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Testing Garlic *(Allium sativum)* Intercropped with Tomato *(Solanum lycopersicum)* In the Control of Aphids.

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Abigail Moono.
Department of Agriculture and Environmental Sciences,
Information and Communications University
Lusaka, Zambia
Moono2806@gmail.com

Danny Chisanga Musenge
Department of Agriculture and Environmental Sciences,
Information and Communications University
Zambia Research and Development Centre
Lusaka, Zambia
musengedanny@gmail.com

Abstract— a research was conducted in north-west of Lusaka, Chunga, Matero area to test garlic (*Allium sativum*) intercropped with tomato (*Solanum lycopersicum*) plants to repel aphids (*Homiptera; aphididae*). The tomato plants and the garlic were intercropped on a *2m* by *3.5m* plot in a Randomized Complete Block Design, (*according to Clewer, A. G., and D. H. Scarisbrick.2001*) using conservation tillage to promote water retention and bioactivity in the soil. The project was done in the period of 4 months from October *2018* to January *2019.* Land preparation was done two weeks before planting by making basins with a hand hoe and breaking the pebbles with a garden folk, then 1kg chicken manure was applied in advance to allow it mix and decompose in the soil and irrigation was done using a hosepipe in each basin. The project had two treatments, the space between treatment 1 and treatment 2 was 1m, to avoid treatment 2 from being affected by the volatile garlic which was close to tomato plant in treatment 1, as treatment 2 was the control. The parameter that was observed is the number of aphids on tomato leaves after planting of tomato plants (as garlic is planted earlier to allow its leaves to grow enough to have the volatile effect). Data collected showed that in the first 6 weeks after planting, aphids delayed to show up on tomato plants, but showed up in the 7^{th} week to 12^{th} week with a higher aphid count on treatment 2. After analysis H_0 proved to be true, hence the researcher concluded basing on research findings that the resource-poor kitchen garden farmers can therefore implement the method of intercropping garlic with their tomato plant as an integrated pest management
to control the aphid population because the intercropping method can significantly reduce

the aphid population, thus reducing the incidences of spraying. Garlic has also proved to be environmentally friendly.

Key words.

Testing, Integrate, Intercropping, Aphids.

I. INTRODUCTION

Tomato (*Solanum lycopersicum L.*) an herbaceous plant of the botanical family solanacae and can be green, yellow or red, the tomato is a widely cultivated crop throughout the world and was introduced to Europe by Spaniards who brought it from Peru and Mexico in the 16th century. However it took more than 200 years for tomato to be accepted in Europe as it is similar to the red fruit of belladonna, a toxic plant of the same botanical family and it led to a belief that it is poisonous, in fact the tomato which is both a fruit and a vegetable was not accepted until the 20th century (Pamplona-Roger 2008). Its nutritional value contains a great deal of water 94 % of its weight, carbohydrates are minimal at 3.54 %, proteins at 0.85 %, fats at 0.33 % but it has a high nutritional value in vitamins, vitamin C is at 19.1mg, pro-vitamin A 62mg and vitamin $B_{1,}$ B_2 B_6 are present with minerals such as potassium 222mg, iron 0.45mg, and phosphorous (ibid). However, the tomato is prone to pest infestation including aphids (*Hemipteran; aphididae*) that attack a tender stage as the plant has tender stems and leaves. In Zambia both subsistence and commercial farmers cultivate it for trade as it is on demand. Due to their asexual and sexual reproduction, they are capable of an extremely rapid increase in numbers. In addition, these insects can transmit viruses and/or bacteria (Dedryver 2010). The damage they cause can be very significant, and cause real economic problems for producers since crops become unsuitable for consumption with poor quality (ibid). Synthetic chemicals are widely used but not everyone can afford to buy them, moreover synthetic chemical through research have been known to pollute the environment by leaving residues in the soil and harvested crop, even killing beneficial biodiversity thus harming both the environment and human life (Foster 2002).This has brought the need for a way control pests by intercropping. Intercropping considers the agricultural practices of cultivating two or more crops in the same habitat. It is commonly used in tropical zones. Intercropping may demonstrate reliable crop yield for the treatment of related pests (Lithourgidis 2011). Intercropping of compatible plants can attract or draw aphids away from the target plant, and this is attributed to companion plant volatiles since they disturb the aphid host plant location, and they react chemically and physiologically with the host plant making it unsuitable for aphids (Moreno, Racelis 2015). In addition, intercropping encourages biodiversity, by providing a habitat for a variety of insects and soil bio-components that would not occur in a

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single crop inhabiting selected environment. This biodiversity can in turn help to limit outbreaks of crop pests, by increasing the diversity of abundance of related natural enemies (Brooker 2015). In Chunga, north-west of Lusaka, Zambia, households that cultivate in kitchen gardens have resorted to cultivating vegetables that are not prone to aphid attack as the area is infested with the pest. Aphids *(Homiptera; aphididae*) are among the most destructive pests in cultivated plants worldwide.

The main research objective was to:

1. To determine the effectiveness of garlic in the control of aphids by intercropping it with tomato.

The specific objectives were:

1. To establish a cheaper means of controlling the aphid population.
2. To encourage the use of organic oriented integrated pest management.

Hypothesis Testing

Hypothesis

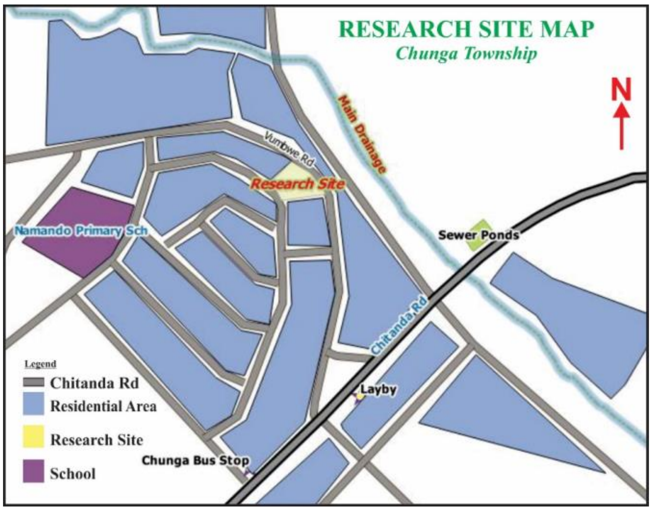
H_0. Garlic is effective in reducing the aphid population.

