Adverse Effect of Rainfall on the Efficacy of some Fungicides Used to Control Chocolate Spot of Faba Bean (*Vicia faba*)

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Abstract -Fungicides are subject to adverse effect of different environmental factors especially wash up by rainfall, which on one side decreases the efficacy of the applied fungicide and in turn the need to repeat the fungicide application which increases the production costs , and on other side the washed fungicides get into soil, in water streams and pollute the environment. Four fungicides (Amistar Top, Topsin-M70, Rovral and Tridex) represent four different fungicides groups were tested on faba bean, to represent the winter crops in Egypt, and to control chocolate spot disease under field conditions. The four fungicides were applied four times at the recommended dose, after the second fungicides application, the plots were exposed to different artificial rainfall amounts (2.5, 5.0, 7.5 or 10.0 mm) after different periods of the fungicide application (6, 12, 24, or 48 hr.). All the tested fungicides resulted in significant decrease of chocolate spot disease severity with different degrees. Amistar Top was the most effective one followed by Topsin-M70 then Rovral and Tridex was the lowest effective one. All the tested fungicides showed decreased fungicide efficacy as a result of exposure of the plants to rainfall; this fungicide efficacy reduction was correlated negatively with the time between the fungicide application and the rainfall; and positively with the rainfall amount. Amistar Top and Topsin-M70 were the least rainfall affected, followed by Rovral, and Tridex was worst affected one. Statistically, the effect of the time on the efficacy of the fungicides Amistar Top, Topsin-M70, Rovral, and Tridex was in descending order when this factor reacts in interaction with the other factor, while the effect of rainfall amount was nearly at the same trend; similar trend was noticed too, in case of the effect of time alone, without any interaction with the other factor, but the effect of the amount of rainfall alone without any interaction with the other factor was in ascending order; which indicates that, systemic fungicides efficacy is rainfall time and amount dependent, while non-systemic fungicides are likely to be more rainfall amount dependent as time dependent. Four prediction equations were generated for the four tested fungicides to predict the loss of fungicide efficacy as a result of exposure of the fields to certain amount of rainfall after certain time of the fungicide application; and help to make the right decision if it is important to repeat the fungicide application or not; avoiding the unnecessary reapplication of the fungicides.

Key wards: Faba bean, chocolate spot, disease severity, rainfall and fungicides efficacy.

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1 INTRODUCTION

Faba bean (*Vicia faba*), is a winter growing legume food crop. It originated in the Middle East in the pre-historic period, and has since spread throughout Europe, North Africa, and Central Asia. It spread to China over 2,000 years ago via traders along the Silk Road, to South America in the Columbian period, and more recently to Canada and Australia (Matthews and Marcellos, 2003). It has the potential to be a valuable component of the arable cropping rotation. It is an excellent break crop for arable growers and it is one of few crops that fit well into a sustainable cropping program. In addition, it has a potential to improve soil fertility and structure through the deep tap roots and nitrogen fixing ability of the crop (Anonymous, 2012).

Chocolate spot disease of faba bean caused by *Botrytis fabae* is the most important limiting factor which causes great annual losses and sometimes complete crop failures (Koike, 1998). In Egypt, it is considered the most destructive disease affecting the crop causing serious damage to the plant and consequent decrease of the seed yield production, especially in North Egypt (Abou Zeid and Hassanein, 2000).

In spite of remarkable progressive development in the field of plant diseases control using untraditional control methods such as application of bioagents or resistance inducers, fungicides have been still the main stone in plant diseases control strategies; and many fungicides, *i.e.* Tridex, Amistar Top, Rovral, and Topsin-M70 were recorded to have high efficacy against this disease (Abo Zeid, *et al.* 1990; and 2002; Mac Leod and Galloway, 2006; El-Kholy, 2007 and 2014). However, fungicides as any other agrochemicals are subject to adverse effect of different environmental factors and over time fungicides efficacy and residues naturally decrease due to weathering, such as degradation by sunlight (UV radiation and photo degradation), chemical reactions, heat or microbial activity, and run off, wash up or redistribution over the plant surface by rainfall, or irrigation water (Schilder, 2011 and Anonymous, 2015). Carisse (2010) stated that, factors affecting fungicide efficacy can be summarized as the factors that affect the amount of fungicide that reach the plant tissue into a dense canopy, which is measured by absolute or relative fungicide residual. He added, the residual period may be negatively influenced by several chemical factors, physical and biological removal or degradation of the active ingredient in the tissues of plants. The absorption rate of fungicides is dependent on several factors among which may be cited the active ingredient, formulation, chemical group, number of droplets cm^{-2} obtained by spraying, biological target, cultivars, age of tissues and interval between application and rainfall. Among all cases the rain has the greatest effect on residual activity and efficacy of products and is considered the biggest detractor of fungicide deposits on the leaf surface and in soil. Another negative consequence is the fact that rain-removed pesticides will reach non-target organisms, soil and water resources, resulting in unnecessary environmental contamination (Wauchope, *et al.*, 2004). In Egypt, in general, three rainfall belts may be distinguished: The Mediterranean coastal belt, where the average annual rainfall ranges from 100 to 150 mm, middle Egypt with average of 20 to 100 mm, and upper Egypt which can be considered almost rainless. In these regions have winter rainfall during the period from November to April, though mainly concentrated in December and January (Hegazi, *et al*., 2005). Hafez and Hasanean (2000) studied the variability of rainfall during the period from 1961 to 1998 and found that, precipitation varies dramatically from winter to winter for the entire period under study. However (Elraai, 2010) reported that the increase of the mean of global temperature degree due to increased emissions endothermic greenhouse gases will lead to a change in wind speed and air masses trends which in turn may lead to change rainfall regions and rainfall seasons.

This work aimed to evaluate some fungicides used to control chocolate spot disease of faba bean caused by *B. fabae* under different situations rainfall amount and fall time. In addition, find the relationship between rainfall amount and rainfall time on one side and the consequence expected fungicides efficiency reduction on the other hand.

2 MATERIALS AND METHODS

Field experiments:

This study was carried out during two successive growing seasons (2010/2011 and 2011/2012) on faba bean (improved Giza 3 cv.) in a field located at Elsadat road, El-Minuofyia Governorate under natural infection. Four fungicides namely, Amistar Top 32.5% Sc. (azoxystrobin + Difenoconazol) 50 ml /100 L. water, Topsin-M70 WP (methylthiopanate) 60 g / 100 L. water, Rovral 50 WP (iprodione) 90 g / 100 L. water , Tridex 80% WP (mancozeb) 250 g /100 L. water.

The field was divided into five parts, each part was used for the application of one of the tested fungicides, and one part was left without any fungicide to serve as control treatment (general control treatment). Each fungicide was applied in three replicates, and each replicate was divided into four plots; each was used for the application of one rainfall time; and each plot was divided into five subplots, each subplot was used for the application of one rainfall amount.

The fungicides were applied 4 times after the natural annual rainstorm (Elfaida Elkopra) on 21 January, 4 February, 19 February and 5 March in order to avoid application of the fungicide at any time of the next natural annual rainstorms (Elkarma, Elshams Elsaghera, Elsalloum, Elhussuom , and Elshams Elkabiera) in order to avoid the interaction between the artificial rain and the possible natural rain. Four amounts of artificial rains represented different rain intensities, light rain (<2.5 mm/ hr.), moderate rainfall (between 2.5 and 7.5 mm /hr.) and heavy rain (> 7.5 mm /hr.) were studied (Abdel-Shafy, *et al*, 2010). The equivalent amount of water required to apply artificial rain representing rain intensities of 2.5, 5.0, 7.5, and 10.0 were calculated as follows:

$$Ra = (aa \times 10000 \times rd) \div 1000$$

Since:

Ra = Rain amount.(amount of required water in liter).
aa = Application area in miter.
rd = Rainfall intensity in cm (2.5mm, 5.0mm, 7.5mm, or 10.0mm).
10000 and 1000 = Constants.

