Sampling procedures and Action threshold level of vectors of Maize Lethal Necrosis Disease causing viruses in Kenya

Namikoye, E. S.[1, 2*], G. M. Kariuki[1], Z.M. Kinyua[2], M.W. Githendu[1] and M. Kasina [2*]
[1]Department of Agricultural Science and Technology, Kenyatta University, P.O. Box 43844-00100, Nairobi.
[2]Kenya Agricultural and Livestock Research Organization, P.O. Box 14733-00800, Nairobi
[*]Correspondance: namikoye.samita@ku.ac.ke

Abstract
Maize lethal necrosis disease (MLND) has emerged as a great threat to maize production in East Africa. The disease is caused by a coinfection of maize by maize chlorotic mottle virus (MCMV) and sugarcane mosaic virus (SCMV) that are vectored by corn thrips and corn leaf aphids. Due to the recent outbreak of MLND in Bomet County, Kenya, a study was carried out to determine the best scouting and sampling regime as well as action threshold levels for vectors of MLND causing viruses. The trial was laid down in randomized complete block design with four replications for each aspect in two seasons, from 1st April 2015 to 8th April 2016 in Bomet County, Kenya. Three maize regions; lower, middle and upper regions were sampled for vectors. Plants were also sampled between 8.30 to 10.30 am, 12.30 -2.30 pm and 3.30- 5.30 pm. Finally, five thunder (Imidacloprid and Beta cyfluthrin) spray regimes carried on a weekly, fortnightly, after three weeks and monthly basis was done. The upper plant region was a preferred target for corn thrips ($P< 0.001$) while the lower part region was more preferred by corn leaf aphids ($P= 0.03$). Scouting results showed the most reliable time for scouting to be either from 8.30 - 10.30am or 3.30 to 5.30 pm ($P = 0.04$). Maize from plots sprayed on a weekly basis had a significant decrease in corn thrips infestation compared to maize from plots not sprayed ($P = 0.01$). Moreover, maize from thunder sprayed plots was MLND negative while the unsprayed maize was infected with MLND ($P <0.001$). Although yield of maize from weekly sprayed plots was higher than any other treatments ($P <0.001$), the net returns from monthly sprayed plots was higher. The action threshold level for corn thrips and corn leaf aphids was found to be 6 and 3 respectively. These findings provide information to farmers and other stake holders on how, when and where to scout and spray. If implemented properly, this will be able to minimize the wide spread of the virus by the vectors and eventually nib the chances of MLND occurring.

Key words: corn thrips, corn leaf aphids threshold level, MCMV, SCMV

Introduction

Corn is the main staple food crop for more than 1.2 billion people in Latin America and Sub Saharan Africa (Iken and Amusa, 2004). It is also the most important cereal crop in Kenya (Khalili *et al.,* 2013). Production of this crop is under threat due to the outbreak of maize lethal necrosis disease (MLND) since 2011. The disease has widely spread in many maize growing regions in Kenya and its neighboring countries (De Groote *et al.*, 2016; Mahuku *et al.*, 2015). Major crop and yield losses associated with this disease have been recorded both at the household and National levels (Wangai *et al.*, 2012).

Maize lethal necrosis disease occurs due to a co infection of maize chlorotic mottle virus (MCMV) and sugarcane mosaic virus. According to Cabanas *et al.* (2013) and Nelson *et al.* (2011), corn thrips (*Frankliniella williamsi* Hood) and corn leaf aphids (*Rhopalosiphum maidis* Fitch) are the main vectors of the two viruses respectively which cause MLND. These vectors have been sampled in areas prevalent to MLND in Kenya (Mahuku *et al.*, 2015). Corn thrips cause maize damage through rasping and transmitting maize chlorotic mottle virus (Beres *et al.*, 2013). Owing to the seriousness of MCMV infection, extensive yield losses have occurred (Mahuku *et al.*, 2015), therefore, discovering and implementing corn thrips and corn leaf aphids management methods is urgently required to reduce the vector infestation.

Scouting helps farmers to make decisions on the need and timing of intervention methods. Close inspection and management of these vectors requires efficient systems of monitoring their infestation. Thus, field scouting is an essential component of their management. Apart from scouting, employing other decision making tools in managing the vectors is important, for example knowledge of action threshold for the vectors would help in understanding when to initiate a pesticide intervention procedure (Nault and Shelton, 2010). According to Nault and Shelton (2010) action threshold is the average number of corn thrips per plant that will cause economic yield loss if the infestation is not controlled. Action threshold for thrips on crops such as onions has been established although it varies with geographical regions, the crop cultivar, effectiveness of the insecticide, plant stage and plant architecture (Gill *et al.*, 2015). Nderitu *et al.,* 2008 also found an action threshold of 3 thrips per flower in French beans in Kenya. Action threshold for corn thrips on maize has not yet been developed, however different thresholds has been set depending on weather conditions and localized insecticide resistance (Bird *et al.,* 2004; Reiners and Petzoldt, 2009) whereas the recommendations in Canada are 0.9 and 2.2 thrips per leaf of onions for wet and dry seasons respectively (Fournier *et al.,* 1995).

Use of insecticides is known to offer effective management against thrips in Kenya (Nderitu *et al.,* 2008). However correct use and time of spray of these products has not been determined for vectors of maize lethal necrosis disease causing viruses. Action threshold of these vectors would require knowledge on economic injury level which is the lowest number of vectors that would cause economic damage. According to Larsson 2005, Economic damage commences when the cost of reducing the injury caused is equivalent to the potential monetary loss from the vector population or damage. Therefore this study determined the spray regime that would provide farmers with the highest economic returns when controlling vectors of MLND causing viruses. This would enhance dependence on monitored spray applications that are economically viable. Furthermore; the study will also determine the scouting regime and action threshold for the vectors transmitting MLND causing viruses.

Materials and methods

To determine the best scouting regime, an experiment was laid in Bomet County in a complete randomized block design with plots measuring 3.75 x 4.75 m. There were two seasons of planting that commenced on 1st April 2015 to 18th August 2015 and repeated from 27th October 2015 to 8th April 2016. The plots were planted with maize variety Olerai 500-22A using a spacing of 75 x 25 cm and replicated four (4) times. There were three (3) treatments composed of sampling on the lower, middle and upper regions of the plant. The plots were separated from each other by a one metre path. Another scouting factor comprising of different times of sampling, 8.30 to 10.30 am, 12.30 -2.30pm and 3.30- 5.30 pm was carried out to determine the best time for sampling in the field. To determine the action threshold level for vectors transmitting MLND causing viruses, plots measuring 3.75 x 4.75m were used. They were planted with maize variety Olerai 500-22A. The treatments were arranged in a randomized complete block design and replicated four (4) times. Five (5) treatments were used with thunder spray (Imidacloprid and Beta cyhalothrin at the rate of 25ml per 20 litres of water) applied on weekly, fortnightly, 3 weeks and monthly intervals. In addition, a control with no spray application was included in the trial. The plots were separated from each other by a two (2) metre alley and covered with a wide polythene paper during spraying to minimize the spray drift from one treatment to another.

For the scouting trial, leaves at each region were randomly selected and gently opened to detect the presence of corn thrips and corn leaf aphids. The number of insects' vectors was counted. The corn thrips damage score per plot was also recorded. Data collection for the threshold trial was done just before spraying by destructive sampling which was repeated every fortnight up to ten weeks after germination. Two samples were randomly picked from plots and each plant stored in a plastic transparent sampling bag. In the laboratory, plants were analyzed by counting present vectors. Apart from vector data, thrips damage and MLND severity of the crop was determined by scoring for the disease infection levels. Direct and Indirect Elisa tests were thereafter carried out to confirm the virus presence and their infection levels. Yield data was taken by randomly selecting ten plants from which cobs were removed and taken to the lab for drying and further analysis of the yield parameters.

The value of maize was used to determine the economic damage of the vectors. Linear regression analysis was used to determine the economic injury level and action threshold level of the vectors. Initially the profitability of each spray regime (gross marginal rate) was measured; the net returns were there after calculated by getting the difference in the cost incurred by each spray regime and the corresponding gross returns from the selling price of maize at that particular period. The most stable price for maize by the Cereal Board of Kenya was Kshs 3,000 per 90Kg bag which was equivalent to Kshs 33.30 per 1Kg of maize during harvesting time. The Total amount of insecticides per treatment was multiplied by the cost of the insecticide and extrapolated per hectare. The cost of Thunder was Kshs 700 per 100ml which was equivalent to Kshs 7 per millitre. The marginal rate of returns was calculated as the change in returns per the insecticide cost per the spray regime. The economic injury level (EIL) was determined by the equation Y = a +bx or x = a-y/b (Nderitu *et al.,* 2008) where a = expected yield at zero infestation level while y = the yield below which the crop loss would be greater than the cost of the chemical control that would be deployed (Stewart and Khaltat, 1980). Hence, a – y = Economic damage, Therefore Economic injury level (x) = economic damage/b (negative terms) or x = Economc damage/slope of regression line (positive term) as explained by Nderitu et *al.* 2008. The action threshold level was there after laid down according to guidelines by Reichelderfer *et al.* 1984. This was determined by picking the point where the curve of EIL against the cost of the pesticide control (Positive slopping) meets the curve of EIL against the net returns (negative sloping).

Data on vector number, damage levels and disease levels were analyzed using Gen Stat 17th edition. Analysis of variance was performed at 95% level of confidence limit. Where necessary, skewed vector data was transformed by square root (x^ (1/2)) method before ANOVA was carried out. Post hoc analyses were performed using the Fishers Protected Least Significance Difference Test (LSD) for significant means. Pearson correlation co efficiency was carried out between vector data, disease data and yield parameters. Regression between yield and vectors, cost of insecticides and economic injury levels of vectors as well as the net returns from maize versus the economic injury level of the vectors was also carried to determine the action threshold level.