$H_0 = M_1 = 0$.

H_1. Garlic is not effective in reducing aphid population.

$H_1 = M_1 \neq 0$.

Location of the study: The testing was done within Lusaka in Chunga area, which is the north-western part of Lusaka as shown figure 1:



Source: google earth Map, digitalized through QGIS

Materials and Methods

Research Methods

The tomato plants and the garlic were intercropped on a 2m by 3.5m plot measured with a measuring tape, in a Randomized Complete Block Design (Clewer, A. G., and D. H. Scarisbrick. 2001), using conservation tillage for moisture preservation and to promote bioactivity in the soil. The project was done in the period of 4 months from October 2018 to January 2019. Land preparation was done two weeks before planting by making basins with a hand hoe and breaking the pebbles with a garden folk, then 1kg chicken manure and water irrigated with a hosepipe were added in each basin in advance to allow it mix and decompose in the soil. After two weeks garlic seedlings were plated first to allow them grow to a size that would emit volatile to so that the tomato for treatment $_1$ will be planted where volatile

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activity already exists. Treatment $_1$ basins were chosen randomly using the random numbers on the random table, a month later tomato seedlings were planted for the remaining basins without garlic plants, and so the project had two treatments, the space between treatment 1 and treatment 2 was 1m, to avoid treatment 2 from being affected by the volatile garlic which was close to tomato plant in treatment 1, and the space between the garlic and the tomato plant in treatment 1 was 25cm which is close enough to observe the volatile effect of garlic. The parameter that was observed is the number of aphids on tomato leaves after planting of tomato plants (as garlic is planted earlier to allow its leaves to grow enough to have the volatile effect). The intercropping was done in such a way that treatment 1tomato plant was planted in the middle of four (4) garlic plants and treatment 2 was the tomato plant only. The topography of the area is hilly therefore care was taken to level the basins in order to ensure equal amounts of water for both T_1 and T_2 using a hosepipe for irrigation.

Research Design

Table 1 shows Randomized complete block design which was used with two treatments.

T_2	**T_1**	**T_2**	**T_2**	**T_2**	**T_1**

T_2	**T_2**	**T_1**	**T_2**	**T_2**	**T_1**

Data Collection

Collection of data was done manually by counting number of aphids on the plant using a magnifying glass and the number of aphids was as shown below:

Table 2 shows Number of aphids in the 1st to 6th week.

Variety	Blocks					
	I	**II**	**III**	**IV**	**V**	**VI**
Treatment$_1$	0	0	0	0	0	0
Treatment$_2$	0	0	0	0	0	0
Total						

Table 3 shows number of aphids in the 7st to 8th week.

Variety	Blocks					
	I	**II**	**III**	**IV**	**V**	**VI**
Treatment$_1$	0	0	0	0	0	0
Treatment$_2$	2	1	3	0	0	0
Total	2	1	3			

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Table 4 shows number of aphids in the 9th to 10th week.

Variety	Blocks					
	I	**II**	**III**	**IV**	**V**	**VI**
Treatment1	0	0	4	1	2	0
Treatment2	8	5	9	0	1	0
Total	9	5	13	1	1	

Table 5 number of aphids in the 11th to 12th week.

Variety	Blocks					
	I	**II**	**III**	**IV**	**V**	**VI**
Treatment1	0	0	13	3	2	0
Treatment2	22	10	25	0	4	0
Total	22	10	38	3	6	

Statistical Analysis

Analysis of data was done using data that was collected from 7th to 12th week (because that's when the aphids showed up) by using ANOVA table as shown in the tables below.

Table 6 shows analysis of data in the 7th to 8th week.

Source of vrtn	Dgrs of frdm	Sum of sqrs	Mean of sqrs	F ca	F tab F (0.05,1,1)
Treatment	1	3	3	3.75	F_{tab} =4.96
Error	10	8	0.8		
Total	11	11			

Vrtn is Variation, Dgrs is variation, frdm is freedom sqrs is squares, ca is calculated, and tab is tabulated. Table 7 shows analysis of data in the 7th to 8th week.

Source of vrtn	Dgrs of frdm	Sum of sqrs	Mean of sqrs	F ca	F tab F (0.05,1,5)
Blocks	5	4	0.8	0.27	F_{tab} = 6.61
Treatment	1	3	3	3.75	
Error	5	4	0.8		
Total	11	11			

Vrtn is Variation, Dgrs is variation, frdm is freedom sqrs is squares, ca is calculated, and tab is tabulated.

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The tables 6 and 7 above show the analysis of data starting from 7th to 8th week, the results showed that F calculated was 3.75< F tabulated 6.61 under 0.05 level of significance.

Table 8 shows analysis of data in the 9th to 10th week

Source of vrtn	Dgrs of frdm	Sum of sqrs	Mean of sqrs	F ca	F tab F (0.05, 1,10)
Treatment	1	18.7	18.7	1.8	F_{tab}=4.96
Error	10	102.2	10.22		
Total	11	120.9			

Vrtn is Variation, Dgrs is variation, frdm is freedom sqrs is squares, ca is calculated, and tab is tabulated.

Table 9 shows analysis of data in the 9th to 10th week.

Source of vrtn	Dgrs of frdm	Sum of sqrs	Mean of sqrs	F ca	F tab F (0.05,1, 5)
Blocks	5	63.9	12.78	0.68	F_{tab}= (6.61)
Treatment	1	18.7	18.7	2.4	
Error	5	38.3	7.66		
Total	11	120.9			

Vrtn is Variation, Dgrs is variation, frdm is freedom sqrs is squares, ca is calculated, and tab is tabulated.

The tables 8 and 9 above show the analysis of data in the 9th and 10th week, the results show that F calculated 2.4 < F tabulated 6.61 under 0.05 level of significance.

