days than the values for BH-543 and AMHQ-760, respectively.

The two-way interaction effects of fungicide application by maize variety showed significant ($p \leq 0.05$) difference among different treatment combinations (Table 4). The highest (1928.13%-days) AUDPC values were noted on the susceptible variety BH-543, followed by AUDPC value of 1863.63%-days on the variety AMHQ-760 grown on untreated plots compared to all treatment combinations. AUDPC of the varieties BH-543, AMHQ-760, BH-546 and BH-661 treated with propiconazole showed significant ($p \leq 0.05$) difference with the respective same varieties treated with mancozeb and untreated control plots (Table 4).

Progress rate of TLB on hybrid Maize varieties and fungicide application

There were highly significant ($p \leq 0.01$) differences on

Table 4. Two-way interaction effects of fungicide application by variety on TLB percent severity index and AUDPC on hybrid maize varieties at Bako in 2014 cropping season.

Fungicides	Variety	AUDPC (%-days)	Terminal PSI
Unsprayed	BH-540	1533.02^{de}	42.82^{de}
	BH-543	1928.13^{a}	58.83^{a}
	BH-546	1651.86^{cd}	50.09^{bc}
	BH-660	1471.79^{ef}	41.08^{e}
	BH-661	1452.59^{efg}	41.06^{e}
	AMHQ-760	1863.63^{ab}	55.82^{ab}
Mancozeb	BH-540	1448.05^{efg}	41.77^{e}
	BH-543	1837.50^{ab}	52.12^{bc}
	BH-546	1498.04^{de}	42.30^{e}
	BH-660	1312.56^{fgh}	36.95^{efg}
	BH-661	1436.46^{efgh}	39.60
	AMHQ-760	1727.21^{bc}	48.27^{cd}
Propiconazole	BH-540	1417.12^{efgh}	37.06^{efg}
	BH-543	1440.02^{efgh}	37.33^{efg}
	BH-546	1302.75^{gh}	34.32^{fg}
	BH-660	1315.99^{fgh}	32.55^{g}
	BH-661	1276.94^{h}	32.48^{g}
	AMHQ-760	1462.10^{efg}	37.75^{efg}
CV (%)		6.46	8.60
LSD (5%)		155.9	5.873

Mean values with the same letter within a column are not significantly different at 5% probability level. CV = coefficient of variation, LSD = Least significant difference; AUDPC = Area under disease progress curve.

disease progress rate among varieties at the start of disease epidemics. Disease progress rate of the varieties AMHQ-760, BH-540, BH-543, BH-546, BH-660, and BH-661 were 0.04172, 0.01546, 0.04834, 0.00945, 0.01140 and 0.00794 units-day^{-1}, respectively (Table 5). These results indicated that the disease progressed considerably on BH-543 and AMHQ-760 varieties, which was 6.08 times faster than the disease progress rate on the variety BH-661.

Disease progress rates of the resistant varieties, namely BH-546, BH-660, and BH-661 showed little increase starting from the time of disease onset onwards, while the susceptible varieties AMHQ-760, BH-540 and BH-543 showed variability in disease progress rates through their growing period (Figure 1).

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, while the infection rate on propiconazole- treated plots decreased starting from fungicide spraying dates onwards. The last disease progress rates were significantly different among the sprayed and unsprayed plots. Propiconazole-sprayed plots had the slowest (0.015717 units-day^{-1}) progress rate, which was 2.6 times smaller than that of the progress rate on the unsprayed plots.

The overall data calculated for disease progress rates also showed highly significant (p≤0.01) difference among hybrid maize varieties in the final assessment. During the last disease progress assessment, the fastest disease progress rate (0.032782 units-day^{-1}) was for the variety BH-543, which had a significant difference from the other hybrid maize varieties and the slowest (0.019503 units-day^{-1}) was for the hybrid maize variety BH-660 (Table 6). This result further confirmed the reaction of BH-543 and BH-660 as susceptible and resistant, respectively, in line with earlier findings.

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 for the same varieties sprayed and unsprayed treatments regardless of the mancozeb-treated variety BH-540, and the propiconazole-treated variety BH-540 as well as the untreated variety BH-661 and the mancozeb-treated variety BH-661, which had no significant difference in disease progress rates (Table 7).

Accordingly, the unsprayed variety BH-543 (with r-value of 0.044337 units-day^{-1}) and AMHQ-760 (with r-value of 0.04384-units-day^{-1}) exhibited the fastest

Table 5. Main effects of fungicide application and varieties on the initial progress rate (units-day^{-1}) of TLB on maize hybrids at Bako in 2014 main cropping season.

