Effect of intercropping and soil amendment on the population dynamics of major pests and natural enemies of white cabbage

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Abstract

Cabbage is an important exotic vegetable widely grown in Ghana. Despite its importance, cabbage production is constrained by insect pests attack, with the diamondback moth (DBM), *Plutella xylostella* L. and the Indian mustard aphid, *Lipaphis erysimi pseudobrassicae* (Davis) as the most important. A field trial was conducted at the Soil and Irrigation Research Centre, Kpong, in Ghana, during the major and minor rainy seasons of 2013 to study the effect of intercropping and soil amendment on the incidence of these key pests, their natural enemies and the yield of crop. The field was laid out as a split-plot design with soil amendment (biochar from rice husk, poultry manure and their combination) as the main plot and cropping system (sole cabbage, sole onion and cabbage-onion intercrop) as sub-plots. Multiple head formation was higher in sole cabbage plots than cabbage intercropped with onion. Similarly, sole cabbage plots supported a higher number of DBM larvae than cabbage intercropped with onion. Cabbage planted on soils without amendment, generally supported a fewer number of DBM larvae and natural enemies than the amended soils. The effect of the different treatments on the aphids population was not significant. The intercrop had the highest number of beneficial insects. The effect of soil amendment on the yield of cabbage and onion was significant with poultry manure plots recording the highest yield. The effect of cropping system was also significant on the yield of onion, with sole onion obtaining higher yields than onion intercropped with cabbage. The use of soil amendment also significantly improved the soil chemical and physical properties. Intercropping and soil amendment, therefore, have a lot of potential in sustainable vegetable production.

Introduction

Cabbage, *Brassica oleracea* var. *capitata* L. which belongs to the family Brassicaceae is an exotic leafy vegetable that originated from Western Europe (FAO, 2000), but is now widely grown in Ghana and most parts of the world (Dickson and Wallace, 1986; Mochiah et al., 2011). It is a very good source of vitamins and minerals, and is used in the preparation of stews, soups and constitutes an important component in vegetable salads, sandwiches and hamburgers (Abbey and Manso, 2004; Baidoo et al., 2012). Apart from serving the purpose of providing the human body with vital nutrients, the early Greeks and Romans grew it for medicinal purposes (Alabama Cooperative Extension, 1999). Presently, the cultivation of cabbage serves as a source of employment and income for farmers and marketers in the rural, peri-urban and urban areas (MoFA, 2011; Fening et al., 2014a). Its production in Ghana also contributes to foreign exchange through export to neighbouring countries (Sinnadurai, 1992; Owusu-Boateng and Amuzu 2013).

Despite its importance, cabbage cultivation is bedevilled with many challenges, most importantly is the attack by insect pests (Baidoo et al., 2012; Amoabeng et al., 2013; Fening et al., 2013). These insect pests include diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera; Plutellidae), cabbage aphid, *Brevicoryne brassicae* L., the mustard aphid, *Lipaphis erysimi erysimi* (Kalt.), the Indian mustard aphid, *Lipaphis erysimi pseudobrassicae* (Davis), the green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), the cabbage webworm, *Hellula undalis* F. (Lepidoptera: Crambidae), the cabbage looper, *Trichoplusia* *ni* H. (Lepidoptera: Noctuidae), the variegated grasshopper, *Zonocerus variegatus* (Orthoptera: Pyrgomorphidae), flea beetles, *Phyllotreta* spp. (Coleoptera: Chrysomelidae) and the whitefly, *Bemisia tabaci* (Genn.), (Homoptera: Aleyroididae) (Müller, 1986; Obeng–Ofori et al., 2007, Fening et al., 2014a). Among these pests, *P. xylostella*, is the most economically important pest of cabbage, which can cause yield loss up to 100% (Lingappa et al., 2004; Obeng-Ofori et al., 2007) and the global cost of controlling this pest has recently been estimated between 4-5 billion US dollars (Zalucki, et al., 2012). Aphids are also increasingly becoming the second most important pest of cabbage due to their ability to cause significantly higher damage to cabbage coupled with the transmission of several viruses and viral diseases to the plant that can result in over 95% yield loss (Flint, 1985).

Management of these key pests of cabbage has been mainly by the application of synthetic insecticides (Ntow et al., 2006). The problems associated with the use of synthetic pesticides include the development of insecticide resistance, destruction of non-target organisms and beneficial insects, contamination of farm produce with insecticide residues, chemical poisoning; and environmental contamination, among others (Timbilla and Nyarko, 2004; Ntow et al., 2006, Fening et al., 2013). These numerous problems associated with the use of synthetic insecticides had led to the search for alternative options for insect pest management in a more sustainable manner (Fening et al., 2013).

The current study was undertaken on the Vertisols (Black clay soils) of the Accra Plains which is part of the Coastal Savanna agro-ecological zone of Ghana. Although, the Vertisol is potentially fertile and can support the growth of many crops, including vegetables, there is difficulty in its utilisation due to physical constraints, mainly swelling and becoming very sticky when wet and hardens and cracks when it's dry (Ahenkora, 1995; Asiedu and Bonsu, 2001). It is also difficult to use agricultural implements to work on this soil during ploughing and harrowing (Darkwa et al., 2001). Another challenge is that the soil becomes flooded as a result of the high clay content (Asiedu and Bonsu, 2001). Therefore the growth of vegetables is hindered as well as nutrient uptake (Fening et al., 2014b). Improving the texture and drainage ability of the Vertisols is important in promoting crop production (Mamman, 2002). The incorporation of soil amendments from organic materials such as animal manure, compost and biochar have proven to be very effective in this regard (Valenzuela et al., 1999).

Cultural methods such as intercropping is known to reduce pest outbreaks on cabbage (Telekar et al., 1986; Asare-Badiako et al., 2010; Baidoo et al., 2012). Contrarily, soil amendment using organically produced materials in some cases also enhances the multiplication of pests on the crop (Altieri and Nicholls, 2003; Mochiah et al., 2011). However, the interaction between intercropping and soil amendment on insect pests of cabbage and their natural enemies as well as on the yield of the crops is not well known (Fening et al., 2014b). Therefore, the current study explores the effect of intercropping and soil amendment on the incidence of insect pests, their natural enemies and yield of cabbage and onion on the Vertisols of the Accra Plains of Ghana.

Materials and Methods

Study site

The research was undertaken at the Soil and Irrigation Research Centre, Kpong (0°04'E, 6°07'N), belonging to the Coastal Savanna agro-ecological zone of Ghana, which is part of the Accra Plains. The main soil type is the black clay known as the Vertisols. They are predominantly montmorilonitic heavy clayey soils (30-95%) with a high water-holding capacity and a high proportion of swelling clays (Brammer, 1967; Yangyuoru et al., 2001). These soils form wide deep cracks from the surface downward when dry and become sticky and swells (40-50% swelling) when wet. Thus, making them difficult to be tilled using farm implements. The rainfall pattern is bi-modal, starting from March to July, which constitute the major rainy season, followed by a brief drought, and the minor rainy season from the middle of August to the middle of November. Kpong has annual rainfall between 700-1500mm, with an average of 1200 mm.

Experimental design and treatments

The experimental field was laid out in a split-plot design with soil amendment (two levels of biochar from rice husk, two levels of poultry manure, control and their combination) as the main plots, and cropping systems (sole cabbage, sole onion and cabbage-onion intercrop) as sub-plots. There were a total of 18 treatments (Table 1) and each treatment was replicated three times.