Results

More Corn thrips were significantly ($P < 0.001$) recorded infesting the upper part of the plant compared with the middle and lower regions in season one. The lower region had significantly lower infestation compared with the rest (Table 1). During season two, there was no significant difference recorded in terms of corn thrips infestation among the three plant regions (Table 4.18). Corn leaf aphids were significantly higher ($P = 0.035$) in the upper region of the plant during the first season. However, the second season showed significantly more ($P = 0.003$) corn leaf aphids on the lower region of the plant compared with the middle and upper regions that did not differ significantly (Table 1). The lower region of the plant had significantly more corn thrips damage compared with the upper region during both seasons significantly (Table 1).

Table 1: Infestation levels of vectors of MLND causing viruses on maize at various plant regions, Bomet County

	Season1			**Season 2**		
Plant region	Corn thrips	Corn leaf aphids	Thrips damage level	Corn thrips	Corn leaf aphids	Thrips damage
Lower	1.736c	0.7b	3.2a	5.7	2.783a	3.1a
Middle	4.639b	0.9b	2.7b	6.4	1.217b	2.9a
Upper	6.167a	5.8a	2.3c	5.7	0.942b	2.2b
P value	<.001	0.035	<.001	0.4	0.003	<.001
Se	0.54	2.2	0.14	0.7	0.5	0.3

***** Means within column followed by the same letter are not significantly different at P= 0.05

When scouting for thrips, both seasons showed the time spans from 8.30 to10.30am and 3.30 to 5.30 pm significantly recording more corn thrips (P= 0.026), P< 0.001) compared to 12.30 to 2.30 pm (Figure1). During the first season, corn leaf aphids were significantly (P = 0.04) more between 8.30 to 10.30 am although this did not vary significantly with the infestation at 3.30 to 5.30pm period. The corn leaf aphids were significantly lower between 12.30 to 2.30pm. Scouting time had no effect on corn leaf aphid infestation during the second season (Figure1).

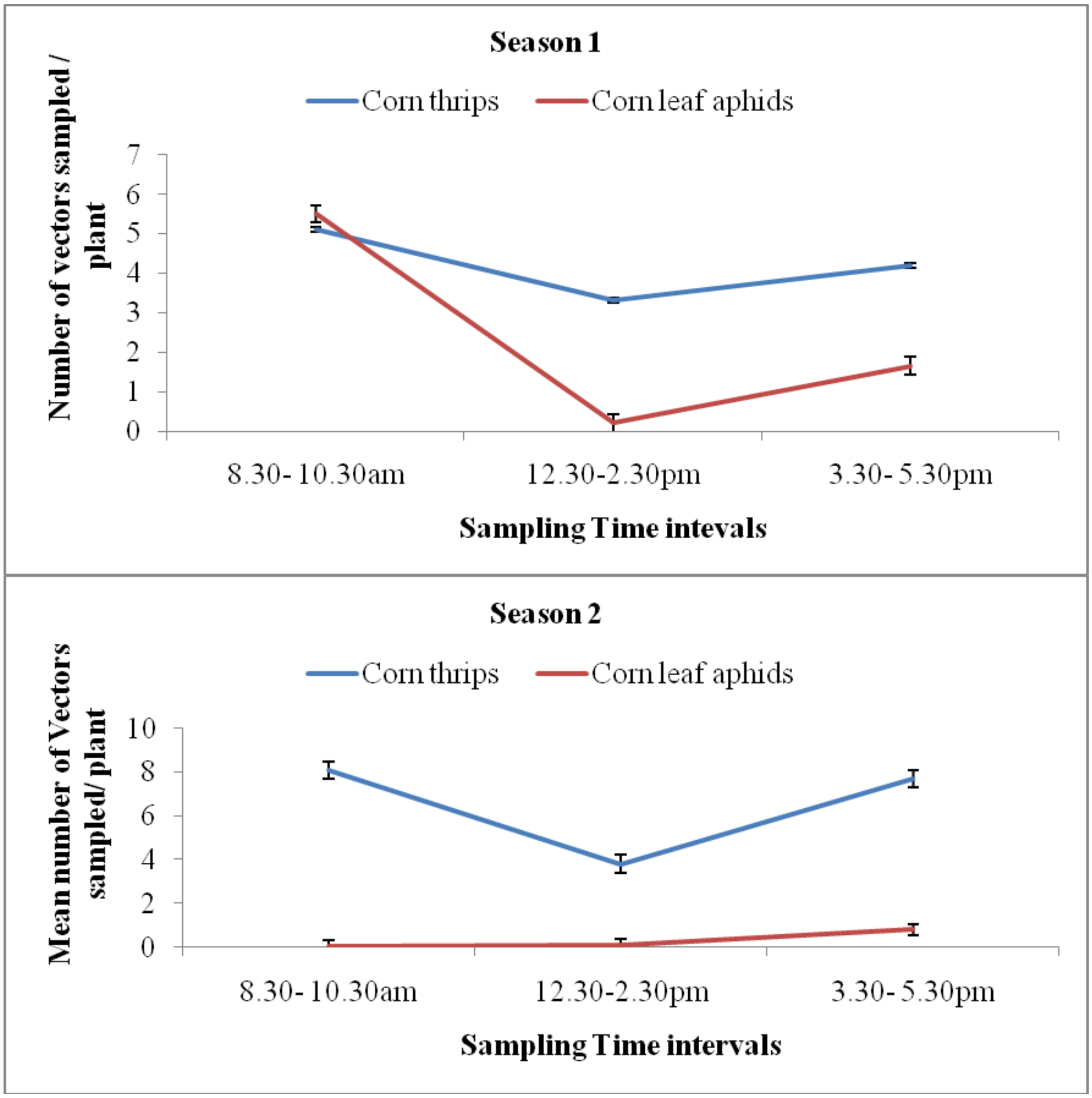

Figure 1: Infestation levels of vectors of MLND causing viruses on maize at different sampling times

The spray regimes had significant effects on the corn thrips infestation during the first and second season (Table 2). Plots sprayed on a weekly basis significantly recorded lower corn thrips infestations (P= 0.01) compared to those sprayed after three weeks, monthly spray intervals as well as the one sprayed with water and those not spayed (Table 2). The same trend was observed during the second season although the general corn thrips infestation levels were lower compared with the first season (Table 2). The spray regimes administered had no effect on corn leaf aphids infestation in both seasons and thrips damage level in season 1 (Table 2). However, thrips damage level was significantly lower in plots sprayed on a weekly basis during the second season (Table 2).

Table 2: Vectors of MLND causing viruses infestation on maize under different spray (Thunder) regimes in Bomet County, Kenya

		Season 1			**Season2**		
spray regime	No. of sprays	Corn thrips	Corn leaf aphids	Corn thrips damage	Corn thrips	Corn leaf aphids	Corn thrips damage
Weekly	10	7.15c	1.9	2.15	3.7c	0.6	2.03b
Fortnight	5	11.05bc	2.1	2.43	4.9bc	0.2	2.31ab
After 3wks	4	14.4ab	3.8	2.53	7.6ab	0.4	2.44a
Monthly	3	16.3ab	4.7	2.45	8.3ab	1	2.47a
No spray	0	18.8a	7.5	2.75	8.6a	0.5	2.44a
P value		0.01	0.3	0.4	0.02	0.4	0.02
Se		3.7	6.9	0.6	1.97	0.6	0.17

***** Means within column followed by the same letter are not significantly different at P= 0.05.

Maize lethal necrosis disease status in maize under different spray regimes

During season 1, maize across the treatments was MCMV positive. The MCMV viral load of maize in plots that were not sprayed and those sprayed with thunder on a monthly basis had significantly (P< 0.001) higher MCMV viral load compared with the viral load on maize in plots sprayed after one, two and three weeks interval (Table 4.20). Maize sampled from plots that were not sprayed were the only ones that were SCMV positive hence were infected with MLND (Table 3).

During season 2, maize in plots sprayed on a weekly and fortnight basis tested MCMV negative while maize in plots sprayed after every 3 weeks, monthly and those not sprayed were MCMV positive (Table 4.21). In addition to that, maize sampled from plots that were not sprayed and those sprayed on a monthly basis tested SCMV positive hence were infected with MLND (Table 4).