Factors	Initial TLB progress rate	SE of (r)^a	(R^2%)^b	P
Fungicides				
Unsprayed	0.02131a	0.004786	53.8	0.0004
Mancozeb	0.02085a	0.004786	63.7	0.0006
Propiconazole	0.02499a	0.004786	52.6	<0.0001
CV(%) (a)	64.14			
LSD (5%)	Ns			
Varieties				
BH-540	0.01546b	0.010803	43.9	0.0519
BH-543	0.04834a	0.010803	54.59	<0.0001
BH-546	0.00945b	0.010803	82.61	0.2255
BH-660	0.01140b	0.010803	54.06	0.1460
BH-661	0.00794b	0.010803	42.65	0.3071
AMHQ-760	0.04172a	0.010803	62.9	<0.0001
CV (%) (b)	102.38			
LSD (1%)	0.02971			

Mean values with the same letter within a column are not significantly different at described probability level; CV = coefficient of variation; ^{a}= standard error of main factor; ^{b} = Coefficient of determination or proportion explained by the model, P = Significance probability level of rates when regressed over time.

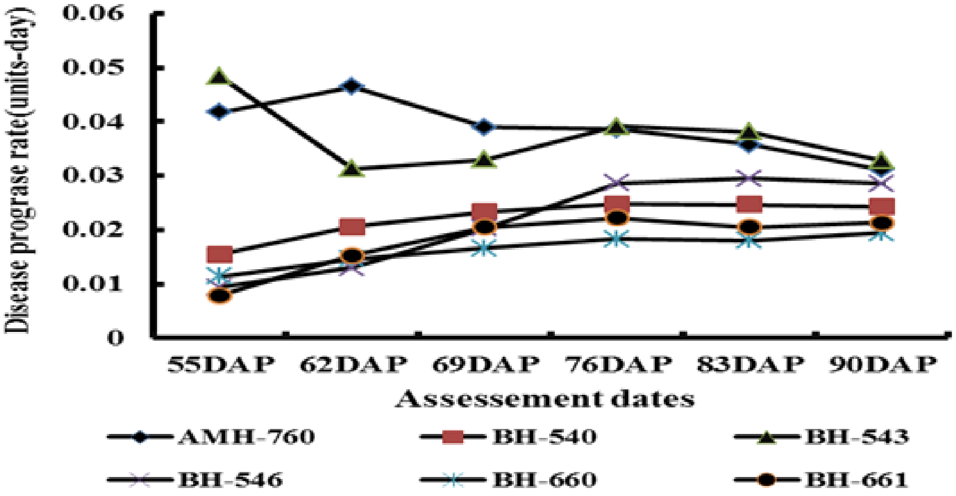

Figure 1. Turcicum leaf blight progress rates on different maize varieties at Bako during 2014 main cropping season.

progress rate and propiconazole sprayed variety BH-660 scores the slowest (with r-value 0.0116 units-day^{-1}) disease progress rate. The disease progress rate of the unsprayed susceptible variety BH-543 was 2.86 times faster than the propiconazole-treated plots. This indicates that propiconazole reduced the TLB progress rate significantly. The range of apparent infection rate in this experiment (0.011-0.0443 unit-day^{-1}) was slightly lower than the range (0.05-0.20 unit-day^{-1}) reported by Levy (1989), but it was closer to the range (0.019-0.032 unit-day^{-1}) reported by Harlapur et al. (2008).

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

Days to physiological maturity

The main effects of fungicide application showed no significant (p>0.05) difference on days to 50% tasselling,

Table 6. Main effects of fungicide application and varieties on the last progress rate (units-day^{-1}) of TLB on maize hybrids at Bako in 2014 main cropping season.

Factors	Final TLB progress rate	SE of (r)^{a}	(R^{2}%)^{b}	P
Fungicides				
Unsprayed	0.035290^{c}	0.0013	53.95	<0.0001
Mancozeb	0.027760^{b}	0.0013	63.76	<0.0001
Propiconazole	0.015717^{a}	0.0013	52.63	<0.0001
CV (%) (a)	14.85			
LSD (5%)	0.005986			
Varieties				
BH-540	0.024287^{c}	0.0020	43.91	<0.0001
BH-543	0.032782^{a}	0.0020	54.59	<0.0001
BH-546	0.028512^{b}	0.0020	82.61	<0.0001
BH-660	0.019503^{d}	0.0020	54.06	<0.0001
BH-661	0.021346^{cd}	0.0020	42.65	<0.0001
AMHQ-760	0.031105^{ab}	0.0020	62.9	<0.0001
CV (%) (b)	16.18			
LSD (0.01)	0.005506			

Mean values with the same letter within a column are not significantly different at described probability level; CV = Coefficient of variation; ^{a} = standard error of main factor; ^{b} = Coefficient of determination or proportion explained by the model; P = Significance probability level of rates when regressed over time.

Table 7. Integrated effect of fungicide application by varieties on progress rate (units-day-1) of TLB on maize hybrids.