Application of soil amendments

The rice-husk biochar was prepared as described by Haefele et al., (2011). It was produced and used in a manner that do not conflict with the international guidelines by the European Biochar Foundation (EBC, 2012). The biochar and poultry manure were thoroughly incorporated into demarcated

TABLE 1

Soil amendments and cropping systems used in the experiment laid out in a split-plot design at SIREC, Kpong during 2013

Soil Amendment	Levels of Application	Cropping system
Biochar	20 t ha^{-1}	Sole cabbage
Biochar	20 t ha^{-1}	Sole onion
Biochar	20 t ha^{-1}	Cabbage-onion intercrop
Biochar	10 t ha^{-1}	Sole cabbage
Biochar	10 t ha^{-1}	Sole onion
Biochar	10 t ha^{-1}	Cabbage-onion intercrop
Poultry manure	20 t ha^{-1}	Sole cabbage
Poultry manure	20 t ha^{-1}	Sole onion
Poultry manure	20 t ha^{-1}	Cabbage-onion intercrop
Poultry manure	10 t ha^{-1}	Sole cabbage
Poultry manure	10 t ha^{-1}	Sole onion
Poultry manure	10 t ha^{-1}	Cabbage-onion intercrop
Biochar + poultry manure	10 t ha^{-1} + 10 t ha^{-1}	Sole cabbage
Biochar + poultry manure	10 t ha^{-1} + 10 t ha^{-1}	Sole onion
Biochar + poultry manure	10 t ha^{-1} + 10 t ha^{-1}	Cabbage-onion intercrop
Control	0 t ha^{-1}	Sole cabbage
Control	0 t ha^{-1}	Sole onion
Control	0 t ha^{-1}	Cabbage-onion intercrop

soil beds, each having an area of 5m^2. The poultry manure used was well decomposed (six months old) and was incorporated into the soil a month before the cabbage and onion seedlings were transplanted.

Land preparation, nursery establishment and transplanting of seedlings

The land was cleared, ploughed and harrowed. Seeds of certified healthy hybrid white cabbage (*B. oleracea* var. *capitata*) (cv. oxyrus) was bought from the AGRIMAT Limited, Accra, Ghana. Cabbage seeds were sown on raised beds in the field on 10th of May, 15th of September, during the 2013 major and minor rainy seasons, respectively. Four weeks old seedlings were transplanted into raised beds. Each bed measuring 2.5 m x 2 m = 5 m^2, with five rows of cabbage, consisting of 6 plants per row. Thus, there were 30 cabbage plants per plot. The inter- and intra-row spacing was 0.5 m x 0.5 m for sole cabbage, and 0.5 m x 0.75 m for cabbage intercropped with onion. The onion seedlings were also transplanted six weeks after emergence. The intra and inter plant distance for the sole onion, and onion intercropped with cabbage was 0.10 m. There were 2 rows of onions between two rows of cabbage, thus making a total of 8 rows of onions. There were 20 onion plants per row, making a total of 160 plants per plot. The inter plot distance or alley was 1.5 m.

Key insect pests, their natural enemies, yield of cabbage and onion

The number of cabbage aphids, diamondback moth and their natural enemies as well as damage by the cabbage webworm were recorded weekly following the methods used by Fening et al., 2013. At harvest, 12 cabbage plants per treatment plot were selected from the three innermost rows, without the border plants, for yield assessment. Thirty fresh bulbs of matured onions were also harvested from each plot from the middle rows for yield assessment.

Identification of pests and their natural enemies

The insect pests and natural enemies collected in this study were identified using reference specimens at the Insect Museum of the Department of Animal Biology and Conservation Science, University of Ghana. Samples of larvae of DBM moth, coccinellids and syrphids 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 collected were also deposited in the insect museum.

Analysis of soil and amendments

Pre-planting top soil (0-20cm) were sampled prior to land preparation and analysed for pH, CEC, OC, available P, particle size distribution and bulk density. The biochar and poultry manure were also analysed for the same parameters as above. At the end of the experiment, all plots were sampled (0-20 cm) and analysed for OC, CEC, pH, available P and bulk density. Soil pH was determined using a glass electrode on a 1:1 soil/water solution. CEC was measured using molybdenum-blue method (Murphy and Riley, 1962), Available P was determined (Olsen P: Olsen and Sommers, 1982). Organic carbon was determined by wet oxidation using the Walkley and Black method as outlined by Nelson and Sommers (1982). Total N was determined by the micro- Kjeldahl as described by Anderson and Ingram (1993).

Data analysis

The insect data were subjected to a two-way ANOVA using a repeated measures procedure of SAS (SAS Institute Inc., 2014). The onion and cabbage yield as well as multiple head damage were analysed using normal two-way ANOVA. Mean separation was done using the Student Newman-Keuls (SNK) test ($P < 0.05$) when ANOVA was significant. A two-way ANOVA was also used to determine the effect of the soil amendments on soil properties (pH, CEC, OC, total N, available P and bulk density). The least significant difference was used for mean separation.

Results

Characterisation of soil and amendments

The soil at the study site was clayey with a clay percentage of 41 % with a bulk density 1.44 Mg m^{-3}. The organic carbon and total N content of the soil were low (Table 2) as typical of the Coastal Savanna (MacCarthy et al., 2014). The available P was low and pH was 6.7. The CEC is moderately high, mainly due to the high clay content. The nutrient characteristics of biochar and poultry manure are shown on Table 2. Addition of soil amendments generally reduced soil bulk density and improved soil available P, CEC and organic carbon content of the soil (Table 3).

Insect abundance and damage

Generally, multiple head formation was significantly higher in the sole cabbage (SC) cropping system than when the cabbage was intercropped with onion during the major season, but was not significant during the minor season (Table 4). The multiple head formation was higher during the minor season than the major rainy season (Table 4). The effect of soil amendment on multiple head formation was significant during the major season (df = 5, F = 65.20, $P < 0.0001$), but was also not significant during the minor

TABLE 2

Characterization of soil and amendments (biochar and poultry manure) used in the study

	Bulk density (Mg m^{-3})	Sand (%)	Silt (%)	Clay (%)	Organic Carbon (g kg^{-1})	Available P (mg kg^{-1})	pH	Total N (g kg^{-1})	CEC ($cmol_c$ kg^{-1})	Total Carbon (g kg^{-1})
Soil	**1.46**	**24**	**35**	**41**	**5.80**	**4.9**	**6.7**	**0.3**	**28**	**–**
Poultry manure					**25.6**	**6.4**	**5.8**	**15**	**–**	**–**
Biochar					**66.67**	**14.2**	**6.9**	**0.1**	**31**	**364**

TABLE 3

Characterization of amended soils at the end of the experiment

Level of amendment	Bulk density (Mg m^{-3})	OC (g kg^{-1})	Avail P (mg kg^{-1})	pH	Total N (g kg^{-1})	CEC
Control	1.44	5.60	3.75	6.5	0.30	24.00
10 t bio-char	1.38	18.00	6.41	6.9	0.35	34.00
20 t bio-char	1.35	25.00	7.20	7.1	0.32	38.00
10 t PM	1.41	10.00	5.20	6.2	1.20	27.00
20 t PM	1.40	16.00	6.20	6.1	1.90	28.00
10 t PM + 10 t Biochar	1.40	20.00	5.90	6.7	1.30	31.00
Lsd (0.05 %)	0.04	4.00	1.20	0.30	0.30	4.00

TABLE 4

Mean (±SE) number of multiple heads per cabbage planted as sole crop and intercropped with onions under different soil amendments during the major and minor rainy seasons of 2013 at Kpong, Ghana

