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Evaluation of Maize Covered Smut (*Ustilago maydis*) Management Options in Eastern Amhara, Ethiopia

Admasie Kassaw*[A], Tesfaye Desale[A], Abebe Ayalew[A], Abate Abtie[A], Abiye Tiruneh[A] and Eshete Wudu[A]

[A] Sirinka Agricultural Research Centre. Woldia, Ethiopia

*Corresponding author, e-mail: admasiek70@gmail.com

Abstract

Maize, one of the most important cereal crops in the world, faces severe production constraints in Ethiopia due to covered smut disease. Field experiments were conducted at Sirinka and Cheffa during the 2022-2023 cropping seasons to evaluate management practices against maize covered smut. Seven treatments consist of five fungicides, cow urine, hot water, and untreated control, arranged in a randomized complete block design with three replications. The study found notable variations in disease intensity, maize grain yield, and yield components among the treatments. The application of proceed plus fungicide and the use of cow urine treatments were effective in reducing maize covered smut disease and higher yields of maize compared to other treatments and control plots. The combined analysis indicated that the highest maize grain yield (3120 and 2806 kg.ha^{-1}) was recorded from carboxin + thiram + imidacloprid, and triadimefon fungicide-treated plots, followed by cow urine seed treatment (2649 kg.ha^{-1}), while the lowest (1601 kg.ha^{-1}) was recorded from untreated control plot. The highest net benefit (125310 ETB) was obtained from carboxin + thiram + imidacloprid, followed by Triadimefon (112986.8 ETB) and cow urine (107084.5 ETB) treated plots. Therefore, based on the partial economic analysis result, carboxin + thiram + imidacloprid fungicide and cow urine as a seed treatment are recommended for maize producers.

Keywords: carboxin, cow urine, imidacloprid, seed treatment, thiram

Introduction

Maize has risen to become the world's second most widely produced crop. Approximately 203 million hectares of world agricultural land are cultivated by maize, the highest-yielding crop, followed by rice and wheat (FAOSTAT, 2022). Maize is currently the most voluminous cereal produced and is expected to remain the most cultivated and traded crop in the first decade of this century. Maize is a multipurpose crop primarily used as animal feed at the global level. Maize is also a highly significant food staple crop, particularly in Sub-Saharan Africa and Latin America, as well as in its numerous non-food applications (Erenstein et al., 2022). In Ethiopia, maize ranks second to teff (*Eragrostis tef*) as the most significant cereal crop, covering an area of 2.5 million hectares and producing 10.5 million tons (CSA, 2021). The Amhara region, Ethiopia's second-largest maize producer, following Oromia, contributes 2.5 million tons across an area of 0.6 million hectares (average productivity of 4.27 t.ha^{-1}) (CSA, 2021). Within Amhara, the North and South Wollo Zones cultivate 7,599.38 and 22,382.59 hectares, respectively. The total production in these zones reaches 22,622.94 and 59,800.36 tons, yielding averages of 2.98 and 2.67 t.ha^{-1} (CSA, 2021). However, plant diseases, including maize smut (*Ustilago maydis*), pose an important constraint to maize productivity in Ethiopia, despite its endemic presence in China, North America, and the United States (Guta and Tilahun, 2021).

The smut pathogen, *U. maydis*, may cause yield losses of up to 60.08 %. It's characterized by systemic formation of galls, or tumor-like growths, on various parts of the maize plant, including ears, tassels, and stalks. These galls replace the inflorescences of infected plants, inducing sterility and substituting the maize grain with the teliospores of basidiomycete fungus (Ramazanova et al., 2024; Radocz et al., 2023). In Ethiopia, a study by Guta and Tilahun (2021) documented *U. maydis* prevalence ranging from 14.65% to 22.99%, with the peak incidence in Dale Sadi district, West Wollega, Ethiopia (22.99%) and Lalo Kile district, West Wollega, Ethiopia (20.65%).

