Economic analysis of habitat manipulation in Brassica pest management: wild plant species suppress cabbage webworm

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Abstract

Chemical insecticide application has been the most widely used form of insect pest management in last six decades and resulted in well-documented negative impacts. Habitat manipulation based on intercropping to exert direct effects on pests and promote biological control has been explored in various systems as a more sustainable option. A range of intercrop plants have been evaluated, with many studies reporting successes in terms of enhanced natural enemy density, reduced pest numbers and, less commonly, reduced crop loss. Economic benefit and cost-effectiveness are less frequently explored, despite the importance of these criteria in farmer adoption and scope to scale. Here we quantify the effects of contrasting experimental habitat management treatments on densities of the pest, cabbage webworm, *Hellula undalis* Fab. (Lepidoptera: Crambidae), crop yield and quality, profitability and cost: benefit ratio in a cabbage *Brassica oleracea* var. *capitata* (Brassicaceae) production system in West Africa. Six wild plant species were evaluated as intercrops to promote pest suppression. *Ageratum conyzoides*, *Tridax procumbens* (Asteraceae), *Crotalaria juncea* (Fabaceae), *Cymbopogon citratus* (Poaceae), *Lantana camara* (Verbenaceae) and *Talinum triangulare* (Talinaceae) intercrop plantings were compared with a no-plant control treatment in a randomised block experiment over three growing seasons in Ghana. Costs of gathering plant propagules and establishing each intercrop plant were recorded, as was the market value of cabbage from each treatment, allowing the calculation of precise cost: benefit ratios. *Hellula undalis* larvae were numerous in the control compared with the intercrop plant treatments. The intercrop treatments had higher undamaged yields compared with the control.

Reflecting this, and establishment costs, intercrop plant treatments had better cost: benefit ratios than the control, ranging from 1:2.8 for *C. citratus* to 1:46.6 for *A. conyzoides*. These findings provide an important evidence base for considering the economic case for habitat manipulation control and highlight that the identity of plants used in this type of agricultural intervention has a major effect on the economic outcome.

Key words: Cabbage, *Hellula undalis*, net benefit, undamaged yield, cost: benefit ratios

1 Introduction

Agricultural intensification has led to enhanced crop productivity per unit area (Bommarco et al. 2013). This has, however, been achieved with less attention to sustaining the natural processes that support agroecosystems (Woodcock et al. 2016). Removal of natural habitats and over dependence on agrochemicals have resulted in declines in beneficial insects and an increase in pest impact (Gurr et al. 2017; Potts et al. 2016). Adverse effects of synthetic insecticides on ecosystem have necessitated the search for alternative approaches to manage pests in agriculture (Bommarco et al. 2013). Minimizing the use of agrochemicals and integrating ecologically prudent practices may reduce their negative impact on ecosystem services (Bommarco et al. 2013). Further, in many less developed regions, insecticide use is not a viable option because of constraints imposed by access and cost (Tefera et al. 2016). So, here, non-chemical pest management strategies are of particular value if they are effective and affordable.

Conservation biological control aims to realize the potential of endemic and naturalized predators and parasitoids by modifying the agroecosystem to remove constraints on their survival and activity (Griffiths et al. 2008). Different groups of arthropod predators, parasitoids and entomopathogenic organisms present in the agroecosystem can provide pest suppression (Gurr et al. 2017). The availability of pollen and nectar resources, as well as shelter and alternative prey, sustains and enhances the survival and performance of natural enemies that are often scarce in simplified agroecosystems (Isaacs et al. 2009). Often, natural vegetation in the agricultural landscapes does not provide sufficient floral resources at the right time and place, hence the need for local manipulation such as flower strips (Karp et al. 2018; Gurr et al. 2017). Optimal survival of predators and parasitoids depends on the availability of pollen and nectar from flowers (Gurr et al. 2017; Gurr et al. 2018). Accordingly, there is need to manipulate the habitat to provide natural enemies with these key resources. Many natural enemies are omnivores (Kean et al. 2003) requiring both prey and plant resources to function effectively. It is important that the cropping environment is positively influenced to suit natural enemies in delivering pest suppression. Availability of shelter habitats among crops enhances the heterogeneity at the farm level and decreases the possibility of extinction of rare but potentially beneficial natural enemy species

(Jonsson et al. 2015). Shelter at the farm scale also provides donor habitat for beneficial organisms during agronomic practices such as tillage, pesticide application and harvesting of crops.