Treatment	Mean no. of multiple heads (%)	
	Major rainy season	Minor rainy season
Sole cabbage – no soil amendment	0.00 ± 0.00e	22.23 ± 2.23a
Sole cabbage – biochar (10 t ha^{-1})	12.73 ± 1.89a	22.20 ± 5.88a
Sole cabbage – biochar (20 t ha^{-1})	7.14 ±1.28b	13.33 ± 3.84a
Sole cabbage – biochar + poultry manure (10t ha^{-1}+10t ha^{-1})	10.83 ± 1.42a	28.90 ± 5.88a
Intercrop – biochar (10t ha^{-1})	0.00 ± 0.00e	23.33 ± 3.30a
Intercrop – biochar (20t ha^{-1})	0.81 ± 0.11d	20.00 ± 5.77a
Intercrop – biochar + poultry manure (10t ha^{-1}+10t ha^{-1})	4.17 ±0.60c	20.00 ± 10.00a
Intercrop – no soil amendment	0.00 ± 0.00e	26.67 ± 6.67a
Sole cabbage – poultry manure (10t ha^{-1})	13.33 ± 1.67a	15.57 ± 4.43a
Sole cabbage – poultry manure (20t ha^{-1})	0.00 ± 0.00e	11.10 ± 2.20a
Intercrop – poultry manure (10t ha^{-1})	0.00 ± 0.00e	26.67 ± 6.67a
Intercrop – poultry manure (20t ha^{-1})	3.70 ± 0.65c	23.33 ± 3.33a
df	11, 35	11, 35
F	91.49	1.17
P	< 0.0001*	0.3554

Means within the same column with the same letter(s) are not significantly different, SNK test (*P< 0.05*). The multiple head formation was mainly caused by the cabbage webworm, *H. undalis*.

season (df = 5, F = 0.0000, P = 0.9871). The interaction between soil amendment and cropping system for multiple head formation was also significant during the major season (df = 5, F = 90.33, P < 0.0001), but was not significant in the minor season (df = 5, F = 1.69, P = 0.1751).

The effect of cropping system on the abundance of DBM was significant during the major rainy season of 2013 ($F_{1, 24}$ = 11.68,

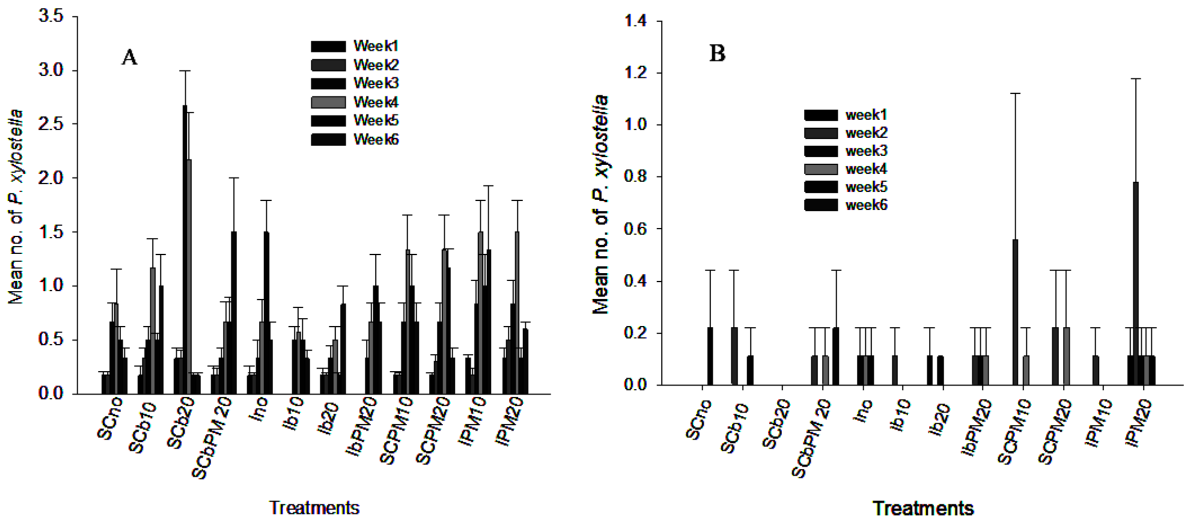

Fig. 1a and b: Mean (± SE) number of *P. xylostella* larvae per cabbage during the major and minor rainy seasons, 2013

SCno – Sole cabbage with no amendment, SCb10 – sole cabbage amended with biochar at 10t/ha, SCb20 - sole cabbage amended with biochar at 20t/ha, SCPM20 – sole cabbage amended with poultry manure at 20t/ha, Ino – intercrop with no amendment, Ib10 – intercrop amended with biochar at 10t/ha, Ib20 - intercrop amended with biochar at 20t/ha, IbPM20 – intercrop amended with biochar and poultry manure at 20t/ha, SCPM10 – sole cabbage amended with poultry manure at 10t/ha, SCPM20- sole cabbage amended with poultry manure at 20t/ha, IPM10 – intercrop amended with poultry manure at 10t/ha, IPM20- intercrop amended with poultry manure at 20t/ha, SCbPM20- sole cabbage amended with biochar and poultry manure at 20t/ha

P = 0.0023), and no significant differences existed during the minor season ($F_{1, 24}$ = 3.66, P = 0.0678) (Figs. 1a and b). Thus, SCb20 plot obtained the highest number of DBM larvae during the major season (Fig. 1a). The effect of soil amendment on the abundance of DBM was not significant during the major ($F_{5, 24}$ = 1.08, P = 0.3948), and the minor seasons ($F_{5, 24}$ = 3.66, P = 0.0678). The soils without amendment, generally supported a fewer number of DBM larvae during the major season than the amended soils (Fig. 1a). The interaction between cropping system and soil amendment was also significant for the major season ($F_{5, 24}$ = 9.18, P < 0.0001), whereas the minor season was not significant ($F_{5, 24}$ = 2.04, P = 0.1094). The effect of sampling week on the abundance of DBM was significant for both the major and minor seasons ($F_{3, 72}$ = 94.56, P < 0.0001, and $F_{3, 72}$ = 3.60, P = 0.0210) as well as the interaction between sampling week and cropping system ($F_{3, 72}$ = 3.74, P = 0.0146, and $F_{3, 72}$ = 3.75, P = 0.0178). The interaction between sampling week and soil amendment was also significant for the major season ($F_{15, 72}$ = 3.74, P = 0.0005), whilst that of the minor season was not significant ($F_{15, 72}$ = 0.34, P = 0.9857). The interaction among sampling week, cropping system and soil amendment was significant for the major season ($F_{15, 72}$ = 4.63, P < 0.0001) although the minor season was not significant ($F_{15, 72}$ = 0.57, P = 0.8787). The effect of soil amendment on the mean score of aphids, *L. e. pseudobrassicae* and *M. persicae* was not significant for both the major and minor seasons (df = 5, F = 0.59, P = 0.7059; df = 5, F = 0.88, P = 0.5085) (Figs. 2a and b). Similarly, the effect of cropping system on the mean score of aphids was also not significant for both seasons (df = 1, F = 0.00, P = 0.9519; df = 1, F = 1.43, P = 0.2432). The interaction between soil amendment and cropping system on the mean score of aphids was also not significant for both seasons (df = 5, F = 0.31, P = 0.9033; df = 5, F = 0.70, P = 0.6300). However, the effect of sampling week on aphids score was significant for both seasons (df = 5, 120, F= 121.99, P < 0.0001; df = 5, 120, F = 24.05, P < 0.0001). As a result, the mean score of aphids kept increasing as the weeks progressed. The interaction between the cropping system, soil amendment and sampling week on the abundance of aphids was not significant for both seasons (df = 55, 120, F= 0.58, P = 0.9689; df = 55, 120, F= 1.18, P = 0.2316).

