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Management of wheat rusts at different growth stages using Nativo 300 SC (trifloxystrobin 100g/L+tebuconazole 200g/L) fungicide

Ruth Wanyera[1], Mercy Wamalwa[2], Mercy Odemba[2], Hannington Wanga[1], Philister Kinyanjui[1], Victoria Onyango[2], James Owuoche[2]

[1]Kenya Agricultural and Livestock Research Organization, P.O. Private Bag, Njoro 20107, Kenya
[2]Egerton University, P. O Box 536, Egerton, Kenya

***Corresponding author: wanyera@plantprotection.co.ke/wanyerar@gmail.com**

Abstract

Rusts (stem, yellow and leaf) remain the most important diseases of wheat worldwide due to their ability to cause severe yield losses in susceptible varieties. Timing of fungicide application in the integrated management of rusts on wheat is critical. This study was conducted to determine the wheat growth stage at which fungicide application can effectively control/reduce the damages caused by rust diseases. Field experiments were conducted in 2013 and 2014 in three locations; Njoro, Eldoret and MauNarok. Three doses of Nativo 300 SC (trifloxystrobin 100g/L+tebuconazole 200g/L) fungicide were applied at seven different growth stages of wheat variety Duma as split plot arrangement using a randomized complete block design with three replications. Results showed significant ($P \leq 0.01$) differences among growth stages for stem rust infection, grain yield, grain and test weights. Area Under Disease Progress Curve (AUDPC) was significant for stem and yellow rusts in MauNarok and for leaf rust in Njoro. Significant ($P \leq 0.01$) effects of environments and fungicide were observed on grain yield, grain and test weights. Environment × growth stage interaction were significant ($P \leq 0.01$) on AUDPC for stem rust, grain yield, grain and test weights. Fungicide application at tillering and flowering growth stages (GS) increased grain yield by 66.3%, grain weight by 41.6% and test weight by 17.27%. Therefore, wheat rusts can effectively be controlled by applying fungicide at tillering and flowering growth stages.

Keywords: Fungicide; Growth stage; Rust; Yield.
Abbreviations: AUDPC_Area Under Disease Progress Curve; Ug99 (TTKSK)_Stem rust race; GS_Growth stage; RWA_Russian Wheat Aphid; BYD_Barley yellow dwarf.

Introduction

Among the wheat (*Triticum aestivum L.*) diseases, stem (*Puccinia graminis*), leaf (*Puccinia triticina*) and yellow (*Puccinia striiformis*) rusts remain the most important in wheat production. This is due to their wide distribution, ability to form new races that can overcome the resistance in the newly released varieties, long distance migration and potential to develop rapidly under optimal environmental conditions resulting in severe yield losses (Roelfs, 1992; Kolmer et al., 2009). The initial epidemic of rusts on wheat was reported in Kenya as early as 1908 (Thorpe, 1959).

Stem (black) rust is a significant disease of wheat worldwide which can cause yield losses of up to 100% in susceptible varieties under conducive environment (Roelfs, 1985a; Leonard and Szabo, 2005). Wheat rust race evolution is a threat to global wheat production, for instance, a new stem rust race *Ug99* (TTKSK), identified in Uganda in 1999 (Pretorius et al., 2000), is of great concern because it has broad virulence to most stem rust *(Sr)* genes (Jin et al., 2007). About one billion people reside in the anticipated path of *Ug99* and most of them consume wheat produced within their borders (Olson, 2012). Although genetic resistance is the most effective method of controlling wheat rusts worldwide stem rust still remains a major threat to global wheat production and food security (Singh and Rajaram, 2002; Singh et al., 2011).