Fungicides	Variety	TLB progress rate	SE of (r) ^{a}	(R^{2}%)^{b}	P
Unsprayed	BH-540	0.03041^{cde}	0.00245222	68.2	0.0001
	BH-543	0.04434^{a}	0.00245222	36.72	0.0001
	BH-546	0.04107^{ab}	0.00245222	80.1	0.0001
	BH-660	0.02716^{def}	0.00245222	55.1	0.0001
	BH-661	0.02491^{efgh}	0.00245222	34.8	0.0001
	AMHQ-760	0.04384^{a}	0.00245222	48.6	0.0001
Mancozeb	BH-540	0.02309^{fghi}	0.00245222	32.47	0.0001
	BH-543	0.03547^{bc}	0.00245222	59.33	0.0001
	BH-546	0.02998^{cdef}	0.00245222	80.77	0.0001
	BH-660	0.01965^{ghij}	0.00245222	85.60	0.0001
	BH-661	0.02753^{defg}	0.00245222	72.89	0.0001
	AMHQ-760	0.03261^{cd}	0.00245222	51.50	0.0001
Propiconazole	BH-540	0.01935^{ghij}	0.00245222	31.01	0.0001
	BH-543	0.018536^{hijk}	0.00245222	67.69	0.0001
	BH-546	0.014489^{jk}	0.00245222	86.89	0.0001
	BH-660	0.011691^{k}	0.00245222	21.43	0.0001
	BH-661	0.013376^{jk}	0.00245222	20.19	0.0001
	AMHQ-760	0.016863^{ijk}	0.00245222	88.57	0.0001
CV (%)		16.18			
LSD (5%)		0.006989			

Mean values with the same letter within a column are not significantly different at 5% probability level; CV = Coefficient of variation; a = standard error of main factor; b = Coefficient of determination or proportion explained by the model, P = Significance probability level of rates when regressed over time.

silking and 90% physiological maturity of hybrid maize varieties (Table 8). However, varietal effect showed significant ($p \leq 0.05$) difference on days to 50% tasselling, silking and 90% physiological maturity. The mean days to

Table 8. Effects of fungicide and hybrid maize varieties on days to 50% tasselling and silking, and days to 90% physiological maturity at Bako in 2014 main cropping season.

Factor	Days to		
	50% Tasseling	**50% silking**	**90% physiological maturity**
Fungicides			
Unsprayed	81.722^{a}	92.7^{a}	154^{a}
Mancozeb	81.667^{a}	93^{a}	154.6^{a}
Propiconazole	81.944^{a}	95^{a}	153.9^{a}
CV (%) (a)	2.92	4.72	1.82
LSD (0.05)	NS	NS	NS
Varieties			
BH-540	80.4^{b}	91.77^{bc}	150.1^{c}
BH-543	80.1^{b}	90^{c}	152.78^{b}
BH-546	80.8^{b}	91.67^{bc}	153.67^{b}
BH-660	84^{a}	96.89^{a}	157^{a}
BH-661	84.4^{a}	96^{ab}	157^{a}
AMHQ-760	80.7^{b}	95.22^{ab}	154.5^{b}
CV (%) (b)	3.69	5. 27	2.28
LSD (0.05)	2.91	4.74	1.54

Mean walues with the same letter within a column are not significantly different at 5% probability level. NS = Non-significant and LSD = Least significant difference.

Table 9. Main effects of maize varieties and fungicides on mean grain yields, TKW and yield losses of maize hybrids at Bako in 2014 main cropping season.

Factors	Grain yield (KG/ha)	TKW (g)	RYL (%)
Fungicides			
Unsprayed	6236^{c}	325.5^{b}	33.36
Mancozeb	7447^{b}	330.6^{b}	18.4
Propiconazole	9193.8^{a}	375.78^{a}	0.74
CV (%) (a)	20.1	30.41	
LSD (0.01)	14.12	Ns	
Varieties			
BH-540	6810.8^{c}	357.78^{b}	12.72
BH-543	7071^{c}	347.78^{bc}	26.99
BH-546	9331^{a}	296d	18.26
BH-660	7476^{c}	390.1^{a}	16.96
BH-661	8375^{a}	343.3^{bc}	17.10
AMHQ-760	6689^{c}	328.89^{c}	13.07
CV (%) (b)	11.47	7.77	
LSD (0.01)	11.34	LSD (0.05)	25.74

Mean values with the same letter within a column are not significantly different at described probability level. Ns = Non significant and LSD = Least significant difference.

90% physiological maturity of BH-540, BH-543, BH-546, BH-661, BH-660 and AMHQ-760 were 150, 152, 153, 157, 157 and 154 days, respectively (Table 8). This could be due to the inherent genetic makeup of the hybrid maize varieties. Interaction effect of fungicide with variety showed no significant difference on days to 50% tasseling, silking and days to 90% physiological maturity.

Grain yield

The yield produced showed significant difference for main effects 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 (Table 9). The highest (9,193.8 kg ha^{-1}) maize yield was

Table 10. Integrated effects of maize varieties by fungicides on mean grain yields of TKW and yield losses of maize hybrids at Bako in 2014 main cropping season.