Table 3: MLND status in plots under various spray regimes during season 1and 2 in Bomet County of Kenya

Spray regime	MCMV	Status	SCMV	Status	MLND status
Blank	0.089d	Negative	0.085d	Negative	Negative
Negative	0.124d	Negative	0.121cd	Negative	Negative
Weekly spray	0.2592c	Positive	0.1373c	Negative	Negative
Positive	0.281c	Positive	0.206b	Positive	Positive
Fortnight spray	0.2995c	Positive	0.145c	Negative	Negative
After 3 weeks spray	0.3335b	Positive	0.1418c	Negative	Negative
Monthly spray	0.4545a	Positive	0.135c	Negative	Negative
No spray	0.4802a	positive	0.2595a	Positive	Positive
P value	<.001		<.001		
Se	0.04		0.02		

***** Means within column followed by the same letter are not significantly different at P= 0.05.

Table 4: MLND status in plots under various spray regimes during season 2 in Bomet County of Kenya

Spray regime	MCMV	Status	SCMV	Status	MLND status
Blank	0.089e	Negative	0.085d	Negative	Negative
Negative	0.124d	Negative	0.121d	Negative	Negative
Weekly spray	0.1333d	Negative	0.1507d	Negative	Negative
Positive	0.281ab	Positive	0.206bc	Positive	Positive
Fortnight spray	0.2102c	Negative	0.1095d	Negative	Negative
After 3 weeks spray	0.259b	Positive	0.1758cd	Negative	Negative
Monthly spray	0.2873ab	Positive	0.2893ab	Positive	Positive
No spray	0.322a	Positive	0.323a	Positive	Positive
P value	<.001		<.001		
Se	0.04		0.08		

***** Means within column followed by the same letter are not significantly different at P =0.05.

Maize sampled at 3 weeks after germination from plots that were not sprayed were MCMV positive while those from plots sprayed by all the other regimes were MCMV negative (Figure 2). Maize sampled at 7 weeks after germination were MCMV positive in plots sprayed after every three weeks, monthly and those that did not receive any spray. Those plots sprayed on a fortnight and weekly basis were all MCMV negative (Figure 2). Similarly the same trend was seen in SCMV infection in maize sampled at 7weeks after germination. At 3 and 7 weeks after germination, only maize from plots that received no spray was SCMV positive (Figure 2). The viral load of both MCMV and SCMV was significantly higher in maize sampled at seven weeks after germination compared the viral load at three weeks after germination (Figure 2 & 3).

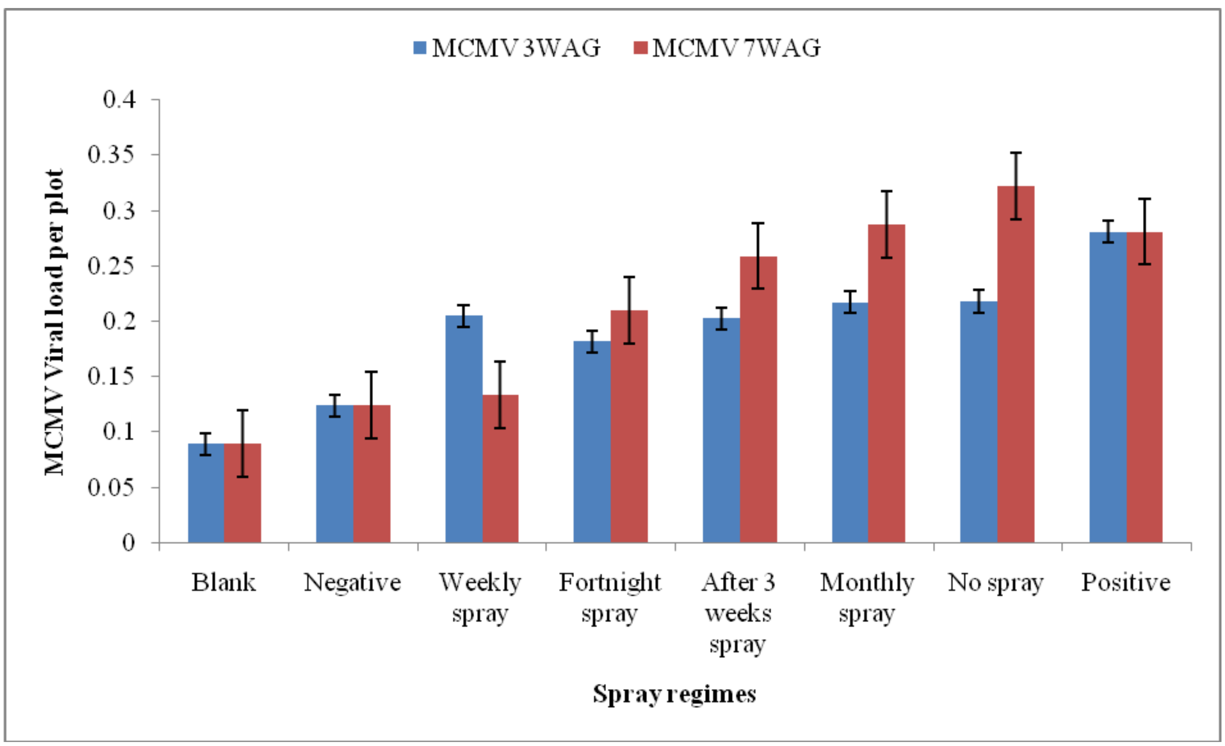

Figure 2: MCMV viral load at 3 and 7weeks after germination

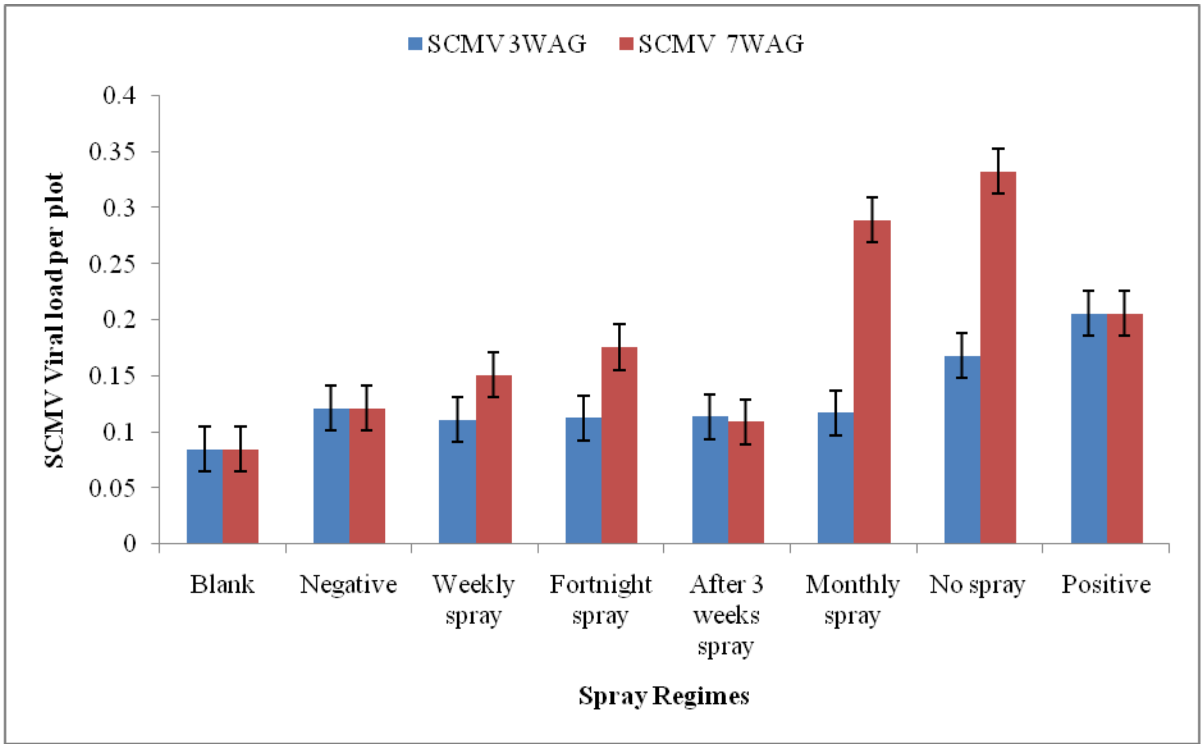

Figure 3: SCMV viral load at 3 and 7weeks after germination

During season 1, plots sprayed on a weekly basis recorded significantly high (P<0.001) and better yield properties compared with plots sprayed with the other regimes (Table 5). However, weight of goods seeds and fresh weight of maize from plots that were sprayed after every two weeks did not differ significantly with those from plots sprayed on a weekly basis (Table 5). Significantly lower yield properties (P<0.001) were registered in maize from plots that were not sprayed compared with yield properties from plots sprayed with thunder (Table 5). During season 2, plots sprayed by thunder on a weekly basis recorded significantly more weight of cobs (P= 0.01) and good seeds (P= 0.02) compared plots that were not sprayed (Table 6).

Table 5: Yield properties of maize grown under different spray regimes during season 1and 2 in Bomet County, Kenya

Spray regime	% cob fill	Weight of cobs (kg) / 18.75m^2	Weight of bad grains (kg) / 18.75m^2	Weight per grains (g)	Weight of good grains (kg) /18.75m^2	Fresh weight (kg) /18.75m^2	Dry weight (kg)/ 18.75m^2
Weekly spray	92.20	16.86a	0.33	0.2695a	11.6222a	11.946a	10.959a
Fortnight spray	94.21	13.94b	0.26	0.2024b	10.02ab	10.346b	7.677b
After 3 weeks spray	95.62	11.88bc	0.6	0.2083b	8.361bc	8.952c	7.569b
Monthly spray	93.00	12.36bc	0.49	0.1784b	8.349bc	8.904c	6.732bc
No spray	95.12	10.56c	0.54	0.2103b	7.659c	8.25c	6.342c
P value	0.78	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	2.95	1.38	0.4	0.02	1.04	1	0.95

***** Means within column followed by the same letter are not significantly different at P= 0.05

To convert to tonnes multiply all figures in kg by 0.5333((10,000/area of plot (kg))/ 1000)

Table 6: Yield properties of maize grown under different spray regimes during season 2 in Bomet County, Kenya

Spray regime	% cob fill	Weight of cobs (kg) / 18.75m^2	Weight of bad seeds (kg) / 18.75m^2	Weight per seed (g)	Weight of good seeds (kg) /18.75m^2	Fresh weight (kg) /18.75m^2	Dry weight (kg)/ 18.75m^2
Weekly spray	79.4	8.758a	0.2506a	0.00016	6.593ba	6.61	6.36a
Fortnight spray	78.8	8.327a	0.2326ab	0.00471	6.123a	6.24	5.917a
After 3 weeks spray	74.8	7.039a	0.2041bc	0.00099	5.257ab	5.38	5.06ab
Monthly spray	77	7.643a	0.1945bc	0.00025	5.699a	5.73	5.419ab
No spray	65	4.759b	0.168c	0.00096	3.605b	4.97	3.075b
P value	0.5	0.01	0.002	0.5	0.02	0.13	0.001
Se	13.5	1.15	0.024	0.00002	0.9	0.94	0.88

***** Means within column followed by the same letter are not significantly different at P= 0.05

To convert to tonnes multiply all figures in kg by 0.5333((10,000/area of plot (kg))/ 1000)

Marginal rate of returns of maize grown under different spray regimes

The spray regimes influenced the corn thrips infestation differently and this eventually resulted into significant yield differences that brought about different marginal rates per each regime (Table 7). Although higher yield was realized in maize from plots that received weekly sprays, the net returns from the same plots was lower due to the increased cost of insecticides (Table 7). Higher net returns were realized from the monthly spray regimes followed by the sprays made after every three weeks and fortnightly (Table 4.24). It is therefore evident that the thunder spray done on a monthly basis is the most economical since it resulted in the highest marginal net return (Table 7).