The teliospores of smut fungi can survive in soil for several years, serving as the primary inoculum source. These spores germinate under favorable conditions (20-40°C and >85% relative humidity)

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infecting the host during its early growth stages (Chemeltorit and Suresh, 2020). Spores can withstand temperature, moisture, and sunlight variations and maintain viability for years, a critical adaptation in the disease cycle. Host resistance, seed treatments, and pesticide applications can control the disease. According to Wright et al. (2006), propiconazole fungicide was effective for the control of maize head smut and showed a less infected (2.5%) plant compared with other treatments. Barley loose smut can be controlled by using a hot water treatment, the use of resistant varieties, and fungicides like propiconazole, tebuconazole, carbendazim, and mancozeb (Woldemichael, 2019). Carboxin+thiram at 3.0 g.kg^{-1} just before sowing recorded significantly higher seed yield, lesser smut incidence, and better seed quality parameters (Sajjan et al., 2011). Cow urine seed treatments reduced the prevalence of sorghum-covered smut disease more than the untreated checks (Azanaw et al., 2020). Hot water treatment at 50°C for 10 minutes can kill the internal pathogen of barley loose smut in the embryo without harming the embryo (Zillinsky, 1983).

Disease spread and incidence are increasing, necessitating improved management strategies. In the study area, maize covered smut exhibits high prevalence during irrigation and main cropping seasons. This disease has become a major maize production constraint, especially in the North Wollo zone. Despite its significant impact, limited research exists on the effective management of maize covered smut disease. Therefore, the present study was conducted to evaluate the efficacy of different disease management practices against maize covered smut in Eastern Amhara and select cost-effective management options.

Materials and Methods

Description of Experimental Site

Field experiments were conducted during the main cropping seasons (July to October) 2022 and 2023 at two locations in Eastern Amhara: Sirinka (11°45’10”Latitude, 39°36’44”Longitude; 1850 m.a.s.l.) and Cheffa (10°50’39”Latitude, 39°48’46”Longitude; 1450 m.a.s.l.). The Sirinka trial site has an annual temperature range of 13.6°C-27.3°C and receives 876 mm of rainfall, while the Chefa trial site has an annual temperature range of 11.6°C-30.4°C and receives 850 mm of rainfall annually.

Experimental Design and Materials

The field trial was conducted using a randomized complete block design (RCBD) with three replications. Seeds were inoculated with spores of covered smut (3 grams of teliospore per 1 kg of maize seeds) artificially. The experiment had seven treatments: five types of fungicides, triadimefon (Noble), cymoxanil+ copper oxychloride (Trust), carboxin + thiram + imidacloprid (Proseed plus), and trifloxystrobin100 g.L + tebuconazol 200 g.L^{-1} (Nativo), hot water treatment, and untreated treatment used as a control check (Table 1). All fungicides, cow urine, and hot water treatments were done before planting as a seed treatment. Cow urine was collected and stored for seven days to ferment. Then, it was mixed with water in a 1:1 ratio, i.e., 1 kg maize seed was inserted in 500 ml fermented cow urine + 500 ml water mixture allowed for 30 minutes (Azanaw et al., 2020).

The plot size of the experiment was 4 m x 4.5 m; each plot contained four harvestable rows with a plant spacing of 25 cm and 75 cm row spacing. Each plot and block were separated by 1.0 and 1.5 m spacing.

Data Collection

Maize covered smut disease incidence data was recorded from the central rows of the plot and expressed as percentage. Measurements were conducted on the following parameters:

Cob width: the average width of 10 cobs was measured using a pocket meter.
Cob weight: the average weight of 10 cobs was measured using a precision balance.

Table 1. Treatment names and their application rates

Trt	Trade name	Active ingredients	Rate
1	Noble	Triadimefon	1.5 g.kg^{-1} seed
2	Trust-Cymocop	Cymoxanil + copper oxychloride	3 g.kg^{-1} seed
3	Proseed plus	Carboxin + thiram + imidacloprid	3 g.kg^{-1} seed
4	Nativo	Trifloxystrobin + tebuconazol	1 mL.kg^{-1} seed
5	Cow urine	-----	1:1 with water for 30 minutes
6	Hot water	-----	50°C for 10 minutes
7	Control	-----	Untreated

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100-seed weight: The average The weight of 100 seeds was measured using a precision balance.
Grain yield: The maize yield from the harvestable rows in each plot was measured and then converted to a per-hectare yield. Relative yield loss, percentage yield advantage, and economic analysis were calculated.