Several forms of habitat manipulation for conservation biological control have been undertaken across the developed world including Australia, New Zealand, Western Europe and the US with some reported successes (Gurr et al. 2017). In the developing world including sub-Saharan Africa, whilst many smallholder farmers do not have the financial capacity to purchase chemical insecticides and insects continue to cause crop losses and imperil food security, farmers fail to capitalize on the low-cost pest management option by promoting endemic natural enemies to effect pest control (Wyckhuys et al. 2013). Ecological information about importance of natural enemies and ways of exploring their potential in pest management is often non-existent, especially in developing countries including Africa (Wyckhuys et al. 2013).

A review a decade ago showed that plants from 35 plant families have been used in most of the habitat manipulation studies; with only four families, Apiaceae, Asteraceae, Fabaceae and Lamiaceae, having at least 10 species tested (Fiedler et al. 2008). Most of the studies have utilized one or more of just four plant species, *Phacelia tanacetifolia* Benth. (Boraginaceae), *Fagopyrum esculentum* Moench (Caryophyllales: Polygonaceae), *Lobularia maritima* L. (Desv.) (Brassicales: Brassicaceae) and *Coriandrum sativum* L. (Apiales: Apiaceae) in regions outside their places of origin. Selection criteria for plant species have focused on the effectiveness shown in earlier habitat management studies (Fiedler et al. 2008). In recent years, however, interest in native plants has increased. Pandey et al. (2018) showed the longevity of the parasitoids, *Diaeretiella rapae* (McIntosh), *Cotesia glomerata* (L.) (Hymenoptera: Braconidae), and *Diadegma semiclausum* (Hellen) (Hymenoptera: Ichneumonidae) exposed to flowers of Australian native plants was comparable with the longevity when exposed to the commonly used *F. esculentum*. Native species can outperform or provide similar resources as non-natives and have several advantages such as local adaptation, habitat perpetuity, and enhanced native biodiversity value (Fiedler et al. 2008).

Regardless of the intercrop plant species used for habitat manipulation, the intervention must ultimately result in pest suppression with an increase in yield and quality of crops to stimulate global patronage as a reliable pest management tactic for use in situations where insecticides are unavailable, unaffordable or undesired. Even though several studies have reported on the benefits of habitat manipulation to suppress pests, there are few that give experimental evidence to support the claim that habitat manipulation enhances yield and quality of crops and is a cost-effective pest management option (Amoabeng et al., 2020; Cullen et al. 2008).

While not a major pest in temperate regions due to its reduced activity in temperatures below 20 °C (Sivapragasam and Chua 1997), the cabbage webworm is an important cabbage pest in tropical and subtropical regions. A single *H. undalis* larva can cause the death of a whole plant or result in the plant forming multiple non-marketable heads (Mewis et al. 2002).

This study aimed to provide experimental evidence on the effect of habitat manipulation on abundance of *H. undalis* and on yield and quality of cabbage (*Brassica oleracea* var. *capitata*) as well as calculating the cost-benefit of this conservation biological control intervention for cabbage pests.

