Grain and Biomass Yield Reduction by the Russian Wheat Aphid on Bread Wheat in Northern Ethiopia

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Abstract
Russian wheat aphid (*Diuraphis noxia* Mordvilko) is an important insect pest of wheat and barley in Northern Ethiopia. We present loss data due to *D. noxia* on wheat from an experiment conducted at Mekelle Agricultural Research Center in the off season with irrigation. Insecticide (Fenitrothion 50 EC and Dimethoate 40 EC) treated and untreated plots were compared for biomass and grain yield, damage, days to heading and maturity. Significant differences were found in all parameters. Control plots also sustained significant leaf chlorosis and rolling damages. *D. noxia* reduced wheat grain yield 67 to 68% and biomass by 44 to 55%. Weight per 1000 seeds was reduced by 20%. Heading and maturity was delayed. Fenitrothion 50 EC, a contact insecticide, controlled *D. noxia* and prevented 67% reduction in grain yield and 44% reduction in biomass yield. This yield loss data highlights the need to develop sustainable *D. noxia* management that would safeguard irrigated and spring season wheat crop.
Keywords: *D. noxia*, yield loss, wheat

INTRODUCTION

Bread wheat, *Triticum aestivum* L. (Poales: Poaceae), is one of the most widely cultivated cereal crops in the highlands of Ethiopia. In the main (*Meher*) season, wheat is the third common cereal crop after sorghum and teff in area coverage and total production (CSA, 2013). Bread wheat is grown in the spring (*belge*) season though the yield is lower than the main season (Bekelle *et al.,* 2000). The crop is grown in diverse agro-ecological conditions with an altitude range of 1500 to 3000 meters above sea level (Demeke and DI-Marcantonio, 2013). National average yield for wheat is 2.0 t/ ha (CSA, 2013). The yield of wheat under farmers' management is far lower than under on-station and on-farm researcher managed plots (Kindie, 2014). Kindie (2014) attributed low productivity to stress from low moisture, shortage of seeds for improved varieties, soil fertility degradation, insect pests, diseases and weeds.

Wheat received increased attention in Africa as African governments endorsed it as one of the strategic commodities for achieving food and nutrition security (WAR, 2013). Wheat is now taken to non-conventional places like West Africa, Southern Africa and other places earlier not considered suitable for wheat. Ethiopia is also expanding wheat to the lowlands using irrigation and is developing wheat varieties suited for irrigation

Russian wheat aphid (*Diuraphis noxia* Mordvilko) is one of the major insect pests of barley and wheat in many areas of the world. It is indigenous to Southern Russia, Iran, Afghanistan and countries neighboring the Mediterranean Sea (Hewitt *et al*., 1984). *D. noxia* was reported in South Africa in 1978 (Jankielsohn, 2011) and the United States in 1986 (Morrison and Peairs, 1998). It was first recorded on barley in Atsbi and Adigrat areas of Northern Ethiopia in 1972 (Adugna and Megenassa, 1987).

D. noxia feeding on leaves of infested plants causes breakdown of chloroplasts thus leading to white and yellow longitudinal streaks (Fouche *et al.,* 1984); additional symptoms include leaf folding and rolling (Khan *et al.,* 2009). Preferential feeding of *D. noxia* on thin-walled sieve tubes and probing of xylem for water is the cause for leaf streaking, leaf rolling and chlorosis (Saheed *et al.,* 2010). South African *D. noxia* biotypes were shown to have differential feeding and water uptake-related damage on phloem and xylem tissues on barley (Jimoh *et al.,* 2011). High CO_2 conditions increased *D. noxia* population and lead to biomass loss on barley with the possibility of an early and severe crop loss (Jimoh *et al.,* 2013). Biotypes of *D. noxia* are reported from the US (Burd *et al*., 2006) and South Africa (Jankielsohn, 2011) while in Ethiopia, *D. noxia* resistant wheat cultivars containing Dn_4 gene were found susceptible to Northern Ethiopian populations (Smith *et al*., 2004). In 2012, however, *D. noxia* resistant barley cultivars (Burton and RWA-1758) from the US were resistant to populations in Northerly Ethiopia (Alemu *et al.,* 2014).