Varieties	Fungicides	Grain yield (kg/ha)	TKW (g)	RYL (%)
	Unsprayed	5262^{jk}	326.60^{defg}	33.69
BH-540	Mancozeb	7842.43^{defg}	370.00^{bcd}	0.00
	Propiconazole	7328^{efg}	376.60^{bc}	4.45
	Unsprayed	5726^{ijk}	300.00^{fgh}	40.70
BH-543	Mancozeb	5808^{hijk}	333.30^{cdef}	40.27
	Propiconazole	9678^{bc}	410.00^{ab}	0.00
	Unsprayed	8186^{def}	286.60^{gh}	28.41
BH-546	Mancozeb	8424^{cde}	260.40	26.01
	Propiconazole	11383^{a}	341.30^{cdef}	0.00
	Unsprayed	6574^{ghij}	400.00^{ab}	27.42
BH-660	Mancozeb	6879^{fghi}	347.00^{cde}	23.49
	Propiconazole	8977^{bcd}	423.00^{a}	0.00
	Unsprayed	6592^{ghij}	323.30^{efg}	35.36
BH-661	Mancozeb	8468^{cde}	353.33^{cde}	15.90
	Propiconazole	10075^{ab}	353.33^{cde}	0.00
	Unsprayed	5088^{k}	316.60^{efg}	34.21
AMHQ-760	Mancozeb	7259^{efgh}	320.00^{efg}	5.01
	Propiconazole	7721^{defg}	350.00^{cde}	0.00
CV (%) (b)		11.47	7.77	
LSD (0.05)		16.89	82.012	

Mean values with the same letter within a column are not significantly different at 5% probability level. Ns= Non significant and LSD= Least significant difference.

obtained from propiconazole-sprayed plots and the lowest (6,236.5 kg ha^{-1}) was obtained from the unsprayed hybrid maize plots.

The ANOVA for grain yield showed highly 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-546 gave the highest (9,331.2 kg ha^{-1}) mean grain yield, followed by the variety BH-661 (8,375.3 kg ha^{-1}) that was significantly different from the other hybrid maize varieties. The analysis of mean grain yields of other maize varieties did not show any significant ($p > 0.05$) differences among themselves (Table 9).

The analysis of the two-way interaction of fungicides by varieties also showed significant ($p \leq 0.05$) difference in hybrid maize grain yield. The highest (11,383 kg ha^{-1}) grain yield was obtained from propiconazole-sprayed variety BH-546 and the lowest (5088 kg ha^{-1}) yield was from the unsprayed maize variety AMHQ-760 (Table 10). Propiconazole-sprayed treatments significantly ($p \leq 0.05$) differed in grain yields from the untreated and mancozeb-sprayed plots of the hybrid maize varieties BH-543, BH-546 and BH-660. Also, the unsprayed plots of the varieties BH-540 and AMHQ-760 showed significant ($p \leq 0.05$) differences in grain yield from those of propiconazole- and mancozeb-sprayed plots of the same maize varieties.

Thousand kernel weight (TKW)

The ANOVA of the main and interaction effects showed significant ($p \leq 0.05$) difference among the treatments in thousand kernel weight (TKW) regardless of the main effects of fungicide applications (Table 9). The result showed significant ($p \leq 0.05$) difference in TKW between BH-660 and BH-546 and also both of these varieties significantly ($p \leq 0.05$) differed from all other hybrid maize varieties. The hybrid maize variety BH-540 significantly ($p \leq 0.05$) differed in TKW from both AMHQ-760 and BH-546 maize hybrids (Table 9). However, there were no significant difference among the maize varieties BH-543, BH-661 and AMHQ-760. The significant difference in

TKW among the three varieties was attributed to the difference in their genetic makeup.

The two-way interaction effects of fungicide by variety showed non-significant difference in TKW for the varieties BH-660 and AMHQ-760 integrated with all the fungicide applications. The highest (423.3 g) TKW was obtained when the hybrid maize variety BH-660 integrated with propiconazole spray and the lowest (260 g) was obtained when the plots of the maize variety BH-546 were sprayed with mancozeb fungicide. Propiconazole-sprayed treatments of the maize varieties BH-543 and BH-546 significantly ($p \leq 0.05$) differed in TKW from the untreated and mancozeb-sprayed plots. But on the maize variety BH-540, the unsprayed plots showed significant ($p \leq 0.05$) difference in TKW from propiconazole and mancozeb-sprayed plots. In these interactions, no significant difference was observed between integration of variety and fungicide application for each of the varieties BH-661 and AMHQ-760 (Table 10).

Relative yield loss

Relative yield losses of maize varieties were calculated from their respective treatments that offered maximum protection and maximum yield. The maximum protected (propiconazole-sprayed) treatment was used as a reference for BH-543, BH-546, BH-660, BH-661 and AMHQ-760 varieties to calculate their relative yield losses and for maize variety BH-540 the mancozeb-sprayed plots was used. These plots had significantly lowest TLB percent severity index, highest yield and no or low yield losses. The highest (33.36%) relative yield loss was recorded from the unsprayed plots.

In the present experiment, disease progress rates and yield reduction (relative yield losses) were determined by the resistance of each variety. Mean yield losses calculated for all the hybrid maize varieties revealed that BH-543 had the highest (26.9%) relative yield loss and the variety BH-540 had the lowest (12.7%) relative yield loss (Table 9). Similarly Raymundo and Hooker (1981) observed yield reduction in the order of 63, 43 and 17% for early maturing, susceptible hybrid; a hybrid with polygenic resistance; and hybrid with Ht and polygenic resistant, respectively.