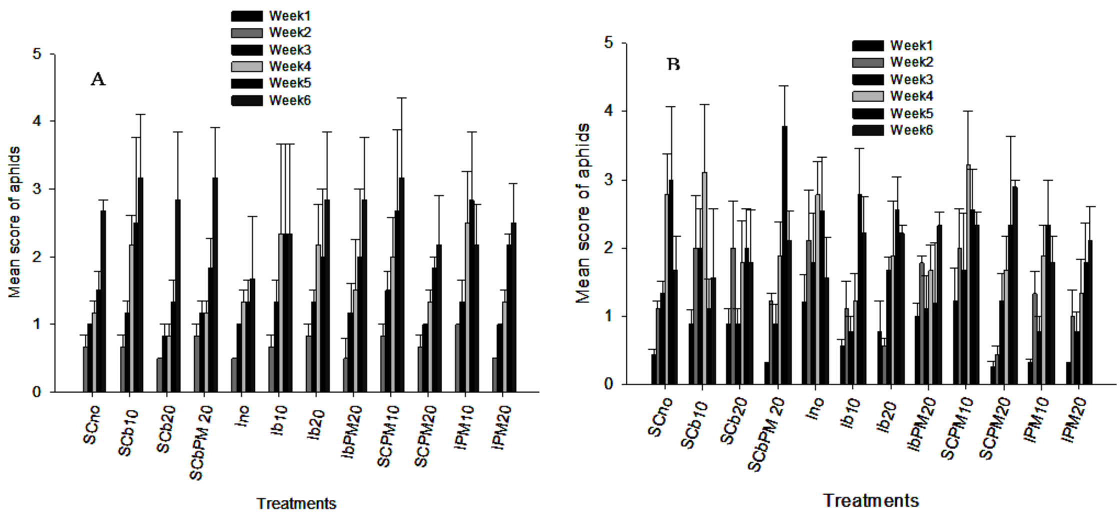

Fig. 2a and b: Mean (± SE) score of aphids (*L. e. pseudobrassicae and M. persicae*) per cabbage during the major and minor rainy seasons, 2013

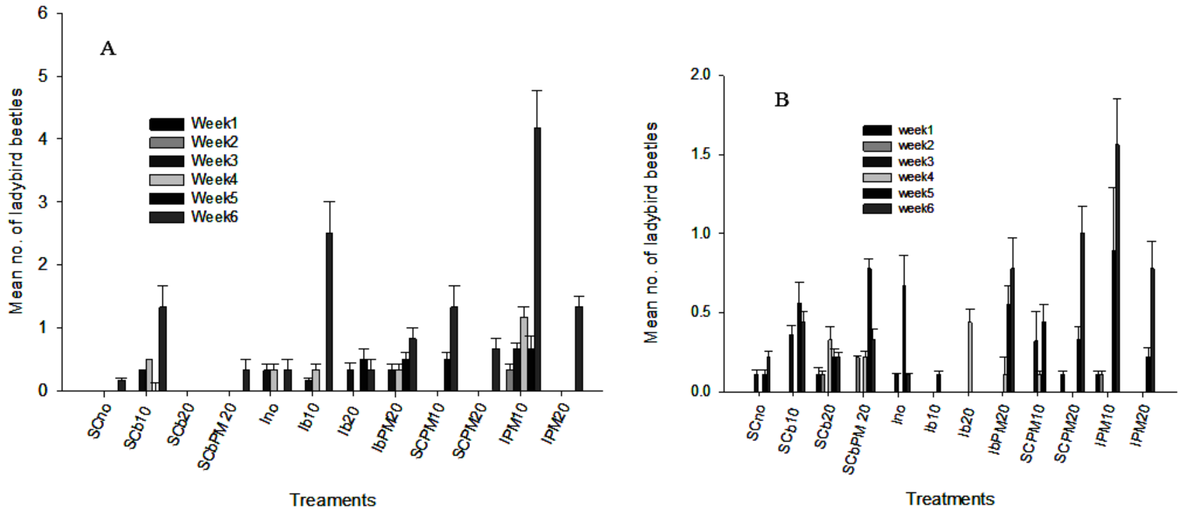

Fig. 3a and b: Mean (± SE) number of ladybird beetles (*Cheilomenes* spp.) per cabbage during the major and minor rainy seasons, 2013

The effect of soil amendment on the mean number of ladybird beetles, *Cheilomenes lunata* (Fabricius) and *Cheilomenes propinqua vicina* (Mulsant) (Coleoptera: Coccinellidae) was significant for both major and minor seasons (df = 5, 24, F = 66.26, P < 0.0001; df = 5, 24, F = 8.17, P = 0.0001) (Figs. 3a and b). Hence, the soils without amendments generally recorded the least number of ladybird beetles. The effect of cropping system on the mean number of ladybird beetles was also significant for the major season (df = 1, 24, F = 41.97, P < 0.0001) but not significantly different during the minor season (df = 1, 24, F = 1.03, P = 0.3201). Therefore, the intercrop generally had the highest number of ladybird beetles. The interaction between soil amendment and cropping system on the mean number of ladybird beetles was significant for both seasons (df = 5, 24, F = 12.60, P < 0.0001; df = 5, 24, F = 10.73, P < 0.0001). The effect of sampling weeks on the mean number of ladybird beetles was significant for both seasons (df = 5, 120, F = 175.18, P < 0.0001; df = 5, 120, F = 72.75, P < 0.0001). Thus, the number of ladybirds generally increased

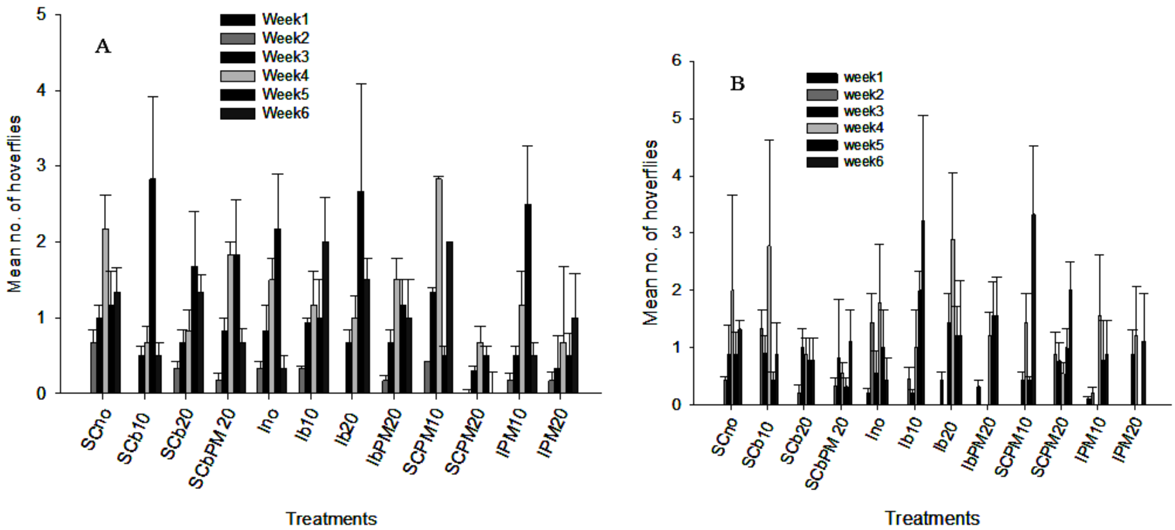

Fig. 4a and b: Mean (± SE) number of hoverflies (*P. borbonicus*) per cabbage during the major and minor rainy season, 2013 as the weeks progressed. The interaction between the soil amendment, cropping system and sampling week on the mean number of ladybird beetles was also significant for both seasons (df = 55, 120, F= 13.28, P < 0.0001; df = 25, 120, F= 8.44, P < 0.0001).