2 Materials and methods

2.1 Experimental location and design

Field experiments were conducted at the Crops Research Institute (CRI), Kwadaso, Kumasi, Ghana (6°43'N,1°36'W; 287m elevation) between January 2017 and March 2018. Cabbage seasons were June - August 2017 (major rainy season - season one), September - November 2017 (minor rainy season - season two) and December 2017 - March 2018 (dry season – season three). Six wild plant species; *Ageratum conyzoides*, *Tridax procumbens* (Asteraceae), *Crotalaria juncea* (Fabaceae), *Cymbopogon citratus* (Poaceae), *Lantana camara* (Verbenaceae) and *Talinum triangulare* (Talinaceae) were established between January and May 2017. These plants were selected based on factors such as their potential as brassica intercrops, their prospects of providing other ecosystem services including botanical pesticides e.g. Amoabeng et al. (2020; 2013), herbal medicines, indigenous vegetables and their adaptability in the ecosystem, even though *L. camara* and *A. conyzoides* are exotic (Rioba and Stevenson, 2017).

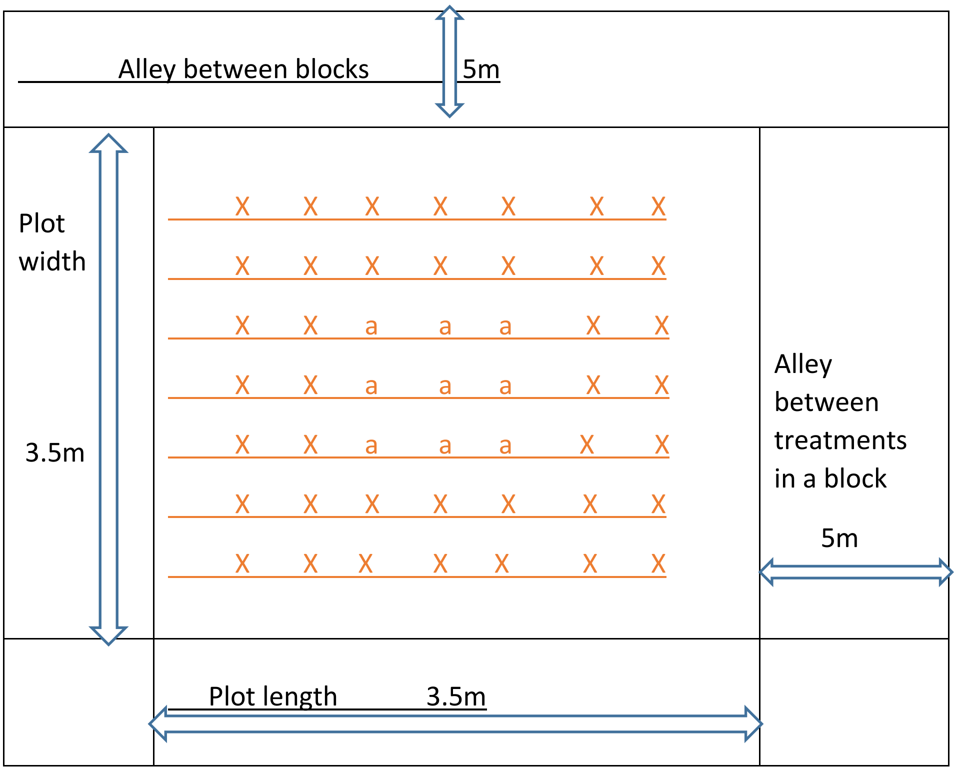
Table 1: Wild plants used in habitat manipulation and person-days and cost required to establish one hectare.

Scientific name	**Family**	**Common name**	**Selection criteria**	**Persons day/Cost of establishing1 ha (US $)**
Ageratum conyzoides	Asteraceae	Billy goat weed	Abundant, easily and freely obtained, multiple ecosystem services e.g. botanical insecticides, herbal medicine,	8 days = 70.40
Crotalaria juncea	Fabaceae	Sun hemp	Abundant, easily and freely obtained, multiple ecosystem services e.g. botanical insecticides, herbal medicine, green manure	10 days = 88.00
Cymbopogon citratus	Poaceae	Lemon grass	Abundant, easily and freely obtained, multiple ecosystem services e.g. botanical insecticides, herbal medicine	10 days = 88.00
Lantana camara	Verbenaceae	Wild-sage	Abundant, easily and freely obtained, multiple ecosystem services e.g. botanical insecticides, herbal medicine,	11 days = 96.80
Talinum triangulare	Talinaceae	Water leaf	Abundant, easily and freely obtained, multiple ecosystem services e.g. herbal medicine, indigenous vegetable, cover cropping	9 days = 79.20
Tridax procumbens	Asteraceae	Coat button	Abundant, easily and freely obtained, multiple ecosystem services e.g. botanical insecticides, herbal medicine	8 days =70.40