Artificial rainfall was applied 6, 12, 24 or 48 hr. after the second fungicide application using knapsack sprayer under low pressure. One treatment without any rain application was performed to serve as control treatment (fungicide control).

Disease severity, fungicides efficacy and efficacy reduction were estimated.

Faba bean leaves were randomize collected from each treatment, the infection on each leaf was rated using a numerical index (containing 5 infection category) ranged from 0 which represented no infection spots on the leaf, to 4 which represented infection spots covered > 1/2 of the leaf area, or the leaf is destroyed.

Disease severity was calculated using the equation developed by Towsend and Heuberger **(**1943).

$$P = [\Sigma(n \times v)/4N] \times 100$$

where :
P = Disease severity
n = Number of leaves within infection category.
v = Numerical value of each category.
N = Total number of leaves.

Fungicide efficacy was calculated using Abbott equation (Frölich, 1979) .

$$Fe = \frac{c - t}{c} * 100$$

Where :
Fe = Fungicide efficacy
c = Disease severity in Control
t = Disease severity in treatment.

Fungicide efficacy reduction (as a result of rainfall) was calculated as follows:

$$Fer = (Fec - Fet) / Fec \times 100$$

Where;
Fer = Fungicide efficacy reduction %
Fec = Fungicide efficacy of the tested fungicide without rainfall (control)

Fet = Fungicide efficacy of the tested fungicide that received certain amount of rainfall after certain time (treatment).

Statistical analysis:

The obtained data were analyzed for LSD and correlation coefficient using MSTAT, statistical software, Michigan State University, in split design.

Prediction of fungicide efficacy reduction:

All the data of fungicide efficacy reduction for each fungicide in the two years were subjected to multi regression analysis to generate a prediction equation using IPM SPSS Statistical analysis software.

3 RESULTS

Four fungicides were used to control chocolate spot of faba bean; the fungicides were applied four times with 14 days interval; after 6, 12, 24 or 48 hr. of the second fungicides application. The treated plants were subjected to different amounts of artificial rainfall. Two weeks after the last fungicide application disease severity, fungicide efficacy and reduction of fungicide efficacy, as a result of the rainfall application, were estimated during the two successive growing seasons (Tables 1 and 2).

The presented data in Table (1) show that all the tested fungicides resulted in significant reduction of chocolate spot severity compared with untreated plots (general control treatment), since, while control treatment recorded in the first season (2010/2011) was 63.33 % disease severity, plots treated with Amistar Top, Topsin-M70, Rovral and Tridex recorded 10.0, 14.3, 17.0 and 27.7 % disease severity; which represent fungicide efficacy of 83.0, 77.4, 73.2 and 56.3% fungicide efficacy, respectively.

As a result of artificial rainfall application, plants treated with Amistar Top showed gradual increase in the mean disease severity parallel to the increased amounts of the artificial rainfall, recording 14.0, 16.0, 18.0 and 24.0 % disease severity when the rain amount were 2.5, 5.0, 7.5 and 10.0 mm, respectively compared with only 10.0 % disease severity on plants treated with the fungicides but did not receive any rain. In contrast to the rain amount, disease severity on plants treated with the fungicides and exposed to rainfall after different rainfall timing was decreased gradually as the time between the fungicide second application and the rainfall application prolonged. Exposing the plant to rainfall 6 hr. after the second fungicide application resulted in 20.3% disease severity, decreased to 17.7, 15.7, and 12.6% when the rainfall timing prolonged to 12, 24, and 48 hr. after the fungicide application respectively.

These data were reflected on the fungicides efficacy and consequently on fungicides efficacy reduction; which indicated that increasing of rainfall amount resulted in pronounced decreasing of the fungicide efficacy. There was a positive correlation coefficient of 0.694 between fungicide efficacy reduction and prolonging the amount of rainfall. Plants treated with the fungicide then were subjected to different amounts of rainfall, *i.e.* 2.5, 5.0, 7.5 and 10.0 mm, showed mean fungicide efficacy reduction of 7.3, 10.5, 15.1 and 22.9 %, respectively. On the other hand, prolonging the period between the fungicide treatment and the rainfall from 6 to 12, 24 and 48 hr. resulted in decreasing fungicide efficacy reduction by from18.8% to14.6,8.1and 3.1% respectively with a negative correlation coefficient of -0.656. In case of Amistar Top fungicide, it is clear that, rainfall at the first 12 hr. was the most harmful time and then the fungicide reduction decreased rapidly (Figs.1 and 2).

In case of Topsin-M70, disease severity was reduced from 63.33% in plots did not receive any fungicide (general control treatment) to 14.3 % in plots treated with Topsin M70 and un-treated with any amount of rainfall. It was noticed that plots received different amounts of rains showed increasing disease severity as the amount of rain increased. Plots received 2.5, 5.0, 7.5 and 10.0 mm. recorded mean disease severity of 20.2, 25.7, 30.7 and 38.0%, respectively. Mean of disease severity in plots received rainfall after 6 and 12 hr. showed no significant differences, recording 29.3 and 29.8%; while delaying the rainfall to 24 or 48 hrs. resulted in obvious decreased disease severity, which were 25.6 and 18.4% respectively. The highest disease severity on plants treated with Topsin-M70, was recorded when the plants were subject to rainfall of 10.0 mm. after 6 hr. of the fungicide application. These data were more obvious by giving a look on the fungicide efficacy, since it was clear that, when the plants were treated with the fungicides and were not subject to any rainfall the mean of the fungicide efficacy was 77.4%; while, when the plants were exposed to rainfall of 2.5, 5.0, 7.5 and 10.0 mm. the mean fungicide efficacy decreased to 68.2, 58.3, 51.9 and 40.3%, respectively. Meanwhile, the fungicide efficacy were 53.8, 53.0, 59.2 and 70.9% when the plants were exposed to rainfall after 6, 12, 24 and 48 hr, respectively. Calculating the fungicide efficacy reduction showed that the fungicide efficacy reduction was correlated negatively with prolonging the period between application of the fungicide and the rainfall event and positively with the amount of rain recording -0.617 and 0.727 respectively. It was found , also, that least fungicide efficacy reduction (1.5%) was recorded when the plants were exposed to 2.5 mm. rainfall after 48 hr., while the highest fungicide efficacy reduction (44.5 and 45.8%) were recorded on plants were exposed to 10 mm. rainfall after 6 or 12 hr. respectively (Figs.3 and 4).

Concerning Rovral fungicide, it was found that while disease severity reached 63.33% on plants did not receive any fungicide treatment (general control treatment), plants treated with Rovral and were not exposing to rainfall recorded only 17.0 % disease severity. In addition, exposing the treated plants to gradual higher amounts of rainfall (2.5, 5.0, 7.5 and 10.0mm.) resulted in corresponding gradual higher disease severity, of 26.0, 31.4, 37.6 and 42.5%, respectively. At the same time, exposing the treated plants to gradual prolonging period between the fungicide application and the rainfall, disease severity was gradually reduced to 35.72, 33.9, 29.4 and 24.5%, respectively. The calculated fungicide efficacy indicated that increasing the amount of rainfall from 0.0 mm. to 2.5, 5.0, 7.5 and 10.0 mm. resulted in gradual reduction to the fungicide efficacy, recording 59.0, 50.4, 40.7 and 32.8%, respectively. Meanwhile, prolonging the period between the fungicide application and the rainfall (6, 12, 24, and 48 hr.), resulted in gradual increasing of the fungicide efficacy to 43.6, 46.4, 53.6 and 61.2%, respectively.