Relative Yield Loss and Percentage Yield Increase

Maize grain yield loss due to maize covered smut disease was calculated as a percentage yield reduction of untreated treatments (YT) compared with the most protected treatment (YP) by using the following formula of Robert and Janes (1991):

$$\text{RPYL} = \frac{YP-YT}{YP} \times 100$$

Relative percent yield loss (RPYL) can be calculated by comparing the yield from the maximum protected plot (YP) to the yield from plots of other treatments (YT).
Percentage yield increase (PYI) was considered based on the following formula:

$$PYI = \frac{yield\ of\ treated\ plot - yield\ of\ control\ plot}{yield\ of\ control\ plot} \times 100$$

Partial Budget Analysis

The cost-benefit assessment of each treatment was calculated partially, and the marginal rate of return was calculated by considering the variable cost available in the corresponding treatment (CIMMYT, 1988). Marginal analysis is concerned with the process of making a choice between alternative factor-product combinations considering small changes. The formula is as follows:

MRR = DIN/DIC

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

The cost-benefit analysis included variable input costs like costs for chemicals and labor for chemical seed treatment and fixed costs, including maize seed and agronomic practices. The cost of triadimefon fungicide was 2500 Birr per kg, while cymoxanil+ copper oxychloride and carboxin + thiram + imidacloprid fungicide were priced at 2000 Birr per kg. Trifloxystrobin + tebuconazol cost 2000 Birr per liter, and the labor cost for seed treatment was 400 Birr per man day. At the end of production, the total gross benefit from the maize grain yield was computed by multiplying the yield by the local market price of 45 Birr per kg.

Data Analysis

Data on disease, yield and yield component parameters were subjected to Analysis of variance (ANOVA) for each data using GenStat version 18.0 Software. Treatments mean separation was done using the least significant ($P<0.05$) difference. Correlation analysis determined the relationship between disease parameters and maize grain yield. The linear regression model was used to predict the relationship between smut disease percentage and maize grain yield by using GenStat version 18.0 Software. Square root data transformation was applied to the 2022 data from the Sirinka location to enhance the normality of the variables.

Results and Discussion

Seeds were artificially inoculated with spores of covered smut at 3 g of teliospore per 1 kg maize seed). Smut disease, particularly covered smut, severely threatens maize crops, especially when seeds are inoculated with teliospores at 3 grams per kilogram of maize seed. Symptoms include dark, swollen galls, primarily on the maize ears, affecting both their appearance and growth. Approximately 30% of the plants showed signs of infection, which is characterized by the production of black, powdery spores that facilitate disease dispersal. Beyond cosmetic injury, they play a role in grain quality loss and huge yield loss. This presents economic issues for the growers, as they may face lowered marketability of their injured crop.

The results of the analysis indicated a significant difference among treatments ($p < 0.05$) in terms of the percentage of cobs affected by smut disease, cob weight (at Sirinka in 2023 and Cheffa in 2022), and maize grain yield. However, there were no significant differences among treatments regarding cob width, cob weight (at Sirinka in 2022 and Cheffa in 2023), and hundred seed weight at both Sirinka and Cheffa during the main cropping seasons of 2022 and 2023 (Tables 1, 2, 3, and 4).

Smut Percentage

The analysis of variance showed significant differences ($p<0.05$) among the treatments concerning the percentage of maize affected by smut across all locations during the 2022 and 2023 cropping seasons, except for the Cheffa location in 2022. In 2022, the highest smut percentages were recorded at Sirinka, with untreated control and cymoxanil+ copper oxychloride -treated plots showing rates of 16.87% and 25.38%, respectively (Table

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2). Conversely, the lowest smut percentage 7.04%, was found in plots treated with carboxin + thiram + imidacloprid fungicide followed closely by triadimefon (7.91%) (Table 2). In the 2023 cropping season at Sirinka, the untreated control and cymoxanil+ copper oxychloride-treated plots exhibited the highest smut percentages of 29.4% and 30.05%, respectively (Table 4), while the lowest percentages were seen in plots treated with Triadimefon (12.2%) and carboxin + thiram + imidacloprid(17.3%).

The combined analysis over locations and seasons revealed significant differences ($P<0.05$) among the treatments concerning maize covered smut disease (Table 6). The lowest percentage of maize covered smut disease was observed in plots treated with Triadimefon (9.51%) and Carboxin + thiram + imidacloprid (9.76%) fungicides. In contrast, the highest percentage of smut disease, 24.43%, was found in the unsprayed control plot, followed by a 20.34% smut incidence obtained from cymoxanil+ copper oxychloride-treated plots (Table 6).