The six habitat manipulation treatments and a no habitat manipulation control, were each allocated to four replications in a randomised complete block design. The habitat manipulation plants often grow in the wild in the study area and are not sold for any purpose and thus were obtained freely for this study so only the cost of collecting and field establishment were counted. Some plant species were more easily obtained whilst others required extra care in nursing the propagules before field planting, hence differences in cost of collecting and establishing. Each plot measured 3 m x 3 m with 5 m border rows between plots. To minimize edge effects and inter-plot interference, the intercrop plants were put at the centre of each plot and covered an area of 1 m^2, whilst cabbage seedlings were planted around them. Two rows of cabbage (cv. Oxylus) seedlings raised in insect-proof cages were planted at 0.5 m x 0.5 m around the intercrop plants. There were 44 plants per plot in the habitat manipulation treatments plots and the control plot had five more plants per plot (49 plants) to cover the centre treatment area. To encourage potential natural enemies before population build-up of pests, intercrop plants were established with enough time for flowering to commence before the first season cabbage was planted and all plants continued to bloom throughout the experiments except for the grass *Cymbopogon citratus*.

For economic analysis, all recordings were extrapolated on a per hectare basis and all monetary values were converted to United States dollars (US$). The number of minutes used in collecting and planting each plot was recorded and varied according to the ease with which each plant was obtained. One person-day at the location of the experiments cost US$ 8.80 during the period of the study. *Lantana* was established using stem cutting requiring a nursery before field establishment. Consequently, 11 person-days were required to establish *Lantana* for a cabbage crop area of one hectare resulting in US$ 96.80.

Though *Cymbopogon* established easily, it was relatively difficult to gather owing to its use as anti-malaria herb in Ghana and therefore 10 person-days were required to gather and establish resulting costs of US$ 88.00. Seedlings were used to establish *Crotalaria* and required replacement of dead seedlings to ensure a good stand, hence 10 person-days at US$ 88.00 were required to establish a crop area of one hectare. *Ageratum* and *Tridax* were the most abundant weed species around the experimental area and were relatively easy to gather so 8 person-days valued at US$ 70.40 for each. Whilst *Talinum* was the easiest to establish, it was relatively difficult to gather owing to its use as an indigenous vegetable in Ghana. Therefore, 9 person-days at US$ 79.20 was required to establish it.



X: Cabbage plants, a: Habitat manipulation plants

Fig. 1: A diagram showing position of habitat manipulation plants and cabbage stands in treatments plots

2.2 Effect of habitat manipulation on *Hellula undalis*

Ten cabbage plants per plot were randomly selected to non-destructively assess numbers of *H. undalis* larvae once every week for four consecutive weeks in each season. Assessment of *H. undalis* infestation commenced three weeks after transplanting of cabbage. Cabbage seedlings were transplanted at five weeks old. Thus, cabbage plants were eight weeks old when assessment of *H. undalis* infestation started.

2.3 Yield assessment

All cabbage plants were used for yield and quality assessment. Cabbage heads from each treatment were separated into undamaged and damaged heads and weighed. Cabbages were classified undamaged if the head had no visible signs of larval feeding or holes. Cabbages were classified as damaged if heads had visible signs of insect feeding but still had market value albeit at a reduced price. The local currency, Ghana cedi (¢) exchange rate to the US$ was 1:0.22 during the period of the study and this exchange rate was used to calculate values in US$. During the first season harvest, 1kg of undamaged cabbage heads was selling for US$ 0.44 and damaged was US$ 0.22 at the local market. During the second and third seasons, the price per kilogram of undamaged and damaged heads were US$ 0.33 and US$ 0.22 respectively. Revenue from the sale of cabbage was converted to per hectare by extrapolating plant population of the habitat manipulation treatments to 35,000 plants per hectare assuming planting distance of 0.5 m x 0.5 m and considering the area occupied by the manipulation plants and spaces for easy movement while the control plots had 35,500 plants per hectare.