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Calculating fungicide efficacy reduction (Figs. 5 and 6) showed that exposing the treated plants to gradual increase of the rainfall amount (2.5, 5.0, 7.5 and10.0) was correlated positively with the fungicide efficacy reduction with 0.737 correlation coefficient, and resulted in increasing mean of fungicide efficacy reduction to 11.7, 20.3, 30.0 and 37.8 %, respectively. While, exposing the treated plants to gradual prolonged period between the fungicide application and the rainfall (6, 12, 24 and 48 hr.), resulted in lowering mean fungicide efficacy reduction, being 29.5, 24.1, 16.9 and 9.3%, respectively, with negative correlation coefficient of -0.624. Highest fungicide efficacy reduction was 48.4% recorded on plants were exposed to 10mm. rainfall after 6hr. of fungicide application, followed by 43.5% recorded on plants were exposed to 7.5 mm. after 6 hr. of fungicide application; then 42.1 and 38.3% were recorded on plants were exposed to 10 mm. rainfall after 12 and 24hr after fungicide application respectively .On the other hand least fungicide efficacy reduction was 3.0% recorded on plants were exposed to 2.5 mm. rainfall after 48 hr. of fungicide application.

Table 1: Disease severity, fungicides efficacy and fungicide efficacy reduction as a result of different amounts of artificial rainfall after different periods of fungicides application in the agricultural year 2010/2011 under field conditions.

Treatments *		Disease and fungicide parameters and time of application of the artificial rainfall after the second fungicides application in hours														
Fungicides	Time in hr.	Disease severity					fungicide efficacy					fungicide efficacy reduction %				
		6	**12**	**24**	**48**	**Mean**	**6**	**12**	**24**	**48**	**Mean**	**6**	**12**	**24**	**48**	**Mean**
Amistar Top 32.5% SC	**0.0**	10.0	10.0	10.0	10.0	10.0	83.0	83.0	83.0	83.0	83.0	0.0	0.0	0.0	0.0	0.0
	2.5	16.3	15.0	12.7	12.0	14.0	74.2	76.3	81.0	81.0	78.1	13.1	11.0	3.1	2.0	7.3
	5.0	20.3	17.3	14.7	11.7	16.0	67.9	72.6	77.8	81.6	75.0	19.4	14.7	6.3	1.4	10.5
	7.5	24.3	20.3	18.3	12.7	18.9	61.6	67.9	69.9	80	69.9	25.7	19.4	12.1	3.0	15.1
	10	30.7	25.7	22.7	16.7	24.0	51.6	59.5	66.8	73.7	62.9	35.7	27.8	18.9	9.3	22.9
	Mean	20.3	17.7	15.7	12.6	16.6	67.7	71.9	75.7	79.9	73.8	18.8	14.6	8.1	3.1	11.2
Topsin-M70 WP	**0.0**	14.3	14.3	14.3	14.3	14.3	77.4	77.4	77.4	77.4	77.4	0.0	0.0	0.0	0.0	0.0
	2.5	24.0	23.3	18.3	15.0	20.2	62.1	63.1	71.3	76.3	68.2	15.7	14.6	6.7	1.5	9.6
	5.0	29.0	31.7	25.0	16.9	25.7	54.2	50.0	55.7	73.3	58.3	23.6	27.8	17.3	4.5	18.3
	7.5	34.7	36.4	31.6	20.0	30.7	45.2	42.4	51.4	68.4	51.9	32.5	35.3	27.8	9.4	26.3
	10	44.3	43.1	38.6	26.0	38.0	30.0	32.0	40.2	58.9	40.3	44.5	45.8	38.9	18.9	37.0
	Mean	29.3	29.8	25.6	18.4	25.8	53.8	53.0	59.2	70.9	59.2	23.3	24.7	18.1	6.9	18.2
Rovral 50% WP	**0.0**	17.0	17.0	17.0	17.0	17.0	73.2	73.2	73.2	73.2	73.2	0.0	0.0	0.0	0.0	0.0
	2.5	32.0	29.2	21.7	21.0	26.0	49.4	53.9	65.8	66.8	59.0	23.7	15.9	4.1	3.0	11.7
	5.0	37.3	36.0	28.3	24.0	31.4	41.0	43.1	55.2	62.1	50.4	32.1	26.7	14.6	7.8	20.3
	7.5	44.6	41.7	36.7	27.3	37.6	29.6	34.2	42.1	56.8	40.7	43.5	35.7	27.8	13.0	30.0
	10	47.7	45.8	43.3	33.3	42.5	24.7	27.7	31.5	47.3	32.8	48.4	42.1	38.3	22.5	37.8
	Mean	35.7	33.9	29.4	24.5	30.9	43.6	46.4	53.6	61.2	51.2	29.5	24.1	16.9	9.3	20.0
Tridex 80% WP	**0.0**	27.7	27.7	27.7	27.7	27.7	56.3	56.3	56.3	56.3	56.3	0.0	0.0	0.0	0.0	0.0
	2.5	43.9	40.0	38.3	34.0	39.1	30.6	36.8	39.4	46.3	40.3	23.0	17.2	14.5	7.7	15.6
	5.0	48.3	44.0	43.3	36.7	43.1	23.6	30.5	31.5	42.1	33.6	30.0	23.5	22.4	11.9	22.0
	7.5	55.4	52.1	48.1	39.3	48.7	12.5	17.7	24.0	37.9	26.0	41.2	36.3	30.0	16.1	30.9
	10	58.9	56.7	56.2	52.1	56.0	6.8	10.4	11.2	17.6	12.6	46.8	43.5	42.8	36.3	42.4
	Mean	46.8	44.1	42.7	38.0	42.9	26.0	30.3	32.5	40.0	33.8	28.2	24.1	21.9	14.4	22.2

*= Mean of disease severity in general control (plots treated only with water without any fungicide) was 63.33.

LSD 0.05 for disease severity:	time	rain amount	time X rain intensities	Correlation Coefficients for	Time	Rain amount
Amistar Top	1.4	2.9	5.8	fungicide efficacy reduction:	-0.656	0.694
Topsin-M70	2.8	2.9	5.9		-0.617	0.727
Rovral	2.7	3.6	7.2		-0.624	0.737
Tridex	0.7	2.7	5.5		-0.490	0.802

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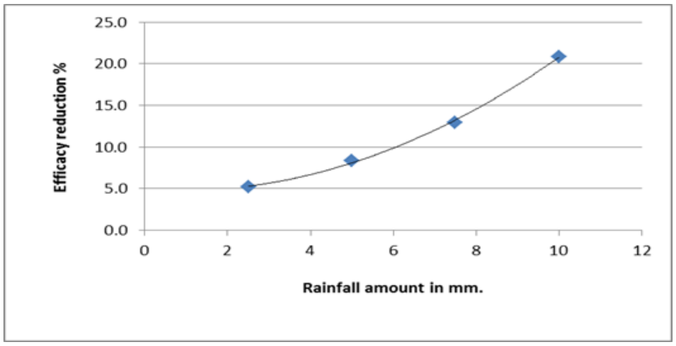