The effect of soil amendment on the mean number of hoverflies, *Paragus borbonicus* Macquart (Diptera: Syrphidae) was significant for both major and minor rainy seasons (df = 5, 24, F = 3.97, P = 0.0092; df = 5, 24, F = 2.73, P = 0.0435) (Figs. 4a and b). However, the effect of cropping system on the mean number of hoverflies was however not significant for both seasons (df = 1, 24, F = 0.00, P = 0.9971; df = 1, 24, F = 1.03, P = 0.3195). The interaction between soil amendment and cropping system on the mean number of hoverflies was not significant for the major season (df = 5, 24, F = 0.90, P= 0.4984), but was significant during the minor season (df = 5, 24, F = 6.29, P= 0.0007). The effect of sampling weeks on the mean number of hoverflies was significant for both seasons (df = 5, 120, F = 59.69, P < 0.0001; df = 5, 120, F = 46.27, P < 0.0001). The interaction between the soil amendment, cropping system and the weeks of sampling on the mean number of hoverflies was also significant for both seasons (df = 25, 120, F= 2.53, P < 0.0001; df = 25, 120, F= 4.12, P < 0.0001).

The effect of soil amendment on the mean number of spiders (Araneae) was significant for the major season (df = 5, 24, F = 3.07, P= 0.0279) (Fig. 5a) but not significant during the minor season df = 5, 24, F = 1.04, P = 0.4148) (Fig. 5b) The effect of cropping system on the mean number of spiders was however not significant for both seasons (df = 1, 24, F = 0.03, P= 0.8596; df = 1, 24, F = 2.38, P = 0.1362). The interaction between soil amendment and cropping system on the mean number of spiders was not significant for both seasons (df = 5, 24, F = 0.35, P= 0.8781; df = 5, 24, F = 2.01, P = 0.1135). The effect of sampling weeks on the mean number of spiders was significant during the major season (df = 5, 120, F = 45.74, P < 0.0001) and not significant during the minor season (df = 5, 120, F = 1.44, P = 0.2162). Therefore, the abundance of spiders was generally low initially, increased in the subsequent weeks and declined during the later weeks. The interaction between the cropping system, soil

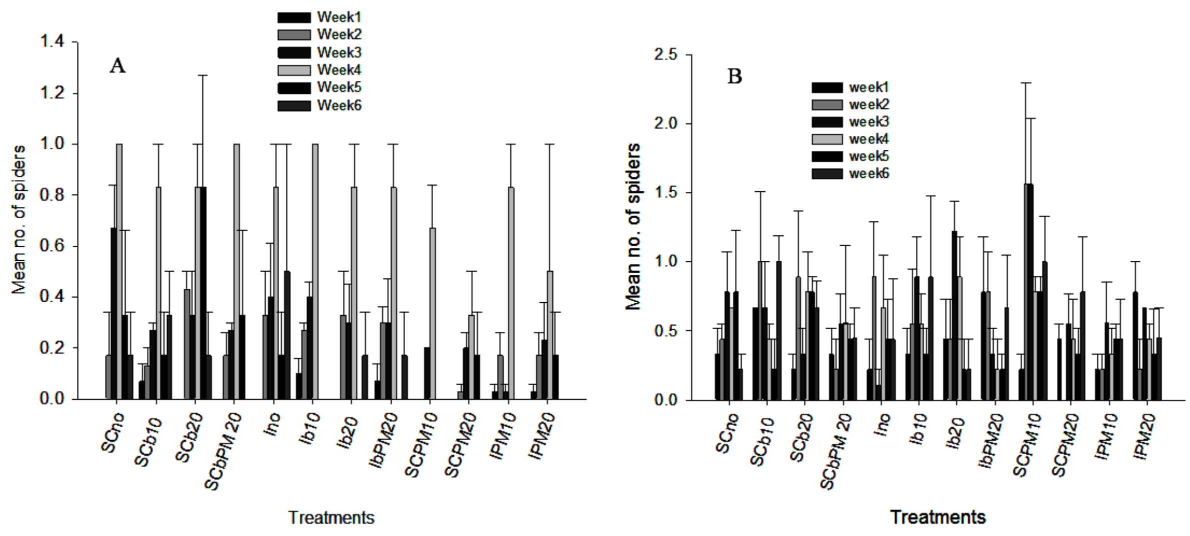

Fig. 5a and b: Mean (± SE) number of spiders (Araneae) per cabbage during the major and minor rainy seasons, 2013

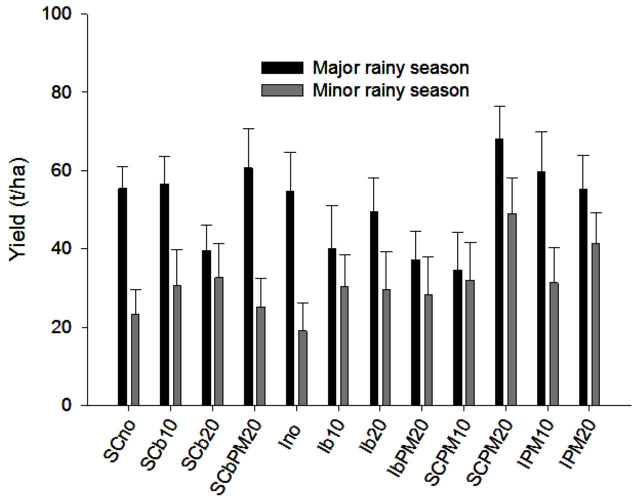

Fig. 6. Mean (± SE) cabbage yield (t/ha), planted as sole crop and intercropped with onions, under different soil amendments during the major and minor rainy seasons of 2013, Kpong, Ghana

amendment and the week of sampling on the mean number of spiders was however not significant for both seasons (df = 25, 120, F= 1.09, P = 0.3417; df = 25, 120, F= 1.01, P = 0.4728).

Yield of cabbage and onion

The effect of cropping system on the yield of cabbage was not significant during both the major and minor seasons (df =1, F = 1.11, P = 0.3021; df =1, F = 0.57, P = 0.4562) (Fig. 6). Thus, the mean yield of SC, and intercrop with onion was similar for both seasons (i.e. 52.4 t ha^{-1} and 49.39 t ha^{-1}; 32.14 t ha^{-1} and 30.00 t ha^{-1}, respectively). However, the effect of soil amendment on the yield of cabbage was significant for both seasons (df =5, F = 3.11, P = 0.0266; df =5, F = 5.28, P = 0.0021). Thus, PM20 recorded the highest yield of cabbage for both seasons (i.e. 61.67 t ha^{-1} and 45.17 t ha^{-1}, respectively), whereas the plots without amendments had the least yield during the minor season (21.7 t ha^{-1}). The interaction between cropping system and soil amendment on the yield of cabbage was significant during the major season (df =5, F = 6.47, P = 0.0006),

TABLE 5

Mean (± *SE*) yield (t ha^{-1}) per fresh onion bulbs from sole crop and intercrop plots under different soil amendments during the major and minor seasons, 2013, at Kpong, Ghana

