Journal of Plant Sciences
2016; 4(6): 139-145
http://www.sciencepublishinggroup.com/j/jps
doi: 10.11648/j.jps.20160406.12
ISSN: 2331-0723 (Print); ISSN: 2331-0731 (Online)

Evaluating the Impact of Border Crops on Aphid (Hemiptera: Aphididae) Infestation and Damage in Butternut Squash (*Cucurbita moschata*)

Sipiwe Gobiye[1], Innocent Pahla[1], Elizabeth Ngadze[2]

[1]Department of Horticulture, Midlands State University, Gweru, Zimbabwe

[2]Department of Crop Science, University of Zimbabwe, Harare, Zimbabwe

Email address:
sipiwegobiye@gmail.com (S. Gobiye)

To cite this article:
Sipiwe Gobiye, Innocent Pahla, Elizabeth Ngadze. Evaluating the Impact of Border Crops on Aphid (Hemiptera: Aphididae) Infestation and Damage in Butternut Squash (*Cucurbita moschata*). *Journal of Plant Sciences*. Vol. 4, No. 6, 2016, pp. 139-145.
doi: 10.11648/j.jps.20160406.12

Received: September 13, 2016; **Accepted**: September 28, 2016; **Published**: November 10, 2016

Abstract: Aphids cause loss of quality and value in butternut crops due to pest injury and the transmission of viruses in a non-persistent manner. A field experiment was conducted in Daylesford, Gweru in August 2012/2013 planting season to evaluate border cropping practice as a management strategy for aphid infestation and damage in butternut squash (*Cucurbita moschata*). The experiment was arranged as a 2 x 2 + 1 factorial in a randomised complete block design (RCBD) replicated 4 times. Treatments were Maize (*Zea mays*) border planted at 25 000 and 45 000 plants/ha and sorghum (*Sorghum bicolor*) border planted at 200 000 and 260 000 plants/ha plus a butternut crop with no border (control). All borders were planted 0.5 m from the butternut crop. Data on aphid counts on borders and on butternuts, disease incidence, yield and land equivalent ratio for the intercrops was recorded. Results showed that, border crops and border density interacted significantly ($p < 0.05$) to to reduce aphid population, disease incidence and yield of butternuts. From the results, butternut plots bordered by maize at 45 000 plants/ha recorded the highest butternut yield (16t/ha), least aphid population and least viral disease incidence during the 7th week after planting when compared to control. Based on these findings it can be concluded that the use of maize border cropping at 45 000 plants/ha can be effective in controlling aphids in butternuts.

Keywords: Butternut, Boarder Crop, Density, Aphids

1. Introduction

Butternut squash (*Cucurbita moschata*) belongs to the genus cucurbita which originated from Central and Southern America. The crop is among the most important vegetables in Southern Africa [1]. Butternuts are common in many Africa countries and used for a variety of purposes including direct consumption from fresh markets as well as in the confectionary and pharmaceutical industries [1].

World production of butternuts and squash was recorded as 16 million tonnes from 1.3 million [2]. African production is estimated at 1.8 million tonnes from 140 hectares, corresponding with an average yield of 12.8 t/ha [2]. The average local price of butternuts in Zimbabwe ranges from $0.30 - $0.40/kg.

Butternuts are susceptible to various pests and diseases as well as temperature fluctuations. Common pests include aphids and pumpkin fly (*Dacus* spp). Aphids are vectors of plant viruses, they transmit viruses in a non persistent manner. [3] noted that about 600 viral diseases are transmitted by aphids and about 290 known aphid borne viruses are non – persistent.

Viral diseases have become one of the major constraints for butternuts production. The potyviruses watermelon mosaic virus (WMV), papaya ringspot virus (PRV), cucumber mosaic virus (CMV) and zucchini yellow mosaic virus (ZYMV), are among the major viruses transmitted by aphids affecting butternuts, with papaya ringspot virus (PRV) and watermelon mosaic virus (WMV) detected most frequently [4]. The viral diseases cause leaf mosaic, mottling (brittleness of the leaves), enation and puckering of the foliage, distortion of the fruit and plant stunting. [5] noted that the effects of viral diseases on yield can be severe by causing stunted growth. This was also supported by [6] who estimated yield losses to be between 0-86% depending on time of infestation.

