https://dx.doi.org/10.4314/gjas.v58i2.15

The influence of cropping system and soil amendment on the diversity and abundance of arthropods in cultivated cabbage and onion

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ABSTRACT

Cabbage and onion are good sources of vitamins and minerals for humans and income to farmers and marketers. The current study sought to investigate the abundance of arthropods associated with cabbage, onion, and their intercrop under field conditions. These two crops were planted as sole and intercrop with different organic soil amendments during the major and minor rainy seasons of 2014 in the vertisols of the Accra Plains of Ghana. Insects on the two crops were counted weekly, in the sole crops and intercrop, and other arthropods were sampled from the topsoil around the crops, as well as catches from pitfall and yellow sticky traps placed in the vicinity of the crops. The highest abundance and diversity of arthropods occurred in the major than in the minor rainy season. Unexpectedly, the diversity indices revealed more diverse arthropods with high abundance occurring in sole onion than intercrop and sole cabbage. However, the intercrop had fewer incidence of pests (diamondback moth, whiteflies and cabbage webworm), and a high abundance of natural enemies. Organic soil amendment resulted in significantly higher diversity and abundance of soil arthropods, than unamended soil.

Keywords: abundance; arthropod diversity; intercropping; soil amendment; vegetables

Original scientific paper. Received 28 Apr 2023; revised 02 Dec 2023

Introduction

Cabbage (*Brassicae oleracea* var. *capitata*) is an exotic vegetable that is grown worldwide. It belongs to the Cruciferae family. The cabbage plant has a short, thickened stem surrounded by a series of overlapping expanded leaves which form a compact head (Rice *et al*., 1989). It is a very good source of minerals and vitamins and is used in the preparation of stews, soups and as a component in vegetable salads and sandwiches (Baidoo *et al*., 2012). Apart from them serving the purpose of providing the human body with vital nutrients, the early Greeks and Romans grew it for medicinal purposes. In Ghana cabbage cultivation serves as a source of employment and income for people in the rural and urban areas through the sale of the produce (Owusu-Boateng & Amuzu, 2013).

Onion (*Allium cepa* L., Alliaceae) is a very important vegetable crop grown worldwide (FAO, 2005). It originated from Southwest Asia and the Mediterranean regions (Valenzuela *et al*., 1999). It is characterized by a bulb with shallow roots and long hollow leaves with overlapping base. Onion is mainly grown in Ghana in the minor and off-seasons, from October to March. It serves as a source of income to farmers who are into its cultivation. It is mainly grown in the Bawku East and Bawku West districts of the Upper East Region by smallholder farmers (Kanton *et al*., 2008). 'Bawku Red' is the main variety grown in Ghana imported from Burkina Faso in the 1930s (Sinnadurai, 1992) alongside 'Malavi' and Red Creole. Ghanaians have more preference for red onion bulbs (Abbey & Oppong-Konadu, 1997). Other exotic varieties cultivated are Texas Early Grano, Crystal White Wax, Lisbon White and Market winner (Awuah *et al*., 2009).

Despite its importance, cabbage cultivation is faced with many challenges, most importantly is the attack by insect pests (Baidoo *et al*., 2012; Amoabeng *et al*., 2013; Fening *et al*., 2013, 2014a, 2020a, b, c.). The issue of insect pest attack on cabbage is global. Different insects attack the cabbage plant at various stages. These insect pests include the green peach aphid, *Myzus persicae* (Sulzer), cabbage aphid, *Brevicoryne brassicae* L., the false cabbage aphid, *Lipaphis erysimi pseudobrassicae* (Davies) (Hemiptera: Aphididae), the diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae), cabbage looper, *Trichoplusia ni* H. (Lepidoptera: Noctuidae), cabbage webworm, *Hellula undalis* F. (Lepidoptera: Crambidae), variegated grasshopper, *Zonocerus variegatus* (Orthoptera: Pyrgomorphidae), flea beetles, *Phyllotreta* spp. (Coleoptera: Chrysomelidae), and whitefly, *Bemisia tabaci* (Genn.) (Homoptera: Aleyroididae) (Obeng-Ofori *et al*., 2007; Mochiah *et al*., 2011; Fening *et al*., 2011, 2013, 2014a, 2020a, b, c.).

Plutella xylostella is the most economically important pest of cabbage worldwide and can cause yield loss up to a 100% (Obeng-Ofori *et al*., 2007; Fening *et al*., 2014a). For example, the global cost of controlling P. *xylostella* has been estimated between 4 and 5 billion US dollars (Zalucki *et al*., 2012). Other pests that can cause major damage to cabbage are the cabbage webworm, H. *undalis* (which is mainly responsible for the multiple head formation, rendering the cabbage heads unmarketable) and the cabbage aphids, which feed on the phloem tissues and serve as vectors for the transmission of several viral diseases in cabbage (Adenka *et al*., 2021; Forchibe *et al*., 2023a, b).