Treatments	Yield of fresh bulbs (t ha^{-1})	
	Major season	Minor season
Sole onion – no soil amendment	9.24 ± 1.23ab	8.22 ± 1.74a
Sole onion – biochar (10 t ha^{-1})	8.72 ± 2.70abc	6.23 ± 1.60a
Sole onion – biochar (20 t ha^{-1})	10.33 ± 1.16a	9.46 ± 1.04a
Sole onion – biochar + poultry manure (10t ha^{-1}+10t ha^{-1})	7.67 ± 1.04abc	7.60 ± 1. 14a
Intercrop – biochar (10t ha^{-1})	4.34 ± 1.04abc	6.23 ± 1.60a
Intercrop – biochar (20t ha^{-1})	3.46 ± 1.01bc	6.35 ± 0.51a
Intercrop- biochar + poultry manure (10t ha^{-1}+10t ha^{-1})	3.51 ± 1.31bc	7.59 ± 1.83a
Intercrop – no soil amendment	3.46 ± 1.05bc	7.81 ± 1.61a
Sole onion – poultry manure (10t ha^{-1})	9.32 ± 0.84ab	7.81± 1.61a
Sole onion – poultry manure (20t ha^{-1})	10.33 ± 1.61a	9.02 ± 0.76a
Intercrop – poultry manure (10t ha^{-1})	4. 18 ± 1.03abc	8.48 ± 0.90a
Intercrop – poultry manure (20t ha^{-1})	2.67 ± 0.74c	8.16 ± 1.33a
df	11, 35	11, 35
F	5.36	1.56
P	0.0003*	0.1745

Means within the same column with the same letter(s) are not significantly different, SNK test (P < 0.05) whereas that of the minor season was not significantly different (df =5, F = 0.29, P = 0.9131).

The effect of the soil amendment on the fresh bulb yield of onion was not significant (df = 5, F = 0.24, P = 0.9410; df = 5, F = 1.24, P = 0.3209) for both seasons (Table 5). However, the effect of the cropping system on the yield of onion was significant (df = 1, F = 54.98, P < 0.0001; df = 1, F = 6.61, P = 0.0168) for both seasons, with the sole onions having higher yields than the onion intercropped with cabbage. The interaction between the soil amendment and cropping system on the yield of onion was also not significant (df = 5, F = 0.55, P = 0.7363; df = 5, F = 0.87, P = 0.5150) for both seasons (Table 5).

Discussion

Multiple head formation in cabbage is mostly attributed to the cabbage webworm, *H. undalis*, which feeds on the apical meristem of cabbage and therefore renders them unmarketable (Baidoo et al. 2012; Fening et al. 2013). The DBM larvae can also feed on the apical bud of cabbage, thus may induce multiple head formation (Ooi, 1986; Telekar and Shelton, 1993). The current trend that multiple head formation was higher in the SC plots and lower in the cabbage plots intercropped with onion during the major season suggests that the odour or volatile smell emanating from the onion may have repelled the webworm from the cabbage or masked the scent of the target plant. The results agree with the findings of other researchers that cabbage intercropped with onion had fewer numbers of *H. undalis* than when it was planted as sole crop (Baidoo et al., 2012). This is expected, as unlike monocropping, where the field is likely to be more prone to pests and diseases, intercropping reduces pest population because of the crop diversity. When other crops are present in the field, pest movement is hindered (Waage, 1990). Sullivan (2003) also stated that if susceptible plants are separated by non-host plants that can serve as a physical barrier to the pest hence, the susceptible plant will suffer less damage (Sheehan, 1986). These non-host plants tend to have stronger odours hence they mask the scent of the target plants, thus making it difficult for insect pests to trace that particular plant in the field.

The results from the present study has indicated the effect of cropping system on the incidence of DBM larvae was significant during the major season, with the SC supporting higher numbers of the DBM larvae as compared to the cabbage intercropped with onion which had fewer number of DBM larvae. For example, SCb20 obtained the highest number of DBM larvae during the major season. The results concur with earlier findings by other researchers, whereby some plant species of the Genus *Allium* (onion, garlic, shallots and leeks) when intercropped with cabbage had fewer number of DBM larvae than when they were planted as sole crops (Telekar, et al., 1986; Messian, 1992; Luchen, 2001; Ogol and Makatiani, 2007; Asare-Badiako et al., 2010). They explained that the aromatic scent of the alliums was responsible for repelling the DBM larvae, hence the observed low numbers in the intercrop. Conversely, Baidoo et al., (2012) reported that intercropping cabbage with onion did not significantly reduce DBM larval population on cabbage.

The effect of sampling week on the abundance of DBM was significant for both the major and minor seasons as well as the interaction between sampling week and cropping system, with the DBM population within the intercrop reducing as the weeks progressed. It could be inferred that even though, the initial protection of DBM larvae was slow, as the onion plant developed more foliage and produced more odour, effective control could be achieved. Thus, it is recommended that the onion is transplanted about two-four weeks earlier before it is intercropped with cabbage, to achieve maximum control of DBM larvae.

The soils without organic amendment, generally supported a fewer number of DBM larvae during the major season than the amended soils. Several studies have supported the above observation that insect pests, including DBM are more attracted to plants that receives good fertilizer (organic and inorganic) application, as nutritious food becomes abundant to the pests (Slansky, 1990; Magdoff and van Es, 2000; Altieri and Nicholls, 2003; Mochiah et al., 2011). Thus, herbivorous insects associated with *Brassica* crops have been reported to increase as a result of increased nitrogen levels in the plant (Letourneau, 1988). Jahn (2004) further explained that the continuous addition of nutrients to soil can bring about insect pest problems leading to increased reproduction, longevity and overall fitness of some insect pests.

The effect of cropping system and soil amendment on the mean score of aphids was not significant for both the major and minor seasons. However, the effect of sampling week on the aphids score was significant for both seasons. As a result, the mean score of aphids kept increasing as the weeks progressed. This suggests that, suppression of the aphids by the pungent smell of the onions was not possible. The current finding differs from the observation made by Baidoo et al., 2012 who indicated that aphid population in the cabbage-onion intercrop was significantly lower than when the cabbage was planted as a sole crop.

The effect of soil amendment on the mean number of natural enemies (ladybird beetles, hoverflies and spiders) was generally significant. Hence, the soils without organic amendments generally supported a fewer number of natural enemies. This is expected, as the soils without amendments had fewer number of pests (DBM and aphids), hence reduced the number of natural enemies of the pests. The effect of cropping system on the mean number of ladybird beetles was also significant for the major season. Therefore, the intercrop generally had the highest number of ladybird beetles during the major season. Intercropping serves as an important way of improving the plant diversity and hence insect diversity. Andow (1991) stated that an increase in the plant diversity in a field provides an opportunity for natural enemies to survive. Based on the current study, the interaction between soil amendment and cropping system on the mean number of ladybird beetles and hoverflies was also significant. Thus, the intercrop and amended soil was rich with resources and habitat to accommodate the natural enemies.

Generally, the effect of sampling weeks on the mean number of these natural enemies was also significant as well as the interaction between soil amendment, cropping system and sampling week. Thus, the number of beneficial insects generally increased as the weeks progressed. This is expected as the natural enemy's population built up gradually as the pest's population also increased.

The mean yield of cabbage planted as a sole crop, and as an intercrop was not significantly different for both seasons. However, the mean yield of onion was significantly higher when planted as a sole crop than when it is intercropped with cabbage. These findings concur with that of Guvenc and Yildirim (2006). This could suggest cabbage as a better competitor over onion, when they are grown together as an intercrop. However, in earlier studies by Baidoo et al., 2012 and Asare-Bediako et al., 2010, the yield of cabbage was significantly higher in cabbage plots intercropped with onion than the SC plots.