Pesticides such as malathion and dimethoate, organophosphates (OPs) such as carbaryl, chlorpyrifos, diazinon and some pyrethroids such as deltamethrin, taufluvalinate were commonly used by commercial farmers in Zimbabwe to control the spread of aphids. However, use of chemicals to control aphids has led to development of chemical resistance, leading to crop failures [7]. Other challenges include pest resurgence in which chemicals may increase, rather than suppress the spread of aphid by destruction of predators and parasitoids or by causing increased vector activity, [8] cost of chemicals, effects on non target hosts and phytotoxicity. [9] observed that the systemic pesticides such as malathion, carbaryl, and dimethoate were persistent and toxic to many beneficial insects such as ladybird beetles, lacewings and predatory midges.

Sometimes the value of the crops produced by the small scale farmers is seldom sufficient to justify or cover the cost of treatment using pesticides. The use of border crops to form a screen around the main crop becomes an alternative strategy for small scale farmers to provide protection against aphids and several non-persistent viral diseases. The crop border method is based on two facts. Aphids that arrive carrying a non – persistent virus on their mouthparts will land on the crop border, start feeding and lose their capacity to transmit the virus to the main crop [4]. Aphids are attracted to the contrast between green (crops) and dark soil hence usually lands on field margins and start feeding thus reducing the population in the main field.

In this study maize (*Zea mays*) and sorghum (*Sorghum bicolor*) have been used as border crops. Height difference with the main crop was the major selection criterion for the border crops. [10] noted that plants markedly taller than the primary crop are chosen as barrier plants because of their likelihood to intercept aphids while in flight. Maize (*Zea mays*) and sorghum (*Sorghum bicolor*) are common crops mainly grown by small scale farmers in Zimbabwe. Plant density and crop placement distance also have an effect on the spread of aphids. [11] proposed that greater plant density contributed to a greater decrease in spread of aphid transmitted diseases. The aim of this study was to evaluate the effects of border crops type and densities in reducing aphid population and aphid transmitted diseases.

2. Materials and Methodology

2.1. Experimental Site

The experiment was carried out at plot number 115 Daylesford in Gweru which falls within latitude 19°27'S and longitude 029°51'E, [12]. This field experiment was initiated in August 2012 on deep clay loam vertisol soil. The area is situated in Midlands Province of Zimbabwe. It lies in natural region III with an altitude of 1429m and receives mean annual rainfall of 500 – 800 mm. Annual temperatures range from 6.51 to 30.1 in winter and summer respectively.

2.2. Experimental Design

The experiment was laid out in a 2 x 2 +1 Factorial in a Randomised Complete Block design replicated 4 times, blocks were used as replicates. Treatments were Maize (Zea mays) border planted at 25 000 (low) and 45 000 plants/ha (high) and sorghum (Sorghum bicolor) border planted at 200 000 (low) and 260 000 plants/ha (high) plus a butternut crop with no border (control). The plant population for each high and low treatments was calculated by multiplying the in-row and the inter-row spacings then divide 10 000. Buttenuts (cucurbita moschata) were used as the test crop in the experiment.

2.3. Experimental Procedure

Land was ploughed to a depth of 30 cm and harrowed to have a fine tilth using a tractor drawn plough and harrow. Plots were marked two weeks before planting. The plots were 4.3 x 5.8 m for the butternut and the border crop. The control plot (with no border crop) measured 3 x 1.5 m. half a meter was left between plots with 1m distance between blocks.

Two weeks after plot construction, border crops were planted in their respective plots. All plots were irrigated to field capacity 24 hours before planting. Maize border was planted at an inter-row spacing of 0.9m and in-row spacing of 0.45m for the 25 000plants/ha treatment and 0.9m inter-row and 0.25m in-row for the 45 000 plants/ha treatment. Three maize seeds were planted per planting station, with one being thinned off after crop emergence. Sorghum border crop was planted at an inter-row spacing of 0.9 m and 0.05 m inter-row for the 200 000 plants/ha and 0.75 inter-row and 0.05 in-row for the 260 000 plants/ha treatment. Seven days after border crop planting, butternuts were planted at the rate of 3 seeds per planting station (at a rate of 3 kg/ha), 1.5 x 1.5 m apart in planting basins 45 cm wide. These were thinned to 1 plant per station at crop emergence. Butternuts were planted 0.5 m away from the border crop in all treatments and were spaced at 1.5 m x 1.5 m. Irrigation and crop management was as per farmer practice in the respective crops. Vines were trained regularly to maintain space between the rows and the border crops. The border crop and butternut were kept weed free throughout the experiment.