Several natural enemies are also known to be associated with the pests of cabbage. Among those recorded in Ghana with high potential of controlling the insect pests include predators, mainly spiders (Araneae), hoverflies (Diptera: Syrphidae), ladybird beetles (Coleoptera: Coccinellidae) and several hymenopterans and parasitoids (Amoabeng *et al*. 2013; Fening *et al*., 2013; Forchibe *et al*., 2023a). Parasitioid species like *Cotesia plutellae* Kurdjumov (Lepidoptera: Plutellidae) have been recorded in Ghana to significantly parasitize the larvae of DBM. Hyperparasitoids that have been recorded to control parasitoid populations are *Oomyzus sokolowskii*, *Aphanogmus reticulatus*, *Elasmus* sp. and *Trichomalopsiis* sp. (Cobblah *et al*., 2012). In India some natural enemies of the order Coleoptera that prey on the nymph and adult stages of the cabbage aphid, *Brevicoryne brassicae* (L.) are *Micraspis discolor* (F.), and *Harmonia dimidiate* (*F*.) (Sarma *et al*., 2021). The Dipteran *Episrphus belteotus* (L.) and *Oxyopes* spp. (Araneae) also prey on the nymph and adult cabbage aphid (Sarma *et al*., 2021).

The dragon fly and damselfly (Odonata) also prey on the above-mentioned insect (Sarma *et al*., 2021) as well as the larvae of DBM (Gavloski, 2023). Additionally, parasitoids like *Diadegma insulare* (Ichneumonidae) are known to parasitize the larvae of DBM, whilst the prepupal and pupal stages are attacked by *Diadromus subtilicornis* in Western Canada (Gavloski, 2023). The different stages of the life cycle of DBM can be preyed on by the lacewings (Gavloski, 2023). Pathogens have the potential to cause disease outbreaks in populations of DBM. Entomophthorales fungi is recorded to be infectious at the larval stage of DBM and hence can stop the growth of new generations (Gavloski, 2023).

Onion characteristically is pungent. This pungency is attributed to the presence of a compounds allylpropyldisulphide and alinase. These compounds can prevent inflammation, cholesterol, cancers and oxidation in the human body (Slimestad *et al*., 2007). The pungency of onion has been proven to be effective in managing insect pests of crops like cabbage as an intercrop (Asare-Badiako *et al*., 2010; Katsaruware & Dubiwa, 2014: Fening *et al*., 2020a). The major insect pest of onion is the onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae). Other minor pests are leaf miners, *Phytobia cepae* (Diptera: Agromyzidae), cut worms, *Agrotis sp*. (Lepidoptera: Noctuidae), onion fly, *Delia antiqua* (Diptera: Anthomyiidae), Western flower thrips, *Frankliniella occidentalis Pergande* (Thysanoptera: Thripidae), leaf worm, *Spodoptera littoralis* (Lepidoptera: Noctuidae) and blister beetle, *Epicauta bilineata* Haag-R. (Coleoptera: Meloidae) (Corgan, 2002; Fening & Moses, 2021). Natural enemies observed to be associated with the control of thrips in onion fields are spiders, lacewings, minute pirate bugs and predaceous mites (Valenzuela *et* al., 1999).

Pest infestation leads to a reduction in the quality and marketable yield of crops and could lead to total crop failure. Over the years, such pests have been controlled with synthetic chemicals. Currently, excessive chemical application has led to environmental contamination, development of resistance in the pests and deposit of chemical residues in the crop which is not safe for human consumption (Fening *et al*., 2013; Fening *et al*., 2020a, b, c.). It has become an issue of concern as the international market rejects consignments that have levels of toxic chemical residues above the maximum residue level (MRL) in them, and this in turn affects the revenue of Ghanaian farmers and exporters. Hence, it is important to find alternative methods that are environmentally friendly to manage the pests which will avert the negative consequences of chemical application (Fening *et al*., 2013; Fening *et al*., 2020a, b, c.).

In this work the method of cropping systems (intercropping cabbage with onion, and sole cropping onions and cabbage) was adopted as a way of reducing pest numbers, whiles leveraging on creating environmental conditions that can help boost the presence of natural enemies of the crops. Intercropping is a cultural method that has widely been used in all the continents of the world to manage insect pests of various crops such as cabbage (Asare -Badiako *et al.*, 2010; Baidoo *et al*., 2012; Fening *et al*., 2020a). Cabbage and onions attract different insects (pests, natural enemies and non-targets) in the field. The purpose of diversifying crops in a field is done on the principle that different pests have different feeding preferences (Baidoo *et al*., 2012; Hahn & Cammarano, 2023), hence pests of a particular crop species are not likely to affect another crop species. Onion is a tested intercrop plant due to its pungent smell which can ward off or repel pests (Baidoo *et al*., 2012;

Fening *et al*., 2020a) of other crops hence promote the presence of natural enemies in the field compared to the crops which are solely grown.