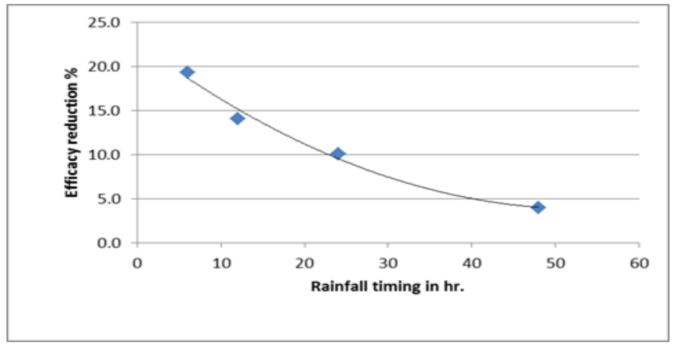
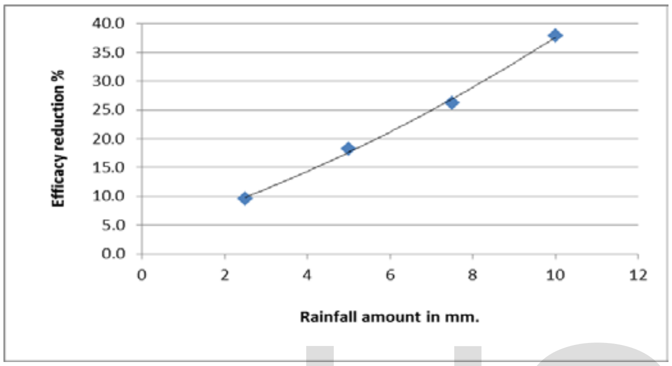


Figure 1: Amistar Top efficacy reduction affected with different amounts of rainfall 2010/2011.

Figure 2: Amistar Top efficacy reduction affected with rainfall timing of rainfall 2010/2011.



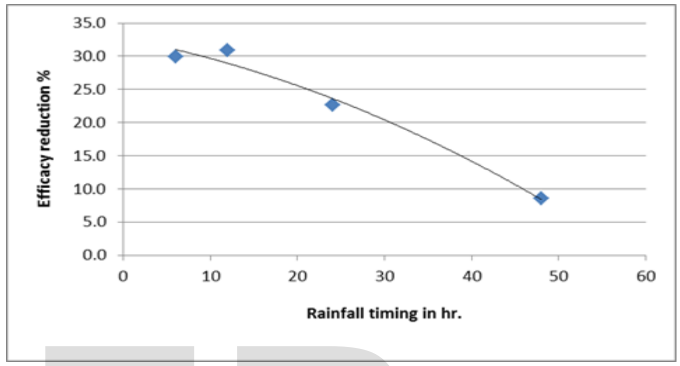
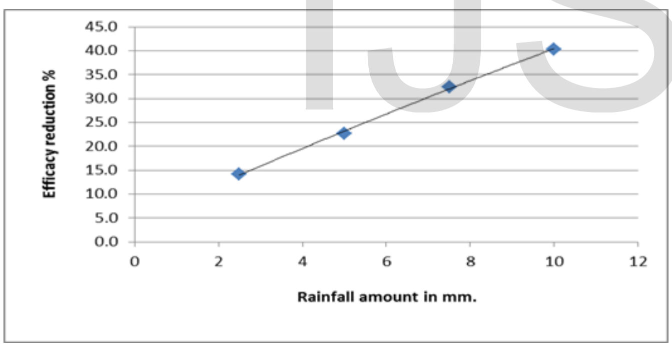


Figure 3: Topsin-M70 efficacy reduction affected with different amounts of rainfall 2010/2011.

Figure 4: Topsin-M70 efficacy reduction affected with rainfall timing of rainfall 2010/2011.



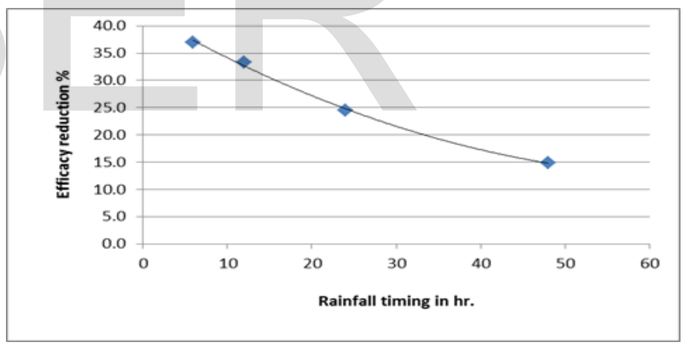
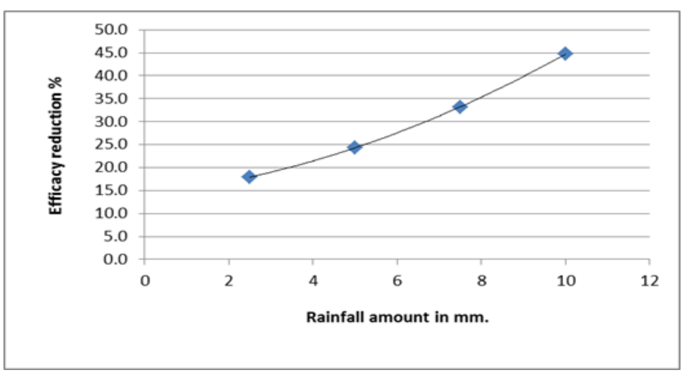


Figure 5: Rovral efficacy reduction affected with different of rainfall 2010/2011.

Figure 6: Rovral efficacy reduction affected with different amounts timing of rainfall 2010/2011.



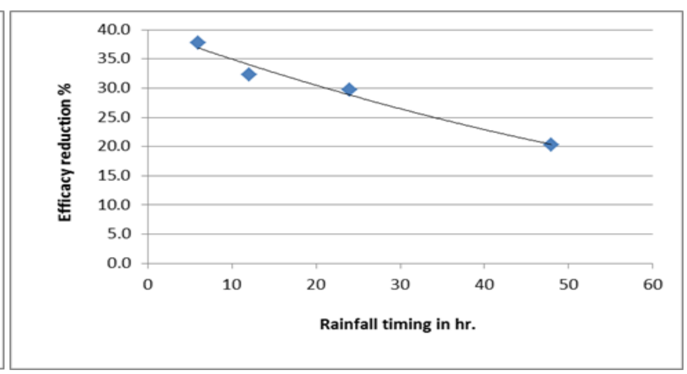


Figure 7: Tridex efficacy reduction affected with different amounts of rainfall 2010/2011.

Figure 8: Tridex efficacy reduction affected with different timing of rainfall 2010/2011.

For Tridex fungicide, disease severity in control treatment (plots did not receive any fungicides) recorded 63.3%, while plots treated with Tridex but were not exposed to rainfall recorded only 27.7% disease severity. Exposing plots treated with Tridex to different amount of rainfall (2.5, 5.0, 7.5 or 10.0 mm.) resulted in ascending disease severity which reached 39.1, 43.1, 48.7 and 56.0 %, respectively compared with only 27.7 % in plots treated with Tridex fungicide but were not exposed to artificial rainfall. Similar data were obtained when plants were treated with Tridex then exposed to rainfall after different periods from the fungicide application (6, 12, 24 or 48 hr.), since mean disease severity in these plots were 46.8, 44.1, 42.7 and 38.0%, respectively compared with only 27.7 % in plots treated with Tridex fungicide but were not exposed to artificial rainfall.

Fungicide efficacy was in turn affected, since gradually descending mean of fungicide efficacy was combined with the increased amount of the rain. While plots treated with Tridex and were not exposed to any artificial rainfall recorded 56.3 mean fungicide efficacy compared with 40.3, 33.6, 26.0 and 12.6% when the plants were exposed to 2.5, 5.0, 7.5 or 10.0 respectively. On the other hand, gradually ascending mean of fungicide efficacy was combined with prolonging the time between the fungicide application and the exposure to rainfall. When the plants were exposed to rainfall after 6 hr., mean of fungicide efficacy was 26.0 compared with 56.3% in plots were treated with Tridex but were not exposed to rainfall; when rainfall time was prolonged to 12, 24, or 48 hr. mean of fungicide efficacy rose and recorded 30.3, 32.5 and 40.0 % respectively.