The findings of this study suggest that plots treated with Carboxin + thiram + imidacloprid and triadimefon fungicides provided better management options, followed by the readily available cow urine treatment. This aligns with the research conducted by Azanaw et al. (2020), which found that the highest inhibition of sorghum-covered smut was achieved in plots treated with cow urine and thiram fungicides. Similarly, Zinabu and Anteneh, (2020) confirmed that thiram fungicides effectively reduced the severity of covered smut disease. This finding aligns with the research conducted by Wright et al. (2006), which demonstrated that fungicides are effective in reducing and managing maize head smut disease. Additionally, fungicides such as carboxin+thiram at a rate of 3.0 $g.kg^{-1}$ showed the highest antifungal activity against maize head smut disease (Sajjan et al., 2011; Kiritai et al., 2024).

Cob Width and Hundred Seed Weight

The analysis of variance revealed no significant

Table 2. Mean of yield, yield component, and disease data of maize at Sirinka (2022)

Treatments	Smut incidence (%)	Cob width (cm)	Cob weight (g)	100 seed weight (g)	Grain yield ($kg.ha^{-1}$)
Triadimefon	7.91(2.2)^{a}	14.23	196.2	25.33	2247
Cymoxanil + copper oxychloride	25.38(5)^{b}	14.53	182.4	24.67	1336
Carboxin + thiram + imidacloprid	7.04(2.6)^{a}	14.2	190.7	24.33	2489
Trifloxystrobin + tebuconazol	9.94(3.1)^{a}	14.33	210.1	23.67	2440
Cow urine	15.84(3.9)^{ab}	14.67	175.4	23	1928
Hot water	10.17(3.1)^{a}	14.67	193.9	24	1711
Control	16.87(4.1)^{ab}	14.53	184.8	22.67	1411
GM	13.31	14.45	190.5	24	1937.3
LSD (5%)	(1.96)	ns	ns	ns	875.32
CV (%)	32.1	2.5	10.3	6.3	25.4

Notes: ns= not significant at $p<0.05$; GM= grand mean; LSD= least significant Difference; CV= Coefficient of variation; () = transformed values.

Table 3. Mean of yield, yield component, and disease data of maize at Cheffa (2022)

Treatments	Smut incidence (%)	Cob width (cm)	Cob weight (g)	100 seed weight (g)	Grain yield ($kg.ha^{-1}$)
Triadimefon	4.74	15.33	238.1^{bc}	30.67	3180^{d}
Cymoxanil + copper oxychloride	6.20	14.87	231.3^{bc}	33.33	2166^{bc}
Carboxin + thiram + imidacloprid	4.05	15.53	239.2^{c}	32.33	3251^{d}
Trifloxystrobin + tebuconazol	5.81	15.53	224.9^{bc}	31	1695^{ab}
Cow urine	2.95	15.2	202.6^{abc}	32.67	2836^{cd}
Hot water	4.00	14.87	194.9^{ab}	30.33	1395^{ab}
Control	6.29	15.33	169.6^{a}	32.67	1147^{a}
GM	4.86	15.24	214.4	31.9	2238.41
LSD (5%)	ns	ns	39.72	ns	738.22
CV (%)	38.8	2.6	10.4	6.8	18.5

Notes: ns= not significant at $p<0.05$; GM= grand mean; LSD= least significant Difference; CV= Coefficient of variation; () = transformed values.

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differences ($p<0.05$) among treatments regarding maize cob width and hundred seed weight at the Sirinka and Cheffa districts during both the 2022 and 2023 cropping seasons (Tables 2, 3, 4, and 5). Likewise, the overall combined means for cob width and hundred seed weight did not show significant differences across treatments. Most treatments produced approximately 20 cm cob widths and 27 grams hundred seed weights (Table 6). The findings indicate that using fungicides, cow urine, and hot water treatments did not significantly affect maize cob width or the weight of a hundred seeds.