Generally, in hybrid maize varieties BH-540, BH-543, BH-546, BH-660, BH-661 and AMHQ-760, the respective relative grain yield losses of 33.68, 40.70, 28.41, 27.42, 35.36 and 34.21% were recorded in the fungicide unsprayed treatments (Table 11). The current results confirm the effectiveness of fungicide integration with maize varieties in reducing the adverse effects or epidemics of TLB. Krausz et al. (1993) reported grain yield loss of susceptible hybrids ranging from 40 to 50%. Babu et al. (2004) reported turcicum leaf blight incidence on maize at Almora and it attained epidemic proportion resulting in 83% yield reduction.

Association of disease parameters with yield and yield components

The percent severity indices, AUDPC-values and disease progress rates were negatively correlated with yield components regardless of relative yield losses. This result is in agreement with the findings of Daniel (2006) who reported that disease parameters of TLB significantly, but negatively, affected the yield components of hybrid maize. However, the significant association depended on the hybrid maize varieties and their respective disease parameters (Table 11).

Most of the disease parameters were not significantly associated with the maize variety BH-540. The only significant associations were observed on AUDPC ($r = -0.73$) and disease progress rate ($r = -0.75$) associated with the number of rows per plant. On the susceptible variety BH-543, most of the disease parameters were strongly (negatively or positively) associated with grain yields and relative yield losses. Percent severity index assessed at 90 DAP had the strongest negative association with maize grain yield ($r = -0.81$), relative yield loss ($r = 0.80$) and TKW ($r = -0.81$) above all other disease parameters.

On another susceptible hybrid maize variety, AMHQ-760, most of the disease parameters was strongly associated with grain yield and relative yield losses. Grain yield of this variety was significantly associated with TLB percent severity index assessed at 90 DAP and AUDPC. Strong associations was observed between disease progress rates with ear size ($r = -0.83$), and followed by relative grain yield loss ($r = 0.80$).

On the hybrid maize varieties BH-546, BH-661 and BH-660, even if all disease parameters were negatively correlated with yield parameters, associations were mostly non-significant. For the maize variety BH-546, there were strong associations of the maize ear size in line with TLB percent severity index ($r = -0.87$), AUDPC ($r = -0.88$) and disease progress rates ($r = -0.87$). On the maize variety BH-660, the only significant association was that of the disease progress rate correlated with the ear size.

To evaluate the association of maize grain yield with TLB parameters, generally, the good estimator of the degree of association was different among the susceptible and moderately resistant varieties. For instance, disease percent severity index assessed at 90 DAP was strongly associated with yield on susceptible hybrid maize varieties, while the disease progress rate was strongly associated with yield on moderately resistant varieties. Similarly, Daniel (2006) indicated that maize grain yield was significantly affected by variety but no significant difference was observed among varieties for TKW.

Models for estimating relationships between percent severity index and AUDPC with grain yield

Regression of TLB percent severity index and AUDPC

Table 11. Association of disease parameters with yield components at Bako in 2014 main cropping season.

Disease parameter	Yield (kg ha^{-1})	Relative yield loss (%)	TKW	Ear size	Number of rows per ear
BH-540					
Percent severity index (%)	-0.23^{Ns}	0.48^{Ns}	-0.21^{Ns}	-0.30^{Ns}	-0.42^{Ns}
AUDPC (%-days)	-0.37^{Ns}	0.48^{Ns}	-0.01^{Ns}	-0.48^{Ns}	-0.73*
Rate (units-day^{-1})	-0.23^{Ns}	0.31^{Ns}	-0.20^{Ns}	-0.68*	-0.75*
BH-543					
Percent severity index (%)	-0.81**	0.80**	-0.81**	-0.89**	-0.25^{Ns}
AUDPC (%-days)	-0.78*	0.77*	-0.78*	-0.83**	-0.10^{Ns}
Rate (units day^{-1})	-0.78*	0.80**	-0.80**	-0.84**	-0.23^{Ns}
BH-546					
Percent severity index (%)	-0.52^{Ns}	0.58^{Ns}	-0.55^{Ns}	-0.87**	-0.77*
AUDPC (%-days)	-0.55^{Ns}	0.61^{Ns}	-0.54^{Ns}	-0.88**	-0.78*
Rate (units day^{-1})	-0.57^{Ns}	0.66*	-0.65^{Ns}	-0.87**	-0.70*
BH-660					
Percent severity index (%)	-0.17^{Ns}	0.34^{Ns}	-0.45^{Ns}	-0.58^{Ns}	-0.29^{Ns}
AUDPC (%-days)	-0.12^{Ns}	0.03^{Ns}	-0.25^{Ns}	-0.36^{Ns}	-0.23^{Ns}
Rate (units day^{-1})	-0.35^{Ns}	0.50^{Ns}	-0.39^{Ns}	-0.71*	-0.58^{Ns}
BH-661					
Percent severity index (%)	-0.54^{Ns}	0.67^{Ns}	-0.33^{Ns}	-0.28^{Ns}	-0.33^{Ns}
AUDPC (%-days)	-0.62^{Ns}	0.71*	-0.33^{Ns}	-0.30^{Ns}	-0.36^{Ns}
Rate (units day^{-1})	-0.55^{Ns}	0.68*	-0.34^{Ns}	-0.30^{Ns}	-0.5^{Ns}
AMHQ-760					
Percent severity index (%)	-0.79*	0.77*	-0.10^{Ns}	-0.72*	-0.69*
AUDPC (%-days)	-0.78*	0.75*	-0.18^{Ns}	-0.75*	-0.63^{Ns}
Rate (units day^{-1})	-0.70*	0.80**	-0.26^{Ns}	-0.83**	-0.64^{Ns}