According to the current study, the effect of soil amendment on the yield of cabbage was significant for both seasons with the PM20 plots recording the highest yield of cabbage for both seasons, whereas the plots without amendments had the least yield during the minor season. This could be due to higher total N concentrations of the PM compared to the biochar which is low in total N thus serving as a source of essential nutrients. Both amendments improved soil physico-chemical properties in this study similar to those reported by Amanullah et al., (2010) and MacCarthy et al., (2020).

Biochar is a heterogeneous substance rich in aromatic carbon and minerals and it is produced by pyrolysis of sustainably obtained biomass under controlled conditions with clean technology and is used for any purpose that does not involve its rapid mineralisation to CO_2 and may eventually become a soil amendment (EBC, 2012). It has the potential to improve soil organic matter, soil structure and the biological life of the soil when applied in adequate quantities and is very important for vegetable cultivation (Jia et al., 2012). Unlike PM, which is rich in soil nutrients, the nutrient content of biochar is low. It however improves nutrient retention and availability as shown in this study with available P as well as the cation exchange capacity values increasing significantly above that of the control. It also enhances the soil physical properties such as bulk density and improves soil-water holding capacity, but does not add any nutrient to the soil (Alburquerque et al., 2014 ; MacCarthy et al., 2020).

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References

Abbey, L., and Manso, F. (2004). Correlation studies on yield and yield components of two cultivars of cabbage (*Brassica oleracea* var. *capitata* L.). *Ghana Journal of Science*, **44**, 3–9.

Ahenkora, Y. (1995). *Management of Vertisols for sustained rain-fed small-holder production Ghana, Ghana-Vertisol IBSRAM Project, Phases 1*. Final Technical Report to ODA and IBSRAM, pp. 40–45.

Alabama Cooperative Extension System. (1999). *Guide to Commercial Cabbage Production,* Alabama A and M and Auburn Universities, USA.

Alburquerque, J. A., Calero, J. M., Barrón, V., Torrent, J., . Carmen del Campillo, M., Gallardo, A. and Villar, R. (2014). Effects of biochars produced from different feedstocks on soil properties and sunflower growth. *Journal of Plant Nutrition and Soil Science*, **177(1)**, 16–25.

Amoabeng, B. W., Gurr, G. M., Gitau, C. W.,

Nicol, H. I., Munyakazi, L. and Stevenson, P. C. (2013)**.** Tri-trophic insecticidal effects of African plants against cabbage pests. PLOS ONE 8 (10). e78651. DOI: 10.1371/ journal. Pone. 0078651

Amanullah, M. M., Sekar, S. and Muthukrishnana, P. (2010). Prospects and potential of poultry manure. *Asian Journal of Plant Science*, **9(4)**, 172–182.

Anderson, J.M., and Ingram, J. S. I. (1993). *Tropical soil biology and fertility: A handbook of methods*, 2nd ed. CAB International, UK.

Andow, D. A. (1991)**.** Vegetational diversity and arthropod population response. *Annual Review of Entomology*, **36**, 561–586.

Asare-Badiako, E., Addo-Quaye, A. A. and Mohammed, A. (2010)**.** Control of Diamondback moth (Plutella xylostella) on cabbage (Brassica oleracea var capitata) using intercropping with non-host crops. *American Journal of Food Technology*, **5(4)**, 269–274.

Asiedu, E.K., and Bonsu, M. (2001). Analysis of the drying efficacy of some vertisol management technologies using a simple model. *Ghana Journal of Science*, **34**, 77–84.

Altieri, M. A. and Nicholls, C. I. (2003)**.** Soil fertility management and insect pests: harmonising soil and plant health in agro ecosystems. *Soil and Tillage Research,* **72**, 203–211.

Baidoo, P. K., Mochiah, M. B. and Apusiga, K. (2012)**.** Onion as a Pest Control Intercrop in Organic Cabbage (Brassica oleracea) Production System in Ghana. *Sustainable Agriculture Research*, **1(1)**: 36–41.

Brammer, H. (1967)**.** Soils of the Accra Plains. Soil Research Institute Memoir No. 3. Kwadaso, Kumasi.

Darkwa E. O., Johnson, B. K., Nyalemegbe, K., Yangyouru, M., Oti-Boateng, C., Willcocks, T. J. and Terry, P. J. (2001)**.** Weed management on vertisols for small-scale farmers in Ghana. *International Journal of Pest Management*, **47(4)**, 299–303.

Dickson, M.H. and Wallace, D. H. (1986)**.** Cabbage breeding pp. 395–432. In M. J. Bassett (ed.) Breeding vegetable crops. AVI Publishing Company, Westport, Connecticut.

(EBC) European Biochar Certificate (2012)**.** *Guidelines for a Sustainable Production of Biochar*. EBC, Arbaz, Switzerland.

(FAO) Food and Agriculture Organization. (2000). Cabbage ecological guide: FAO Inter-country programme for IPM in vegetable in South and Southeast Asia. FAO, Rome, Italy.

Fening, K. O., Adama, I. and Tegbe, R. E. (2014a)**.** On-farm evaluation of homemade pepper extract in the management of pests of cabbage, *Brassica oleraceae* L. and French beans, Phaseolus vulgaris L., in two agro-ecological zones in Ghana. *African Entomology*, **22(3)**, 552–560.

Fening, K. O., Amoabeng, B. W., MacCarthy, D. S., Obeng-Ofori, D. and Afreh-Nuamah, K. (2014b). *Evolution of pest management options in Ghana*, pp. 153–169. In *M. Yangyuoru, A. Naazie, D. S. Maccarthy, G. O, Nkansah, and S. K. Torkpo. (eds.), The role of biopesticides and botanicals. Agricultural Research for Food Security and Sustainable Livelihood.* University of Ghana Readers, Physical and Life Sciences Series Number 3. Institute of Agricultural Research, College of Agriculture and Consumer Sciences, Didibooks Ghana Ltd, Accra, Ghana.

Fening, K. O., Amoabeng, B.W., Adama, I.,

Mochiah, M. B., Braimah, H. and Owusu-Akyaw, M., Narveh, E. and Ekyem, S.O. (2013). Sustainable management of two key pests of cabbage, Brassica oleraceae var. capitata L. (Brassicaceae), using homemade extracts from garlic and hot pepper. *Organic Agriculture*, **3(3)**, 163–173.

Flint, M. L. (1985). *Cabbage Aphid, Brevicoryne brassicae.* Pp. 36-39. *In Integrated Pest Management for Cole Crops and Lettuce*. University of California Publication **3307**, 36–39.

Fukai, S. (1993). Intercropping-bases of productivity. *Field Crops Research*, **34**, 239–245.

Guvenc, I. and Yildirim, E. (2006). Increasing Productivity with Intercropping Systems in Cabbage Production. *Journal of Sustainable Agriculture*, **28(4)**, 29–44.

Haefele, S. M., Konboon, Y., Wongboon, W., Amarante, S., Maarifat, A. A., Pfeiffer, E. M. and Knoblauch, C. (2011). Effects and fate of biochar from rice residues in rice-based systems. *Field Crops Research*, **121**, 430–440.

Jahn, G. E. (2004). Effect of soil nutrients on the growth, survival and fecundity of insect pests of rice: an overview and a theory of pest outbreaks with consideration of research approaches. Multi trophic interactions in soil and integrated control. *IOBC-WPRS Bulletin,* **27 (1)**, 115–122.

Jia, J., Li, B., Chen, Z., Xie, Z. and Xiong, Z. (2012). Effects of biochar application on vegetable production and emissions of N2O and CH4. *Soil Science and Plant Nutrition*, **58**, 503–509.