Wheat yellow (stripe) rust is also a significant disease of wheat worldwide (Chen, 2005; Hovmoller et al., 2010; Wellings, 2011). Yellow rust epidemic has been reported in South Africa, Kansas, China and Central Asia (Morgounov et al, 2004; Wan et al., 2004; Chen et al., 2005). The disease can cause significant reductions in both grain quality and yield in susceptible varieties (Dimmock and Gooding, 2002). Yield losses of up to 71% have been reported in Ethiopia (Worku, 2014). In Kenya yellow rust has remained an important disease since 1908 and no commercial variety is resistant (Bonthuis, 1985; KARI, 1990-2012). Yellow rust occurs in temperate regions with cool and moist-weather for spore germination, infection and survival (Danial et al., 1994; Chen, 2005). The pathogen is a global problem evolving into different races. In Kenya it is prevalent in the Rift valley region (Danial et al., 1994). Attacks by the pathogen occur annually and newly introduced resistant varieties lose their resistance within a short time. Wheat leaf (brown) rust is the most common and widely distributed of the three wheat rusts and occurs in more regions more often than stem rust and stripe rust (Cherukuri et al., 2005; Kolmer, 2005; Kolmer, 2013). Yield losses caused by leaf rust have been reported to range from 5% to 16% on average, and up to 40% in epidemic years (Bolton et al., 2008). In Kenya, the disease appeared sporadically and has not been a problem for the past 20 years, but it has recently emerged in the wheat fields and experimental plots (KARI, 2011). Understanding plant disease epidemiology and the role of practical approaches in disease evaluation is important in the development of management strategies (Jeger, 2004). Although wheat rusts are widely studied plant diseases, more knowledge is required to optimize their management in Kenya where they continue to be among the major factors limiting wheat production. The use of genetic resistance in controlling wheat rusts has been adopted worldwide. However, the problem of race evolution still persists and therefore the resistance of released varieties breaks down within a short period. This means that breeding programmes must continue to develop new resistant varieties with an increasing broad and stable type of resistance. This takes too long to accomplish. The ineffectiveness of resistance to new races necessitates new interventions in the management of the rusts. Therefore, the use of foliar fungicides as alternative management strategy for rust diseases should be adopted to maintain wheat production before the release of new resistant varieties. The importance of proper timing of chemical applications to control rust has been emphasized repeatedly (Hobbs, 1966; Walter *et al*., 2007). Timing of fungicide application to reduce/control wheat rust is not properly understood in Kenya. Therefore this study was conducted to determine the growth stage of wheat at which fungicides can be applied to control/reduce rust infection.

Results

In 2013, stem rust infection was observed across the three locations. Infection of yellow rust on the leaves was mainly observed in Njoro and MauNarok, while infection on the glumes was noted only in MauNarok. Leaf rust infection occurred mainly in Njoro in 2014. The effects of fungicide rates were not significant on the AUDPC for stem rust, while the effects of environment and growth stage were significant ($P \leq 0.01$) for AUDPC, grain yield, a thousand grain weight and test weight. Significant ($P \leq 0.01$) interaction effects (environment × fungicide and environment × growth stage) were observed for AUDPC, grain and test weight. In addition, the environment × growth stage interaction effects were significant ($P \leq 0.01$) for grain yield (Table1).

AUDPC for Stem rust and yellow rust

Among the environments, Eldoret had the highest AUDPC mean for stem rust while the means for Njoro 2013, Njoro and MauNarok 2014 were not significantly different (Table 3). Plots sprayed with Nativo 300 EC (trifloxystrobin 100 g/L+tebuconazole 200 g/L) at the rate of 1.25L ha^{-1}showed a reduction in AUDPC compared to the wheat plots that were sprayed at the rate of 1.0L ha^{-1} and 0.75L ha^{-1}, respectively. Plots sprayed at tillering (20-29) GS and booting (40-49) GS; tillering (20-29) GS and flowering (60-69) GS had the lowest AUDPC for stem rust (81.79 and 65.99, respectively) (Table 3) while plots that were sprayed at flowering (60-69) GS had the highest AUDPC for stem rust (Table 3). Non-significant ($P \leq 0.05$) effects of the fungicide treatment rates for yellow rust on the leaves and glumes were noted at Njoro and MauNarok in 2013 (Table 4). Infection of yellow rust on the glumes was significantly controlled when spraying was done at tillering (20-29) GS and booting (40-49) GS; tillering (20-29) GS and flowering (60-69) GS; first spray at 5% infection and 2 weeks later (Table 4). Infection of leaf rust was reduced in plots that were sprayed at the rate of 0.75L ha^{-1} and the highest leaf rust infection was observed in plots that were sprayed at booting (40-49) GS. However, leaf rust infection was low in plots sprayed at tillering (20-29) GS; tillering (20-29) and flowering (60-69) GS (Table 4).