In Butternuts, Basal fertiliser Compound D (8N:14P:7K) was broadcasted and incorporated into the soil at the rate of 600 kg/ha at planting. Each plot size measured 4.5 m^2. Therefore a total of 0.27 kg was broadcasted in each plot. A split application of ammonium nitrate was applied i.e 100 kg/ha, 3 weeks after emergency and also 100 kg/ha at 6 WAE. Each planting station received 7.5 grams of ammonium nitrate. A digital hook type scale was used to measure amount of fertilizer. In Maize, a basal compound D fertiliser (8N:14P:7K) was applied at the rate of 300 kg/ha at planting. This was followed by top dressing of ammonium nitrate at the rate of 200 kg/ha at 6 WAE. In Sorghum, a basal dressing of compound D fertiliser at a rate of 200 kg/ha was applied at planting and top dressing with ammonium nitrate at the rate of 100 kg/ha at 6 WAE. One m diameter trap water basins were used to trap aphids, the interior of the basins was painted yellow to attract aphids, 1 basin was placed at the centre in each plot. The water traps were half filled with water and one teaspoon of Sodium hypochlorite (Jik) was added to the water to break the surface tension

2.4. Data Collection

2.4.1. Aphid Population Assessment

The aphid population was determined in yellow water basins and an aphid score count was done.

Aphids caught in water basins were collected and stored in 70% ethyl alcohol before counting under a stereo dissecting microscope. Aphids on border crops were counted on a weekly basis using a magnifying glass from 3rd WAE up to physiological maturity. The scoring system was used to record aphids (Table 1). A simple scoring system that involved scoring of aphid density on the third and fourth main stem node below the terminal was used. Random sampling of location was done in each plot. At each location three plants of the border crops was randomly selected. Aphid count was then done on the third or fourth leaf below the terminal.

Table 1. *Aphid scoring system [13].*

Number of aphids	Score
No aphids	0
1 – 10 aphids	1
11 – 20 aphids	2
21 – 50 aphids	3
50 – 100 aphids	4
More than 100	5

2.4.2. Disease Incidence Determination

Four plants per plot were randomly selected. The number of leaves showing virus disease symptoms per selected plants were determined fortnightly from three weeks after crop emergence until physiological maturity. Indicator symptoms for virus infection included leaf roll, erectiveness, mosaic, brittle leaves, and feathery leaves, mild and severe mottling [13]. Disease incidence was calculated using the formular.

Disease incidence = Number of infected leaves per plant x 100 / Total number of leaves per plants assessed

2.4.3. Determination of Yield

All Butternuts from each plot were harvested, graded, counted and classified as healthy or diseased based on the presence or absence of green mottling, knobby swellings, and or shape deformation. Yield of healthy, diseased and total fruit was expressed by weight in kg using a digital hook type weighing scale

Yield on border crop was determined by sun drying all maize cobs and sorghum heads from each plot. The maize cobs and sorghum heads were threshed and their weight recorded using a digital hook type weighing scale.

2.5. Data Analysis

The data was subjected to analysis of variance (ANOVA) using Genstat computer software package version 14.1. Where significant difference of means was noted, separation of means was done by Duncans Multiple Range Test. All data were square root transformed to meet the assumptions of ANOVA.

3. Results

3.1. Effect of Border Type and Border Density on Aphid Population in Water Traps

There was a significant interaction ($p < 0.05$) between border type and density on aphid population in the water basins during the 3rd, 8th and 10th week (Figure 1). Basins in plots bordered by lower crop densities recorded higher aphid populations when compared to basins in plots bordered by high crop densities in both maize and sorghum border. However, when the two borders were compared, water basins in plots bordered by maize recorded lower aphid populations throughout the growing period. Basins in Maize bordered plots planted at high density (45 000 plants per hectare) had the lowest aphid population mean count of 0.90 during the 3rd WAP when compared to all treatments. Highest aphid populations were recorded in the water basins in the no border treatment followed by basins in low density sorghum treatment. In all treatments aphid population in the water basins increased from the 3rd week reaching a peak aphid population in the 8th week and then declined at 10 WAP (Figure 1).