Cob Weight

There was a significant difference ($p<0.005$) in maize cob weight among treatments at Sirinka in 2023 and Cheffa in the 2022 cropping season (see Tables 3 and 4). The highest average cob weight of 218.4 grams was observed in plots treated with triadimefon at Sirinka in 2023 (Table 3). Likewise, at Cheffa, the highest average cob weight of 239.2 grams was recorded in plots treated with Carboxin + thiram + imidacloprid fungicide. In comparison, the lowest average cob weight of 169.6 grams was found in the untreated control plots during the 2022 cropping season (Table 4). The combined means of the treatments also showed a significant difference ($p<0.05$) in maize cob weight (Table 6), with the maximum cob weight of 213.8 grams recorded in the Trifloxystrobin + tebuconazol treated plots and the minimum of 186.2 grams in the untreated control plots. The current study aligns with the CIMMYT maize program (2004), indicating that the infection spreads to younger leaves and ears (cobs) that are affected tend to be lighter and have loose kernels.

Grain Yield

The present study revealed statistically significant differences ($p<0.05$) in maize grain yield among treatments at all locations during the 2022 and 2023 cropping seasons. The highest maize grain yields (2489 kg.ha^{-1} at Sirinka and 3251 kg.ha^{-1} at Cheffa) were recorded from plots treated with Carboxin + thiram + imidacloprid fungicide during the 2022 cropping season (Tables 2 and 3). In contrast, the lowest yields (1411 kg.ha^{-1} at Sirinka and 1147

Table 3. Mean of yield, yield component, and disease data of maize at Cheffa (2022)

Treatments	Smut incidence (%)	Cob width (cm)	Cob weight (g)	100 seed weight (g)	Grain yield (kg.ha^{-1})
Triadimefon	4.74	15.33	238.1^{bc}	30.67	3180^{d}
Cymoxanil + copper oxychloride	6.20	14.87	231.3^{bc}	33.33	2166^{bc}
Carboxin + thiram + imidacloprid	4.05	15.53	239.2^{c}	32.33	3251^{d}
Trifloxystrobin + tebuconazol	5.81	15.53	224.9^{bc}	31	1695^{ab}
Cow urine	2.95	15.2	202.6^{abc}	32.67	2836^{cd}
Hot water	4.00	14.87	194.9^{ab}	30.33	1395^{ab}
Control	6.29	15.33	169.6^{a}	32.67	1147^{a}
GM	4.86	15.24	214.4	31.9	2238.41
LSD (5%)	ns	ns	39.72	ns	738.22
CV (%)	38.8	2.6	10.4	6.8	18.5

Notes: ns= not significant at $p<0.05$; GM= grand mean; LSD= least significant Difference; CV= Coefficient of variation; () = transformed values.

Table 4. Mean of yield, yield component, and disease data of maize at Sirinka (2023)

Treatments	Smut incidence (%)	Cob width (cm)	Cob weight (g)	100 seed weight (g)	Grain yield (kg.ha^{-1})
Triadimefon	12.2^{a}	25.67	218.4^{b}	26.59	3068.28
Cymoxanil + copper oxychloride	30.05^{c}	25.27	206.5^{ab}	26.14	2625.27
Carboxin + thiram + imidacloprid	20.28^{abc}	25.47	210^{b}	26.65	3289.43
Trifloxystrobin + tebuconazol	17.3^{ab}	26.2	217.5^{b}	24.74	2430.92
Cow urine	21.16^{abc}	25.53	212^{a}	26.88	2650.76
Hot water	27.1^{bc}	26.2	188.8^{b}	27.25	2558.73
Control	29.4^{bc}	26.33	199.4^{ab}	25.13	2106.92
GM	22.5	25.81	207.51	26.2	2675.76
LSD (5%)	11.25	ns	26.19	ns	ns
CV%	28.1	5	7.1	5.9	20.5

Notes: ns= not significant at $p<0.05$; GM= grand mean; LSD= least significant difference; CV= coefficient of variation.

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$kg.ha^{-1}$ at Cheffa) were obtained from untreated control plots in the same season (Tables 2 and 3). In the 2023 cropping season, the highest maize grain yield at Sirinka was recorded from the Carboxin + thiram + imidacloprid treated plot (3289.4 $kg.ha^{-1}$), followed by triadimefon fungicide (3068.3 $kg.ha^{-1}$), while the lowest yield (2106.9 $kg.ha^{-1}$) was observed in untreated control plots (Table 4). At Cheffa, the maximum yield (3450 $kg.ha^{-1}$) was achieved in plots treated with carboxin + thiram + imidacloprid, while the minimum yield (1740 $kg.ha^{-1}$) was from untreated control plots in 2023 (Table 5).