Table 10. shows analysis of data in the 11th to 12th week

Source of vrtn	Dgrs of frdm	Sum of sqrs	Mean of sqrs	F ca	Ftab F (0.05,1,1)
Treatment	1	154.08	154.08	2.1	F_{tab} =4.96
Error	10	732.84	73.3		
Total	11				

Vrtn is Variation, Dgrs is variation, frdm is freedom sqrs is squares, ca is calculated, and tab is tabulated

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Table 11. Shows analysis of data in the 11th to 12th week.

Source of vrtn	Dgrs of frdm	Sum of sqrs	Mean of sqrs	F ca	F tab F (0.05,1, 5)
Blocks	5	516.42	103.28	0.67	F_{tab}= 6.61
Treatment	1	154.08	154.08	3.56	
Error	5	216.42	43.28		
Total	11	886.92			

Vrtn is Variation, Dgrs is variation, frdm is freedom sqrs is squares, ca is calculated, and tab is tabulated.

Tables 10 and 11. Show the analysis of data in the 11th and 12th week, the results show that F calculated 3.56 < F tabulated 6.61 under 0.05 level of significance.

Therefore, since in all cases F calculated is less than F tabulated, there was insufficient evidence to reject H_0 and I concluded that H_1 is false.

The bar charts below show the differences between F calculated and F tabulated in cumulative weeks, as calculations decreased further.

Figure 2.

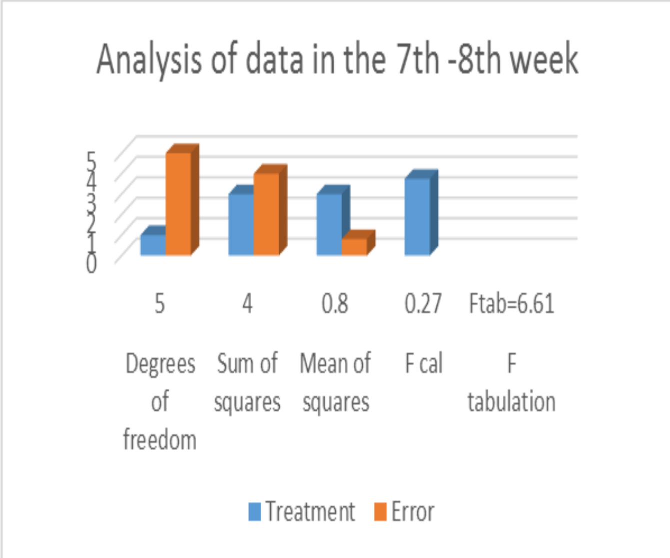


Figure 3.

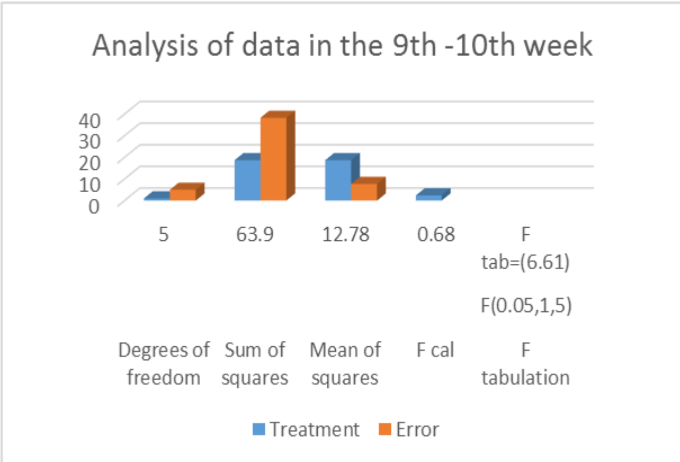
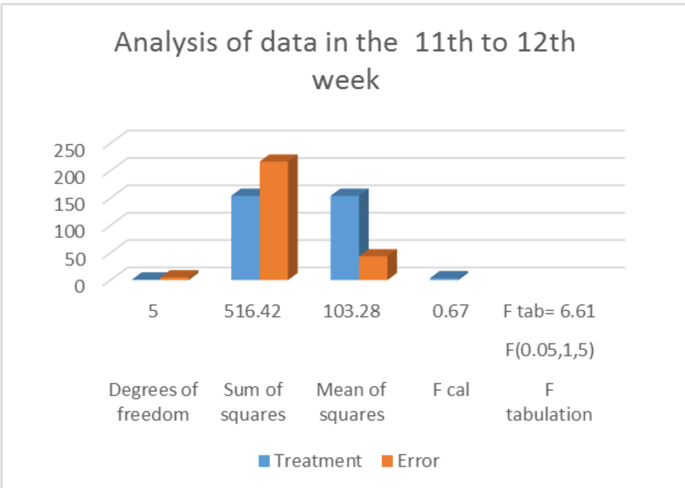


Figure 4.



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From the bar charts, the decreasing further of F-calculated just confirmed the fact that we had insufficient evidence to reject H_0 which stated that garlic is effective in reducing the aphid population hence reject H_1 which stated that garlic is not effective in reducing the aphid population which is false.

Results And Discussion.

The project had two treatments, the space between treatment 1 and treatment 2 was 1m, to avoid treatment 2 from being affected by the volatile garlic which was close to tomato plant in treatment 1, and the space between the garlic and the tomato plant in treatment 1 was 25cm which is close enough to observe the volatile effect of garlic. The parameter that was observed is the number of aphids on tomato plants` after planting of tomatoes (as garlic is planted earlier to allow its leaves to grow enough to have the volatile effect). The intercropping was done in such a way that treatment 1tomato plant was planted in the middle of four (4) garlic plants and treatment 2 was the tomato plant only. The topography of the area is hilly therefore care was taken to level the basins in order to ensure equal amounts of water for both T_1 and T_2 using a hosepipe for irrigation. Data collected showed that in the first 6 weeks after planting, aphids delayed to show up on tomato plants. However in the seventh and eighth week they showed up with the first ones being on treatment two, data count was consistent for the next two weeks and changed, increasing a bit from the previous counts done, in the ninth and tenth week thus again for two weeks data showed the same number of aphids, then in the eleventh and twelfth week data counts increased a bit and was consistent in two weeks' time. The data however had a higher number of aphids on treatment $_2$ compared to treatment $_1$. The result after the analysis using the ANOVA table (Clewer, A. G., and D. H. Scarisbrick. 2001), showed that garlic had significant effect in controlling the aphid population on treatment$_1$ compared to treatment$_2$ (with monoculture) that had a high aphid population.