However, the soil type at the study site is known as vertisols. It is a black clay soil that is potentially fertile but have a lot of challenges and limitations for crop production. The challenge is that it hardens and cracks when dry and becomes slippery when wet (Ametapkor *et al*., 1993). Therefore, the incorporation of organic soil amendments such as manure, compost and biochar have proven to be very effective in enhancing its fertility (Özsoy & Aksoy, 2007; Nyalemegbe *et al*., 2011; Fening *et al*., 2020a). This soil amendment can help the plant to withstand pest attack by promoting its vigorous growth. And in association with the cropping system the crops will have a strong chance to withstand pest attack naturally. This work, therefore, sought to find out the effect of sole cropping, intercropping and organic soil amendment on the diversity and abundance of insects and other soil arthropods in the vertisols of the Accra Plains of Ghana. The information obtained would be useful in designing sustaining crop production methods that will suppress the growth of pests and enhance the survival of beneficial insects of crops and other non-target organisms.

Materials and Methods

Study area

The research was undertaken at the Soil and Irrigation Research Centre, Kpong (0^0 04' E, 6^0 09' N), in the Coastal Savanna agro-ecological zone, part of the Accra Plains of Ghana. The main soil type is the Akuse series or vertisols (black clay soil) (Amatekpor *et al*., 1993). The rainfall pattern is bimodal, starting in March to July for the major rainy season, followed by a brief drought and the minor rainy season from the middle of August to the middle of November (MoFA, 2011). Annual rainfall is between 700–1500 mm, with an average of 1200 mm.

Experimental design and treatments

The experimental field was laid out in a split-plot design with soil amendments (rice husk biochar, poultry manure and their combination) as the main plots and cropping systems (sole onion, sole cabbage and cabbage-onion intercrop) as sub-plots. All soil amendments were applied at two levels each, i.e., 15 kg per 15 m^2 (10 t/ha) and 30 kg per 15 m^2 (20 t/ha) and control (no amendment). There were three experimental blocks, representing the three replications for each treatment. Each cropping block consisted of 21 plots or beds. The rice-husk biochar was prepared as described by Haefele *et al*. (2011). A well decomposed poultry manure (6 months old) was utilized in this experiment. The biochar and poultry manure were thoroughly incorporated into demarcated beds.

Land preparation, nursery establishment and transplanting of seedlings

The land was cleared of weeds, ploughed and harrowed. Seeds of certified healthy hybrid white cabbage (*B. oleracea* var. *capitata*) (*cv. oxyrus*) was bought from AGRIMAT Limited, Accra, Ghana. Cabbage seeds were nursed on raised beds in the field in May, and September during the 2014 major and minor rainy seasons, respectively. The young seedlings were protected from attack by insect pests with a mosquito-proof net following the procedure by Fening *et al*. (2014a). Healthy cabbage and onion (cv. Red Creole) seedlings were transplanted four and six weeks, respectively, after germination on raised beds.

The seedlings were planted 2 cm deep into the soil. The planting distance within and between the cabbages on the sole cabbage plots was 0.5 m × 0.5 m. The sole cabbage plots were having six rows with 10 cabbage plants in a row, making a total of 60 plants per plot. The planting distance between and within sole onion crops was 0.15 m. There were eighteen (18) rows with 28 onion plants per row, making a total of 504 plants per plot. In the intercrop, the planting distance between rows of cabbages was 0.75 m x 0.5 m, whilst that of onion was 0.15 m x 0.15 m. The area per bed was 3 m × 5m = 15 m^2. The space between each bed was 1 m, whilst between the blocks was 2 m.

Insect and soil arthropods sampling and data collection

Data was collected on pest diversity and abundance weekly on cabbage and onion from two inner rows. Five plants from the two inner rows were randomly selected per sole cabbage or sole onion plots and examined for the presence of insects. In the intercrop, five inner row plants each of cabbage and onion were selected at random and examined for the presence of insects weekly. The number of insects found were counted. Pitfall and yellow sticky traps were placed in the middle of each plot to account for crawling and flying insects, respectively and non-target organisms. Empty milo tins were used for the pitfall traps. A hole or pit of depth 11.7 cm and 10.3 cm wide was dug per treatment plot for each tin. The tins were placed in the holes and were made to be at ground level with the soil surface to catch crawling insects unaware. About 0.5 litres of water was poured into each Milo tin and a detergent was also added in the ratio of 20:1 to make a solution. The traps were emptied after three days in every week. The insects were collected using forceps, counted and recorded.

The yellow sticky trap was made of wooden plywood which measured 30 cm × 30 cm and painted yellow on both sides. Temostick (glue), was applied thinly and uniformly on both sides of the plywood to trap the insects. The traps were fixed in the field and placed at the same height as the cabbage (canopy height). The traps were inspected weekly. The insects were collected, counted and recorded. The insects that were collected had glue on them, hence acetone was used to remove the glue before being stored in 70% alcohol. Soil arthropods that may affect onion bulb quality were also investigated. Five onions were randomly harvested from both sole and intercrop plots and soil 0-5 cm deep was scooped from where the bulbs were taken (by modifying the method used by (Fening *et al*., 2014b) onto a tray, and sieved to check for soil arthropods (using hand lens). These arthropods were counted and recorded. Samples were kept in glass jars and preserved in 70% alcohol for identification. Data were taken three weeks after transplanting up to two weeks before harvesting. Data were taken from 6:00 am to 8:30 am weekly.