D. noxia, is the major insect pest of wheat in the spring season and under irrigation. Control recommendations in Ethiopia include the use of systemic insecticides Dimethate 40 EC, Gaucho WS 70, Cruiser 70 WP, Furathicarb 400 CS as well as Pirimiphos-methyl 50 EC (fumigant action) (Bayeh *et al.,* 2011). Rolled leaves, resulting from its feeding habit that causes the leaves to roll around the aphid colony, protected *D. noxia* from contact insecticides (Dahleen *et al*., 2012; Khan *et al*., 2009; Tolmay *et al.,* 2000; Givovich and Niemeyer, 1996). But rolled leaves may not completely protect aphids from contact insecticides and provided there are contact insecticides available that are safe for the environment, rolled leaves are not beyond the reach of such a kind of treatments.

In the US cumulative losses in small grain production due to *D. noxia* for eight years, beginning 1986 were $1 billion (Morrison and Peairs, 1998). Recent studies in the US indicated that *D. noxia* reduced wheat grain yield 50.2 to 82.9% and biomass by 55.4 to 76.5% (Mirik *et al.,* 2009). Yield loss projections for Australia ranged from 60-100% though the insect is not yet recorded within its borders (Brennan and Ballantyne, 1994). In South Africa, 35-60% yield loss from *D. noxia* was recorded on wheat (Du-Toit and Walters, 1984) while in Kenya, yield loss ranged from 25 to 90% on wheat (Macharia *et al*., 1999). The information regarding the importance of *D. noxia* on wheat in Ethiopia is, however, limited. The only yield loss data available is for barley (41-79%) in Central Ethiopia (Miller and Adugna, 1988). Since its first record of *D. noxia* in Northern Ethiopia in 1972 (Adugna and Megenassa, 1987), no loss data has been available for the area with no control recommendations or exercises including the use of insecticides. While crop protection is meant to prevent and control crop losses (Oerke, 2006), crop loss information is required to determine if *D. noxia* is important and needs attention. In this study, the effect of *D. noxia* inflicted damage on grain and biomass yield; thousand seed weight and maturity of wheat under irrigation in Northern Ethiopia were determined.

MATERIALS AND METHODS

The field experiment was carried out at the Mekelle Agricultural Research Center (13°5'0" N, 39°6'0" E, at 1970 meters above sea level). The area is situated in the semi-arid agro-ecological zone, which is characterized by low and erratic rainfall (Legesse, 1999). Annual rainfall ranges from 344 to 710 mm; while the average temperature range is between 11.3 and 26.8°C (Table 3 and 4). The soil type is mainly clay loam with a pH of 7.47.

The field experiment was conducted during the winter-spring season of 2013 and 2014. In both years, planting was conducted on the 21st of January. Insecticide treatment and control plots were replicated three times in randomized complete block design. Plots of 2.5 m x 2 m with 10 rows spaced 0.2 m apart were used in 2013. In 2014, plots were 2 m x 1 m and had five rows at the same row spacing. Plots and blocks were spaced 1 and 2 m apart. Two sprays at 10-day intervals were applied. Fenitrothion 50 EC and Dimethoate 40 EC (Adami Tulu Pesticide Processing SC Ziway, Ethiopia) were used in 2013 and 2014, respectively. Manufacturer rates of 1.0 Lt/ha (Fenitrothion) and 1.5 Lt/ha (Dimethoate) were used. Dimethoate 40 EC is recommended for control of RWA on barley (DBARC 2003). Fenitrothion 50 EC is a contact insecticide registered in Ethiopia for the control of armyworm and locusts on cereals and pastures (MOA, 2013). In 2013, Fenitrothion 50 EC was used instead of Dimethoate 40 EC because of unavailability in the market at that time.