Table 7: Mean Yield of maize, cost of insecticide and marginal rate of return for different spray regimes at Bomet County Kenya

Spray regime	No. of spray	Yield (Kg) per 75m^2	Yield (Kg) per ha	Value in (Kes) per ha	Total Thunder cost (Kes) /ha	Marginal rate (Kes)
Monthly spray	3	24.302	3240.27	107998.09	28,800	79,198
After 3 weeks spray	4	25.258	3367.73	112246.55	46300	65,947
Fortnight spray	5	27.188	3625.07	120823.47	55,400	65,423
Weekly spray	10	34.638	4618.4	153931.27	110,800	43,131

Action Threshold levels of vectors in Bomet County, Kenya

The linear function of yield against corn thrips infestation shows declining maize yield as the number of corn thrips density increases (Figure 4). The cost of thunder insecticide linearly and positively relates to economic threshold level of corn thrips (EIL) (Figure 5). The higher the economic injury levels the higher the cost of insecticide. Contrary to this observation, net returns of maize yield had a linear and negative relationship with the EIL of the corn thrips (Figure 6). Therefore using the equation in Figure 5 and 6 action threshold was 12 corn thrips per two plants hence 6 corn thrips per maize plant. At the point where they meet the action taken to control vectors is equal to the net returns realized from maize sales (y = 11.06x – 21.87, y = -4.571x+ 166.8).

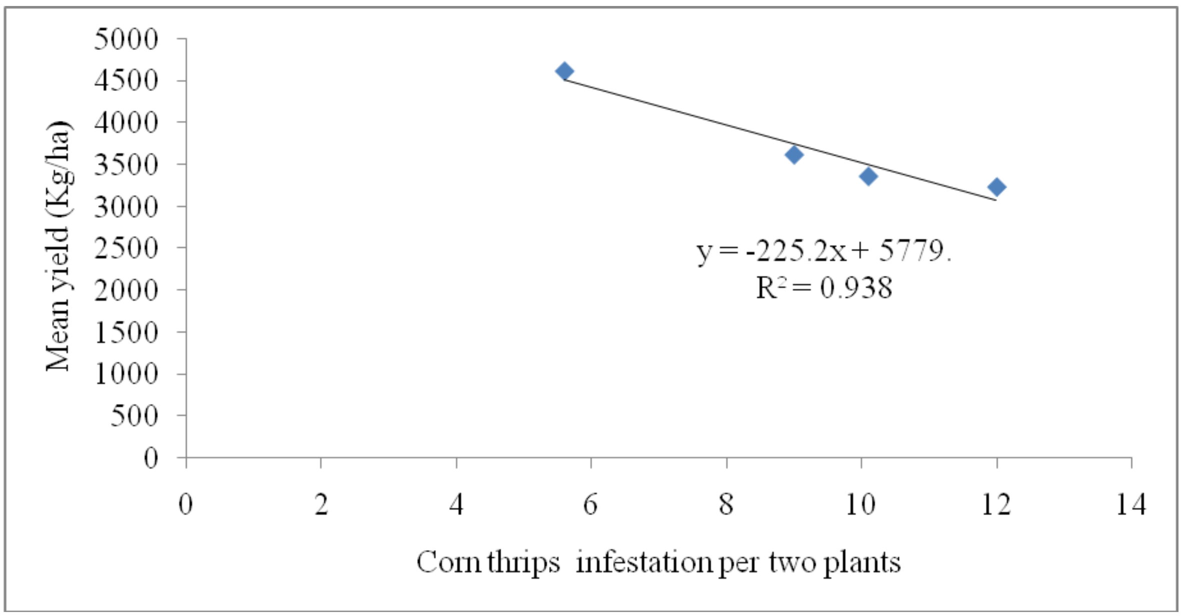

Figure 4: Regression of maize yield against mean number of Corn thrips on maize at Bomet County, Kenya

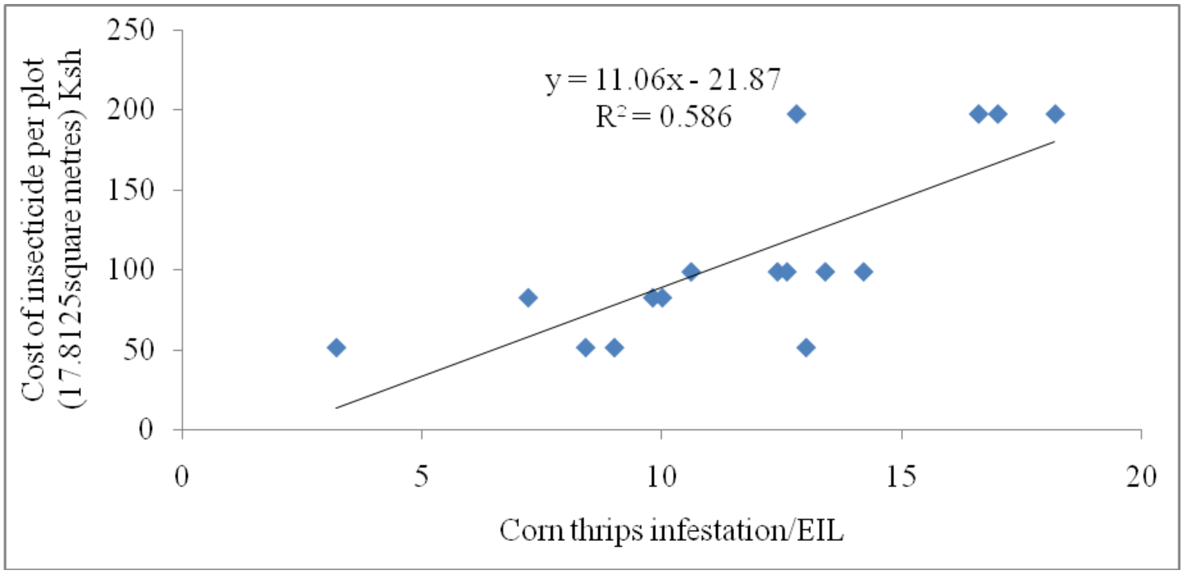

Figure 5: Regression ofcost of insecticide against Economic injury level of Corn thrips on maize at Bomet County, Kenya

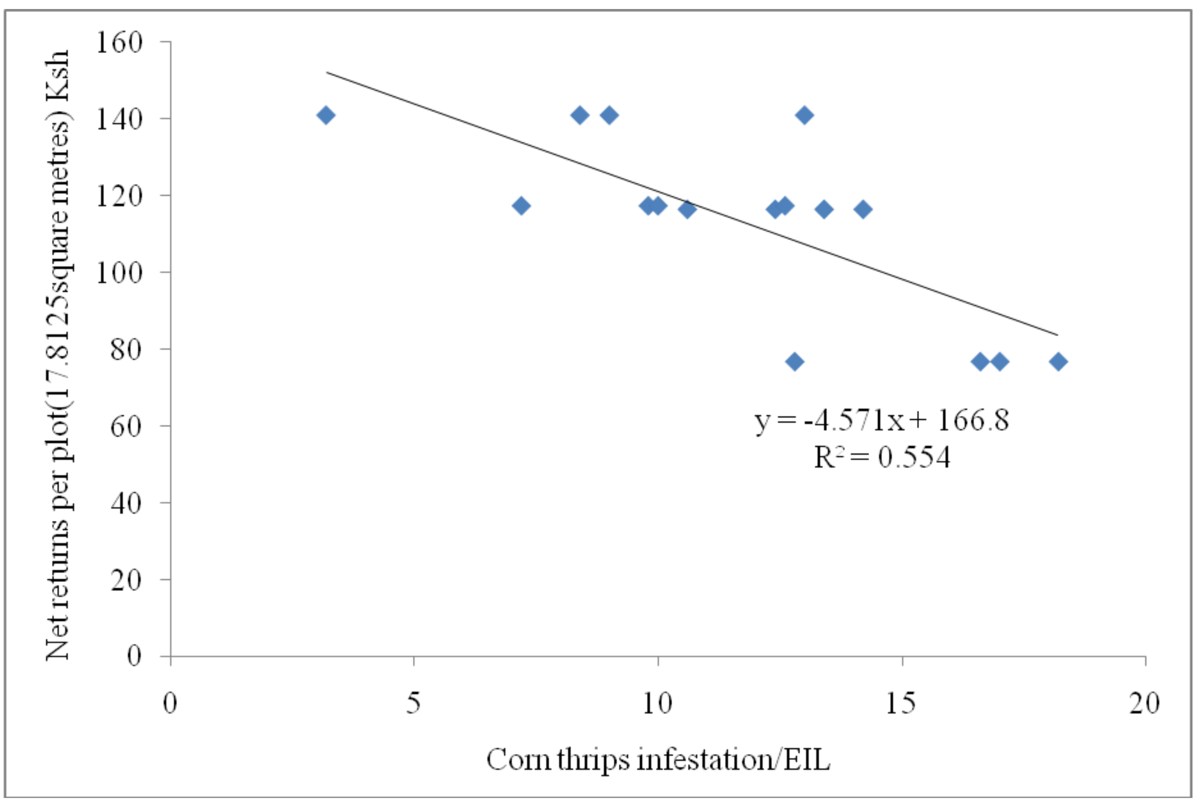

Figure 6: Regression of Net returns against Economic injury level of Corn thrips per two maize plants at Bomet County, Kenya