Insects and other soil arthropod identification

The insect pests, their natural enemies and other soil arthropods collected in this study were identified using reference specimens at the Insect and Arthropod Museum of the Department of Animal Biology and Conservation Science, University of Ghana, Accra. Samples of larvae of various insects were cultured in the laboratory to the adult life stage to allow identification by comparison with labelled specimens in the insect museum. Voucher specimens of all the insect species and other arthropods collected were also deposited in the museum. The aphids species were identified using taxonomic keys by Blackman & Eastop (1984).

Statistical analysis

The insects and other arthropod diversity were measured among the different cropping systems, soil amendments and planting seasons.

Data on crop insect counts, trap catches and soil arthropods' counts were pooled together for the abundance and diversity index calculations. The diversity of insects collected was computed using the Shannon Wiener Index and Shannon evenness (Magurran, 1988). These indices measured the diversity and abundance of the collected insect and other soil arthropod species. The diversity among the different treatment plots within each season was tested for significance using the general linear model (GLM) ANOVA procedure of SAS (SAS, 2014). However, data on insect pests and their natural enemies were subjected to a two-way ANOVA using a repeated measures procedure of SAS. Comparison of the means was done using the student Neuman - Keul's (SNK) test ($p \leq 0.05$). Student's t test ($p \leq 0.05$) was used to compare the diversity between the two seasons. The number of insects and other soil arthropods that were collected was square root transformed before analysis.

The Shannon Diversity Index = H' was calculated as:

$$H' = -\sum Pi \ln Pi$$

Where; $Pi = S/N$

S = number of individuals of one species

N = total number of all individuals in the sample

Ln = logarithm to base e

The Shannon evenness = (E) was calculated as

$$(E) = H'/\ln S$$

Where; S = the number of species sampled

H' = Shannon Diversity Index

The Primer software, version 6.1.5, was used to analyse data on insect diversity.

Results and Discussion

Diversity and abundance of insects and other soil arthropods sampled from cabbage and onion fields

The study recorded a total of 50,042 insects from 17 orders, 34 families and 47 species (Table 1). A total of 32,714 and 17,328 insects were sampled from the various treatment plots in the major and minor rainy seasons, respectively. It was observed that the mustard aphid, *Lipaphis erysimi pseudobrassicae* (Davis) (Homoptera: Aphididae) recorded the highest number of individuals on cabbage in both the major and minor seasons.

TABLE 1

Diversity and abundance of arthropods sampled from the field in the major and a minor raining season, 2014

Order	Family	Species Name	Major Season	Minor Season
Polydesmida	Paradoxosomatidae	*Anoplodesmus saussurii*	6	0
Archaeognatha	Machilidae	*Machilis* sp.	0	1
Hymenoptera	Formicidae	*Paedalgus termitolestes*	5	4
	"	*Pheidole* sp.	5	2
	"	*Odontomachus* sp.	2672	830
	"	*Oecophylla longinoda*	5	0
	Braconidae	*Diaeretiella rapae*	5480	216
	Pompilidae	unidentified	2	0
Coleoptera	Carabidae	*Microlestes* sp.	5	0
	Coccinellidae	*Scymnus* sp.	6	4
	"	*Chnootriba similis*	2	3
	"	*Micraspis* sp.	2	0

	"	*Cheilomenes propinqua vicina*	438	90
	"	*Cheilomenes lunata*	46	47
	Meliodae	*Mylabris variabilis*	1	0
	Chrysomelidae	*Podagrica uniformis*	1	0
	"	*Phyllotreta* sp.	35	105
	"	*Cassida* sp.	1	0
Lepidoptera	Plutellidae	*Plutella xylostella*	506	321
	Crambidae	*Hellula undalis*	46	0
Dermaptera	Labiduridae	*Euborellia annulipes*	5	7
Homoptera	Aphrophoridae	*Poophilus costalis*	8	287
	Aphididae	*Lipaphis erysimi pseudo-brassicae*	15000	11755
	"	*Myzus persicae*	7560	2170
	"	*Eulachnus* sp.	0	9
	Aleyroididae	*Bemisia tabaci*	19	14
	Flatidae	*Colgar* sp.	3	0
	Psylidae	unidentified	1	0
Orthoptera	Gryllidae	*Brachytrupes sp.*	149	88
	Gryllotalpidae	*Gryllotalpa* sp.	206	201
	Pyrgomorphidae	*Zonocerus variegatus*	6	23
		Atractomorpha sp.	8	0
Araneae	Sparassidae	Unidentified	295	929
Diptera	Calliphoridae	*Calliphora* sp.	46	44
	Muscidae	*Musca domestica*	72	88
	Syrphidae	*Paragus borbonicus*	17	39
	Tephritidae	*Bactrocera dorsalis*	1	1
	Stratiomyidae	*Prosopochrysa* sp.	1	0
	Diopsidae	*Diopsis* sp.	12	16
Glomerida	Glomeridae	*Glomeris* sp.	23	5
Polydesmida	Xystodesmidae	*Harpaphe haydeniana*	7	9
Hemiptera	Pyrrhocoridae	*Dysdercus superstitiosus*	4	0
Dictyoptera	Blattidae	*Periplaneta Americana*	4	0
		Blattella germinica	0	18
Mantodea	Mantidae	*Mantis religiosa*	1	0
Odonata	Gomphidae	*Ictinogomphus* sp.	1	2
Phasmida	Phasmatidae	-	1	0
		TOTAL	**32714**	**17328**