The first spray was applied two weeks after planting on 5th of February and at this time *D. noxia* incidence was nearly 100%. The second spray was carried out ten days later on 15th of February. Plants' were checked for *D. noxia* damage symptoms and for the presence of the aphid itself (Wysocki, 1990). Bird damage at maturity was protected by scaring method. The bread wheat variety used was Mekelle 1and is susceptible to *D. noxia* (Tesfay B, Unpublished data). Mekelle 1 is an early bread wheat variety developed by Mekelle Agricultural Research Center of the Tigray Agricultural Research Institute. A seed rate of 150 kg/ha was used. Drift during spraying was protected by fencing sprayed plots with canvas, and it worked nicely as nearby untreated plots were heavily infested by *D. noxia*.

Leaf chlorosis (1-9 score) and leaf rolling (1-3 score) following the procedures of Burd *et al*. (1993) were recorded on the 14th of March. Other data, including days to heading and maturity, grain and biomass yield and weight of 1000 seeds were also taken. Pictures of treated and untreated ones were as well taken to show any differences in *D. noxia* damage.

Independent-samples t-test was performed after conducting homogeneity of variance test (Levene's Test). Independent-samples t-test procedure of the IBM SPSS Statistics 20 (IBM-SPSS, 2011) software was employed to compare differences in days to heading and maturity, chlorosis and leaf rolling damages, biomass and grain yield.

RESULTS

The Levene's test for equality of variances was not significant ($p>0.01$) for all parameters considered indicating that the variances of the treatments were homogenous. There were significant differences between Fenitrothion 50 EC and the control ($P<0.05$) in mean biomass and grain yield as well as weight of thousand seeds (Table 1). *D. noxia* inflicted damage caused a reduction of 2200 Kg/ha biomass yield (44%) and 1633.8 Kg/ha grain yield (67%) on the bread wheat variety (Table 1). The decrease in weight per 1000 seeds due to RWA damage was 6.9 g (20%). Severe leaf chlorosis and rolling was observed in the control (Fig. 1).

Likewise, the results from the independent-samples t-test for days to heading and maturity, leaf chlorosis, leaf rolling, biomass and grain yield for the 2014 data on Dimethoate 40 EC are presented in Table 2. There were highly significant differences ($P<0.001$) in chlorosis and leaf rolling between Dimethoate 40 EC treated and the unsprayed (Table 2). Chlorosis (8.1 on a scale of 1-9) was severe and plants in the untreated plots had leaf tip necrosis. Leaf rolling (2.8 on a scale of 1-3) was also significantly higher on untreated plots and plants as a result had prostrate growth thus preventing emergence of the head (Figure 2). Dimethoate 40 EC treated plots recovered from *D. noxia* damage and looked healthy with no significant leaf chlorosis (1.2 on a scale of 1-9) or leaf rolling (1.1 on a scale of 1-3) damages (Fig. 2). There were statistically significant differences (p<0. 01) in mean days to heading and maturity between Dimethoate 40 EC treated and the unsprayed treatment. Treated plots headed 9 days and matured 6 days earlier than the untreated plots; this is significant for the dry lands where late-season stress from low moisture is limiting crop production. Significant differences (p<0. 01) in mean biomass and grain yield were also obtained between Dimethoate 40 EC treated and the unsprayed treatment. In the 2014 study, *D. noxia* inflicted damage caused a reduction of 5583 Kg/ha biomass yield (55%) and 2958 Kg/ha grain yield (68%).

The insecticides used controlled *D. noxia* infestation on wheat. Of special interest was that two sprays of Fenitrothion 50 EC at 10-day intervals prevented 67% biomass and 44% grain yield loss. There was a rain shower hours after the application of the second spray, suggesting effectiveness of Fenitrothion 50 EC is robust.