2.4 Statistical and economic analysis

Weekly data on *H. undalis* were analysed using a mixed model analysis with treatment as a fixed effect and block as a random effect, and assuming equal variance, using statistical package for social scientists (SPSS IBM version 24) (Corporation, 2016). Mean head weight per plant, undamaged and damaged head weight per tonne were subjected to analysis of variance (ANOVA) of statistical analysis system (SAS) (SAS Institute 1985). When significant differences were observed ($P < 0.05$) means separations were performed using Tukey's honest significance difference test. The economic analysis followed the procedure used in Amoabeng et al. (2014). See footnote - Table 2 for details.

3 Results and discussion

3.1 Effect of habitat manipulation on abundance of *H. undalis*

Figure 2: *Hellula undalis* feeding through the growing point of cabbage in control (no habitat manipulation) treatment at initial stage of attack (left) and advanced stage of attack (right)

All habitat manipulation treatments (intercrop) had lower numbers of *H. undalis* compared to the control. The larva of *H. undalis* (Fig 2) typically attacks the plant from the growing point and bores through the stem.

In week one (and throughout) of the first season, the control treatment had significantly (F=21.88, df 6, 20, P = 0.001) higher numbers of *H. undalis* per plant than all other treatments. Among the six treatments, *Talinum* and *Lanta* had significantly lower numbers of *H. undalis* in week one than the remaining treatments which were not different from each other (Fig 3). Numbers of *H. undalis* in the control treatment increased steadily from 0.50 ± 0.00 per plant in the first week to 1.50 ± 0.25 in the 4th week. In week two, *Talinum* had significantly (F = 21.88, df 6, 20, P = 0.001) lower numbers of *H. undalis* compared with the remaining treatments. This was followed by *Tridax* and *Lantana* which were also significantly lower in numbers of *H. undalis* whilst *Ageratum* was also significantly lower than that of *Crotalaria*. (Fig 3). In the third week, *Tridax* and *Talinum* were significantly (F = 21.88, df 6, 20, P=0.001) lower than the remaining treatments which were also lower than the control. In week four *Talinum* and *Lantana* were significantly (F = 21.88, df 6, 20, P = 0.001) lower than the remaining treatments whilst *Tridax* and *Cymbopogon* were also lower than *Crotalaria*. All treatments were significantly lower in *H. undalis* numbers than the control. There was significant (F = 21.88, df = 3,18, P=0.0001) week effect as well as significant (F = 21.88, d

f= 6, 20, P=0.0001) treatment x week interaction on *H. undalis* during the first season.

In week one of the second season, mean *H. undalis* per plant in the control treatment was 0.80 ± 0.25 and was significantly higher (F=21.88, df 6, 20, P=0.001) than all the intercrop treatments. Numbers of the pest increased to 2.0 ± 0.25 in the 4th week which was also significantly higher (F=21.88, df 6, 20, P=0.0001) than the intercrop treatments (Fig 4). There was a significant (F=21.88, df= 1, 20, P= 0.000) week effect, but a non-significant (F=1.742, df=6, 20, P=0.068) treatment x week interaction on *H. undalis* in season two.

In the third season, *H. undalis* were not observed in the first and second weeks. No significant differences were observed in numbers of the insect in the remaining weeks (data not shown).