Shannon Weiner diversity indices and Shannon Evenness for insects and other soil arthropods

From the study, the highest diversity (*H'* = 1.69) of arthropods in the major rainy season was observed on the sole onion PM 20 t/ha and PM+BC 10 t/ha plots (Table 2). The least diverse (*H'*= 1.12) plot was observed in the sole cabbage control plot. In the minor season, the highest diverse (*H'* = 1.80) plot was observed on the sole onion PM+BC 20 t/ha plot. The sole cabbage BC 20t/ ha plot recorded the least (*H'* = 0.74) Shannon diversity index in the minor season (Table 2). In terms of evenness, the sole onion plots were the highest, followed by the intercrop and the sole cabbage. Thus, the most diverse were the sole onion plots than the intercrop and sole cabbage. Even though the diversity of insects was generally higher in the sole onion plots. There were however fewer pests (diamondback moth, whiteflies and cabbage webworm) and more natural enemies, mainly spiders, in the intercrop than the other sole cropping systems (Table 3, Figs. 1-8).

The effect of cropping systems on the abundance of *p. xylostella* for the major season was significant ($F_{1, 28} = 8.18$, $p = 0.0079$). The interaction between the weeks of sampling of *p. xylostella* and the cropping system was also significant for the major and minor seasons ($F_{4, 112} = 4.79$, $p = 0.0040$ and $F_{4, 112} = 4.14$, $p = 0.0035$), with the intercrop having a smaller number of *p. xylostella* larva as the weeks progressed. Cropping system significantly affected the whitefly, *B tabaci* numbers in the minor season ($F_{1, 154} = 104.16$, $p < 0.0001$). Clearly, the intercropped cabbage had fewer whiteflies as compared to the sole cabbage, which recorded high numbers of whiteflies during the minor season. The cropping system was also significant in contributing to the multiple head damage, which was largely attributable to the cabbage webworm, *H. undalis*, in the major season ($F_{1, 13} = 16.15$, $p = 0.0004$).

Overall, the multiple head damage on the intercrop was lower than that in the sole cabbage plots (Table 3) and hence contributed to the reduction of *H. undalis* in those plots. There was a significant difference in the number of spiders among the cropping systems for the major and minor seasons ($F_{1, 28} = 11.30$, $p = 0.0001$ and $F_{1, 28} = 24.39$, $p < 0.0001$). The highest number of spiders was recorded on the intercrop biochar 20t/ha plot (Fig. 7). The sole onions had the least number of spiders in both seasons (Figs. 7 and 8). It was observed that spider numbers were higher in the minor season than the major season.

TABLE 2

Diversity indices per treatment for insects and other soil arthropods collected from the cabbage and onion field for major and minor seasons, 2014

Cropping System	**Soil Amendment**	**Shannon Diversity (*H'*)**		**Shannon Evenness (*E*)**	
		Major	Minor	Major	Minor
Sole cabbage	PM 20 t/ha	1.23	1.18	0.49	0.48
Sole cabbage	BC 10 t/ha	1.43	1.17	0.54	0.44
Sole cabbage	PM+BC 20 t/ha	1.19	1.29	0.51	0.49
Sole cabbage	Control	1.12	1.21	0.50	0.51
Sole cabbage	PM+BC 10 t/ha	1.41	1.38	0.58	0.50
Sole cabbage	BC 20 t/ha	1.30	0.74	0.53	0.29
Sole cabbage	PM 10 t/ha	1.33	1.03	0.56	0.40
Intercrop	PM+BC 10 t/ha	1.39	1.11	0.57	0.46
Intercrop	BC 20 t/ha	1.33	1.10	0.53	0.43
Intercrop	PM+BC 20 t/ha	1.41	1.10	0.56	0.43
Intercrop	PM 20 t/ha	1.29	1.10	0.49	0.43
Intercrop	Control	1.45	0.93	0.55	0.38
Intercrop	PM 10 t/ha	1.30	1.35	0.52	0.53
Intercrop	BC 10 t/ha	1.34	1.13	0.51	0.46
Sole onion	PM 20 t/ha	1.69	1.36	0.68	0.67
Sole onion	PM+BC 10 t/ha	1.69	1.32	0.71	0.64
Sole onion	PM+BC 20 t/ha	1.65	1.80	0.69	0.81
Sole onion	Control	1.41	1.76	0.65	0.76
Sole onion	PM 10 t/ha	1.35	1.16	0.63	0.56
Sole onion	BC 10 t/ha	1.67	1.27	0.69	0.56
Sole onion	BC 20 t/ha	1.43	1.09	0.59	0.46

TABLE 3
Mean number (± SE) of multiple heads (%) attributable to the cabbage webworm, H. undalis during the major season, 2014.