DISCUSSION

D. noxia is one of the major insect pests of wheat and barley since its first record in Northern Ethiopia in 1972 (Adugna and Megenassa, 1987). There is, however, no information on the yield loss in wheat (Miller and Adugna, 1988). This study shows the yield loss (grain and biomass) due to *D. noxia* and its effect on heading, maturity and weight of 1000 seeds on wheat in Northern Ethiopia. *D. noxia* caused a grain yield decrease ranging from 67-68% on irrigated wheat while it considerably reduced the biomass yield by 44-55%, determined by insecticide treatment. Seed weight of wheat was also reduced by 20% besides to delay in heading and maturity. It is regrettable that *D. noxia* was not considered an important insect pest in Northern Ethiopia for the last 42 years while *D. noxia* was robbing farmers harvest. The grain yield loss obtained from this study was in the range reported by Miller and Adugna (1988) for barley in Central Ethiopia, South Africa (Du-Toit and Walters, 1984), Kenya (Macharia *et al.,* 1999) and the US (Mirik *et al*., 2009). Under heavy infestation of Russian wheat aphid grain weight reductions of 80% was also reported in the US (Khan *et al*., 2009). Kiplagat (2005) reported a 29-31% reduction in weight per 1000 seeds due to *D. noxia* damage on wheat in Kenya, with extensive chlorosis and leaf rolling causing retarded plant development and delayed head emergence.

We show Fenitrothion 50 EC controlled RWA infestation. Fenitrothion 50 EC is a contact insecticide (ETN, 1995) and the efficiency obtained here is similar with other insecticides though contact insecticides are not suggested for *D. noxia* control (Dahleen *et al.,* 2012; Khan *et al.,* 2010; Tolmay *et al*., 2000; Givovich and Niemeyer, 1996). The rolled leaves in which the aphids live may not be as air tight to prevent contact insecticides with residual or fumigant action from acting on the aphids. Contact insecticides can gain entry into rolled leaves if applied at early stages of the infestation before the damaged plants assume prostrate growth. These are several possible reasons for the control of *D. noxia* infestation by Fenitrothion application. Provided there are contact insecticides that are safe for the environment, these results suggest including them in efficacy trials for *D.noxia* management.

CONCLUSION

The statistical evidence showing the damage caused by *D. noxia* is of considerable interest in Northern Ethiopia. *D. noxia* might therefore be a menace to the planned expansion of wheat with irrigation in Ethiopia and other parts of Africa. It is also corroborated in the controlled environment modeling by Jimoh *et al.* (2013) that showed elevated CO_2 to increase *D. noxia* population and cause severe crop loss on barley. These results highlight the need for comprehensive research program into the management of *D. noxia* in Ethiopia including host-plant resistance, biological control, cultural control and identification of suitable insecticides.

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FIGURE CAPTIONS

Figure 1. Fenitrothion 50 EC sprayed (A) and untreated plots (B), 2013 season (note leaf rolling and colour on B).