AUDPC = Area under disease progress curve, Ns =Non-significant, *significant, **highly significant.

values on grain yield data revealed significant difference as compared to regressions of other disease parameters on yield for all hybrid maize varieties. Therefore, these two parameters (percent severity index and AUDPC) could be used as good predictors and grain yield as dependent variable to estimate hybrid maize grain yield losses.

The percent severity index calculated for the last date disease assessment data revealed better coefficient of determination and showed significant relationship with yield for the maize varieties BH-543 (R^2 = 66.88) and AMHQ-760 (R^2 = 61.79) (Figure 2). However, for the maize varieties BH-540 (R^2 = 13), BH-660 (R^2 = 20), BH-546 (R^2 = 30.6) and BH-661 (R^2 = 38.9), AUDPC predicted grain yield losses better than the TLB percent severity index because R^2 of AUDPC was higher than that of the R^2 for percent severity index (Figure 3).

The regression equations illustrated that for every 1% increase in disease percent severity index assessed on the varieties at the final day of assessment, there were grain yield losses of 142.2, 170.83, and 50.8 kg ha^{-1} for the maize varieties AMHQ-760, BH-543 and BH-660, respectively (Figure 2A to C). Similarly, based on the regression equations, for every 1% increase in AUDPC there were 7.9, 6.9 and 10.3 kg ha^{-1} yield losses that were calculated for the varieties BH-540, BH-546 and BH-661, respectively (Figure 3A to C).

Cost/benefit analysis

The employment of integrated TLB management resulted in higher maize grain yield, gross revenue, marginal benefit and marginal rate of return (MRR) than use of the control group alone, excluding the grain yields from mancozeb-treated BH-543, BH-546 and BH-660 that showed less marginal benefit and marginal rate of return than the control plots. Since the dominance analysis