The combined analysis of results indicated a significant difference ($p<0.05$) in maize grain yield among the treatments (Table 6). The highest yields were observed in plots treated with Carboxin + thiram + imidacloprid (3120 $kg.ha^{-1}$) and triadimefon fungicide (2806 $kg.ha^{-1}$), while a moderate yield (2649 $kg.ha^{-1}$) was obtained from cow urine treatment. In contrast, the untreated control plot produced the lowest yield (1601 $kg.ha^{-1}$) (Table 6). These findings align with Sajjan et al. (2011), which demonstrated that applying carboxin+thiram at a rate of 3.0 $g.kg^{-1}$ just before sowing resulted in significantly higher seed yields, reduced smut incidence, and improved seed quality under field conditions. Additionally, the study is consistent with Azanaw et al. (2020), which reported that the highest yields were achieved in plots treated with cow urine, followed by those treated with thiram.

Relative Yield Loss and Percentage Yield Advantage

The results of relative yield loss and percentage yield advantage were calculated based on the average grain yield from all locations during the 2022 and 2023 cropping seasons. Yield loss was calculated for all treatments relative to the yield from the maximum protected plot treated with carboxin + thiram + imidacloprid. The yield loss varied among plots treated with fungicides, cow urine, and hot water treatments. Losses were notably higher in untreated control plots compared to treated plots with Carboxin + thiram + imidacloprid, triadimefon, and cow urine (Table 7). Regarding relative yield loss, the lowest losses were observed in plots treated with Carboxin + thiram + imidacloprid, triadimefon, and cow urine.

Table 5. Mean of yield, yield component, and disease data of maize at Cheffa (2023)

Treatments	Smut incidence (%)	Cob width (cm)	Cob weight (g)	100 seed weight (g)	Grain yield ($kg.ha^{-1}$)
Triadimefon	13.19[ab]	25.33	196.09	27.96	2727[abc]
Cymoxanil + copper oxychloride	19.74[b]	25.13	205.42	26.76	1869[a]
Carboxin + thiram + imidacloprid	8.78[a]	21.67	173.33	25.48	3450[c]
Trifloxystrobin + tebuconazol	14.57[ab]	25.27	202.61	26.75	2762[abc]
Cow urine	10.65[ab]	25.27	188.9	26.66	3181[c]
Hot water	12.73[ab]	24.93	180.1	25.36	2394[b]
Control	29.17[c]	25	191.04	30.1	1740[a]
GM	15.54	24.66	191.07	27.01	2589.03
LSD	9.36	ns	ns	Ns	941.02
CV%	33.8	9.3	13.4	6.8	20.4

Notes: ns= not significant at $p<0.05$; GM= grand mean; LSD= least significant difference; CV= coefficient of variation.

Table 6. Combined mean of yield, yield component and disease data of maize

Treatments	Smut incidence (%)	Cob width (cm)	Cob weight (g)	100 seed weight (g)	Grain yield ($kg.ha^{-1}$)
Triadimefon	9.51(2.83)[a]	20.14	212.2[b]	27.64	2806[cd]
Cymoxanil + copper oxychloride	20.34(4.33)[b]	19.95	206.4[ab]	27.72	1999[ab]
Carboxin + thiram + imidacloprid	9.76(2.92)[a]	19.22	203.3[ab]	27.2	3120[d]
Trifloxystrobin + tebuconazol	11.91(3.33)[a]	20.33	213.8[b]	26.54	2332[bc]
Cow urine	12.93(3.45)[ab]	20.17	188.9[a]	27.3	2649[cd]
Hot water	13.5(3.43)[b]	20.17	195.2[ab]	26.74	2015[ab]
Control	22.43(4.34)[b]	20.3	186.2[a]	27.64	1601[a]
GM	14.05	20.04	200.86	27.25	2360.29
LSD (5%)	7.05 (0.99)	ns	19.47	ns	500.9
CV%	34.6	28.2	11.9	13.4	26.1

Notes: ns= Not significant at $p<0.05$; GM= Grand mean; LSD= Least significant Difference; CV= Coefficient of variation; () =numbers in bracket are the transformed values.