Letourneau, D.K. (1988). *Soil management for pest control: a critical appraisal of the concepts, pp. 581–587. In: P. Allen and D. Van Dusen (eds.), Proceedings, Sixth International Scientific Conference of IFOAM, on Global Perspectives on Agro ecology and Sustainable Agricultural Systems,* Santa Cruz CA,.

Lingappa, S., Basavanagoud, K., Kulkarni, K. A., Patil, R. S. and Kambrekar, D. N. (2004). *Threat to vegetable production by diamondback moth and its management strategies*, pp. 357–396. In: *K. G. Mukerji(ed.), Fruit and Vegetable Diseases*. Springer, Dordrecht, Netherlands.

Luchen, S. W. S. (2001). Effect of intercropping cabbage with Alliums and Tomato on the incidence of the diamondback moth, Plutella xylostella (L.). M.S. Thesis. The University of Zambia, Lusaka.

MacCarthy, D. S., Darko, E., Nartey, E. K., Adiku, S. G. K., Tettey, A. (2020). Integrating Biochar and Inorganic Fertilizer Improves Productivity and Profitability of Irrigated Rice in Ghana, West Africa. *Agronomy,* **10**, 904. https://doi.org/10.3390/agronomy10060904

MacCarthy, D. S., Nyalemegbe, K. K., Yangyuoru, M. and Bationo, A. (2014). *Contributions of soil fertility management research to the production of Cereals in Ghana, pp.185–202. M. Yangyuoru, A. Naazie, D. S. Maccarthy, G. O, Nkansah, and S. K. Torkpo. (eds.), Agricultural Research for food security and sustainable livelihoods. University of Ghana Readers. Physical and Life Science Series No 3.* Institute of Agricultural Research, College of Agriculture and Consumer Sciences, Didibooks Ghana Ltd, Accra, Ghana.

Magdoff, F., and van Es, H. (2000). *Building Soils for Better Crops. 2nd ed. Sustainable Agricultural Research and Education (SARE)*, Washington, DC.

Mamman, E. (2002). *Soil bin investigations* *of drought of model chisel furrowers in a vertisol.* Ph.D. Thesis. University of Illorin, Nigeria.

Messian, C. M. (1992). *The Tropical vegetable garden*. Macmillan Press, UK, in cooperation with CTA Wageningen, Netherlands.

Mochiah, M. B., Baidoo, P. K. and Owusu-Akyaw, M. (2011). Influence of different nutrient applications on insect populations and damage to cabbage. *Journal of Applied Bioscience*,. **38**, 2564– 2572.

(MoFA) Ministry of Food and Agriculture. (2011). *Ghana Commercial Agricultural Project (GCAP). Pest Management Programme (PMP)*, Accra, Ghana.

Müller, F. P. (1986). The role of subspecies in aphids for affairs of applied entomology. *Journal of Applied Entomology*, **101**, 295–303.

Murphy, J. and Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, **27,** 31–36.

Nelson, D. W. and Sommers, L. W. (1982). *Total carbon and organic matter. pp. 301–312. In: Page AL, et al (ed.), Methods of soil analyses. Part II, 2nd edn. Agronomy Series No. 9*. ASA & SSSA Madison, Wisconsin, USA.

Ntow, J. W., Gijzen, H. J., Kelderman, P. and Drechsel, P. (2006). Farmer perceptions and pesticide use practices in vegetable production in Ghana. *Pest Management Science*. **62**, 356–365.

Obeng-Ofori, D., Yirenkyi-Danquah, E. and Ofosu-Anim, J. (2007). *Cabbage and cauliflower, pp. 119–122. In K. Ofori (ed.), Vegetable and Spice Crop Production in West Africa.* City Publishers Ltd, Accra, Ghana.

Ogol, C. K. P. O. and Makatiani, J. (2007). *Potential of companion crops in managing the diamondback moth in cabbage/kale cropping system in Kenya. African Crop Science Conference Proceedings*, **8**, 1029–1033.

Olsen, S. R. and Sommers, L. E. (1982). *Phosphorus, pp. 403–430. In A. L. Miller and R. H. Keeny (eds.), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. Agronomy. No. 9*, 2nd edn, American Society of Agronomy, Madison, WI, USA.

Ooi, P. A. C. (1985). *Diamondback moth in Malaysia, pp. 25–34. In N. S. Telekar and T. D. Griggs (eds.) Diamondback moth management. Proceedings of the first International Workshop*, 11– 15 March 1985. AVRDC, Shanhua, Taiwan.

Owusu-Boateng, G. and Amuzu, K. K. (2013). Levels of organochlorine pesticide residue in cabbage cultivated in farms along River Oyansia, Accra-Ghana. *AJSIR*, **4(5)**, 489–498.

SAS Institute Inc. (2014). *SAS user's guide: statistics version 9.4. edn.* SAS Institute, Cary, USA.

Sheehan, W. (1986). Response of specialist and naturalist natural enemies to agro ecosystem diversification: A selective review. *Environmental Entomology*, **15,** 456–461.

Sinnadurai, S. (1992). *Vegetable Cultivation.* Asempa Publishers, Accra.

Slansky, F. (1990). Insect nutritional ecology as a basis for studying host plant resistance. *Florida Entomology*, **73(3)**, 354–378.

Sullivan, P. (2003). *Intercropping principles and production practices*. (http://attra.ncat.org/attra-pub/intercrop.html)'

Talekar, N. S., Lee, S. T. and Huang, S.

W. (1986)**.** *Intercropping and modification of irrigation method for the control of Diamondback moth*, pp. 145–152. In *N. S, Telekar and T. D. Griggs (eds.), Diamondback moth management. Proceedings of the first International Workshop,* 11- 15 March 1985, AVRDC, Shanhua, Taiwan.

Talekar, N. S. and Shelton, A. M. (1993)**.** Biology, ecology and management of the diamondback moth. *Annual Review of Entomology*, **38**, 275–301.

Timbilla, J. A. and Nyarko, K. O. (2004)**.** A survey of cabbage production and constraints in Ghana. *Ghana Journal of Agricultural Science,* **37**, 93–101.

Valenzuela, H., R. Shimabuku, B. Kratky, and R. Hamasaki (1999). Bulb Onion Production in Hawaii. *College of Tropical Agriculture and Human Resources,* University of Hawaii in Manoa.

V**arghese, L.** (2000)**.** Indicators of production sustainability in intercropped vegetable farming on montmorillonitic soils in India. *Journal of Sustainable Agriculture*, **16(4)**, 5–17.

Varghese, L. T., Umale, S. B. and Kawthalar, M. P. (1990)**.** Effect of intercrops on the growth and yield of cabbage. *South Indian Horticulture*, **38 (4)**, 196–198.

Waage, J. K. (1990)**.** *Ecological theory and selection of biological control agents,* pp. 135–158. In *M. Mackauer, L. E. Ehler, J. Roland (eds.), Critical issues in Biocontrol.* Intercept Press, Andover, UK.

Y**angyuoru, M., Darkwa, E. O., Oteng, J. W., Nyalemebge, K., Terry, P. J., Willcocks, T. J., Acquah, D. and Mawunya, F.** (2001)**.** Yield of Maize and Cowpea under Variable Seasonal Rainfall, Landform, Tillage and Weed Management on the Vertisols of the Ghana. *West African Journal of Applied Ecology*, **2**, 9–19.

Zalucki, M. P., Shabbir, A., Silva, R., Adamson, D., Liu, S. S. and Furlong, M. J. (2012)**.** Estimating the economic cost of one of the world's major insect pests, Plutella xylostella (Lepidoptera: Plutellidae): just how long is a piece of string? *Journal of Economic Entomology* **105(4)**, 1115–1129.