Crop system/ soil amendment	Mean no. of multiple heads (%)
Intercrop/ BC 10 t/ha	3.51±1.55
Intercrop BC 20 t/ha	1.39±0.57
Intercrop/no amendment	6.76±3.11
Intercrop/ PM+BC 10 t/ha	5.44±1.18
Intercrop/ PM+BC 20 t/ha	6.17±2.95
Intercrop/ PM 10 t/ha	4.08±1.67
Intercrop/ PM 20 t/ha	4.11±1.96
Sole cabbage/ BC 10 t/ha	3.82±1.89
Sole cabbage/ BC 20 t/ha	7.66±1.89
Sole cabbage/ no amendment	3.48±1.42
Sole cabbage/ PM+BC 10 t/ha	7.42±0.38
Sole cabbage/ PM+BC 20 t/ha	4.48±1.95
Sole cabbage/ PM 10 t/ha	11.99±5.49
Sole cabbage/ PM 20 t/ha	8.42±2.03
	P = 0.0220 LSD = 8.894

ANOVA, $p < 0.05$.

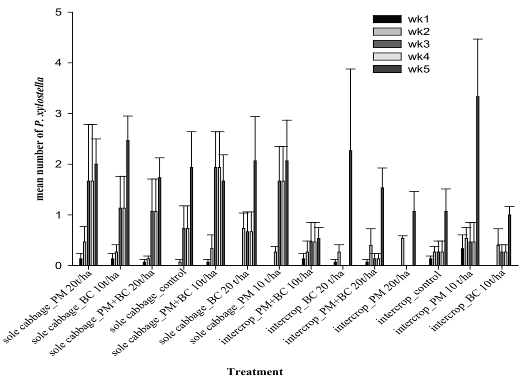

Fig. 1: Mean no. of *P. xylostella* on cabbage per week in the major season, 2014

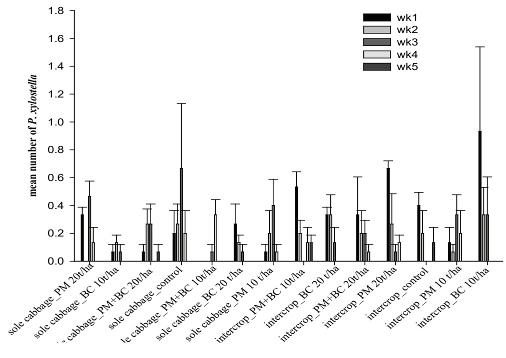

Fig. 2: Mean no. of *P. xylostella* on cabbage per week in the minor season, 2014

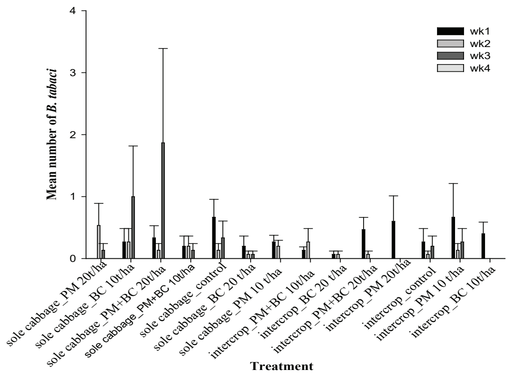

Fig. 3: Mean no. of *B. tabaci* sampled per week on cabbage in the major season, 2014

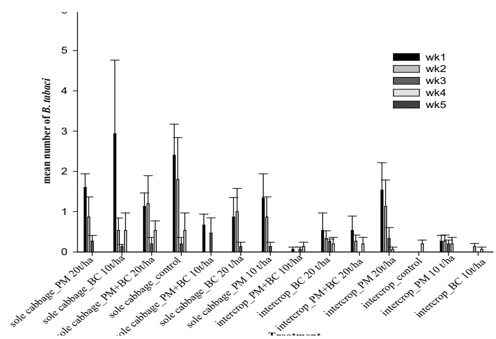

Fig. 4: Mean no. of *B. tabaci* sampled per week on cabbage in the minor season, 2014