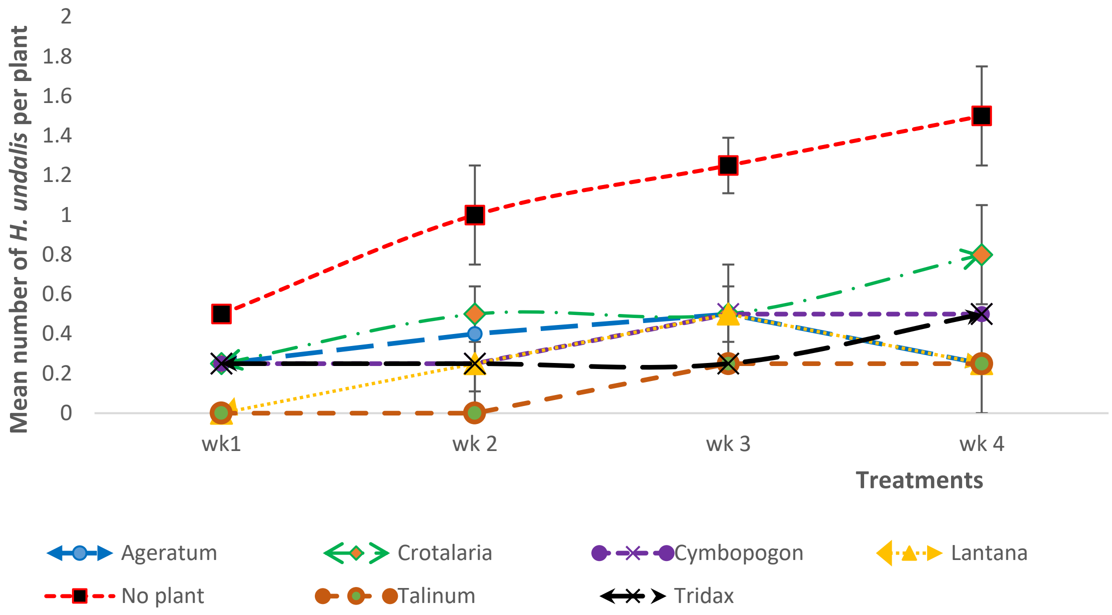


Figure 3: Effect of habitat manipulation using six plant species on mean (±SE) of *Hellula undalis* during the first season (June-August, 2017) in Kumasi, Ghana. (Cabbages were eight weeks old and three weeks post transplanting in assessment week 1)

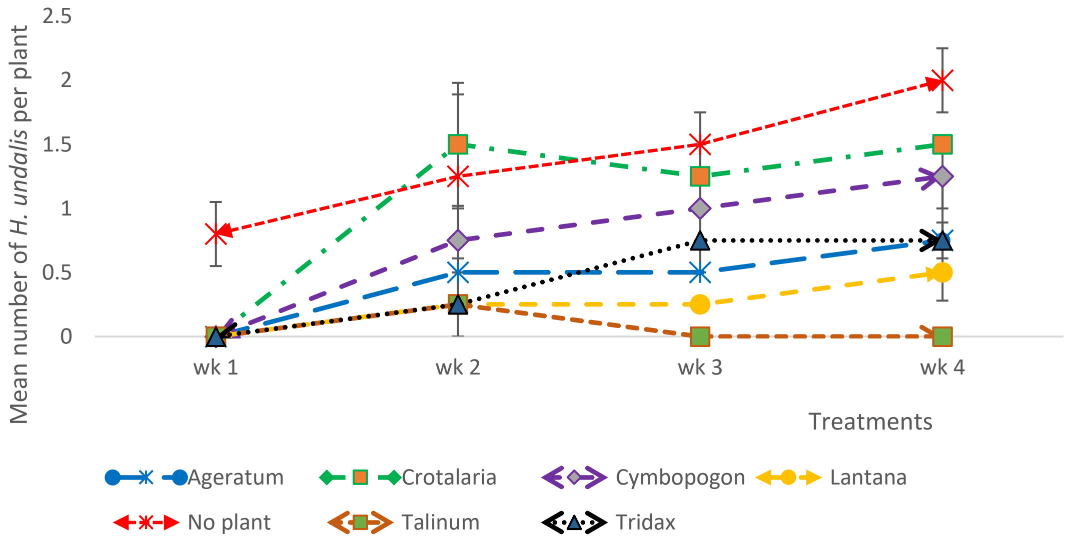


Figure 4: Effect of habitat manipulation using six plant species on mean (±SE) of *Hellula undalis* during the second season (September-November, 2017) in Kumasi, Ghana. (Cabbages were eight weeks old and three weeks post transplanting in assessment week 1)