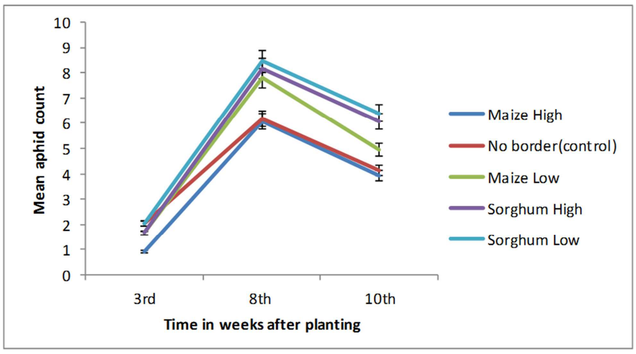

Figure 1. *Effect of border type and border density on aphid population assessed at 3, 8 and 10 weeks after butternut planting.*

3.2. Effects of Border Type and Density on Colonising Aphid Population on Border Plants

There was significant interaction ($p < 0.05$) between border type and density on aphid population on border plants (Figure 2). An increase in border density resulted in an increase in aphid population in both maize and sorghum borders. During the 4th and 9th week after planting the sorghum border at high density recorded the highest aphid population when compared to all treatments. Maize border recorded the lowest population of aphids of 0.71 during the

4th and 9th week. There was no significant difference in aphid means for the different maize densities at both weeks of recording. During the 4th week aphid means in low and high density sorghum were also not significantly different. Sorghum border type at low density had a mean aphid score of 1.28 during the 4th week which increased to 1.99 in the 9th week. There was an increase in aphid population on the sorghum border type as the density increases (Figure 2). Thus at high density the sorghum border type recorded an aphid score of 1.45 during the 4th week and 2.27 during the 9th week.

Maize border type at high and low density recorded mean aphid score of 0.71 during the 4th and 9th week after planting. The maize border type aphid scores in the 4th and 9th week were significantly different from sorghum border type during the same period. During the 4th week, the aphid population in the maize border type at low density decreased by 28.4% lower than the sorghum border at low density. The same trend was noticeable in the 9th week when 45.5% lower aphids were recorded on the maize border at high density than the sorghum border type at high density. Maize border type at either density therefore performed better than the sorghum border type densities. The worst performer was sorghum border type at high density.

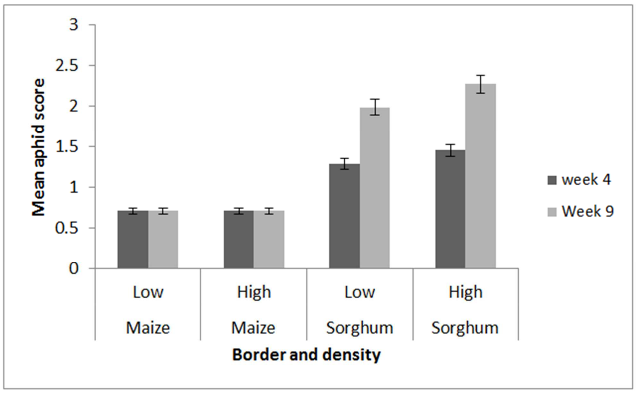

Figure 2. Effects of border and border density on aphid population in borders recorded at 4 and 9 weeks after crop planting.

3.3. Effect of Border Type on Viral Disease Incidence on Butternuts

From the results there was no significant interaction between border type and density on virus disease incidence on butternuts. However there was a significant difference on the effect of border type on virus disease incidence. Butternut plants bordered by sorghum recorded a higher disease incidence as compared to those bordered by maize. In all treatments there was a general increase in virus disease incidence as time from planting increased from 3rd week to 11th week. The control butternut (unbordered) recorded the highest disease incidence throughout the growing period as compared to bordered butternut. At week 3 and 5 virus disease incidence in butternuts bordered with maize and sorghum border type was not significantly different (Figure 3). There was a 188.6% and 79.1% decrease in virus disease incidence on the butternuts protected by the maize and sorghum border type respectively when compared to control during the 7th week. Maize and sorghum border types showed significant differences during the 7th 9th and 11th week while no significant difference was noted between maize and sorghum border types during the 3rd and 5th week (Figure 3).