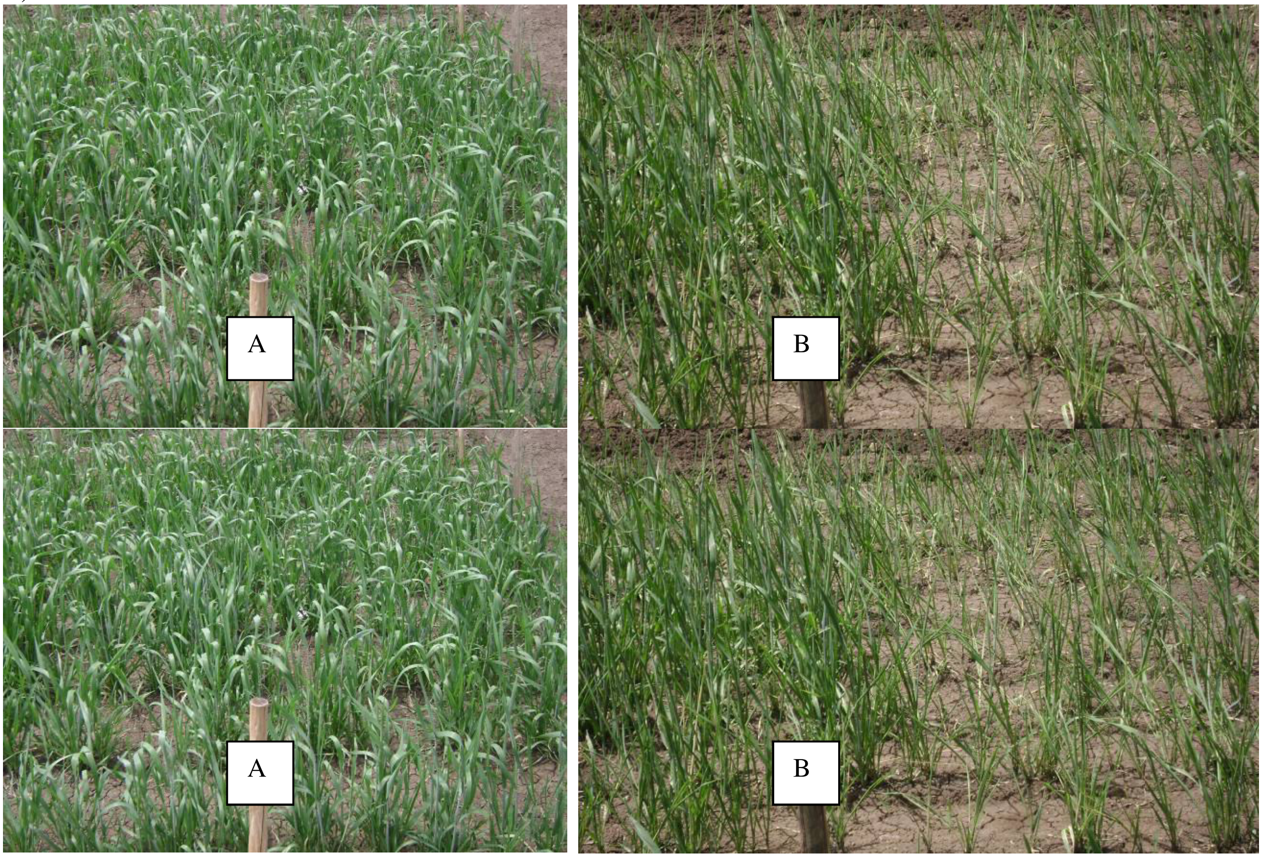
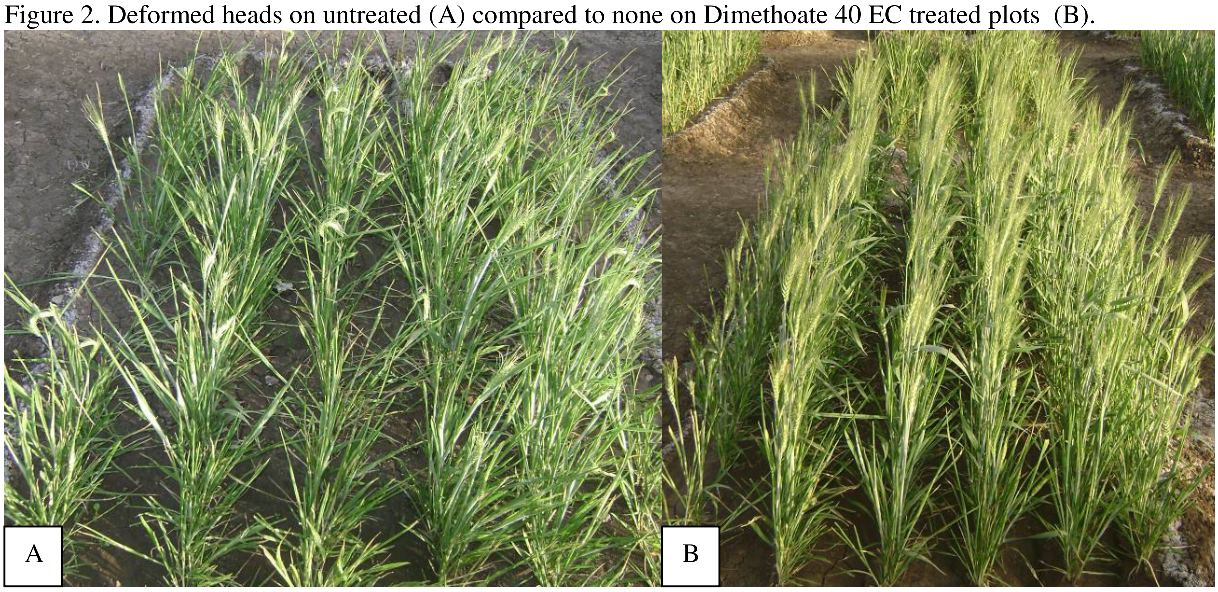