Grain yield

The environment and growth stage of the crop at which different fungicide rates were applied influenced grain yield. In 2013, mean grain yield for Njoro (3.36t ha^{-1}) was the highest compared to the other three environments (Table 3). Application of the fungicide at the rate of 1.25L ha^{-1} increased grain yield by 10.3% compared to the plots that were sprayed at the rate of 0.75L ha^{-1}. Spraying at the rates of 0.75L ha^{-1} and 1.0L ha^{-1} did not show any comparative advantage on grain yield. Plots that were sprayed at tillering (20-29) GS and flowering (60-69) GS had grain yield increase of 66.3% compared to the control (unsprayed) plots. Fungicide application when the rust infection was at 5% and another spray two weeks later had a significant yield increase of 54.7%. In addition, fungicide application at tillering (20-29) GS and booting (40-49) GS had significant grain yield increase of 53.5% while spraying at flowering (60-69) GS had significant grain yield increase of 49.5% over the control (Table 3).

Thousand grain weight

Among the test environments, the highest mean for thousand grain weight was observed at Njoro (38.39g) and Eldoret (38.77g) in 2013. Plots that were sprayed with the fungicide at the rate of 1.25L ha^{-1} had grain weight advantage of 9.61% over plots that were sprayed with the fungicide at the rate of 0.75L ha^{-1}. Plots that were sprayed at tillering (20-29) GS and flowering (60-69) GS and when the infection was at 5% followed by another spray two weeks later had a thousand grain weight of 39.6g and 38.69g which showed an increase of 41.6% and 38.67%, respectively, over the control plots (Table 3).

Test weight

The mean test weight for the four environments was not significantly different. The lowest test weight (60.75 Kg HL) was observed at Njoro in 2014. Plots that received the fungicide at the rate of 1.25L ha^{-1} had increased test weight of 4.61 % compared to plots that received the fungicide at the rate 0.75 and 1.0L ha^{-1}. Plots that were sprayed when the rust infection was at 5% followed by another spray two weeks later and tillering (20-29) GS and flowering(60-69) GS had the higher test weight of 73.13 and 72.92 with an increase of 17.56% and 17.27% over the control, respectively (Table 3).

Regression

From the stepwise regression analysis, yellow rust infection on the glumes at milk (70-79) GS contributed to grain yield reduction (R^2=0.85) in MauNarok (Table 5). In addition, yellow rust infection on the glumes at dough (80-90) GS contributed to the reduction of a thousand grain weight (R^2=0.92) and test weight (R^2=0.91). However, stem rust infection was detected as the major cause of grain yield (R^2 =0. 85) and test weight (R^2 =0.93) reduction at flowering (60-69) GS in 2013 at Njoro. The infection of stem rust at milk (70-79) GS had also the greatest effect on reduction of thousand grain weight (R^2= 0.94) at the same site. In the subsequent season at Njoro and Eldoret, stem rust infection contributed to the reduction of grain yield (R^2=0.91;

Table 1. Coordinates, elevation, mean temperature and annual rainfall for the experimental locations.

Location	Coordinates	Elevation (MASL)	Temperature (^oC)	Rainfall (mm)
Njoro	0^o 20' S, 35^o 56'E	2185	9.7 (min), 23.5 (max)	900
Eldoret	0^o 31' N, 35^o15' E	2180	12 (min), 23 (max)	1,250
MauNarok	0^o39' S, 35^o 57' E	2754	6-14 (min), 22-26 (max)	1,200-1,400

Source: Jaetzold et al., 2005

Table 2. Mean squares from combined analysis for Area Under Disease Progress Curve (AUDPC) for stem rust, grain yield, thousand grain weight and test weight across four locations (Njoro 2013, Eldoret2013, MauNarok 2013, Njoro 2014).