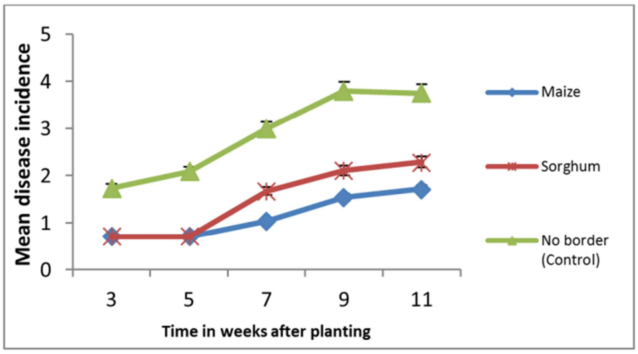

Figure 3. Effect of border type on viral disease incidence.

3.4. Effects of Border Type on Butternut Yield

From the results there was no significant interaction between border type and density on butternut yield. However there was a significant difference ($p < 0.05$) on the effect of border type on butternut yield (Figure 4). Maize bordered butternuts recorded higher yields when all treatments were compared. There was 116.55% increase in yield on butternuts with maize border while a yield increase of 64.4% was recorded on butternuts bordered with sorghum border when compared to control (Figure 4).

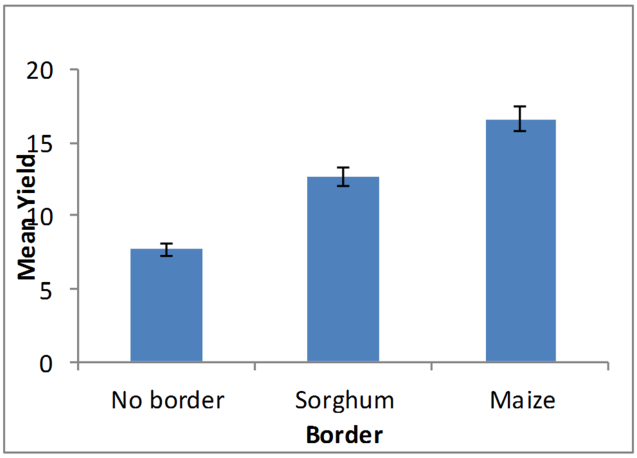

Figure 4. Effects of border type on butternut yield.

4. Discussion

There was significant interaction ($p < 0.05$) between border type and density in aphid population during the 3rd, 8th and 10th weeks after crop planting. This trend might imply that a high density border type is associated with minimal number of aphids captured in the water traps while a low density border type is synonymous with high population of aphids. Thus maize border type at high density recorded lower alatae aphid population (0.70) than the lower density (1.52). This is in line with what was revealed by [11] who noted an inverse relation between plant population and aphid density in Brassica crop.

Similarly, in a study conducted by [14] in Uganda, high densities of *Aphis craccivora* on cowpea tended to be associated with low plant density. The same trend has been observed with *Aphis gossypii* in cotton crops in Texas, USA [15] where the mean number of aphids per leaf in lower densities was 4.71 significantly higher than where cotton was at higher density (1.82).

Lower number of aphids found on butternuts protected by high density maize border type could be associated with aphid inappropriate landing. This was suggested by [16] who concluded that insects flying over plant mixtures will have several inappropriate landings on non host plants. Aphids respond strongly to visual stimuli [17] and locate host plants by contrasting the soil background with the green colour of plant foliage [18]. Therefore, the greater the percentage of vegetative cover in a crop field, the lower the probability an aphid will alight in that area [19].

On the other hand there was no significant difference between the sorghum border type at high (260 000) and at low density (200 000). The difference in sorghum densities seem not to have much impact on aphid population due to the fact that the lower density normally will partially compensate by developing at least one additional head per plant. [20] noted that in most field settings grain sorghum plant densities are rarely uniform. This is mainly due to the extra head development and high potential for tillering by sorghum. It then acts as a better physical barrier at the 10th week onwards than in its earlier stages due to the development of a full canopy. Therefore in order for sorghum densities to have a differential impact on aphid population they must be widely different.