The analysis in the seventh and eighth week showed that F calculated was 3.75 < F tabulated 6.6, in the ninth and tenth week the result was F calculated 2.4< F tabulated 6.6 and the eleventh and twelfth week the results showed F calculated 3.6 < F tabulated 6.6, all of them under 0.05 level of significance, therefore the conclusion was that we accepted the H_0 hypothesis since in all cases F calculated is < F tabulated hence rejecting the H_1 hypothesis as it was false. In this case we can conclude further basing on research findings that the resource-poor kitchen garden farmers can therefore implement the method of intercropping garlic with their tomato plants as an integrated pest management to control the aphid population because it has been proven through research findings that intercropping control methods can be an important component of integrated pest management (IPM) programs since it reduces the aphid population significantly.

In comparison to this research Patterson 2014. Confirms that garlic (Allium sativum), has natural fungicidal and pesticide properties that work effectively to control pests, makes an excellent economical, non-toxic biological pesticide for use in agriculture. The natural pesticide (garlic) has a strong aroma that can provide an olfactory camouflage against insects, masking their normal host-finding or feeding cues (Perrin and Phillips, 1978). Aphids, ants, termites, white flies, beetles, borers, caterpillars, slugs and army worms are some of the pests that can be suitably controlled using garlic (Kaluwa and Kruger, 2012).

According to Brooker 2015 intercropping encourages biodiversity by providing a habitat for a variety of insects and soil bio-components that would not occur in a single crop inhabiting selected environment as it has been proven the research studies reviewed with different environmental factors that affected them. This biodiversity can in turn help to limit outbreaks of crop pests, by increasing the diversity of abundance of related natural enemies (ibid), hence improve production. Moreover Awal 2006 confirms that intercropping is a simple and inexpensive strategy and has been recognized as a potentially befitted technology to increase crop production due to its substantial yield advantage than sole cropping. The purpose of intercropping is to generate beneficial biological interactions between the crops. Intercropping can increase yields, more efficiently use available resources, reduce weed, insect and disease pressures and provide greater biological and economic stability (Vander Meer 1989). According to research scientists, companion plant odors can mask host plant odor and make them unsuitable resources. This concept was firstly developed by Tahvavainen and Root associational resistance and was then supported by other researchers (Thiery D. and Visser J.H. Different forms of action on aphids, on host plant or volatiles released by host plant have been proposed to explain it. However, many studies using chemicals have shown this potential masking effect of non-aphid host plant only a few studies were run with living companion plant, it was discovered that "masking is a disturbance of the attractive complex by artificially changing the relative proportion of the components". Therefore, the insects receive different chemical information and cannot locate their host plant (Schröder 2008). The masking effect results from the inhibition of the locomotive aphid movements toward an attractant source, so volatiles emitted by companion plant are masking substances that reduce the ability of aphids to find their host plant (ibid). Mechanisms which explain the interference between host and non –host plant are not well known but have been explained in many cases, by a neutralization of the behavioral responses using repellent compounds working with whole living companion plant are rare. However, resent research has shown that Plants are able to sense changes in their environment and adjust their morphology, physiology and phenotype accordingly (Trewavas 2005). There are a number of stimuli that plants perceive and can react to: chemicals, temperature, light, moisture, gravity, pathogens, physical disruption and touch (Osakabe 2013). Reduction in the red to far-red ratio of canopy light can be used by plants as a warning signal of future competition (Keukamp 2010), however according to Ninkovic in his study, they observed that changes in aphid migration in the field occurred at the early seedling stage of plants, so plant responses to shading are unlikely to have contributed to the changed aphid behavior in the field. Plants are able to detect volatile organic compounds released from herbivore damage plants and these herbivore-induced volatile organic compounds (VOC_S) play important roles in interactions between plants and arthropods (Dicke 2009). Many studies have shown that intact plants growing in the neighborhood of a damaged VOC-releasing plant respond to these chemical cues with biochemical changes (Kessler 2006). Neighboring plants can respond to VOCs by changing transcription patterns of defense-related genes (Arimura 2002), and they May increase the production of hormones and other VOCs (Engelberth 2004). This phenomenon has been defined as a prophylactic reaction. Toward future herbivore attack (Dicke 2001). The study according to Ninkovic shows that for the first-time plants also respond to VOCs from undamaged neighbors, broadening the potential ecological significance of plant-plant chemical interaction. If these adaptations involve changes in plant physiology, then herbivores that are sensitive to host quality, such as winged aphids, may be able to detect and respond to them. This represents a novel mechanism by which the structure of plant communities can affect insect herbivores.

Amarawardana 2007 proposed a test in a cage chamber to demonstrate how whole companion plant odor and affects green peach aphid (myzus persicae) behavior. The study showed that M. Persicae is normally attracted by their host plant (sweet pepper, capsicum annum) and repelled by the odor of chives (Allium schoenoprasum). When the odors of the two plants are blended, aphids were neither attracted nor repelled by their plant host, but five days later the sweet pepper alone became repellent to the aphids. Authors suggested that the odor of chives adheres on the leaves of sweet pepper, masking its odor and preventing sweet pepper identification by the aphid (ibid). The simplest explanation is an interaction between the