Source	Df	AUDPC	Grain yield	Grain weight	Test weight
Environment	3	15579.73**	84302512.20**	1062.39**	54478.20**
Replicate within Environment	8	4912.02	175796.6	27.37	384.85
Fungicide	2	4912.01	344667.5*	218.64**	5328.49**
Environment × fungicide	6	7999.47**	152437.6	67.71**	2340.45**
Replicate × fungicide within Environment	16	5246.67	120425.8	12.89	434.46
Growth Stage	6	80151.32**	1511692.7**	538.16**	12610.08**
Environment × Growth Stage	18	16433.23**	428089.1**	49.5**	2212.14**
Fungicide × Growth Stage	12	3082.54	53216.4	13.99*	256.10
Environment × fungicide × stage	36	2019.09	73887.1	4.34	137.29
Cv		39.59	22.79	7.68	4.57

** and * significant at P<0.01 and P<0.05, respectively.

Table 3. Mean comparison for four locations, fungicide rates and growth stage for AUDPC for stem rust, grain yield, thousand grain weight and test weight on wheat variety Duma.

Environment	AUDPC	Grain yield (Ton ha^{-1})		Grain weight (g)		Test eight(HL Kg^{-1})	
Eldoret	143.49a	0.76 b		38.39a		72.58a	
Njoro 2013	123.92b	3.36 a		38.77a		72.79a	
Mau Narok	114.42b	0.87b		32.89		72.09a	
Njoro 2014	107.19b	0.77 b		30.47 c		60.75b	
$Lsd_{0.05}$	17.05	0.12		0.95		5.59	
Mean	122.26	1.44		35.13		69.55	
Fungicide			Grain yield gain (%)		Grain weight gain (%)		Test weight gain (%)
0.75L/ha	128.89a	1.37b	-	33.49c	-	67.83c	-
1.0L/ha	124.0ab	1.43b	4.38	35.19 b	5.08	69.88b	3.02
1.25L/ha	113.89b	1.52a	10.93	36.71 a	9.61	70.96a	4.61
$LSD_{0.05}$	14.76	0.10		0.82		4.85	
Growth Stage (GS)							
Control	202.72a	1.01d	_	27.9e	_	62.21e	_
First spray at 5% infection and 2 weeks later	111.18c	1.59ab	57.43	38.69	38.67	73.13a	17.56
Sprayed at tillering GS	100.24cd	1.27c	25.74	33.31d	19.39	67.97d	9.27

Table 3. (Continued)**.**

Growth Stage (GS)	AUDPC	Grain yield (Ton ha^{-1})	Grain yield gain (%)	Grain weight (g)	Grain Weight gain (%)	Test weight (HL Kg^{-1})	Test weight gain (%)
Sprayed at booting GS	135.71b	1.47b	45.54	34.45cd	23.48	69.11cd	11.09
Sprayed at flowering	158.19b	1.51b	49.50	36.35 b	30.29	71.06 b	14.22
Sprayed at tillering and booting GS	81.79de	1.55ab	53.47	35.70 bc	27.96	70.46bc	13.26
Sprayed at tillering and flowering GS	65.99e	1.68a	66.34	39.52a	41.65	72.92 a	17.27
$LSD_{0.05}$	20.55	0.15	_	1.26	_	7.4	_

Grain yield gain (%); Grain Weight gain (%); Test weight gain (%) = (treated-untreated) x100/treated
Means with different letters are significantly different at P< 0.05 within a column.

Table 4. Means of fungicide rates and growth stage for AUDPC for yellow rust (Yr) on the leaves ,glumes (1,2) and leaf rust (Lr) in Njoro and Mau Narok 2013.