These data were reflected on the fungicide efficacy reduction (Figs.7 and 8); since highest fungicide efficacy reduction was 46.8% recorded on plants were exposed to 10.0 mm rainfall after 6 hr. of fungicide application, followed by 43.5 and 42.8% recorded on plants were exposed to 10.0 mm rainfall after 12 and 24 hr. of fungicide application. Lowest fungicide efficacy reduction was 7.7% recorded in plots were exposed to 2.5 mm rainfall after 48 hr. of fungicide application. Calculation of correlation coefficient fungicide efficacy reduction showed that fungicide efficacy reduction was correlated negatively with prolonging period between the fungicide treatment and the rainfall with -0.490 and positively with the rainfall amount with 0.802.

In the second agricultural year (2011 / 2012) it can be noticed that the obtained data were in the same trend as that in the previous year (2010/ 2011); since the reaction of the fungicides to the rain fall was similar to that in the last year (Table 2).

While mean disease severity in plots did not receive any treatment (general control) recorded 75.33 mean disease severity, in plots treated with Amistar Top, Topsin-M70, Rovral or Tridex and were not exposed to rainfall recorded 12.0, 19.0, 23.0 and 32.7 disease severity respectively.

Exposing plants treated with Amistar Top to rainfall resulted in notable increased disease severity, compared with that, were treated with Amistar Top but not with any artificial rainfall (fungicide control).

Gradual increase of the rainfall amount from 0 to 2.05, 5.0, 7.5 or 10.0 mm. resulted in increased mean of the disease severity from 12.0 to 18.3, 21.4, 25.0 and 29.4 respectively; while gradual prolonging the time of rain fall after the fungicide application (6, 12, 24, or 48 hr.) resulted in gradual decreased mean of the disease severity recording 25.5, 23.2, 20.5 and 15.6 respectively.

These date were reflexed on fungicide efficacy since, Amistar Top mean efficacy decreased gradually from 84.1 on plants were not exposed to rainfall to 75.5, 71.1, 66.2 and 60.3% when the plants were exposed to 2.5, 5.0, 7.5 or 10.0 mm rainfall respectively. On the other hand, Amistar Top mean efficacy increased gradually from 66.2 in plots were exposed to rainfall after 6 hr. of the fungicide application to 67.4, 72.8 and 79.2 % on plants exposed to rainfall after 12, 24 or 48 hr. respectively after fungicide application. Calculating Fungicide efficacy reduction showed that, highest Amistar Top efficacy reduction was 32.3% which was recorded on plants exposed to 10.0 mm (Figs. 9 and 10) . rainfall after 6 hr. after fungicide application; followed by 28.2 recorded on plants exposed to 10.0 mm. after 12 hr. after fungicide application. The least adversely affected plots were those were exposed to 2.5 and 5.0 mm rainfall after 48 hr. after fungicide application recording 1.7 and 3.0 % Amistar Top efficacy reduction respectively. It was clear that fungicide efficacy reduction was positively correlated with rainfall amounts recording 0.634 correlation coefficient and negatively with prolong of the time between the rainfall and the fungicide application with -0.72 correlation coefficient.

Topsin-M70 reacted to the rainfall at the same manner; since, plants treated with Topsin-M 70 but not with rainfall, showed mean disease severity of 19.0 compared with 24.1, 31.4, 35.7 and 43.6% when the plants were exposed to 2.5, 5.0, 7.5 or 10.0 mm. rainfall respectively. In contrast, prolonging the time between the fungicide application and rainfall resulted in decreased disease severity from 35.7 in plots exposed to rainfall after 6 hr. of fungicide application to

33.0, 31.1and 23.2% in plots exposed to rainfall after 12, 24 and 48 hr. of fungicide application respectively.

According to fungicide efficacy, pronounced decreasing was noticed, this decreasing was combined with the increaseing of the rainfall amounts. While plots treated with Topsin-M 70 without exposure to rainfall recorded mean fungicide efficacy of 74.8%, plots were exposed to 2.5, 5.0, 7.5 or 10.0mm. rainfall recorded only 67.5, 57.5, 51.8 and 41.1% respectively. Prolonging the time between the fungicide application and rainfall from 6 hr. to 12, 24, or 48 hr. resulted in increased mean of fungicide efficacy from 52.6% to 53.7, 58.7 and 69.1% respectively. Calculating the fungicide efficacy reduction indicated that, the least fungicide efficacy reduction was 1.1 and 3.4% found in plots exposed to 2.5 mm. rainfall after 48 and 24 hr. respectively, followed by 3.9% in plots were exposed to 5.0 mm. rainfall after 48hr. The highest fungicide reduction 44.5 and 41.0% were found in plots exposed to 10.0 mm. rainfall after 6 and 12 hr. (Figs. 11 and 12) respectively. Topsin-M fungicide efficacy reduction was positively correlated with rainfall amounts with 0.710 correlation coefficient, and negatively with the prolonging of the time between the rainfall and the fungicide application with -0.610 correlation coefficient.

As for Rovral fungicide, while plants treated with Rovral and were not exposed to rainfall showed disease severity of 23.0% plants treated with the fungicides and were exposed to arising amount of rainfall (2.5, 5.0, 7.5 or 10.0 mm.) showed regular arising of disease severity recording 27.8, 34.0, 42.0 and 47.2% respectively. Prolonging the time between the fungicide application and rainfall resulted in descending mean of disease severity from 42.3 on plots were exposed to rainfall after 6 hr. of fungicide application to 37.5, 31.9 and 27.3% in plots were exposed to rainfall after 12, 24 and 48 hr. of fungicide application respectively.

Rovral fungicide efficacy was adversely affected with rainfall, increased amount of rainfall resulted in decrease of Rovral fungicide efficacy; since, while plots treated with fungicide but not exposed to rainfall showed 69.5% efficacy, plots exposed to 2.5, 5.0, 7.5 or 10.0 mm. rainfall showed descending order of fungicide efficacy recording 62.4, 54.1, 43.2 and 36.5% efficacy respectively; while prolonging the time between the fungicide application and rainfall showed ascending order of mean of fungicide efficacy, since when plots were exposed to rainfall 6 hr. after fungicide application mean of fungicide efficacy was 43.8%, when the time prolonged to 12, 24 or 48 hr. mean of fungicide efficacy rose to 47.4, 57.6 and 63.8% respectively.

Calculation the fungicide efficacy reduction showed that, the most adverse effect of rainfall on Rovral fungicide was recorded in plots exposed to 10.0 mm. rainfall after 6 and 12 hr. after the fungicide application recording 44.0 and 41.1% followed by plots were exposed to 7.5 mm. rainfall after 6 hr. of fungicide application recording 37.1% then, plots exposed to 10.0 mm. rainfall after 24 hr. after the fungicide application recording 36.5 and plots exposed to 7.5 mm. rainfall after 12 hr. after the fungicide application recording 35.3%. The least fungicide efficacy reduction was recorded in plots exposed to 2.5 mm. rainfall after 24 and 48 hr. of fungicide application recorded 4.6% for both. Followed by 7.8 % fungicide efficacy reduction in plots exposed to 5.0 mm. rainfall after 48 hr. of fungicide application (Figs. 13 and 14). Rovral fungicide efficacy reduction was positively correlated with rainfall amounts recording 0.742 correlation coefficient and negatively with the prolonging of the time between the rainfall and the fungicide application with -0.546 correlation coefficient.