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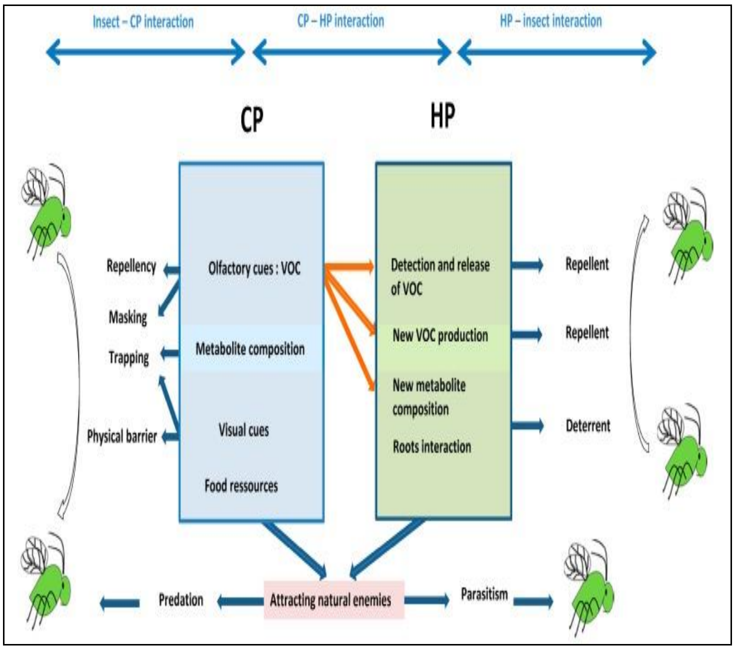
companion plant and host plant that generate an odor blend unrecognizable by aphids. In fact, the process is more complex and the odor perception by aphids and their behavioral response may depend on the nature, quantity and the proportion of components present in the mixture. For example, Zaka etal 2009, found that the response to odor was dose-dependent, and the dose of volatiles had to be increased to achieve an effective level against pests. Thus the presence of a repellent volatile in a companion plant profile does not guarantee that this plant is effective (Ben Issa 2016), as the effect of a volatile compound may change with its concentration and its effect may be influenced by other compounds via synergy, suppression (masking effect, or hypoadditivity (the more attractive effect of host plant) (Duchamp-Viret 2003).

Apart from companion plants having masking odor effect they may also possess a repellent effect depending on the type of companion plant used. According to Bruce 2005, repellent plants are defined as neighboring non-host plant that disrupt insect behavior and avoid feeding activity on host plant. In many cases the repellent effect of companion plant was mentioned to explain lower aphid colonization on their host. However, companion plant repellency has not been experimentally supported. Indeed, Finch and collier, 2012, developed a biological approach based on the hypothesis that insects only react to volatiles emitted by their host plant; those from non-host plant are chemically neutral. Hence, they believed that using companion plant is only effective when insects land on them (inappropriate landings) and suggested that it is their green leaves and not their odor that disrupt insect behavior. This theory was not supported by other reports, which showed that insects can detect and distinguish host and non-host odors to manage their movement. For example, researchers tested volatiles of plants to detect the reception of aphids as well as their relative reaction (ibid). Results showed that electroantennogram responses differed between aphid species. Also, laboratory assays found that aphids can individually select their host plant from a wide range of non-host vegetation. Recently, evidence of the role of volatiles from living companion plant was provided by olfactory tests, (Ben Issa 2012). In the field, Lai conducted an experiment over two years by planting white garlic *(allium sativum*) one month before transplanting tobacco plant *(Nicotiana tabacum)*. The appearance of winged green peach aphids (*Persicae*) was delaying in the host crop and their abundance was decreased even during the aphid peak period, thereby reducing tobacco mosaic virus transmission as compared with monoculture (ibid) Authors suggested a repellent effect of garlic volatiles on aphids. When the habitat contains repellent volatiles, these may rescind host location and require aphids to change their orientation. Similar effects were obtained with mustard aphids *(Lipaphis erysimi*) by intercropping mustard (*Brassica napus*) with onion *(Allium cepa*) and garlic (*A. Sativum*) in different ratios (Sarker 2009). The strong aphid-repelling action of allium spp. Is well established, (Mutiga 2010). It could be connected with the high sulfur compounds *(94 %).* These compounds are degradation products of alkyl sulfate, which are known for their protective potential against storage insects (ibid).

According to Ben-Issa et al using companion plants in intercropping with target crops is a promising alternative method to chemicals to improve aphid management. According to research findings they have shown that many companion planting schemes have been designed to reduce the aphid management, they have also shown that many companion planting schemes have been considered (in the figure below).However the choice of adapted companion plant remains an issue and their efficacy might not be guaranteed in all cases (Moreno 2015). Indeed, many factors that affect the success of an intercropping system design need to be considered. For instance, intercropping companion plants may take several forms, and its efficiency may depend on the arrangement, the density, and the distance between companion plant and host plant (Ben Isa 2017). Similarly, the timing of the most effective phonological stage of companion plant with respect to the aphid life cycle must be taken into account (ibid). A companion plant also should not offer a home for other pests per se (Heil 2009), and a companion plant needs to be in the most appropriate phonological stage to provide shelter and food resources, especially for early natural enemies such as hoverflies (Dib 2017).

Figure.5. Potential interactions between companion plants, aphids, natural enemies, and host plants. Companion plant, host plant volatile organic compound.



Source: Ben-Issa 2017.

On the other hand, using companion plant in a crop system may create constraints for farmers

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(for example with respect to tillage and irrigation). Therefore, the choice of companion plant may depend on their economic return. For example, aromatic or medicinal plants may be harvested to offset part of the costs and provide a direct income. Ben-Issa et al suggest that companion plant be introduced and tested at different scales (in greenhouses or orchards, for example) as they can be used without reducing the space. They have noted in their previous experiment that sweet pepper can be commercially produced under protected environments using companion plants (Ben Isa 2017).

Companion plants may work simultaneously, influencing both top-down (i.e. reinforcing host plant defense) and bottom-up (i.e. enhancing biological control) mechanisms. In several cases companion plants have been shown to simultaneously have a repellent effect against pests and an attractive effect on natural enemies (Song 2010), which might be useful to enhance the functionality of companion plants. In addition, several push-pull systems with trap crops have been successfully combined with repellent plants. Further research is needed in order to test the potential effect of combined companion plants. For example, introducing flowering plants within fields may enhance the abundance of natural enemies and simultaneously create barriers to aphids. Additionally, the selection of an adequate oviposition site by natural enemies such as *Syrphidae* females, that is, the laying of eggs close to an aphid colony, is essential to the survival and development of their offspring (Dib 2017). In this case, the presence of trap plants near companion plant that attract natural enemies may be of potential interest.