	Njoro		MauNarok		
			Yr	Yr on the glumes	
Fungicide	Yr	Lr	AUDPC	1	2
0.75L/ha	1.0a	1.6b	175.83a	17.14a	25.71a
1.0L/ha	1.2a	3.95a	159.36a	17.86a	24.28ab
1.25L/ha	1.0a	2.86ab	164.50a	15.71a	21.43b
$Lsd_{0.05}$	0.32	1.34	45.09	2.45	4.00
Growth Stage (GS)					
Control	1.0a	5.22ab	245.17a	27.78a	35.56a
First spray at 5% infection and 2 weeks later	1.0a	1.0c	238.06a	6.11d	9.44e
Sprayed at tillering (GS20-29)	1.0a	1.0c	102.11b	22.22b	32.78ab
Sprayed at booting (GS40-49)	1.0a	7.0a	211.00a	13.33c	20.56d
Sprayed at flowering (GS60-69)	1.0a	3.3b	231.83a	21.11b	27.78cb
Sprayed at tillering and booting	1.4a	1.0c	43.67b	12.78c	22.22cd
Sprayed at tillering and flowering	1.0a	1.0c	94.11b	15.00c	18.33d
$Lsd_{0.05}$	0.48	2.04	68.88	3.75	6.12

Yr on the glumes1 (first severity notes1); Yr on the glumes 2 (second severity notes 2) at an interval of 1 week one. Means with different letters are significantly different at P< 0.05 within a column.

Table 5. Stepwise regression analysis: Effects of stem rust, yellow (stripe rust), and leaf rust on grain yield, thousand grain weight and test weight on wheat variety Duma at Mau Narok, Njoro and Eldoret.

Mau Narok	Variable	Parameter estimate	Standard error	Partial R^2	Model
Grain Yield	Intercept	1129.05	69.4921		
	Milk GS	-20.3859	3.8218	0.8505	0.8505
Grain weight	Intercept	37.77	0.049		
	Hard dough GS	-0.5284	0.0038	0.9229	0.9229
	Milk GS	-1.0082	0.0074	0.0341	0.9570
	Soft dough	1.0318	0.0083	0.0301	0.9871
	Milk growth stage	0.5981	0.0089	0.0111	0.9982
	Endof flowering GS	-0.0624	0.0023	0.0018	1.0
Test weight	Intercept	382.83	6.63		
	Hard dough	-2.6033	0.3225	0.9136	0.9136
	Milk GS	-6.8956	1.1730	0.0249	0.9385
	Soft dough GS	1.8765	0.4136	0.0176	0.9560
	Soft dough GS	5.4172	1.1690	0.0247	0.9807
	Stem elongation GS	2.1354	0.7126	0.0174	0.9981
Njoro 2013					
Grain Yield	Intercept	3086.21	59.31		
	Endof flowering GS	-86.3600	15.3204	0.8572	0.8572
	Heading GS	186.6127	13.0589	0.1285	0.9856
	Milk GS	-51.8014	9.7331	0.0097	0.9953
	Tillering GS	-27.0485	7.9075	0.0040	0.9993
Grain weight	Intercept	43.8614	0.068		
	Milk GS	-1.1722	0.0044	0.9465	0.9465
	Grain filling GS	1.1619	0.0043	0.0420	0.9886
	Heading GS	-0.2452	0.0018	0.0066	0.9952
	End of flowering	-0.4597	0.0060	0.0038	0.9989
	Tillering	0.6191	0.0137	0.0011	1.0
Test weight	Intercept	409.056	0.14		
	Tercept				
	Flowering GS	-4.6786	0.0063	0.9312	0.9312
	Flowering GS	2.4169	0.0073	0.0409	0.9720
	Tillering GS	-4.9755	0.0348	0.0125	0.9845
	Heading GS	0.8060	0.0049	0.0155	1.0
		0.6094	0.0763	0.0	1.0
Njoro 2014					
Grain Yield	Intercept	1182.94	36.67		
	Dough GS	-8.7596	0.7959	0.9118	0.9118
	Heading GS	3.5514	15.8651	0.0629	0.9746
	FloweringGS	23.7074	6.2820	0.0117	0.9864
	BootGS	-50.6238	20.4478	0.0038	0.9901
	Endofflowering(GS)	-15.4960	6.7743	0.0083	0.9984
Grain Weight	Intercept	35.47	3.89		
	Dough GS	-0.0919	0.0871	0.9655	0.9655
	Milky GS	0.3623	0.3558	0.0056	0.9711
	HeadingGS	2.2611	1.0403	0.0092	0.9803
	Watery GS	-1.1962	0.7565	0.0083	0.9887