Maize yield declined as the number of vector density increased according to linear regression (Figure 7). Moreover, the cost of thunder insecticide was linearly and positively related to the economic threshold level of corn leaf aphids (EIL) (Figure 8). The results showed a direct proportion between the economic injury level and the cost of insecticide. However, net returns of maize yield had a linear and negative relationship with the EIL of the corn leaf aphids (Figure 9). Using the equation in Figure 8 and 9 action threshold was 6 corn leaf aphids per two plants hence 3 corn leaf aphids per maize plant. At the point of interception for the two graphs, action taken to control vectors is equal to the net returns realized from maize sales (y = 10.40x + 44.29, y = -3.811x+ 136.4).

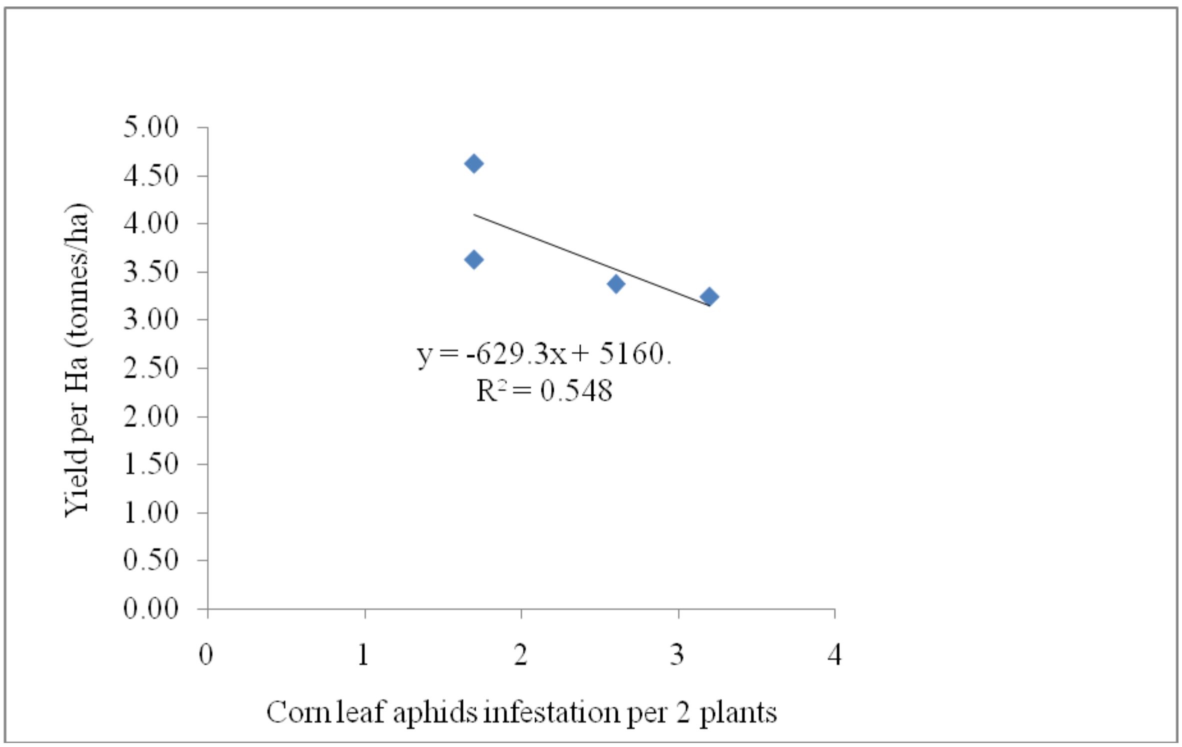

Figure 7: Regression of maize yield against mean number of Corn leaf aphids on maize at Bomet County, Kenya

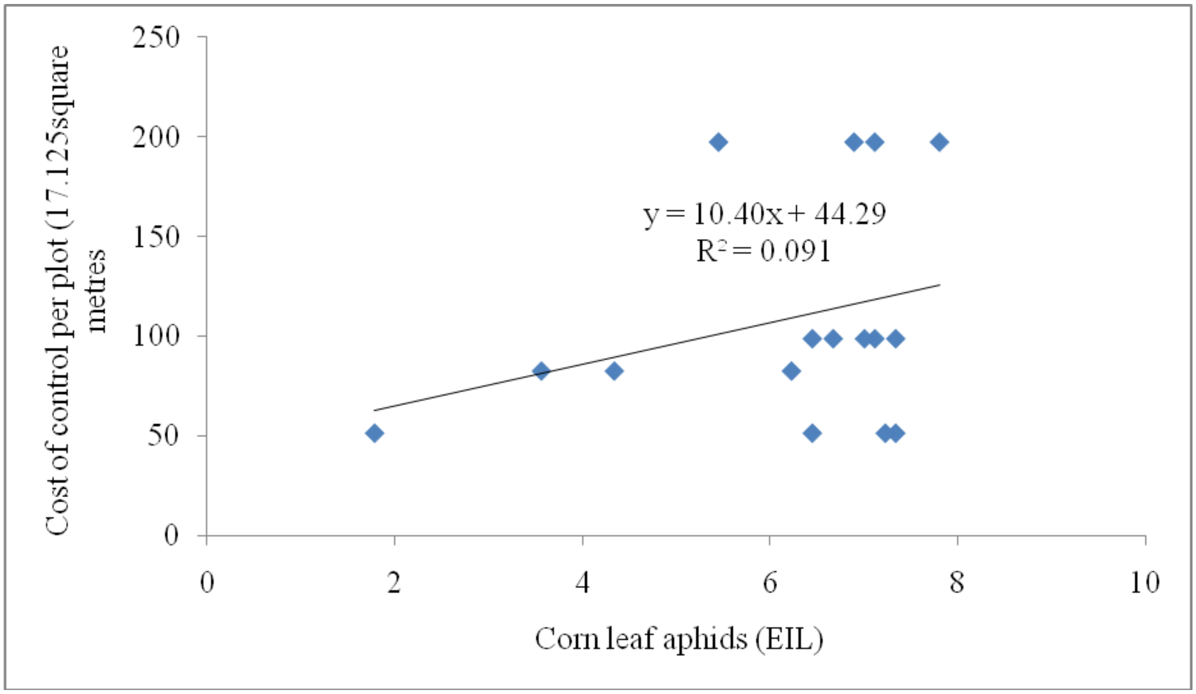

Figure 8: Regression of Economic injury levels (EIL) of Corn thrips and Corn leaf aphids against cost of insecticide control at Bomet County, Kenya

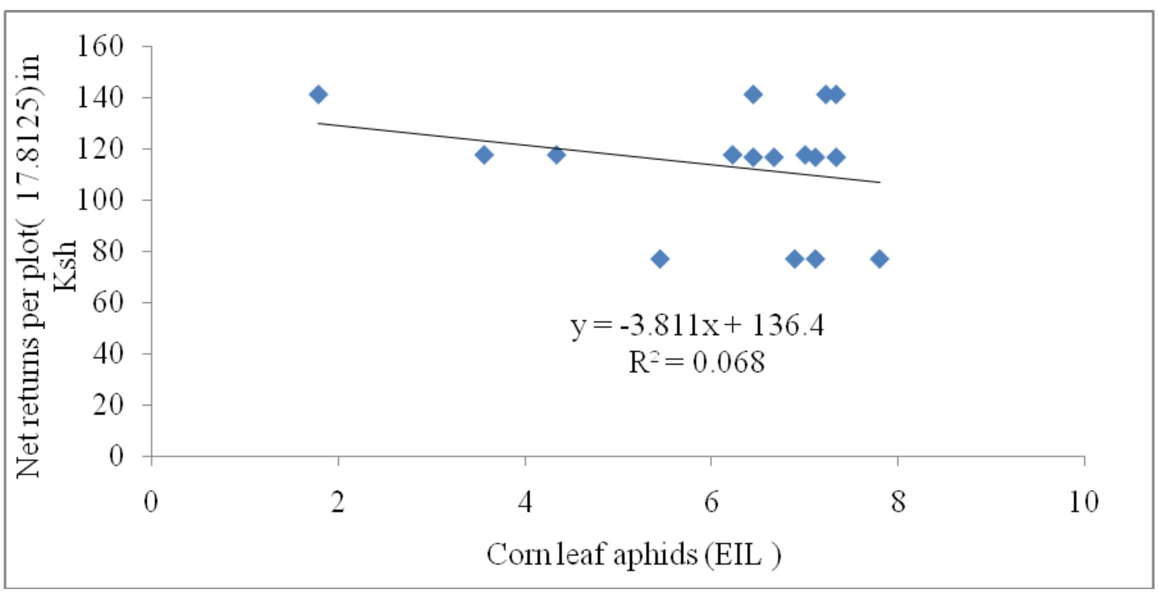

Figure 9: Regression of Economic injury levels of vectors against the Net returns per plot at Bomet County, Kenya

Correlation and Regression relationship between vector infestation, MLND infection and yield characteristics in maize sprayed using different regimes

Increased, corn leaf aphids infestation resulted into lower yield as observed in weight per seed ($r = -0.82$, $P = 0.04$), weight of good seeds per plot $r = -0.87$, $P = 0.02$), weight of cobs per plot ($r = -0.88$, $P = 0.02$) and fresh weight per plot ($r = -0.86$, $P = 0.02$) in season 1. (Table 8). Similarly, increased corn thrips infestation resulted into reduced weight per seed ($r = -0.94$, $P = 0.006$, weight of good seeds ($r = -0.95$, $P = 0.003$), weight of cobs per plot ($r = -0.96$, $P = 0.002$), fresh weight and dry weight of seeds per plot ($r = -0.94$, $P \leq 0.001$) (Table 8). Moreover, increase in corn leaf infestation led to an increase in SCMV viral load ($r = 0.87$, $P = 0.02$) and MCMV viral load ($r = 0.91$, $P = 0.01$) (Table 8).