Ben-Issa has shown that the host plant location is a crucial factor in the life cycle of aphids as well as a critical element for crop protection. Indeed, the presence of companion plant appears to be a preventive intervention with regard to the sensitivity of the winged aphids to companion plant volatiles. For example, the presence of a companion plant may prevent aphid colonization or delay their settlement during the spring and autumnal return, and consequently reduce the number of sprays needed during periods of lower aphid activity (ibid). Many laboratory trials have demonstrated the efficiency of certain companion plant due to their volatiles. However, under field conditions and due to the fluctuations of abiotic factors, the concentration of volatiles might not be enough to disturb aphid host selection. Optimizing volatile emission may be a solution to make them more effective. Indeed, the production of volatiles is sensitive to several environmental factors (Filella 2009). For instance, their production may be affected by water availability. A water deficit (4 days) decreases the emission of sesquiterpenes from rosemary plant (R. officinalis) (ibid). Clipping of companion plants can also promote volatile emission and essential oil production (Ramesh 2008). According to Ben-Issa it is clear that there is still much work to be done in order to optimize the services provided by the intercropping of companion plant in crop systems, they believe that using only a companion plant strategy will not completely replace chemical control or provide satisfactory control because of only partial effectiveness, which may be limited by several constraints (climatic conditions, companion plant density, companion plant phenology). However, the researcher has also concluded that the use of companion plant can be associated with other integrated pest management approaches (i.e. use of resistant host plants, spraying of extracts and essential oils, early release of natural enemies and use of Alt' carpo nets).

With regard to aphid olfactory responses, according to Ninkovic V, 2013 Changes in plant volatile emission can be induced by exposure to volatiles from neighbouring insect-attacked plants. However, plants are also exposed to volatiles from unattacked neighbours, and the consequences of this have not been explored. (ibid). The researcher investigated whether volatile exchange between undamaged plants affects volatile emission and plant-insect interaction. Consistently greater quantities of two terpenoids were found in the headspace of potato previously exposed to volatiles from undamaged onion plants identified by mass spectrometry. Using live plants and synthetic blends mimicking exposed and unexposed potato, the researcher tested the olfactory response of winged aphids, Myzus persicae. The altered potato volatile profile deterred aphids in laboratory experiments, Ninkovic V. 2013.showed that growing potato together with onion in the field reduces the abundance of winged, host-seeking aphids. Their study broadened the ecological significance of the phenomenon; volatiles carrying not only information on whether or not neighbouring plants are under attack, but also information on the emitter plants themselves. In this way responding plants could obtain information on whether the neighbouring plant is a competitive threat and can accordingly adjust their growth towards it. According to the researcher, this was interpreted as a response in the process of adaptation towards neighbouring plants. Furthermore, these physiological changes in the responding plants have significant ecological impact, as behaviour of aphids was affected. Since herbivore host plants are potentially under constant exposure to these volatiles, their study had major implications for the understanding of how mechanisms within plant communities affect insects. This knowledge could be used to improve plant protection and increase scientific understanding of communication between plants and its impact on other organisms (ibid).

Volatile organic compounds (VOCs) released by herbivore damaged plants are involved in a wide range of interactions and play important roles in coexistence between plants and organisms on other trophic levels. They can repel herbivores and attract the herbivore's natural enemies (Hare 2011). They are also involved in rapid defence signaling and neighbouring plants can eavesdrop on them, inducing their own defences and changing their volatile profiles (Heil M, Ton J. 2008). Ninkovic V. 2003 confirms that plants release VOCs even when they are not attacked or mechanically damaged, and these volatiles are available as cues for neighbouring plants. Studies have shown that plants can respond to undamaged neighbours via chemical signals and that these responses affect patterns of growth and biomass allocation. Plants are limited in their ability to choose their neighbours but they are able to sense their environment, and volatile cues may be one of several ways in which they gather information about neighbours and respond with appropriate morphological and physiological responses (Kegge W, Pierk 2010). Plants that grow in high canopy density can also detect neighbours through changes in light quality, which can induce a set of phenotypic traits associated with shade avoidance (Kemskamp et al 2010). Recently it has been shown that volatile chemical exchange between unattacked plants can affect the receiving plant's interaction with insect herbivores (Glinwood etal 2011). Thus, volatile exchange between plant individuals within stands may affect insect host choice.

Russel E.P 1991 confirms that intercropping which is the practice of growing two or more crops in proximity, can offer advantages in terms of pest control, and a range of mechanistic explanations have been proposed to explain the effects on insect colonization and population development. A role for plant volatiles has been both questioned and supported Finch S, Collier R.H 2012). However, while direct effects of host volatiles on insects have been considered, the possibility that volatile interaction between plants can affect insect host choice through changes in the receiving plant has not been addressed (Hassanali et al 2008).

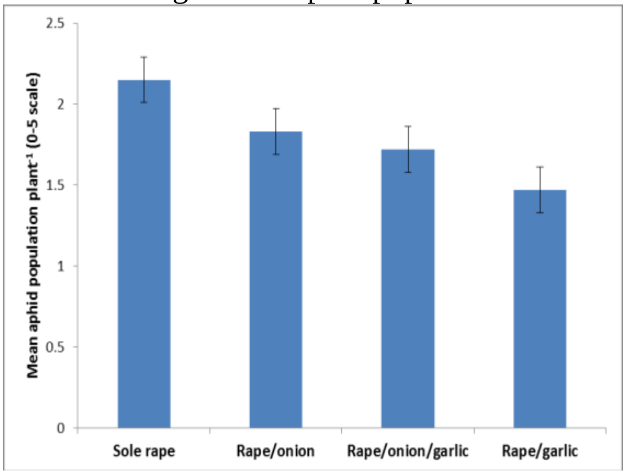
The aim of this study was to investigate whether volatile transfer between undamaged plants can contribute to the effects of intercropping on herbivores. The researchers tested this idea in a system consisting of potato (Solanum tuberosum L.) intercropped with onion (Allium cepa L.) or garlic (Allium sativum L.), and the green peach aphid Myzus persicae (Sulzer), which uses potato as a host plant. Aphids are an ideal model herbivore since they are major insectpests in many crops and are sensitive to changes in host plant quality (Petterson et al 2007). In a field experiment the researcher measured aphid migration into plots of intercropped potatoes and potatoes in pure stands. In laboratory studies they investigated whether exposure of potato to volatiles from neighbouring onion plants influenced aphid olfactory orientation via induced changes in potato volatile emission. The hypothesis was that volatile exchange between unattacked plants can reduce insect herbivore attraction to an intercrop. According to the researcher, they found that exposing potato to VOCs from undamaged onion plants altered its volatile profile and this had a deterrent effect against host-seeking M. persicae. In a field experiment, migration of aphids into potato was significantly reduced by intercropping with onion. Their findings represented a novel bottom-up effect of plant co-existence on insect herbivores and provide new evidence of the role of chemically-mediated mechanisms in intercropping.