Njoro 2014	Variable	Parameter estimate	Standard error	Partial R^2	Model
	Boot GS	-1.0439	0.8006	0.0071	0.9958
Test Weight	Intercept	365.35	1.84		
	Dough GS	-1.5741	0.1922	0.9395	0.9395
	Milky GS	-3.2711	0.7674	0.0300	0.9695
	Fowering GS	4.4364	0.5040	0.0163	0.9858
	End flowering GS	-2.4854	0.5844	0.0112	0.9970
	Milky GS	1.9248	0.7347	0.0026	0.9996
Eldoret					
Grain Yield	Intercept	728.1422	27.37		
	Flowering GS	-4.1574	2.1806	0.4210	0.4210
Grain Weight	Intercept	41.63	0.69		
	Heading GS	-0.2185	0.1393	0.7904	0.7904
	Flowering GS	-0.1636	0.0714	0.0798	0.8703
Test Weight	Intercept	369.26	2.094		
	Heading GS	-0.5899	0.4210	0.6555	0.6555
	Flowering GS	-0.2280	0.2158	0.0752	0.7306

GS -Growth stage.

R^2=0.42), thousand grain weight (R^2 =0.96; R^2=0.79) and test weight (R^2 = 0.93; R^2=0.65).

Discussion

Foliar fungicides are used to manage diseases caused by fungi in wheat in order to achieve high yield and quality. Fungicides do not give a 'yield bump' rather they protect yield potential that is already built into the crop. This protection can only be achieved if attention is paid to the details of application of fungicide. Not all the three rusts were observed in the three locations where the experiments were conducted. This could probably be due to unfavourable environmental conditions for disease infection and development.

Effects due to environments and fungicide on AUDPC for stem rust and grain yield suggest that there was variation among the test environments and the rates at which the fungicides were applied. Significant environment × fungicide indicates that the effect of fungicide on the rate of application also varied with environment. Plots that had the highest AUDPC had low grain yield, thousand grain and test weights. In a different study on barley, Ochoa and Parlevliet (2007) found out that yield loss due to leaf rust was related to AUDPC. Timing of fungicide application is critical for control of fungal diseases (Walter et al., 2007). In this study, spraying at tillering and flowering growth stages resulted in the reduction of stem rust infection. Similar studies on timing for foliar fungicide application concluded that the best time for application was at early anthesis (Wiersma and Motteberg, 2005; D'Angelo et al., 2014).

Results showed that there were environmental effects on AUDPC for stem rust, grain yield, grain weight and test weight. The variations in environment on AUDPC for stem rust were probably due to weather related factors that prevailed at the experimental sites. In this study, three locations Njoro, Eldoret and MauNarok were selected because of favourable weather conditions for rust infection and development. Generally Njoro and Eldoret have hot days of 23 ^{o}C -30^{o}C, mild night temperatures below 15^{o}C and adequate moisture for night dews. MauNarok often experiences cool weather, frequent rainfall during the growth seasons which is highly favourable for yellow rust infection and development (Wanyera et al., 2009). The warm moist conditions in Eldoret favoured stem rust infection hence the high AUDPC for stem rust. A study on the effect of Amistar 250 EC (azoxystrobin 250 g/L) and Dithane M-45 (mancozeb 800g/Kg) on growth parameters of maize showed that an increase in the concentration of the fungicide led to increase in growth parameters of maize seedling (Aisha, 2014). Increasing the rate of Nativo fungicide to 1.25L ha $^{-1}$ reduced the rust severity, hence the reduction in AUDPC.