It is clear from the foregoing account of *H. undalis* abundance results that the habitat manipulation treatments in general tended to reduce pest density compared with the non-plant control. Importantly, however, suppression of this pest was not consistently high in all weeks of all seasons and for all intercrop treatments. This demonstrates that the identity of the plant species used in habitat manipulation interventions is important and that biodiversity per se is not always sufficient to support greater pest regulation, in agreement with Karp et al. (2018). Reduced numbers of *H. undalis* on cabbages translated into higher cabbage head yield per hectare in habitat manipulation treatments compared with the control. A similar study assessing effects of intercropping cabbage with tropical basil, *Ocimum gratissimum* (Lamiaceae), resulted in significant reduction of *H. undalis* in the intercrop compared with the no intercrop control (Yarou et al. 2017). Even though *Ocimum* plants in that study were established among brassicas purposely to repel insect pests, their presence might have provided conducive habitat and floral resources for important natural enemies to enhance their potential for suppressing pests of the brassica crop.

The reduced number of *H. undalis* in the manipulation treatments may be attributed to the direct effect of the wild plants on pests or natural enemies that might have been attracted and nourished. Previous studies have shown that predators are important in managing *H. undalis*, as they can significantly reduce the population of this pest (Mushtaque et al., 1986; Sivapragasam & Chua, 1997). Parasitoids are, however, of little importance as they are more active at the end of the growing season which is too late to provide meaningful control of *H. undalis* (Sivapragasam & Chua, 1997; Ebenebe et al., 2011). The habitat manipulation treatments varied in their ability to reduce pest numbers and damage. These differences could be due to the divergent plant morphology and floral architecture (Begum et al. 2004).. Other important arthropod pests of cabbage such as diamondback moth, cabbage aphids and other defoliators were observed in the present study as often is the case in the cabbage cropping system in Ghana. The present study, however, focused only on the effects of habitat manipulation on *H. undalis* and head yield and quality of cabbage.

3.2 Plant yield and quality

(Table 2, Figure 5). In season two, there were no significant differences but the control treatment had numerically the lowest head weights. In season 3, *Ageratum, Talinum* and *Crotalaria* had significantly higher head weights than the control. Manipulation treatments were superior in yield per hectare in all seasons, as well as in damaged yield per hectare in season one. In season two, all treatments were significantly better than the control in undamaged yield per hectare. Despite efforts to minimize inter-plot interference (a 5 m alley between treatments), the spatial scale of the experiment was small compared with the movement patterns of agricultural arthropods. Accordingly, results need to be interpreted in this light. Potentially, the control treatment would have derived some benefit by movement of natural enemies to it after deriving benefit in the (relatively nearby) plots with flowering plants, so underestimating the overall benefit of habitat manipulation. Alternatively, the benefits of some flowering plant treatments may have been magnified under these testing conditions, above the level of benefit that would apply if there were a sole treatment applied across a wider scale, if the plant species were preferred and attracted natural enemies from other flower treatments that were less preferred but still provided resources to a greater extent than un-manipulated donor habitat

A chemical insecticide positive control was not included in the current study. This was to avoid potential negative impacts on natural enemy numbers at the whole-experiment-scale and by possible spray drift. Accordingly, it is not possible to calibrate the present findings against the efficacy and economics of insecticide-based pest control as is common in Ghana and internationally. That approach is, however, increasingly questioned in terms of sustainability because chemical insecticides often disrupt natural enemies at lethal and sub-lethal levels resulting in pest resurgence and secondary pest outbreaks (Roubos et al. 2014). Notwithstanding the exclusion of chemical insecticide treatment, cabbage yields in the current study were higher compared to an earlier study at the same site where insecticide treatment was involved (Amoabeng et al. 2013). This suggests that habitat manipulation for conservation biological control can be a viable option for pest suppression with corresponding high yield and quality.