Unlike sorghum border type, the maize border type remains invariable due to neither the presence of tillering nor development of additional heads. This concept distinguishes the performance of the maize and sorghum border type densities in aphid control.

Notably, butternuts are widely spaced both within and between rows thus increasing the abundance of contrast between soil and plant interfaces until the development of sufficient cover. The butternuts with no borders tend to have wider spaces that promote high aphid landing than those within borders.

As the aphids migrate into the field they tend to land more on edges of fields than the middle because they are attracted to the contrast between green crop and dark soil. Thus more aphids were captured on butternuts with no borders as the aphids land on the main crop itself. This behaviour was confirmed by [19]. Similarly, [5] established that flora diversification can result in reduced pest population.

In some studies though, no significant differences were found between the monoculture and diculture in the aphids caught in traps. This was observed by [21] whose results in terms of aphid numbers in water traps in pepper plants with no border and those with borders were not different.

Though this study did not deliberately record the population of beneficial insects, their presence cannot completely be ruled out in such mixed cropping pattern. Thus, the low aphid population in the bordered crops can also be attributed to the presence of such beneficial insects as the ladybirds - Coccinellidae. Other studies carried out by [22] have shown that there tend to be a higher enemy abundance in more diverse vegetative patterns mainly associated with lower aphid density. The use of border crop is therefore an effective tool in controlling aphid population by exploiting several aspects of the aphid.

There was significant interaction ($p < 0.05$) between border type and density on aphid population on borders (Figure 2). The sorghum border type was highly infested with aphids than the maize border type. This is attributable to the fact that sorghum border type is a more favourable host for aphid infestation than maize border type. From this study it is evident that sorghum border type proved to be a less effective border than maize border type because of its ability to attract aphids which will result in aphid migration to the main crop. That aphid migration from the sorghum border type to the butternuts results in reduction in leaf photosynthetic area causing great damage. This was in line with the findings of [23] who in a study of sunflower, maize and sorghum as barrier crops on cucurbits recorded maize as the best border crop. The lower mean aphid counts recorded on the maize border densities suggest that maize is a non host plant for aphids.

There was significant difference in viral disease incidence at the 3rd, 5th and 7th weeks after emergence due to border types. The highest mean incidence (3.752) was recorded on the no border (control) while the lowest mean of 0.707 was recorded on maize and sorghum border type during the 3rd and 5th week. These results suggest that border crops are important in reducing virus symptoms. The two border types which were established a week before the butternut crop, was already providing some cover which substantiated the virus sink hypothesis [24] and [21] postulates that a crop border should be established before or at the same time as the main crop, but not after in order to be effective.

Thus the border types tend to capitalise on the known aphid behaviours. [25] revealed that aphids tend to probe the plant tissues using their stylet (mouthparts) in order to determine suitability of a plant as a host. By so doing aphids carrying the non-persistent viruses will lose the virus in the plants they probe first. This phenomenon is associated with high disease virus symptoms manifesting in the peripherals (border) than interiors.

On the other hand maize border type and sorghum border type showed significant differences from the 7th week onwards. This could be attributed to the fact that sorghum border type is a comparatively more attractive host than maize border type. Thus as the alatae aphids are attracted by the sorghum border type they quickly gain access to another favourable host (butternuts) where the non-persistent virus will be deposited.

Another suggestion distinguishes the border type by their differential heights. In this study the short (1.1m) Macia variety of sorghum was used as compared to tall (1.6m) maize variety. Maize provides the tallest barrier to alate landing [26]. This could mean more alatae aphids impeded by the taller maize variety before accessing the interior butternut crop. This is in agreement with [5] who concluded that the success of barrier plants depends on the height of the barrier crop at the time of maximum risk of the primary crop; virus spread pattern and competition of barrier crop and the protected crop. [27] proposed that tall borders form a physical barrier to alatae aphid landing resulting in delayed virus disease development in the main crop. Conversely, though, the results tend to contradict with earlier findings by [24] who suggested that the height of a crop border is not important for virus disease control.