In case of Tridex fungicide, similar data were obtained; since while plots treated with Tridex but not with rainfall showed mean disease severity of 32.7, plots treated with the same fungicide but were exposed to 2.5, 5.0, 7.5 or 10.0 mm. rainfall showed ascending order of mean disease severity of 41.1, 45.7, 51.9 and 63.1 respectively. Prolonging the time between the fungicide application and rainfall resulted in descending mean of disease severity from 51.0 on plots were exposed to rainfall after 6 hr. of fungicide application to 48.3, 45.4 and 42.8 in plots were exposed to rainfall after 12, 24 and 48 hr. of fungicide application. Correlation coefficient for disease severity showed weak negative correlation (-39.0%) with prolonging period between the fungicide treatment and the rain fall with and high positive correlation (86.4%) with the rainfall amount.

Tridex fungicide efficacy was affected too; since, while plots treated with Tridex but not with rainfall showed mean efficacy of 56.6%, this efficacy was decreased to 45.4, 39.4, 31.2 and 16.2 as a result of exposing the plots to 2.5, 5.0, 7.5 and 10.0 mm. rainfall respectively. Prolonging the time, between the fungicide application and rainfall, from 6 hr. to 12, 24, and 48hr. resulted in arising mean of fungicide efficacy from 32.3% to 35.9, 39.7 and 43.1% respectively.

Calculating fungicide efficacy reduction indicated that 10.0 mm. rainfall had the most adverse effect on Tridex since, the fungicide efficacy reduction on plants exposed to 10.0 mm. recorded fungicide efficacy reduction of 45.4, 43.2, 38.1 and 35.5% when the rain were applied after 6, 12, 24 and 48 hr., while least adverse effect 7.7 and 5.0 % were recorded in plots were exposed to 2.5 mm. rainfall after 24 and 48 hr. respectively (Figs. 15 and 16).

Tridex fungicide efficacy reduction was positively correlated with rainfall amounts recording 0.864. correlation coefficient, and negatively with prolonging the time between rainfall and fungicide application with -0.390 correlation coefficient.

Table 2: Disease severity, fungicides efficacy and fungicide efficacy reduction as a result of different amounts of artificial rainfall after different periods of fungicides application in the agricultural year 2011/2012 under field conditions..

Treatments *		Disease and fungicide parameters and time of application of the artificial rainfall after the second fungicides application in hours														
Fungicides	Time in hr.	Disease severity					fungicide efficacy					fungicide efficacy reduction %				
		6	**12**	**24**	**48**	**Mean**	**6**	**12**	**24**	**48**	**Mean**	**6**	**12**	**24**	**48**	**Mean**
Amistar Top 32.5% SC	**0.0**	12.0	12.0	12.0	12.0	12.0	84.1	84.1	84.1	84.1	84.1	0.0	0.0	0.0	0.0	0.0
	2.5	22.7	20.3	16.7	13.3	18.3	69.9	71.7	77.9	82.3	75.5	14.1	12.3	6.1	1.7	8.6
	5.0	26.3	24.3	20.7	14.3	21.4	65.0	65.6	72.6	81.0	71.1	19.0	18.4	11.4	3.0	13.0
	7.5	30.0	28.3	24.3	17.3	25.0	60.2	60.0	67.7	77.0	66.2	23.8	24.0	16.3	7.0	17.8
	10	36.3	31.3	28.7	21.3	29.4	51.7	55.8	61.9	71.7	60.3	32.3	28.2	22.1	12.3	23.7
	Mean	25.5	23.2	20.5	15.6	21.2	66.2	67.4	72.8	79.2	71.4	17.8	16.6	11.2	4.8	12.6
Topsin-M70 WP	**0.0**	19.0	19.0	19.0	19.0	19.0	74.8	74.8	74.8	74.8	74.8	0.0	0.0	0.0	0.0	0.0
	2.5	29.4	25.6	21.6	19.8	24.1	61.0	63.9	71.3	73.7	67.5	13.8	10.9	3.4	1.1	7.3
	5.0	36.0	34.5	33.3	21.9	31.4	52.2	51.2	55.7	70.9	57.5	22.6	23.6	19.0	3.9	17.3
	7.5	41.7	39.2	36.6	25.5	35.7	44.7	44.8	51.4	66.1	51.8	30.1	29.9	23.4	8.6	23.0
	10	52.5	46.8	45.0	30.0	43.6	30.3	33.7	40.2	60.2	41.1	44.5	41.0	34.5	14.6	33.7
	Mean	35.7	33.0	31.1	23.2	30.8	52.6	53.7	58.7	69.1	58.5	22.2	21.1	16.1	5.6	16.2
Rovral 50% WP	**0.0**	23.0	23.0	23.0	23.0	23.0	69.5	69.5	69.5	69.5	69.5	0.0	0.0	0.0	0.0	0.0
	2.5	36.3	30.0	22.5	22.5	27.8	51.7	57.8	70.1	70.1	62.4	17.7	11.6	4.6	4.6	9.6
	5.0	45.0	37.5	28.5	24.9	34.0	40.2	47.2	62.2	66.9	54.1	29.2	22.2	12.6	7.8	18.0
	7.5	51.0	46.5	39.0	31.5	42.0	32.3	34.1	48.2	58.2	43.2	37.1	35.3	26.6	16.6	28.9
	10	56.2	50.7	46.5	34.5	47.0	25.4	28.3	38.2	54.2	36.5	44.0	41.1	36.5	20.6	35.6
	Mean	42.3	37.5	31.9	27.3	34.8	43.8	47.4	57.6	63.8	53.2	25.6	22.0	16.1	9.9	18.4
Tridex 80% WP	**0.0**	32.7	32.7	32.7	32.7	32.7	56.6	56.6	56.6	56.6	56.6	0.0	0.0	0.0	0.0	0.0
	2.5	46.1	43.5	38.4	36.3	41.1	38.7	42.2	49.0	51.7	45.4	18.0	14.5	7.7	5.0	11.3
	5.0	52.5	47.6	42.4	40.2	45.7	30.3	36.7	43.7	46.7	39.4	26.4	20.0	13.0	10.0	17.4
	7.5	56.9	52.5	52.4	45.7	51.9	24.5	30.3	30.4	39.4	31.2	32.2	26.4	26.3	17.3	25.6
	10	66.8	65.1	61.3	59.3	63.1	11.3	13.5	18.6	21.2	16.2	45.4	43.2	38.1	35.5	40.6
	Mean	51.0	48.3	45.4	42.8	46.9	32.3	35.9	39.7	43.1	37.7	24.4	20.8	17.0	13.6	19.0

*= Mean of disease severity in general control (plots treated only with water without any fungicide) was 75.33

LSD 0.05 for disease severity:	time	rain amount	time X rain intensities	Correlation coefficients for	Time	Rain amount
Amistar Top	1.21	2.33	4.47	fungicide efficacy reduction:	-0.720	0.634
Topsin-M70	3.67	2.50	7.00		-0.610	0.710
Rovral	4.83	4.49	8.93		-0.546	0.742
Tridex	2.55	3.11	6.21		-0.390	0.864

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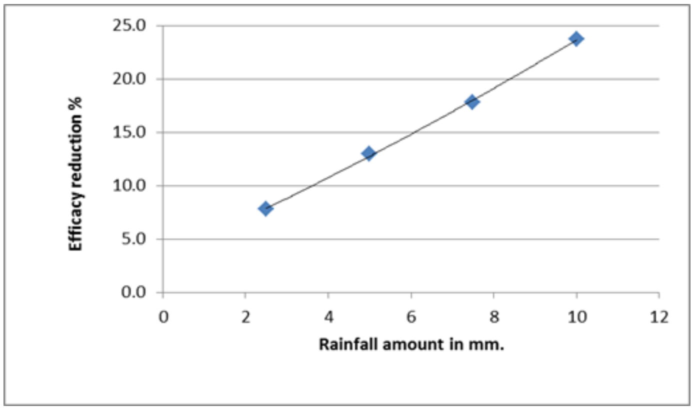

Figure 9: Amistar Top efficacy reduction affected with different amounts of rainfall 2011/2012.