During season 2, severe corn thrips damage led to reduced weight per seed ($r = -0.95$, $P = 0.020$, weight of good seeds($r = -0.86$, $P = 0.02$), weight of cobs ($r = -0.91$. $P = 0.01$), fresh weight and dry weight per plot ($r = 0.86$, P value = 0.02) (Table 9). However, increased spray frequency resulted into an increase in dry weight of maize per plot ($r = 0.9$, $P = 0.01$) as well reduced MCMV viral load ($r = -0.81$, $P = 0.04$). Correlation analysis also showed a decrease in MCMV viral load in maize led to heavier weight per seed ($r = -0.82$, $P = 0.04$) while increase in the spray frequency led to increased weight per seed ($r = 0.87$, $P = 0.02$), weight of good seeds ($r = 0.95$, $P = 0.002$) and fresh weight per plot ($r = 0.96$, $P = 0.001$).

Table 8: Correlation among the vector infestation MLND viral load and yield characteristics, season 1 in Bomet County

		1	2	3	4	5	6	7	8	9	10	11
Corn leaf aphids	1	-										
Corn thrips	2	0.94**	-									
Thrips damage	3	0.88**	0.92**	-								
Dry weight	4	-0.79	-0.94**	-0.89*	-							
Fresh weight	5	-0.86*	-0.94**	-0.85*	0.93	-						
MCMV	6	0.91**	0.92**	0.79	-0.82*	-0.76	-					
SCMV	7	0.87*	0.73	0.76	-0.63	-0.75	0.63	-				
Spray frequency	8	0.94**	-0.97**	-70.85*	0.90*	0.97**	-0.87*	-0.82*	-			
Cob weight	9	-0.88*	-0.96***	-0.92**	0.95	0.99	-0.78	-0.76	0.96**	-		
Weight good seeds	10	-0.87*	-0.95**	-0.86*	0.93	0.99	-0.78	-0.74	0.97***	0.99	-	
Weight per seed	11	-0.82*	-0.94**	-0.96**	0.98	0.89	-0.82*	-0.67	0.87*	0.923	0.89	-

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

Table 9: Correlation among the vector infestation MLND viral load and yield characteristics season 2, Bomet County

		1	2	3	4	5	6	7	8
Corn thrips	1	-							
Corn thrips damage	2	0.9089**	-						
Dry weight	3	-0.8131*	-0.7197	-					
Fresh weight	4	-0.8441*	-0.6937	0.9713	-				
MCMV	5	0.9686***	0.9463**	-0.8724	-0.8653	-			
SCMV	6	0.8409*	0.638	-0.7031	-0.7062	0.797*	-		
Weight of good seeds	7	-0.7836	-0.6169	0.956	0.9928	-0.812*	-0.6653	-	
Weight per seed	8	-0.96**	-0.8979**	0.9289	0.9149	-0.9877***	-0.8272	0.8679	-

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

The spray frequency showed a negative linear relationship with corn thrips and corn leaf infestation on maize (Figure 10).

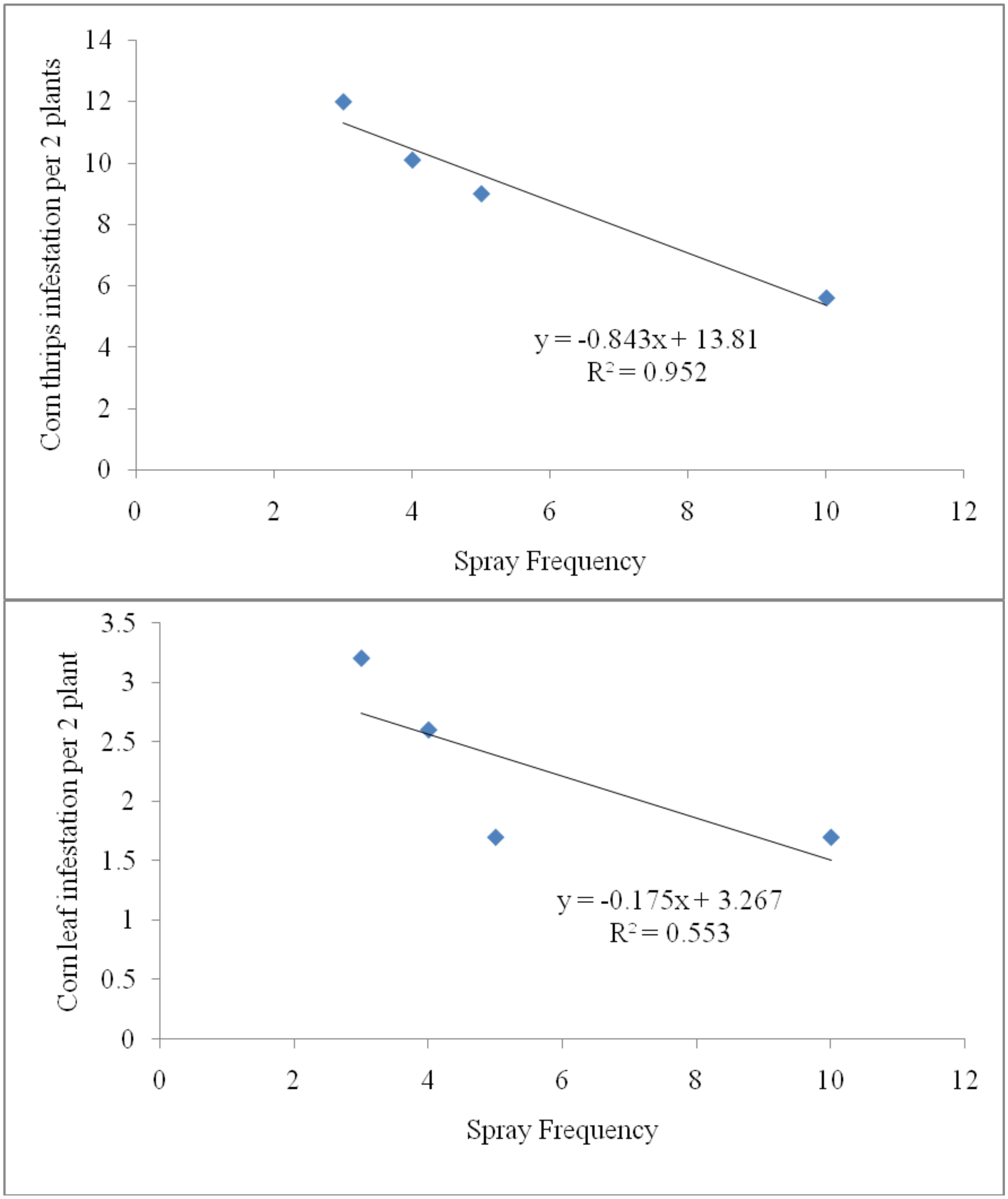

Figure 10: Regression of mean number of vectors against the spray frequencyon Maize at Bomet County, Kenya

Increase in the number of corn thrips and corn leaf aphids subsequently led to the increase in the viral load of MCMV and SCMV virus respectively (Figure 11).