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The highest relative maize grain yield loss (48.69%) was recorded in untreated control plots, followed by triadimefon-treated plots with a loss of 35.93% (Table 7). However, all fungicide and cow urine treatments resulted in reduced yield losses compared to untreated control plots. This finding aligns with the research of Azanaw et al. (2020), which reported the maximum sorghum grain yield losses in untreated control plots.

The percentage yield advantage was calculated for all treatments compared to untreated control plots. The results of percentage yield advantage showed differences among treatments. The maximum yield advantage (94.88%) was observed in plots treated with carboxin + thiram + imidacloprid fungicide, followed by a 75.27% yield increase in plots treated with triadimefon fungicide and a 65.46% yield increase in plots treated with cow urine (Table 7). Azanaw et al. (2020) observed a maximum yield increase of 35% in plots treated with cow urine, while Thiram-treated plots showed up to a 30% yield increase.

Linear Regression between Maize Covered Smut Percentage and Grain Yield of Maize

A linear regression analysis was conducted to predict maize grain yield loss based on the percentage of maize covered smut. The percentage of covered smut was chosen as the independent variable, and maize grain yield was considered the dependent variable to estimate the yield loss caused by the disease. Linear regression is a better analytical model for illustrating the relationship between disease effects and yield loss. As the percentage of covered smut increases, the yield decreases, approaching zero, indicating an inverse relationship between the severity of covered smut disease and maize grain yield.

The regression model $Y=-90.643X+3660.1$ describes the relationship between the severity of maize covered smut disease (X) and maize grain yield loss (Y), where Y represents maize grain yield loss in kg.ha^{-1} X is the percentage of maize plants affected by covered smut. The slope of the equation (-90.643) indicates that for each 1% increase in disease severity, maize grain yield decreases by 90.64 kg.ha^{-1}. The intercept (3660.1) represents the potential yield in the absence of the disease (i.e., when X = 0). The model suggests that 75.21% of the maize grain yield loss can be attributed to covered smut disease. In fields with high disease severity, this could lead to significant economic loss due to reduced grain production. This finding is consistent with the work of Ramazanova et al. (2024), which indicated that maize covered smut disease could cause up to a 60.08% yield loss under field conditions. The small difference in percentages may be attributed to variations in environmental conditions, maize varieties, or disease control measures.

The pathogenesis cycle of *Ustilago maydis*, the pathogen responsible for maize covered smut, begins when the fungus infects maize plants through wounds or natural openings (such as stomata) on young tissues. The fungus targets the plant's meristematic tissues, forming galls or tumors that disrupt normal plant growth and development. The most significant yield loss occurs when galls form on the ears, replacing kernels and reducing grain yield. Galls on stalks and leaves reduce the plant's photosynthetic efficiency and structural integrity, increasing the risk of lodging (toppling over).

Partial Budget Analysis

A simple cost-benefit analysis was computed for each treatment using the formula of partial budget analysis (CIMMYT, 1988) to determine the profitability of maize covered smut disease management through different fungicides, cow urine, and hot water treatments. The average grain yield of all locations of 2022 and 2023 cropping season was used for partial budget analysis (Table 8). The partial budget analysis indicated that the highest (125310 ETB.ha^{-1}) net benefit had been obtained from Carboxin + thiram + imidacloprid seed treated plot followed by (112986.8 and 107084.5 ETB.ha^{-1}) triadimefon and cow urine treated plot. The maximum (21122 and 3129.7%) MRR was obtained from cow urine and Carboxin + thiram + imidacloprid

Table 7. Relative Yield loss and percentage yield advantage of maize

Treatments	Grain yield (kg.ha^{-1})	Relative yield loss (%)	Percentage yield increase (%)
Triadimefon	2806	10.06	75.27
Cymoxanil + copper oxychloride	1999	35.93	24.86
Carboxin + thiram + imidacloprid	3120	0.00	94.88
Trifloxystrobin + tebuconazol	2332	25.26	45.66
Cow urine	2649	15.10	65.46
Hot water	2015	35.42	25.86
Control	1601	48.69	0.00