Results of the study regarding flight activity of aphids in the field was that the emergence of potatoes coincided with the peak of aphid flight because of dry weather conditions after sowing. For this reason, the greatest number of M. persicae was observed at the first observation occasion and then successively decreased until the middle of July after which aphid flight activity was sporadic.

Apart from the research studies that were conducted on a global scale, in the southern African region a trial was conducted at the Midlands State University Research Field in Zimbabwe (2013) by Innocent Pahla to determine the effectiveness of intercropping rape with garlic (Allium sativum) and onion (Allium cepa) on cabbage aphid infestation and yield of rape (Brassica nupus), Giant rape. The experiment was laid out as a Randomized complete block design with 4 treatments (sole cropped rape, rape + onion intercrop, rape + garlic + intercrop and onion + garlic + rape intercrop) replicated 5 times. Data was collected on aphid counts; cumulative rape mass and rape leaf damage was collected from week 3 to 6 after planting.

According to Innocent Pahla effects of intercropping rape with garlic and onion on aphid infestation; results showed that intercropping rape with garlic and onion had a significant ($p<0.001$) effect on aphid population throughout the data collection period except in week 1 (week 3 after planting rape), thus the researcher confirms that garlic has repelling effects on aphid population. Aphid populations in sole cropped rape exponentially increased from week 4 and had the highest number of aphids from week 4 to week 6. Garlic + rape recorded the least aphid populations throughout the experiment followed by garlic + onion + rape and onion + rape (ibid). Data collected from onion + rape treatment was significantly different from garlic + rape from week 4 to week 6. Garlic + onion + rape treatment was however not significantly different from any of the other 2 intercrop treatments from week 4 to week 6.

Fig.7. Effect of intercropping rape with onion and garlic on aphid population



Source: Pahla 2014.

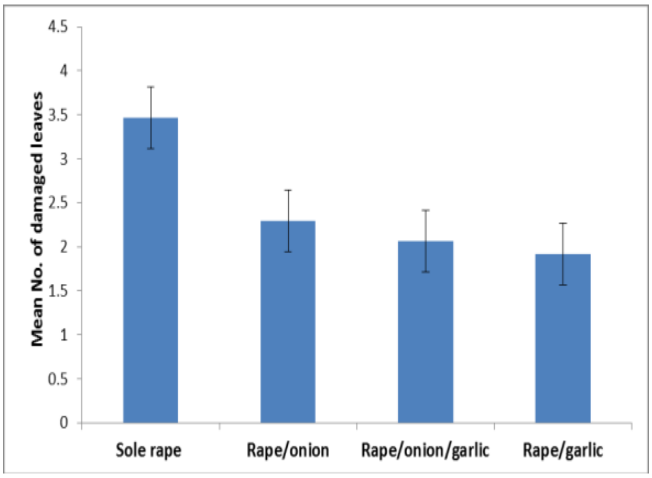
No significant differences on aphid population amongst all treatments were observed in the first week of data collection (week 3 after planting rape). This could have been a result of the stage of development of the intercrops (garlic and onion) which was possibly still premature to render any notable repellent effect on pests. However, from week 4 onwards, intercrop treatments significantly reduced aphid population as compared to sole cropped rape. This could have been a result of the improved exhibition of repellent characteristics by the intercrops. Aphids are wingless but can produce wings and fly away when food resources are limited (Dube., 1998) hence low aphid populations on intercropped treatments can be attributed to the repellent effect of garlic and onion which could have led to migration of the aphids to other target areas.

Highest aphid populations noted in the sole cropped rape treatment through the sampling period concur with findings by Minja. (2001) who observed that if aphid population is left unchecked, they multiply enormously and are only limited by food source besides other selection pressures. Mudzingwa. (2013) reported that the rapid aphid proliferation could be attributed to their rapid development time (8-12 days) from first instar nymph to adult, possible reproduction in absence of males and extended reproductive life span (30 days at 5-6 nymphs day-1).According to the researcher, high aphid population in sole cropped rape plants also complements findings by Hai-bo. (2013) who observed that monoculture plants show more aphids than intercrops as a result of lack of any protective measure against pests.

Mudzingwa 2013 also confirms that effectiveness of garlic in reducing aphid population can be attributed to the fact that the plant contains a group of closely related compounds (allicin) which are responsible for the pesticidal properties and repellence against aphids. This is due to the presence of Sulphur containing amino acid derivatives in garlic which reacts with the enzyme allinase to form allicin and other Sulphur compounds. Allicin breaks down into Diallyl disulphide, which is largely responsible for the pungent garlic odour. This is in agreement with findings by Sarker. (2007) who noted that garlic intercrop treatments showed positive effectiveness as evidenced by lowest aphid population because of the high levels of volatile substances (allicin) that repel aphids. Simmonds. (1992) reported that *Allium* spp. are very effective antifeedant and Kirtikar and Basu (1975) reported that *Allium* spp. have strong pungent repelling action. Therefore, the differences in the efficacies of the treatments are a result of the differences in the physical properties and potency of the active compounds in the various treatments used. These results are similar to Asare-Bediako. (2010) who reported that onion and garlic intercropping systems were also found to have repellent effects on diamond back moth to reduce pest's populations because the company plants act as physical barriers to the movement of the insect pest, natural enemies are more abundant and/or the chemical or visual communication between DBM and the cabbage is disrupted.