It was evident throughout the season that disease symptoms on no border (control) were significantly higher than the crop with borders. This was due to increased aphid landing on plots without borders resulting in increased level of virus symptoms in edge rows of the no border (control). The crop borders thus eliminated bare soil/crop interfaces reported to be attractive to alate aphids [26].

When aphids probe on the less favourable maize border type they tend to migrate for a relatively longer distance which in this case, could be the sorghum bordered butternuts, thus increasing the disease symptom pressure. Thus the crop border should be established before or at the same time as the main crop, but not after in order to be effective [21].

The butternuts crop bordered by maize border type recorded the highest yield than those bordered with sorghum border type and the no border (control). The different mechanisms of border types and the effectiveness are reflected in the yield differences.

The effectiveness of a control strategy should ideally be reflected in the yield levels where better yields should be recorded on those border types with lowest aphid population and infestation levels. In the present study butternuts bordered by maize border type had the highest yield as a result of lower aphid population. This led to reduced crop damage and disease incidence, with less severe symptoms as reflected by the higher yield in the maize bordered crop.

The no border (control) on the other hand recorded the highest aphid infestation, and disease incidence resulting in highest damage and lowest yield in weight as compared to other treatments. This is in agreement with the findings of [28] who indicated maize border type as the most effective barrier among other different border cropping systems namely; maize, bajra and pigeon pea for the management of aphid pest in okra. In that study, okra plots bordered by maize had the lowest aphid population with the highest parasitized aphids and increased yields compared to sorghum border type and pigeon pea bordered plots.

Other studies that concur well with this present study include that of [29] who also reported the effectiveness of the maize border type against Aphis gossyppii infesting Irish potato;[30] in a study on chilli crop confirmed a 60-65% reduction in sucking pests bordered by maize in comparison with monoculture.[31] also reported a reduced aphid population on soya bean bordered with maize as compared to the sole crop of soya bean. In all these cases yield gains were reported due to reduced aphid population.

This implies that better yields can be obtained with growing of butternuts surrounded by maize or sorghum border types.

5. Conclusions

Significant interaction exists between border and density in controlling aphid population. As the border density was increased the aphid population was reduced. Maize border type provides a better physical barrier than sorghum border type by reducing the number of alatae aphids, delaying virus onset thereby promoting growth and yield of butternut. The sorghum border type tends to attract aphids that will migrate to the main crop.

References

[1] Thresh, L., (2003). Control of plant virus disease in sub Saharan Africa. The possibility and feasibity of an integrated approach. UK.

[2] Food and Agriculture Organisation statistics. (2003). National production, crops. Zimbabwe.

[3] Hull, R. 2002. Virus Infection, Plant. Encyclopedia of Molecular Biology. John Innes Centre, Colney, Norwich, United Kingdom.

[4] Murphy, F, J. Micky, D. (2009). Reflective plastic mulch but not a resistance- inducing treatment reduced watermelon mosaic virus incidence and yield losses in squash. International journal of vegetable science. USA.

[5] Hooks, C. R. R. Johnson, M. W. (2003). Review: impact of agricultural diversification on the insect community of cruciferous crops. Crop Prot. 22 223–238.

[6] Doodson, J. K. and Saunders, P. J. W. (1970a). Some effects of barley yellow dwarf virus on spring and winter cereals in glasshouse trials. Annals of App Biol. 65: 317–325.

[7] Cameron, P. J. and Walker, G. P. (1988). Insecticide resistance in green peach aphid from potatoes in South Auckland. Proceedings of the 41st New Zealand Weed & Pest Control Conference: 85-89.

[8] Gibson, R. W., Rice, A. D., (1989). Modifying aphid behavior. Aphids: their biology. In: Minks, A. K., Harewijn, P. (Eds.), Natural Enemies and Control, Vol. 2c. Elsevier, Amsterdam, pp. 209–224.

[9] Dewar, A. M. & Smith, H. G. (1999) Forty years of forecasting virus yellows incidence in sugar beet. CABI Publishing, Wallingford.