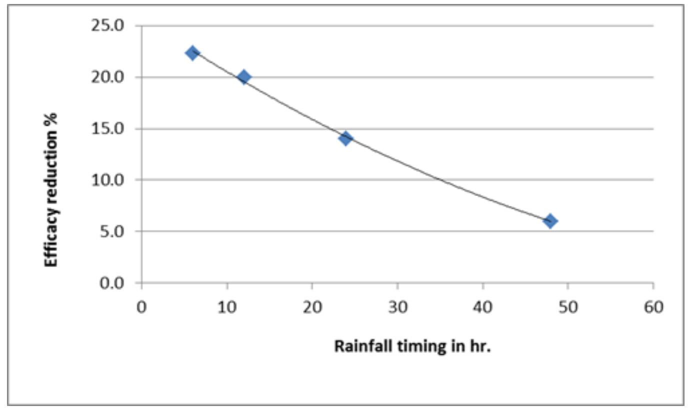

Figure 10: Amistar Top efficacy reduction affected with different timing of rainfall 2011/2012.

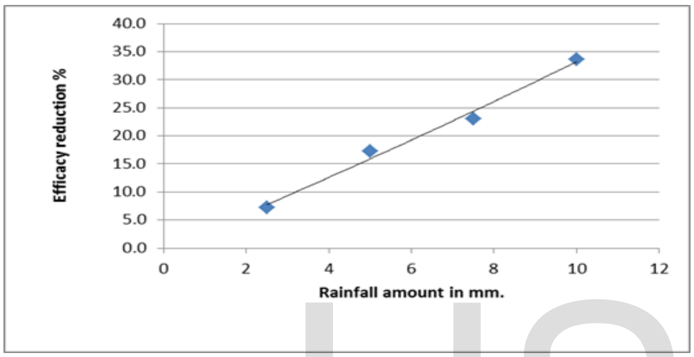

Figure 11: Topsin-M70 efficacy reduction affected with different amounts of rainfall2011/2012.

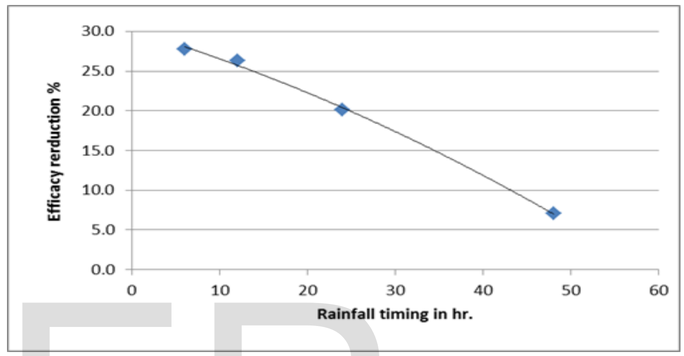

Figure 12: Topsin-M70 efficacy reduction affected with different timing of rainfall 2011/2012.

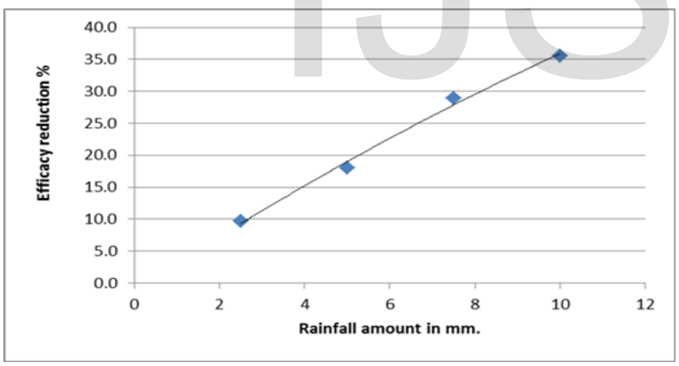

Figure13: Rovral efficacy reduction affected with different amounts of rainfall 2011/2012.

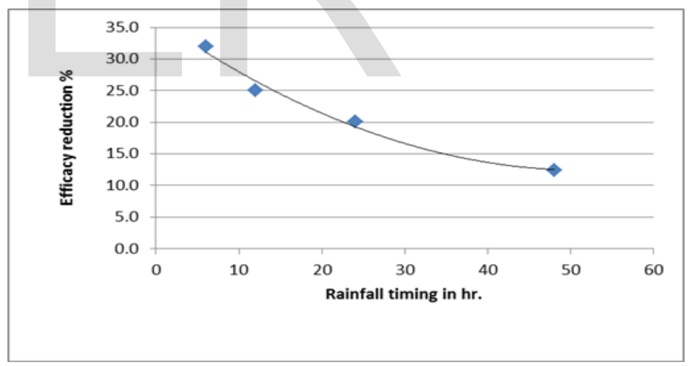

Figure 14: Rovral efficacy reduction affected with different timing of rainfall 2011/2012.

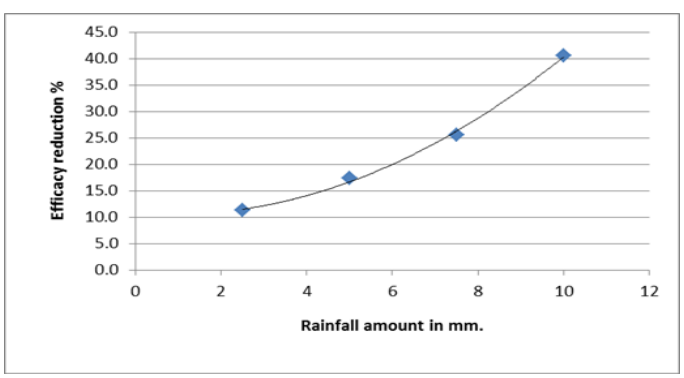

Figure 15: Tridex efficacy reduction affected with different amounts of rainfall 2011/2012.

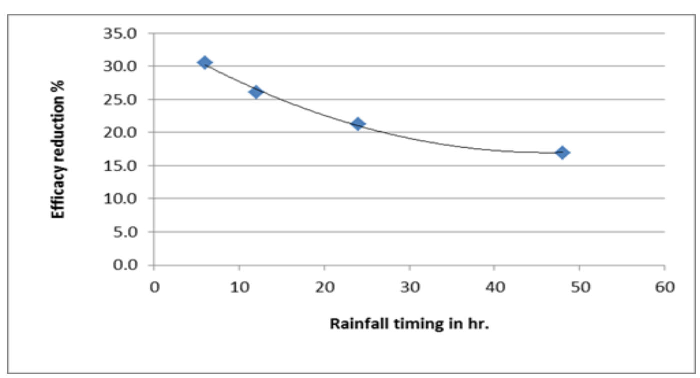

Figure 16: Tridex efficacy reduction affected with different timing of rainfall 2011/2012.

Prediction of fungicide efficacy reduction:

All the data of fungicide efficacy reduction, for each fungicide in the two years, were subjected to multi regression analysis. From this analysis correlation, partial correlation, overlap and predictive equations for each fungicide were obtained. These equation help to calculate and predict the fungicides efficacy reduction if the field exposed to rainfall after the application of one of these fungicide, in order to come on the decision if it is important to repeat the fungicide application or not.