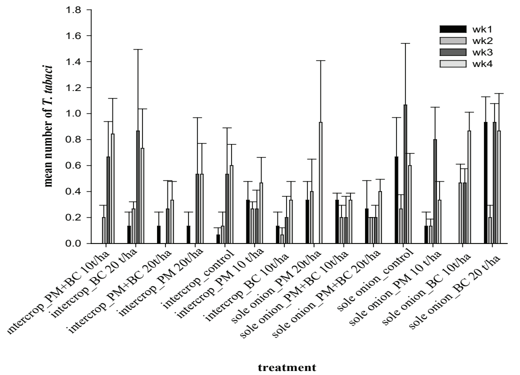

Fig. 5: Mean no. of *T. tabaci* per week on onion in the major season, 2014

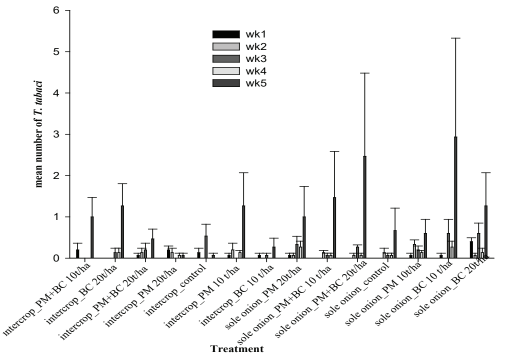

Fig. 6: Mean no. of *T. tabaci* per week on onion in the minor season, 2014

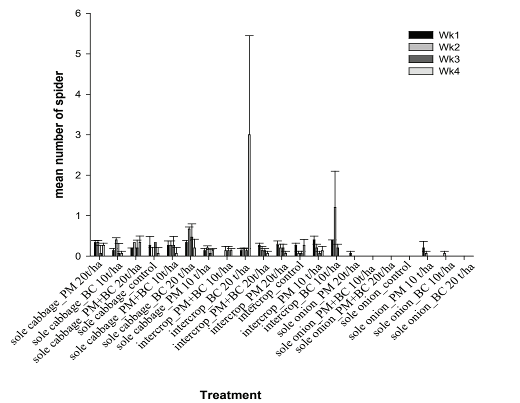

Fig. 7: Mean no. of spiders sampled weekly season in the major season

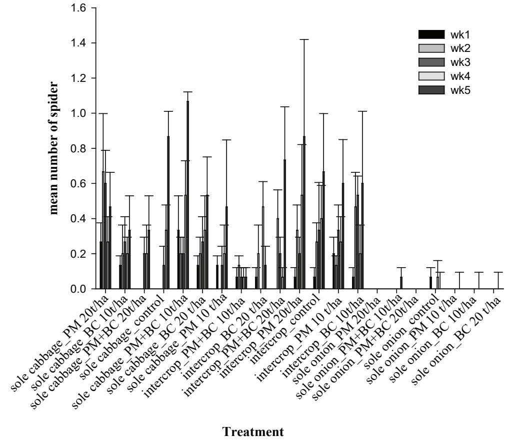

Fig. 8: Mean no. of spiders sampled per week in the minor season

Effect of cropping system and soil amendment on the diversity of the arthropods

*The cropping system had a sign*ificant effect ($p = < 0.0010$ and $p = 0.0310$), respectively on the diversity of the insects and other soil arthropods sampled from the field for both seasons, (Table 4). In the major rainy season, the soil amendment, and the interaction between the cropping system and the soil amendment had no significant effect on the insect and arthropod ($p = 0.3170$ and $p = 0.4050$), respectively. In the minor season also, the soil amendment recorded p value of 0.3500 and the interaction between the soil amendment and the cropping system recorded a p value of 0.4950.

Although, the effect of organic soil amendments was not significant, from observation, it resulted in higher diversity and abundance of soil arthropods, than the soils without amendment (Fig. 9). The major season had a significantly higher Shannon diversity index and evenness than the minor season ($t = 3.88$, $p < 0.0010$; $t = 3.60$, $p < 0.0010$, respectively), when data was pooled together. The Shannon diversity index and evenness were significantly higher during the major season than the minor for the intercrop cropping system (Table 4). Similarly, the Shannon evenness was significantly higher during the major season than the minor for the sole cabbage cropping system. More soil arthropods were recorded in the major season than the in minor season. The soil arthropods collected were from 8 orders and 5 families. The Coleopterans and Hymenopterans were the most diverse orders of soil arthropods observed in the field.

TABLE 4

The effect of cropping systems on the diversity of insects and other soil arthropods sampled in the field in the major and minor rainy seasons

Cropping system	Mean (*H*') Major season	Mean (*H*') Minor season	df, *t*, *p*	Mean (*E*) Major season	Mean (*E*) Major season	df, *t*, *p*
Intercrop	1.359±0.095 B	1.116±0.172 B	20, 4.23, < 0.0010*	0.535±0.045 B	0.446±0.064 B	20, 4.19, < 0.0010*
Sole cabbage	1.286± 0.103B	1.142±0.158 B	20, 3.88, 0.0850	0.529±0.049 B	0.444± 0.054B	20, 2.91, 0.0090*
Sole onion	1.557± 0.107A	1.396±0.230 A	20, 1.56, 0.1350	0.663±0.047 A	0.637±0.093 A	20, 0.60, 0.5530
p value	< 0.0010	0.0310		< 0.0010	< 0.0010	
LSD	0.118	0.227		0.050	0.085	

Means represented by different letters within a column are significantly different (ANOVA, $p < 0.05$). Means between the same row for both seasons, were compared using *t* test ($p < 0.05$)