Effect of intercropping rape with garlic and onion on leaf damage: According to the researcher, there were significant differences (p=0.001) in leaf damage from week 3 to week 6. However, there were no significant differences amongst all intercrop treatments. Garlic + rape recorded the lowest mean leaf damage compared to all other treatments with sole cropped rape treatment recording the highest number of aphid damaged leaves thus the lowest number of marketable leaves.

Figure. 8: Effect of intercropping rape with garlic and onion on leaf damage



Source: Pahla 2014.

Sole cropped rape had the highest leaf damage which can be attributed to the highest aphid population observed and generally the diversity of pests that affected rape plants in this treatment. This is consistent with Townsend (2013) who reported that leaves become severely distorted when the saliva of aphids are injected into it. Hamman (1985) observed that if left unchecked, aphids in agro-ecology can deform and discolor or cause galls on leaves hence high leaf damage. Most of these sap sucking pests cause shriveling and wilting of leaves as a result of their feeding habits. The results are also similar to the findings of (Asare-Bediako., 2010) who observed that lower leaf and head damage accompanied with a higher yield were reported in cases of intercropping cabbage with onion and tomato. Yellowing of leaves which was the other determinant of unmarketability and damage of leaves could have been a result of low nutrient levels caused

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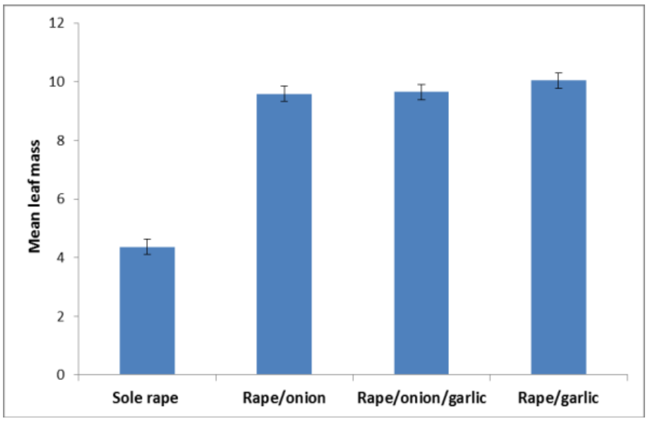
by slow release of nutrients by cattle manure which was the only source of nutrients. Garlic and onion alter pest host finding behavior (Nottingham, 1987) and they deter insects' olfactory organs (Calvo-Gomez, 2004) leading to reduction in leaf damage. Moreover, natural enemies can be abundant in intercrops and the intercrops block visual communication between insect and host plant (Asare-Bediako., 2010) hence low leaf damage.

Effect of intercropping rape with garlic and onion on mean cumulative leaf mass: Significant effect ($p<0.001$) was observed on the effect of intercropping on cumulative mean rape leaf mass between sole rape and all the intercrops throughout the experimental period. Sole cropped rape recorded the lowest cumulative mean leaf mass, with garlic + rape treatment recording the highest cumulative mean leaf mass. No significant differences on cumulative leaf mass were however observed amongst the 3 intercrops. Below is the table showing the effect of onion and garlic on cumulative rape leaf mas

Figure.9: Source: Pahla 2014



The highest yields were obtained from garlic + rape intercrop, whilst sole cropped rape had the least. This could be attributed to the fact that rape plants under garlic or onion intercrops benefited indirectly from low aphid population and low damage level thus increasing yields. This is due to the repellency effect of garlic and onion on various microorganisms. The low mean cumulative fresh mass in sole cropped rape plants can be explained by the fact that aphids extract photosynthates from plant tissue and excrete toxic compounds which affect the growth of the plant. This is in agreement with Minja. (2001) who reported that aphid infestation and feeding damage results in curling and yellowing of leaves and stunted plant growth which in turn reduce leaf area index and consequently the quantities of carbohydrates that contribute to plant biomass resulting in lower fresh leaf yields of rape. The greater the number of aphids that feed on the plant, the greater the amount of assimilates that are extracted from the plant. These assimilates are vital raw materials for cell division and cell elongation which determine the eventual growth, development and yield of the rape crop (Borror., 1976; Mudzingwa., 2013). All these characteristics combined give rape plants intercropped with garlic or garlic + onion combination a greater yield advantage since they reduce aphid populations.

The study by Innocent showed that intercropping rape with garlic and onion is effective in controlling aphids and improving rape yield, with garlic being the most effective intercrop as evidenced by lowest aphid population, lowest leaf damage and highest rape fresh leaf mass. Garlic and onion intercrops can thus be utilized as good non-chemical and environmentally friendly aphid control alternatives to insecticides, recommendable for adoption by resource poor Small holder vegetable growers in Zimbabwe.

The results showed that intercropping rape with garlic and onion had significant ($p<0.001$) effect on rape fresh mass, leaf damage and aphid population. Intercropping rape with garlic recorded the lowest aphid population, least leaf damage and highest leaf mass as compared to all other treatments. However, results from intercropping rape with garlic and onion were not significantly different from intercropping rape with garlic. Basing on the research findings, the researcher concluded that intercropping with garlic is an effective practice in the control of aphids in rape recommendable for adoption by resource-poor small holder vegetable producers.

Intercropping had been an essential production method in tropical regions for hundreds of years, and to a lesser extent in temperate regions (Li *et al*. 2001). Intercropping was once common in temperate regions, but has been largely replaced in the last 150 years by monocultures (Francis 1986).

Conclusion

All in all, the findings in the research prove that we can accept the H_0 hypothesis which states that garlic has an effect on the reduction of aphid population. Since studies in different countries have shown that exposure to plant volatiles can result in differences in volatile emission in the exposed plant and greatly reduces aphid population, thus reducing incidences of spraying. Using this knowledge, it is possible to develop novel crop protection strategies by engineering or selecting crop plants with altered volatile production, hence the intercropping system of garlic with tomato is worth being adopted by farmers who want to cultivate with a cheaper and healthy means without destroying their harvest content, the environment and their lives.

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