For Amistar Top, 84.4% of Amistar Top efficacy reduction can be attributed to the time between the fungicide application and rainfall, 47.1% efficacy reduction can be attributed to this factor itself without any interaction, while 83.5% of efficacy reduction can be attributed to the rainfall amount, and 44% efficacy reduction can be attributed to this factor itself without any interaction with 4% overlapping between the two factors.
The equation is:

$$FER = 10.829 – 0.388\ T + 2.161\ RA$$

For Topsin M70, 76.9% of Topsin-M efficacy reduction can be attributed to the time between the fungicide application and rainfall, 37.4% efficacy reduction can be attributed to this factor itself without any interaction, while 81.9% of efficacy reduction can be attributed to the rainfall amount, and 51.2% efficacy reduction can be attributed to this factor itself without any interaction with 10.0% overlapping between the two factors.
The equation is:

$$FER = 11.324 - 0.527\ T + 3.548\ RA$$

For Rovral, 74.1% of Rovral efficacy reduction can be attributed to the time between fungicide application and rainfall, 34.5% efficacy reduction can be attributed to this factor itself without any interaction, while 81.9% of efficacy reduction can be attributed to the rainfall amount, and 53.8% efficacy reduction can be attributed to this factor itself without any interaction, with 10.7% overlapping between the two factors.
The equation is:

$$FER= 12.490 - 0.490\ T + 3.538\ RA$$

And for Tridex, 59.2% of Tridex efficacy reduction can be attributed to the time between fungicide application and rainfall, 19.2% efficacy reduction can be attributed to this factor itself without any interaction, while 83.7% of efficacy reduction can be attributed to the rainfall amount, and 67.5% efficacy reduction can be attributed to this factor itself without any interaction, with 11.4% overlapping between the two factors.
The equation is:

$$FER = 10.250 - 0.343\ T + 3.706\ RA$$

Since:
FER = predicted fungicide efficacy reduction.
10.829, 11.324, 12.490 and 11.324 are constants.
T = time between the fungicide application and rainfall event in hour.
RA = rain amount in mm.

From the last data it is to be noticed that, effect of the time on the efficacy of the fungicides Amistar Top (systemic fungicide with SC formulation), Topsin-M70 (systemic fungicide with WP formulation), Rovral (local systemic fungicide with WP formulation), and Tridex (non-systemic fungicide with WP formulation), was in descending order, when this factor react in interaction with the other factor, while the effect of rainfall amount was nearly the same; similar trend is noticed too, in case of the effect of time alone, without any interaction with the other factor, but the effect of the amount of rainfall alone without any interaction with the other factor is in ascending order; which indicates that, systemic fungicides efficacy is rainfall time and amount dependent, while non-systemic fungicides are more likely to be rainfall amount dependent as time dependent.

4 DISCUSSION

In this study the four tested chemical fungicides resulted in significant disease control compared with the control treatment, but with different degrees in the two successive years. The data are in harmony with those obtained by Abo Zeid *et al*. (1990) and (2002); Mac Leod and Galloway (2006); El-Kholy(2007); Anonymous (2010); Scrimshaw (2013); El-Kholy, (2014) and Aitchison (2015). The differences in fungicides efficacy may due to the different mode of action of each fungicide. Amistar Top containing two different active ingredients with two different modes of action, azoxystrobin and difenoconazole; both asoxystrobin and difenoconazole are systemic and broad spectrum fungicides with protective and curative properties. Azoxystrobin belongs to strobilurin-class of fungicides (Nithyameenakshi *et al*., 2006); inhibits fungi by inhibition of mitochondrial respiration, inhibition of spore germination, mycelial growth and spore production. In addition, it is active at very low doses against a wide range of fungal pathogens (Bartlett *et. al*. 2001; Bartlett *et al.* 2002 and Anonymous, 2009). On the other hand, difenoconazole acts by inhibition of demethylation during ergosterol synthesis (Hamilton, 2008). The synergism between these two active ingredients may lead to a very wide range of fungal pathogens with high fungicide efficacy. On the other hand, thiophanate-methyl (TM) the active ingredient of Topsin-M70 is a member of benzimidazole fungicides group which acts systemically; this product is a tubulin inhibitor disturbing cell division, In addition, it inhibits cytochrome c oxidase by about 40-60%. (Hirschfeld *et al.,* 2011). Rovral (iprodione) is local systemic fungicide, it represents another fungicide group (the dicarboximide fungicides), with other mode of actions; it inhibit mycelial growth much more than spore germination. It inhibits DNA synthesis and chitin biosynthesis (Pappas and Fisher, 1979), and causes a slow but generalized leakage of pool metabolites; this release precedes cell lysis (Silvia *et. al*, 1997). On the other hand, Tridex fungicide belongs to dithiocarbamate fungicides groups, is non-systemic fungicides, with multi-site action; since, this group act by one or more of, chelation of required heavy meals, attachment of a 1:1 complex of metal and dithiocarbamate ions co-enzymes, reaction of free radical intermediates with cellular components or/and react as lethal catalysis (Nene and Thapliyal, 1979). These different fungicide modes of action have to lead to different fungicide efficacy degrees.

Exposing the plots treated with the tested fungicides to different amounts of rainfall and at different timing after the fungicides application resulted in pronounced decreasing of the fungicides efficacy with different degrees; These data are in harmony with those obtained by Parry (1990); Pigati *et al*. (2010) and Schilder (2011). Amistar Top was the lowest affected one; followed by Topsin-M70 then Rovral and Tridex. This difference may attribute to chemical and physical properties and the ability of active ingredient to penetrate the treated plants or the endurance of active ingredient in/on the plant tissues.

Amistar Top containing two different active ingredient azoxystrobin and difenoconazole; both are systemic fungicides, which can be absorbed through the roots and translocate in the xylem to the stems and leaves, or through leaf surfaces to the leaf tips and growing edges; Topsin-M70 is also a systemic fungicide; however, both fungicides showed corresponding reduced fungicide efficacies specially when plants were exposed to small rainfall amounts; higher amount of 10.0mm rainfall resulted in more Topsin-M70 efficacy reduction compared with Amistar Top; These two fungicides were more repost to rainfall after 48hr. of the fungicide application. Rovral (local systemic fungicide) and Tridex (non-systemic fungicide) were more sensitive to rainfall, especially when high amount of rain falls in a short time after fungicide application, with high fungicide efficacy reduction similarity, however when the plots were exposed to rainfall after 24 hr. or more. Rovral was more reposting as Tridex. These data are in agreement with that of Anonymous (2011) who recorded that, since systemic fungicides are absorbed by plant tissues and get redistributed in/on the plant, they tend to be less susceptible to wash-off by rain compared to protectant fungicides which remain on the outside of the plant. However, this depends on the type of fungicide, and research has shown that even systemic fungicides are affected by rainfall. A general rule of thumb that is often used is that 1 inch of rain removes about 50% of the protectant fungicide residue and over 2 inches of rain will remove most of the spray residue. In addition most systemic fungicides are rainfast after 2 hours but a longer period (up to 24-48 hours) will help the fungicide fully penetrate the plant surface.

At the last few years abnormal rainfall events took place in Egypt, especially on the north coast, Alexandria, Damietta, El-Behera, El-Dakahleia, Kafr El-Sheikh and Sinai provinces. Special effort have to be done in the field of plant protection to save the crops and lower the cost of pesticides application and save the environment by avoiding the unnecessary repeat of fungicide application as a result of pesticides wash off caused by rainfall.

In this study systemic fungicides efficacy was rainfall time and amount dependent, while non-systemic fungicides were likely to be more rainfall amount dependent than time dependent.

Four prediction equations were generated for the four tested fungicides to predict the loss of fungicide efficacy as a result of exposure of the fields to certain amount of rainfall after certain time of the fungicide application. According to the available literatures, it is the first time to generate such equations, however, further studies must be done to assess the correlation between the percent of fungicide efficacy reduction and the crop losses and the subsequent economic value of fungicide reapplication.

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