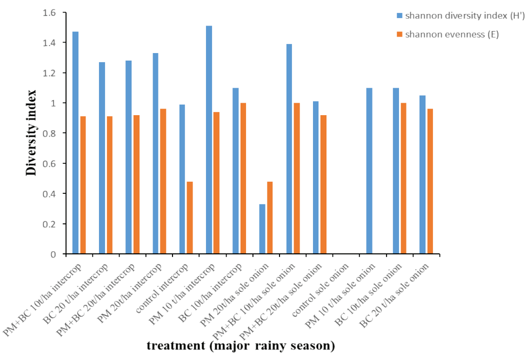

Fig 9: Graph showing diversity and evenness of soil arthropods sampled in the major season, 2014

Effect of cropping systems and soil amendments on the diversity and abundance of insects and other soil arthropods

Regarding, this study, the diversity of insects and other soil arthropods on the cabbage and onion fields were monitored. It was found that generally, the sole onion plots had higher insect and arthropod diversity than the intercrop and sole cabbage cropping systems. Asare-Badiako *et al*. (2010) showed in their work that although onions contain a chemical called allicin, which repelled insect (arthropod) pests, however it creates an enabling environment for natural enemies. Hence, the observance of more catches of diverse species of natural enemies especially in the onion fields, e.g., ladybird beetles in the order Coleoptera on the yellow sticky traps. Conversely, in an earlier study at the same location, the cabbage and onion intercrop generally had the highest number of ladybird beetles on the crop than the sole crops (Fening *et al*., 2020).

The intercrops may have offered more crop diversity and niche for more spiders, who are generalist predators, to catch their prey, especially support for the webbing type of spider to build its nest (web) for trapping its prey. This may have contributed to the lower abundance of insect pests within the intercrop. Agricultural diversification, such as intercropping, is therefore known to increase the abundance, distribution, and pest control potential of spiders in crop farming (Sunderland, 1999; Sunderland & Samu, 2000). The current study also revealed that the soils with an organic amendment had more soil arthropods. Altieri & Nicholls (2003) stated in their earlier work that amending the soil increased the number of soil arthropods and their activity. This is expected as the organic amendment contributed to loosening the soil and increasing its organic matter, thereby promoting the activities of soil arthropods.

From the study, the highest number of pests recorded on cabbage were aphids, and they are among the major insect pests on cabbage in Ghana (Asare-Badiako *et al*., 2010; Baidoo *et al*., 2012; Fening *et al*., 2014a). The two species of aphids observed on the cabbage were the mustard aphid, *Lipaphis erysimi pseudobrassicae* and the green peach aphid, *Myzus persicae,* but *L. e. pseudobrassicae* was the most abundant. Important natural enemies of the aphids observed in the field were *Cheilomene*s spp., the hoverfly, *P. borbonicus* and the braconid parasitoid, *D. rapae*. These natural enemies are known to prey on the aphids on cabbage (Fening *et al*., 2013, 2014a, 2020a; Forchibe *et al*., 2023a). It was realized in the current study that their numbers increased because of the rising pest numbers. This is in accordance with the enemy hypothesis proposed by Root (1973), which states that there is likely to be variations in the number of aphid specialist predators like *D. rapae*, which are expected to accumulate in simpler habitats where their specific prey (aphids) achieved higher densities and are easier to find (Sheehan, 1986). According to this hypothesis, their numbers fell behind that of the aphids (K strategists). Non-target insect like the *Diopsis* sp. which is an important stem borer pest of rice, was observed in the cabbage and onion fields, and the reason being its proximity to the rice fields at the study location.

In comparing the general diversity of insect and soil arthropod species for the two seasons, the major rainy season recorded higher diversity of species than the minor season and this could be partly due to favourable environmental conditions such as optimum relative humidity (76%), temperature (28^{o}C) and rainfall (1200 mm), which is characteristic of the major rainy season. This might have had a positive effect on the diversity and abundance of insects and other soil arthropods. This is because temperature and relative humidity are known to stimulate insect development and hence the increase in their numbers (Fening *et al*., 2010; MoFA, 2011; Forchibe *et al*., 2023a).

Conclusion and Recommendation

The current study has revealed that insect and other arthropod diversity was not always in agreement with the complexity of the environment. Even though, the diversity of insects generally was highest in the sole onion plots, there were also more natural enemies, specifically spiders, in the intercrop than in the sole cropping systems. Furthermore, soils without organic amendments also had no or fewer soil arthropods. It could therefore be concluded that the cropping system and to some extent, soil amendment influenced the diversity and the abundance of arthropods in the field. The use of onion as an intercrop with cabbage and organic soil amendment could be an effective and safe way of increasing the natural enemy diversity on cabbage and onion, hence reducing the insect pest population for sustainable vegetable production. Thus, intercropping, and organic soil amendment could become an integral part in integrated crop management of cabbage and onion.

Acknowledgment

We appreciate the financial support of the University of Ghana Research Fund (UGRF), administered by the Office of Research, Innovation & Development (ORID). We thank the technical staff of the Soil and Irrigation Research Centre (SIREC), University of Ghana for their support during field work.

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