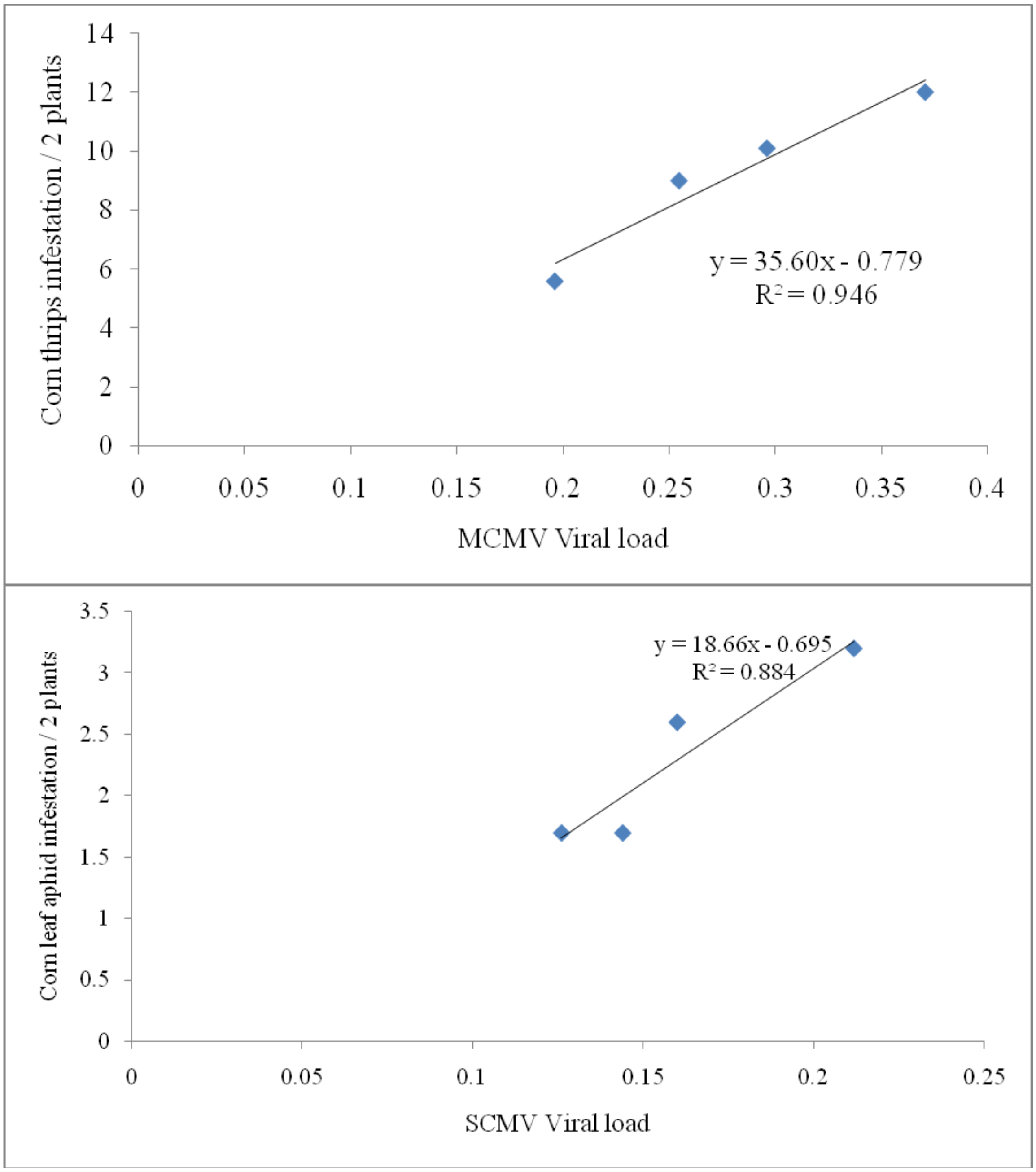

Figure 12: Regression of mean number of vectors against the MCMV and SCMV viral load on Maize at Bomet County, Kenya

Increase in MCMV and SCMV viral load in maize crops resulted into a decrease in maize yield (Figure 4.24). Every increase in MCMV viral load by one unit decreased 0.9532 tonnes per ha while increase in SCMV by 1 unit decreased maize yield by 0.1tonnes of maize per ha (Figure 13).

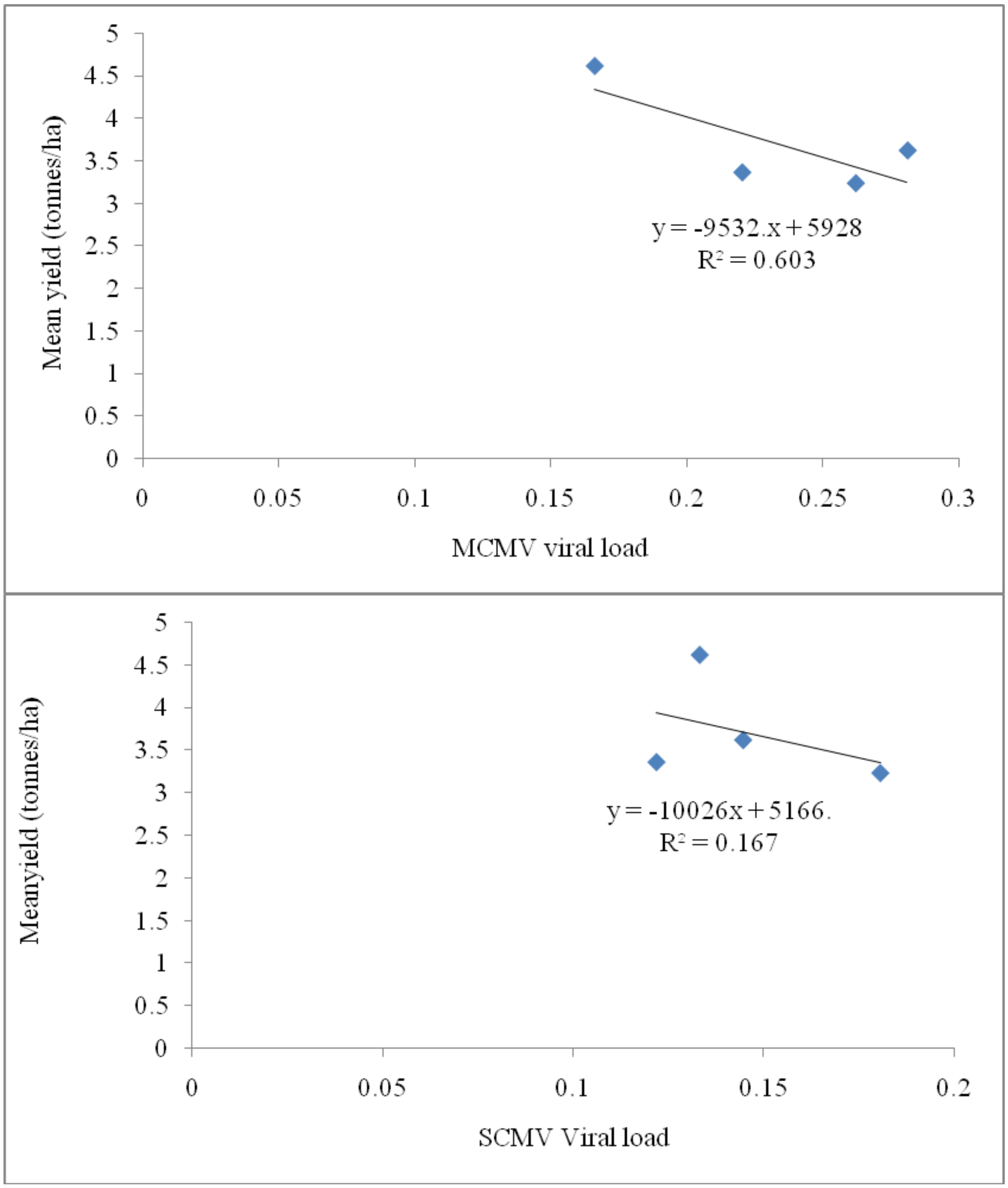

Figure 13: Regression of mean yield of maize against the MCMV and SCMV viral load on Maize at Bomet County, Kenya

There was a linear negative relationship between the corn thrips damage level on maize and the maize yield produced (Figure 14). Every increase in thrips damage per unit led to a decease of 8kg per plot (17.8125 m^2) (Figure 14).

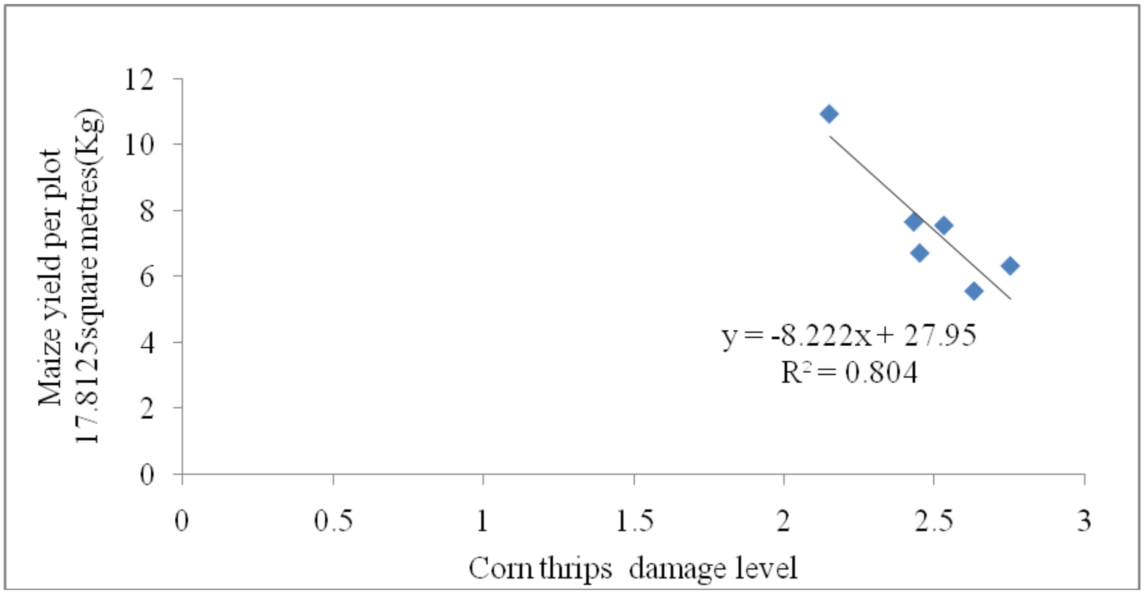

Figure 14: Regression of mean yield of maize against the corn thrips damage on Maize at Bomet County, Kenya

4.4.2. Discussion

The most effective region for estimating corn thrips infestation level on maize is the upper region. The thrips could have preferred this region due to its succulence nature that was easy to feed from. In this region the corn thrips are able to easily suck sap and cause scarification of the plant (Ssemwogerere *et al.*, 2013). These areas could also be offering an excellent protection area from the harsh weather and insecticides. Similarly, Razmojou and Golizadeh (2010) reported infestation of *R. maidis* on all the above ground plant parts. This study thus provides information that can be used to optimize spraying towards the control of the two vectors.