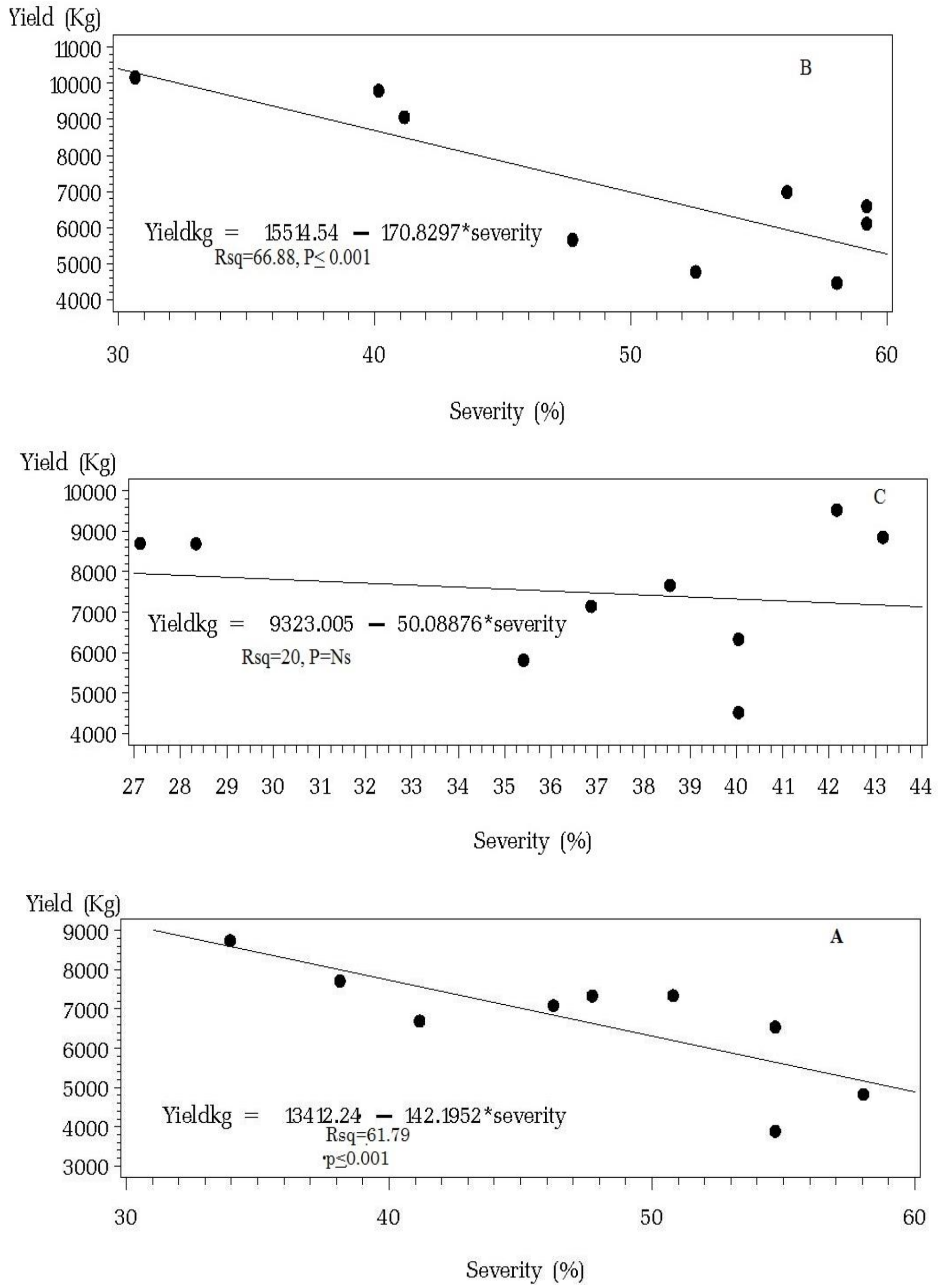

Figure 2. Estimated relationships between maize TLB severities and grain yields of three maize varieties at Bako in 2014 main cropping season. A, B & C: Percent severity index vs yields of the maize varieties AMHQ-760, BH-543 and BH-660, respectively.

carried out before the analysis of the marginal rates of return revealed that these treatments were dominated by other treatments, they were not included in the analysis of the marginal rate of return.

The highest (ETB 48,801.28 ha^{-1}) marginal benefit was obtained from maize variety BH-546 sprayed with propiconazole, followed by BH-661 (ETB 42,912.35 ha^{-1}) and BH-543 (ETB 41,125.62 ha^{-1}) and the lowest (ETB 22,898.41 ha^{-1}) obtained from unsprayed variety AMHQ-760 (Table 12).

An easier way of demonstrating the relationship of cost and benefit is calculation of the marginal rate of return, which is the rate of return of the marginal net benefit (that is, the change in net benefits) divided by the marginal