Figure 2. Deformed heads on untreated (A) compared to none on Dimethoate 40 EC treated plots (B).



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TABLES

TABLE 1. The effect of spraying with Fenitrothion 50 EC on yield parameters of wheat (Mekelle 1) in the field trial of 2013.

Treatments	Biomass yield Kg/ha	Grain yield Kg/ha	1000 seed weight g
Untreated	2800.00	818.20	27.07
Fenitrothion 50 EC Treated	5000.00	2452.00	33.93
Levene's Test			
F	1.00	0.264	0.082
probability	*0.374*	*0.634*	*0.789*
Independent-samples t-test			
t value	-3.012	-5.333	-5.073
df	4	4	4
probability	*0.039*	*0.006*	*0.007*

TABLE 2. The effect of spraying with Dimethoate 40 EC on yield parameters of wheat (Mekelle 1) in the field trial of 2014.

Treatment	Chlorosis	Leaf rolling	DTH	DTM	Biomass yld (Kg/ha)	Grain yld (Kg/ha)
Untreated (no spray)	8.1	2.8	65	105	4500	1375
Dimethoate 40 EC sprayed	1.2	1.1	56	99	10083	4333
Levene's Test						
F	0.000	0.000	3.2	16.00	0.474	1.474
probability	*1.000*	*1.000*	*0.148*	*0.016*	*0.529*	*0.2292*
Independent-samples t-test						
t	55.3	20.8	6	9.5	-5.8	-7.9
df	4	4	4	4	4	4
probability	*0.000*	*0.000*	*0.004*	*0.001*	*0.004*	*0.001*

DTH, days to heading; DTM, days to maturity

TABLE 3. Weather data of the trial site for 2013.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean max $T^{O}C$	26.5	27.2	28.2	29.3	29.7	28.7	25.7	23.8	26.6	26.6	25.7	24.5
Mean min $T^{O}C$	8.4	9.1	12	13.4	13.3	13	13.7	13.4	11.2	10.6	10.4	6.6
Mean RH (%)	50	46	48	50	40	44	58	74	57	50	52	47
Mean wind speed (Km/hr)	6.7	8.1	8	7.3	5.3	3.4	3.5	2.4	2.7	5.3	6.6	6.4
Mean Sunshine (hr)	9.7	10.4	7.9	9.6	9.3	5.7	4	3.9	7	9.4	10	9.6
Mean Evaporation	5.7	6.9	7.3	7	7.9	6.8	4.6	3.2	4.35	5.8	5.4	5.7
Rainfall (mm)	0	0	24	26.5	2	20.5	121.8	178.1	17.9	0	7.7	0

TABLE 4. Weather data of the field trial site for 2014.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Mean max $T^{O}C$	26.1	26.8	27.5	28.7	28.5	29.4	26	24.9	25.7
Mean min $T^{O}C$	8.3	10.3	12.1	13.2	13.5	12.8	12.9	13.4	11.4
Mean RH (%)	52	56	49	45	48	51	67	74	63
Mean wind speed (km/hr)	5.92	6.54	7.66	7.63	5.41	3.45	2.28	2.05	2.53
Mean Sunshine (hr)	9.6	9.6	10.1	9.6	9	7.8	6.3	4.8	5
Mean Evaporation	5.61	5.64	7.75	8.25	NA	NA	NA	2.84	4.67
Rainfall (mm)	0	0	33.2	75.9	24.9	35.9	260.7	275	71.6

NA, not available