Scouting and monitoring results show that the most reliable time for scouting of vectors is either between 8.30 to 10.30 am or 3.30 to 5.30 pm. This is the first report on scouting and monitoring of corn thrips and corn leaf aphids on maize. However, a similar study carried out by Pizzol *et al.* (2006) reported more flower thrips (*Frankliniella occidentallis*) trapped just before noon and then decreased through the afternoon. Findings by Atakan *et al.* (2001) also reported more corn thrips being captured by sticky traps between 8.00 am to 2.00 pm. Results from this study agree with those of Atakan *et al.* (2001) during the morning hours but not the afternoon time. In this study, the scouting of *F. williamsi* and *R. maidis* was done by visually identifying vectors on examining the leaves while sticky traps were used for *F. occidentalis*. This may account for the time sampling differences in corn thrips and corn leaf aphids especially in the afternoon.

Results from the threshold study confirm the effectiveness of thunder (Imidacloprid and Cyhalothrin) in controlling corn thrips as reported by Kasina *et al.* (2015). Studies by Nderitu *et al.* (2008) on the use Cyhalothrin insecticide towards the control of *Megalurothrips sjostedti* on French beans was also found effective. This study also showed that more frequent sprays (10 sprays of thunder) significantly reduced corn thrips infestation. Being the first report on action threshold of corn thrips and corn leaf aphids on maize, 6 corn thrips and 3 corn leaf aphids per plant agree with results reported by Nault and Shelton, (2010) when action threshold for thrips was developed on fruits and vegetables and that of Nderitu *et al.* 2008 when developing action threshold level of thrips on French beans. It was also noted that although most frequent sprays reduced MCMV and SCMV viral load, the monthly spray regime equally worked well with all thunder sprayed plots testing negative for MLND during the first season. These results relate to those reported by Kinyua *et al.* (2015) who found that maize plots that were sprayed on a fortnight basis had lower MLN disease severity levels compared to those not sprayed. Therefore, less frequent sprays are suggested to safeguard economic returns.

In this study, it is also confirmed that crops infested by corn thrips are affected by the corn thrips damage as well as the MCMV virus that it transmits. Regression analysis shows that both affect yield negatively. This is similar to a report by Beres *et al.* (2013) who reported on the damage caused by corn thrips and their ability to transmit MCMV. Although thunder had no effect on corn leaf aphids, regression analysis indicate that their presence causes a significant increase in SCMV infection. This could probably explain how the interaction of the two viruses occurs for MLND to manifest itself (Cabanas *et al.*, 2013; Nelson *et al.*, 2011).

Conclusion

- Sampling the upper region of the maize plant gives significantly more vectors compared the middle and lower regions of the maize
- More significant numbers of corn thrips and corn leaf aphids are sampled between 8.30 am to 10. 30 am and 3.30 to 5.30 pm.
- Monthly sprays regime is the most economical spray regime with higher marginal rate of returns
- Thunder treated plots had no maize lethal necrosis disease except for the monthly spray regime plots.
- There was no significant difference in corn leaf aphid infestation across all treatments. However, SCMV was significantly higher in plots that were not sprayed and those sprayed
- Corn thrips causes significant damage to maize crops which eventually causes the yield

decrease.

- MCMV causes significant yield decrease in most of the yield characteristics.

Recommendations

- Farmers should adopt the monthly thunder spray regime because it is the most economical spray regime.
- For scouting purposes farmers should monitor and scout for corn thrips during morning hours or late in the evening. The upper part of the plant should always be targeted during scouting and also spraying.

Acknowledgement

The study was conducted with financial support from the Association of Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) through the Kenya Agricultural and Livestock Research Organization and Kenyatta University. “The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.”

References

Aulakh, J. and Regmi, A. (2013). Post-harvest food losses estimation: development of consistent methodology: Working paper, Rome, *Food and Agriculture Organization of the United Nations.* (Accessed on April 23 2017).

Beres, P. K., Kucharczyk, M., Halina, K. and Kucharczyk, M. (2013). Thrips abundance on sweet Corn in South East Poland and the impact of weather conditions on their population dynamics. *Bulletin of Insectology* 66 (1): 143-152.

Bird, G., Bishop, B., Grafius, E., Hausbeck, M., Lynnae, J., William, K., Pett, W. (2004). Insect, diseases and nematode control for commercialvegetables. Michigan State University Extension Bulletin. E-312: 81–82.

Cabanas, D., Watanabe, S., Higashi, C.H.V. and Bressan, A. (2013). Dissecting the Mode of Maize Chlorotic Mottle Virus Transmission (Tombusviridae: Machlomovirus) by *Frankliniella williamsi* (Thysanoptera: Thripidae). *Journal of Economic Entomology* 106(1): 16-24.

De Groote, H., Oloo, F., Tongruksawattana, S. and Biswanath, D. (2016). Community-survey based assessment of the geographic distribution and impact of maize lethal necrosis (MLN) disease in Kenya. *Crop protection*. 82: 30-35.

Fournier, F., Boivin,G. and Stewart, R.(1995). Effect of *Thrips tabaci* (Thysanoptera: Thripidae) on yellow onion yields and economic thresholds for its management. Journalof Economic Entomology 88: 1401–1407

Gill, H.K., Garg. H., Gill, K.A., Gillet-Kaufman, L.J. and Nault, A.B. (2015). Onion thrips (Thysanoptera: Thripidae) Biology, Ecology and management in onion production systems. *Integrated pest management* 6 (1): 6

Iken, J.E. and Amusa, N.A. (2004). Maize research and production in Nigeria. *African Journal Biotechnology* 3: 302-307.

Khan, Z.R., Midega, C.A.O., Pittchar, J.O., Murage, A.W., Birkett, M.A.M., Bruce, T.J.A. and Pickett, J.A. (2014). Achieving food security for one million sub-Saharan African poor through push – pull innovation by 2020. *Philosophical Transactions of The Royal Society B Biological Sciences* 369: 20120284.

Kinyua, Z.M., Kasina, M., Wangai,A.W., Langat, B. and Gichobi,D.W. (2015). Development of a robust severity assessment scale for maize lethal necrosis disease. *Paper KAPAP conference proceedings at KALRO Westlands* 10-12th June 2015

Larsson, H.(2005). Economic damage by *Limothrips denticornis* in rye, triticale and winter barley. *Journal of Applied Entomology* 129 (7)386-392.

Mahuku, G., Lockhart, B.E., Wanjala, B., Jones, M.W., Kimunye, J.N., Stewart, L.R., Cassone, B.J., Sevgan, S., Nyasani, J.O., Kusia, E., Kumar, P.L., Niblett, C.L., Kiggundu, A., Asea, G., Pappu, H.R., Wangai, A., Prasanna, B.M. and Redinbaugh, M. (2015). Maize lethal necrosis (MLN), an emerging threat to maize-based food security in sub-Saharan Africa. *Phytopathology* 105(7): 956-965.

Nault, B.A. and Shelton, A.M. (2010). Impact of insecticide efficacy on developing action thresholds for pest management: A case study of onion thrips (Thysanoptera: Thripidae) on onion. *Journal of Economic Entomology* 103: 1315–1326.

Nderitu, J. H., Kasina, M.J., Nyamasyo, G. N. and Waturu, C. N. and Aura, J. (2008). Management of thrips (Thysanoptera: Thripidae) on French beans (Fabaceae) in Kenya: economics of insecticide applications. *Entomology* 5: 148–155.

Nelson, S., Brewbaker, J. and Hu, J. (2011). Maize Chlorotic Mottle Virus. *Plant Disease* 79: 1-6.

Pizzol, J., Poncet, C., Hector, S. and Ziegler, J. P. (2006). Mise en place d’une protection biologique intégrée préventivecontre les ravageurs des cultures de rosiers sous serre dans le sud de la France. IOBC/WPRS Bull.2006; 29: 31–36.

Razmjou, J. and Golizadeh, A. (2010). Performance of corn leaf aphid, *Rhopalosiphum maidis* (Fitch) (Homoptera: Aphididae)on selected maize hybrids under laboratory conditions. *Applied Entomology and Zoology* 45 (2): 267-274.

Reichelderfer, K. H., Karlson, G. A. and Norton, G. A. (1984). Economic guidelines for crop pest control. FAO Plant Production Paper, 58

Reiners, S. and Petzoldt, C. H. (2009). Integrated crop and pest management guidelines for commercial vegetable production. Cornell Cooperative Extension, Ithaca, NY.

Ssemwogerere, C., Nyaburu, M. K., Ssemakula, O. and Karungi J. (2013). Special composition and occurance of thrips on tomato and paper as influenced by farmer management practices in Uganda. *Plant Protection Research.* 53: 2.

Stewart, K. K. and Khatat, (1980). Economic Injury level of the tarnished plant bug, *Lygus lineoralis* (Hemiptera (Heteroptera): Miridae), on green beans in Quebec. Canadian Entomologist 112: 306- 310

Wangai, A., Kinyua, Z.M., Otipa, M.J., Miano, D.W., Kasina, J. M., Leley, P. K. and Mwangi, T.N. (2012a). Maize (Corn) Lethal Necrosis Disease.*KARI Information Brochure* [eds by Ministry of Agriculture].

“The authors have declared that no competing interests exist.”