[10] Dhanju, K. S. Chowfla, S. C. Handa, A. K., (1995). Effect of barrier crops and spacing on the incidence of mosaic disease and yield of French bean. Legume Res. 18, 113–116.qd

[11] Jones, R. A. C. (1993). Effects of cereal borders, admixture with cereals and plant density on the spread of bean yellow mosaic potyvirus into narrow-leafed lupins (Lupinus angustifolius) Ann. Appl. Biol. 122, 501-518

[12] US Naval Observatory report (2010). The guardian. America.

[13] Blackman R. L and Eastop V. F. (1994). Aphids on the World's Trees. An Identification and Information Guide. Wallingford: CAB International. ISBN 0-85198-877-6.

[14] Karungi, J., Adipala, E., Ogenga-Latigo, M. W., Kyamanywa, S. and Oyobo, N. (2000) Pest management in cowpea. Part 1. Influence of planting time and plant density on cowpea field pests infestation in eastern Uganda. Crop Protection.

[15] Parajulee, M. N. Montadon, R. Slosser, J. E. (1997). Relay intercropping to enhance abundance of insect predators of cotton aphid (aphis gossypii clover) in Texas cotton. International journal of pest management. Volume 43. Issue 3. Texas.

[16] Finch, S. and Kienneger, M., (1997). A behavioural study to help clarify how undersowing with clovers affects host-plant selection by pest insects of brassica crops. Entomologia Experimentalis et Applicata 84, 165–172.

[17] Kring, J. B. (1972). The life cycle of the melon aphid Aphis gossypii Glover, an example of facultative migration. Annals of the Entomological Society of America.

[18] Kennedy, J. S., Booth, C. O., Kershaw, W. J. S. 1959. Host finding by aphids in the field. III. Visual attraction. Ann. Appl. Biol. 49, 1–21.

[19] A'Brook, J. (1968). The effect of plant spacing on the numbers of Aphids trapped over the groundnut crop. Ann. Appl. Biolo. 61: 289-284.

[20] Conway. K. E., B. D. McGraw, J. E. Motes and J. L. Sherwood. (1989). Evaluation of mulches and row covers to delay virus diseases and their effects in yellow summer squash. Appl. Agric. Res. 4: 201-207.

[21] Fereres, A. (2000). Barrier crops as a cultural control measure of non-persistently transmitted aphid-borne viruses. Virus Research 17

[22] Root, R. B., (1973). Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (Brassica oleracea). Ecol. Monog. 43, 95–120.

[23] Anandam, R. J and Doraiswamy, S. (2002). Role of barrier crops in reducing the incidence of mosaic disease in chilli. J. Plant Dis. Prot. 109, 109–112.

[24] Difonzo, C. D., Ragsdale, D. W., Radcliffe, E. B., Gudmestad, N. C., Secor, G. A., Ebesu, R. H., (1996). Crop borders reduce potato virus Y incidence in seed potato. Ann. Appl. Biol. 129, 289-

[25] Powell, G., Hardie, J., Pickett, J. A., (2006). The effects of antifeedant compounds and mineral oil on stylet penetration and transmission of potato virus Y by Myzus persicae (Sulz.) (Hom., Aphididae). J. Appl. Ent. 122, 331–333.

[26] Damicone, J. P., Edelson, J. V., Sherwood, J. L., Myers, L. D., and Motes, J. E. (2007). Effects of border crops and intercrops on control of cucurbit virus diseases. Plant Dis. 91: 509.

[27] Simons, J. N. (1957). Effects on insecticides and physical barriers on field spread of pepper vein-banding mosaic virus. Phytopathology. 47, 139-145

[28] Nderitu, J. H. Kasina, M. and Malenge, F. (2008). Evaluating border cropping system for management of aphids (Hemiptera: Aphididae) infecting okra (Malvaceae) in Kenya. Journal of Entomol. 5: 262-269.

[29] Kibaru, A. (2004). Management of aphids and aphid transmitted viruses in seed potato production in Kenya. MSc. Thesis University of Nairobi, Kenya

[30] Mohammad Roff, M. N. and Ho, B. L., (1991). Maize as a barrier crop in reducing aphids, the virus vector of chilli. MARDI Res. J., 19 (1): 251-258.

[31] Wang, A. U., Zheng, Y., Hai, Y. Y. and Yue, Y. W., 1998, Effects of interplanting and mixed sowing of soya and maize on infestation by insects and infection by diseases. Plant Prot., 24 (1) 13-15.