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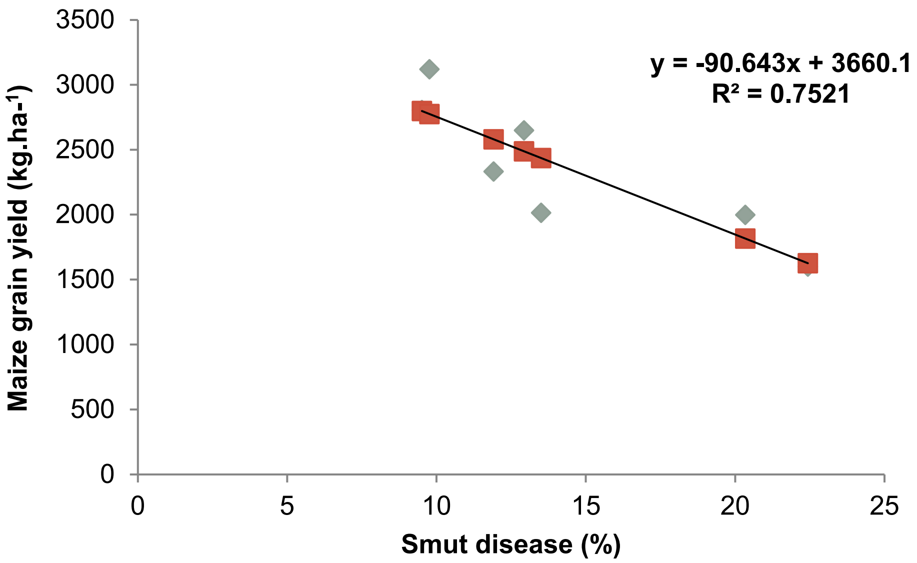

Figure 1. Regressions analysis of combined maize grain yield and covered smut disease

Table 8. Partial budget analysis of fungicides for the management of maize covered smut

Treatments	Grain yield (kg.ha^{-1})	Adjusted grain yield per ha	Price per kg (B.ha^{-1})	Gross benefit per ha	Marginal cost (B.ha^{-1})	Net benefit (B.ha^{-1})	Marginal net benefit (B.ha^{-1})	Marginal rate of return (%)
Triadimefon	2806	2525.4	45	113643	656.25	112986.8	5902.3	1293.7
Cymoxanil + copper oxychloride	1999	1799.1	45	80959.5	350	80609.5	D	
Carboxin + thiram + imidacloprid	3120	2808	45	126360	1050	125310	12323.25	3129.7
Trifloxystrobin + tebuconazol	2332	2098.8	45	94446	350	94096	D	
Urine	2649	2384.1	45	107284.5	200	107084.5	42244	21122.0
Hot water	2015	1813.5	45	81607.5	200	81407.5	D	
Control	1601	1440.9	45	64840.5	0	64840.5	D	

seed treated plot followed by (1293.7%) triadimefon fungicide treated plot. The findings of this study are supported by Azanaw et al. (2020); cow urine, apron star, and thiram fungicide-treated plots were given the highest net benefit and maximum marginal rate of return as compared with the untreated plots.

Conclusions

The results showed significant differences between treatments ($p<0.05$) in smut disease percentage and grain yield at the Sirinka and Cheffa trial sites. The variance analysis indicated that using carboxin + thiram + imidacloprid and triadimefon fungicides, followed by cow urine as seed treatments, significantly reduced maize smut disease and increased maize grain yield. Carboxin + thiram + imidacloprid is commonly used as a seed treatment for managing smut diseases, such as *Ustilago maydis* (maize smut). One of its active ingredients, thiram, is a multi-site inhibitor that disrupts fungal enzymes and metabolism. Thiram suppresses spore germination by inhibiting the respiratory chain and energy metabolism, thereby preventing infection. When used as a seed treatment, carboxin + thiram + imidacloprid forms an effective protective coating, preventing fungal spores from coming into contact with the seed or germinating tissues, which provides effective early-stage disease control. The combination of carboxin + thiram + imidacloprid fungicide and cow urine in a 1:1 ratio with water as a seed treatment is highly recommended for integrated maize smut control, as it can reduce the disease and increase maize grain yield by up to 94.88% and 65.46%, respectively.

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