It was evident that grain yield increased with the increase in the rate of fungicide application. This increment is attributed to the reduction of stem rust destruction which results to premature death of spikelets or entire spikes hence the development of shrivelled grains. The yield increase due to fungicide applications could also be partially due to phytonic effect of fungicides. This stimulatory effect of fungicide treatments on growth may result in significant yield increases even in the absence of the disease (Wegulo et al., 1998). In the United Kingdom, application of fungicides to winter wheat resulted in a yield response of up to 89% (Cook et al., 1999). Rust infection at tillering GS had greater effects on grain yield, a thousand grain and test weights reduction across the three environments. Kolmer et al. (2005) findings showed that greater yield losses result from infections before the jointing and tillering growth stages.

Wheat rusts interfere with photosynthetic activities and reduce the mobilization of the carbohydrates to the kernels. Increasing the fungicide rate restricted the development of rust uredinia hence reducing the destruction of the photosynthetic area. The low grain yield, grain and test weights at the rate of 0.75L ha^{-1} was attributed to the reduction of the photosynthetic area and destruction of the phloem tissues on variety Duma. Effects of fungicide rates and growth stages on plots infected with yellow rust on the glumes were noted at Njoro in 2013 and MauNarok in 2014. Increase of application rates from 0.75 L ha^{-1} to 1.25L ha^{-1} reduced yellow rust infection on the glumes by 17%. This was also observed on stem rust when application rates were. Infection of yellow rust on the glumes at milk stage contributed to the reduction of grain yield. In contrast to yellow rust, stem rust infection had greatest effect in the reduction of grain and test weight at dough stage, leading reducing grain yield.

The effects of stem rust on grain yield varied across environments. In 2013, stem rust infection contributed to the reduction of grain yield and thousand grain weight at Njoro. Lackermann et al. (2011) found that both location and disease contributed to the reduction of grain yield. Grain yield, thousand grain weight and test weight were highly affected by the rust infection at different growth stages. In Eldoret, stem rust infection at the dough growth stage highly contributed towards yield reduction. Therefore, timely detection of rusts and application of fungicides are important factors in controlling wheat rusts (Roelfs, 1985b; Beard et al., 2004).

Materials and Methods

Experimental sites

Field experiments were conducted in 2013 and 2014 in three locations (Table 1).

Plant material and Fungicide

Wheat commercial variety Duma from KALRO–Njoro which is highly to moderately susceptible to stem, leaf and yellow rust was used. A commercial foliar fungicide Nativo 300 SC (trifloxystrobin 100g/L+tebuconazole 200g/L) was used. Nativo 300 SC is a systemic broad spectrum fungicide which controls fungal diseases and improves quality and yield of crops. The fungicide was obtained from Bayer East Africa Limited.

Experimental procedures

Wheat variety Duma was planted for evaluation in a randomized complete block design (RCBD), split-plot arrangement with three replications in the three locations. Plot size was 9 m^2 with a length of 6 m and an inter-row spacing of 0.2 m. Sowing was done by an experimental drill at a seeding rate of 125Kg ha^{-1} in May 20 and 21, 2013 at Njoro; October 3 and 4, 2013 at MauNarok; May 14, 2014 at Eldoret and June 23, 2014 at Njoro. Di-ammonium phosphate (D.A.P, 18% N, 46% P, 0% K) fertilizer was used at the recommended rate of 150 Kg ha^{-1} at planting. Hussar Evolution (fenoxaprop-p-ethyl 64g/L +idosulfuron methyl sodium 8g/L +mefenpyr-diethyl 24g/L) was applied as post-emergence herbicide at 1.0L ha^{-1} for the control of both grass and broadleaved weeds. Another application of Buctril MC (bromoxynil+ MCPA) labelled for control of broad-leaved weeds was applied at the rate of 1.25L ha^{-1} at tillering (20-29) GS. Thunder OD 145 (imidachloprid 100g/L +beta-cyfluthrin 45g/L) insecticide was applied at the rate of 0.3L ha^{-1} at tillering (20-29) GS, flowering (60-69) GS and milk (70-79) GS to control Russian Wheat Aphid (RWA) and other aphid vectors for barley yellow dwarf (BYD) disease. The growth stages were based on Zadocks et al. (1974) scale. Nativo 300 SC (trifloxystrobin 100 g/L+tebuconazole 200 g/L) was applied at the rates of 0.75L ha^{-1}, 1.0 L ha^{-1} and 1.25 L ha^{-1}. The untreated plots served as the control. The fungicide was applied using a knapsack sprayer at a recommended water volume of 200 Lha $^{-1}$ at six different stages (1. First spray at 5% infection and 2 weeks later, 2. Tillering, 3.Booting, 4. Flowering, 5. Tillering and booting, 6. Tillering and flowering).