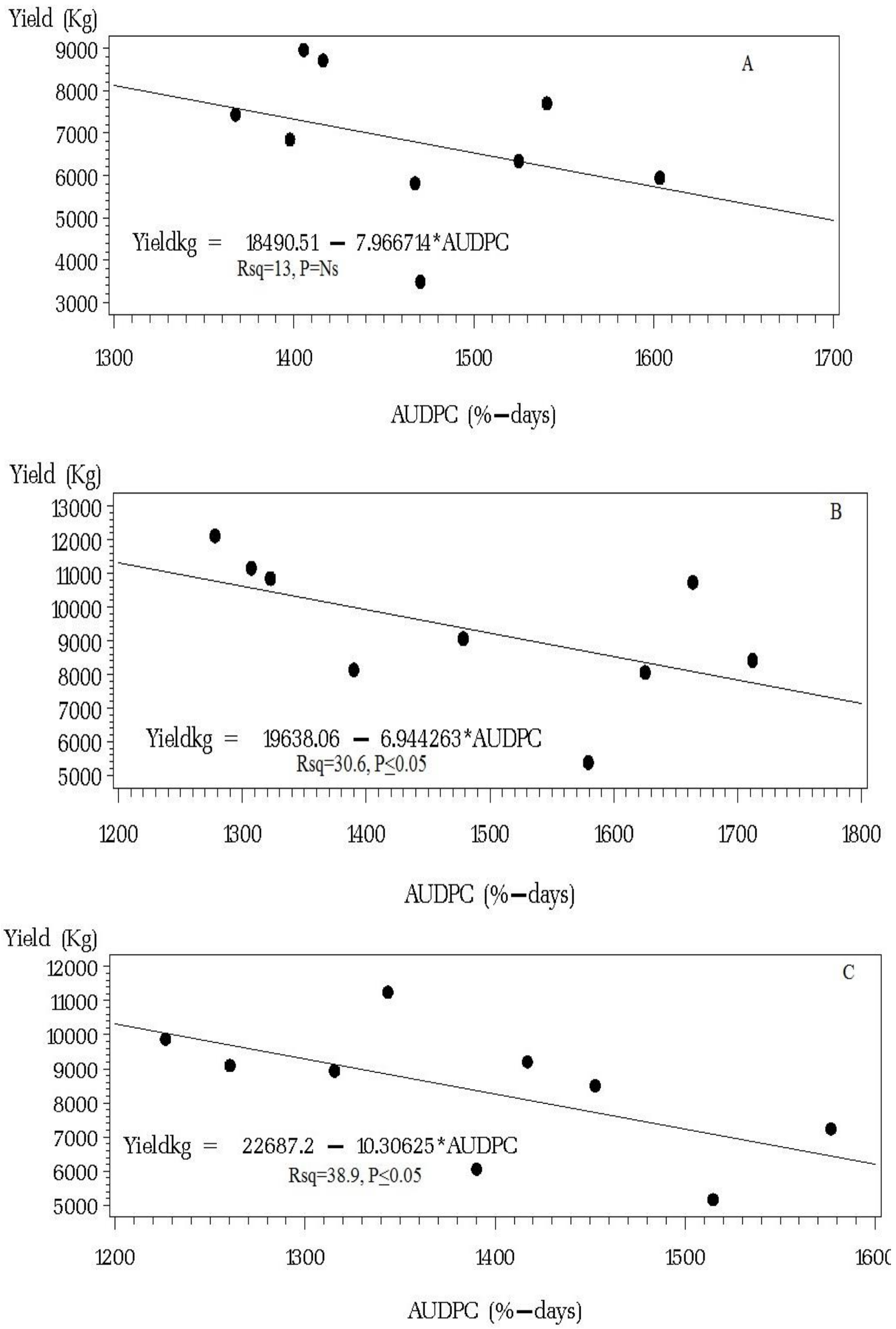

Figure 3. Estimated relationships between maize TLB AUDPC and grain yields of three maize varieties at Bako in 2014 main cropping season. A, B and C: Percent severity index vs. grain yields of the maize varieties BH-540, BH-546 and BH-661, respectively.

cost (that is, the change in costs), expressed as a percentage. The highest (ETB 633.30) marginal rate of return was obtained from BH-543 when it was treated with propiconazole, followed by BH-661 (ETB 548.10) treated with propiconazole. In other words, for every ETB1.00 investment in propiconazole cost and spraying, there was a gain of ETB 6.33 for the maize variety BH-543 and ETB 5.48 for the variety BH-661.

Generally the highest maize grain yield, highest marginal benefit, and marginal rate of return were obtained from the moderately resistant maize varieties BH-546 and BH-661 as compared to the other treatment combinations at Bako. So from the economic point of view, production of hybrid maize varieties BH-543, BH-546 and BH-661 under propiconazole-spraying practices is the most profitable of all other integrated management

Table 12. Cost/benefit assessment of fungicide application against TLB on six hybrid maize varieties at Bako in 2014 main cropping season.

Fungicides	Variety	Yield (kg ha^{-1})	Adjustable yield (%)	SR (ETB ha^{-1})	TIC (ETB ha^{-1})	MC (ETB ha^{-1})	NP (Birr ha^{-1})	MB (Birr ha^{-1})	MRR (%)
Unsprayed	BH-540	5262.34	4736.108	23680.54	4375	0	19305.54	23680.54	0
	BH-543	5726.07	5153.459	25767.3	4375	0	21392.3	25767.3	0
	BH-546	8186.33	7367.698	36838.49	4375	0	32463.49	36838.49	0
	BH-660	6573.16	5915.843	29579.21	4375	0	25204.21	29579.21	0
	BH-661	6582.51	5924.257	29621.28	4375	0	25246.28	29621.28	0
	AMHQ-760	5088.54	4579.682	22898.41	4375	0	18523.41	22898.41	0
Mancozeb	BH-540	7842.54	7058.286	35291.43	6860	2485	28431.43	32806.43	367.3
	BH-661	8468.34	7621.51	38107.55	6860	2485	31247.55	35622.55	241.5
	AMHQ-760	7258.78	6532.898	32664.49	6860	2485	25804.49	30179.49	293
Propiconazole	BH-540	7327.43	6594.689	32973.45	6800	2425	26173.45	30548.45	283.2
	BH-543	9677.91	8710.123	43550.62	6800	2425	36750.62	41125.62	633.3
	BH-546	11383.62	10245.26	51226.28	6800	2425	44426.28	48801.28	493.3
	BH-660	8977.59	8079.83	40399.15	6800	2425	33599.15	37974.15	346.2
	BH-661	10074.97	9067.47	45337.35	6800	2425	38537.35	42912.35	548.1
	AMHQ-760	7721.09	6948.98	34744.9	6800	2425	27944.9	32319.9	388.5

SR = Sale revenue, TIC = Total input cost, MC = Marginal cost, NP = Net profit. MB = Marginal benefit, MRR = marginal rate of return CB = Cost benefit ratio.

options against TLB at the current maize market prices at Bako.

Conclusions

Main effects of fungicides and varieties showed highly significant ($p \leq 0.01$) differences among disease parameters that included percent severity index, AUDPC and disease progress rates at the last date of disease assessment. The systemic fungicide propiconazole-sprayed plots had the lowest score for all disease parameters assessed and it significantly reduced the disease severity. Therefore, this fungicide efficiently controlled maize TLB by reducing the progress of the disease over time. Use of resistant hybrid maize varieties also showed significant difference among all disease parameters assessed and the highest scores were for susceptible varieties BH-543 and AMHQ-760 and the lowest score was for the moderately resistant maize variety BH-660. However, the hybrids BH-540 could be better categorized as tolerant varieties due to their promising yields. This current study contributes to integrated TLB management options, especially under commercial hybrid maize production.

Conflicts of interests

The authors have not declared any conflict of interests.

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