Data collection

Rust severities in the plots were based on the modified Cobb scale (Peterson et al., 1948), on a weekly basis before and after fungicide application. At maturity, each plot was harvested by hand using sickles and threshed by a stationery thresher (Model LPT D, serial no. T09235 ALMACO USA. Specialized agricultural equipment. NEVADA Iowa, USA). Harvesting dates for Njoro 2013, 2014; MauNarok 2013/2014 and Eldoret were October 17-18, 2013, November 17-19, 2014; April 1, 2014; and October 17, 2014, respectively. Grain weight measurements were taken after cleaning and drying to moisture content of 13%-14%. A sample of grain was taken from each plot for determination of grain weight based on the weight of a thousand grains and test weight (a measure of the density).

Statistical analysis

Area under Disease Progress Curve (AUDPC) was calculated by a computer programme developed at the International Centre for Maize and Wheat Improvement (CIMMYT). AUDPC for combined analysis was calculated for stem rust in all environments. For yellow and leaf rusts, the ANOVA for each environment was used and means separated by LSD at ($P \leq 0.05$). The analysis was done using the following statistical formula:

$$Y_{ijk} = \mu + E_i + R_{j(i)} + F_k + EF_{ik} + FR_{jk(i)} + S_l + ES_{(il)} + FS_{(kl)} + FSE_{(ikl)} + \varepsilon_{ijklm}$$

: Where μ = mean of the observations, E_i = the effect of the i^{th} environment, $R_{j(i)}$ = effect of the j^{th} replicate within i^{th} environment, EF_{ik} = effect due to the interaction between i^{th} environment and the k^{th} fungicide rate within i^{th} environment and j^{th}replicate, F_k= effect of the k^{th} fungicide rate within i^{th}environment and j^{th}replicate, S_l = the effect of the l^{th} stage of application of fungicide in the j^{th}replicate in the within i^{th} environment. ES_{il}= effect due to the interaction between i^{th} environment and l^{th} stage of application of fungicide in the j^{th}, FS_{kl} = effect due to the interaction between k^{th} fungicide rate and l^{th} stage of application of fungicide in the j^{th}replicate in the withini^{th} environment, FSE_{ikl}= effect due to the interaction of k^{th} fungicide rate within j^{th}replicate and l^{th} stage of application of fungicide in the j^{th}replicate and i^{th}environment; ε_{ijklm} = random error of the experiment.

Stepwise regression backward selection was used to determine the effects of rusts and growth stage on grain yield, a thousand grain weight, test weight using SAS (SAS 1999).

Conclusion

Fungicides can significantly increase wheat grain yield by effectively reducing rust infection and development on susceptible varieties. The study showed that, growth stage is an important factor in the management of wheat rusts using fungicides. Tillering and flowering were the most appropriate growth stages at which Nativo 300 SC (trifloxystrobin 100g/L+tebuconazole 200g/L) foliar fungicide applied at the rate of 1.25 L ha^{-1} effectively reduced/controlled the rust infection and increased grain yield. It was also noted that, early spraying when the disease was at 5% infection and 2 weeks later significantly reduced yellow and leaf rust. This study showed that foliar fungicides can be used to manage wheat rust as a short term control strategy and that Integrated Rust Disease Management will be an appropriate strategy for reducing the disease damage and maintaining grain yield of wheat in Kenya.

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