3.3 Economic analysis

3.3.1 Cost of crop protection and income from produce

The differences in both undamaged and damaged yields were reflected in total and net incomes. In season one, the *Lantana* treatment had the highest net income and cost benefit while the control treatment had the lowest net income (Table 3). In season two, the *Tridax* treatment had the highest net income of US$ 9931/ha while the control had the lowest US$ 6749/ha. The range of net income in season three was narrower, with US$ 10,662 for *Talinum* and US$ 9,020 for the control (Table 3).

In season one, the *Lantana* treatment was not higher yielding than *Talinum*, *Ageratum* and *Cymbopogon* per plant, but its superior income resulted from having the lowest number of damaged heads. The control had the highest number of damaged heads and the lowest number of undamaged heads which resulted in the lowest income. Total income was highest in the treatment in the second season and the third season, the *Talinum* treatment had the highest total income. The price of undamaged cabbage heads was US$ 0.44 in season one and US$ 0.33 in season two, which resulted in the incomes of the control treatment being similar for the two seasons. This reflects the fact that total yield, quality and prevailing market price all determine income and profitability. Whilst the market price in season one was 25% higher than that in season two, improved yields in season two led to higher total income which was enough to compensate for the fallen market price of the produce. Income for the control was higher during season three compared with season one and two because there was an increase in both yield and quality of cabbage heads more compared to season one even though the market price was higher in season one. The cost of the manipulation treatments varied according to the work needed to get the plants established and maintained in the field. This was the only variable cost associated with the study hence its use in calculating the cost benefit ratios. No commercial value was assigned to any of the plants used for the manipulation, but potentially these could be harvested as a secondary income since each of them may provide provisioning and regulating ecosystem services. Since quantifying these was beyond the scope of this study, the pest management-related economic benefits of intercropping reported herein are conservative.

All cabbage heads had market value. Whilst cabbage heads with signs of insect damage may be rejected by consumers elsewhere in the world, in Ghana, many consumers prefer to buy cabbage heads with obvious signs of insect damage, as an indicator of pesticide-free status. Cabbage yield may be influenced by several factors including pests and diseases, soil fertility and soil moisture. In the present study, all treatments received similar agronomic inputs except whether a treatment was intercropped with a wild plant and which type of plant that was used. Thus, differences in yield and quality observed among the treatments in the study could be attributable to the habitat manipulation type.

3.3.2 Cost: benefit ratios

Cost benefit: ratios between 1:2.8 (season three) and 1:46.6 (season one) were evident in the study. For season one, cost: benefit ratios were between 1:8.8 and 1:46.6 (Table 3). In season two, cost: benefit ratios were lower than season one and lower again in season three (Table 3). These results suggest that wild plants in habitat manipulation lead to decreased herbivory and enhanced plant growth, resulting in yields higher than the no manipulation control. The reduction in damage of cabbage in the habitat manipulation plots could be attributable factors including activities of predators and parasitoids that might have been attracted to the non-crop plants. Similarly, plants such as *C. citratus* may have volatile compounds that may repel insect pests. For instance, *Ocimum basilicum* as an intercrop with cabbage was successful in repelling *H. undalis* compared with plots without basil (Yarou, et al. 2017). Reflecting the agricultural context of this enhanced yield, the economic value of the plant product was significantly increased using native/naturalised plants in habitat manipulation treatments. Finally, the costs of implementing the conservation biological control were modest, with the cost: benefit ratio ranging from 1:2.8 to 1:46.6.

Cost: benefit ratios in this study show the economic viability and biological effectiveness of this pest management tactic. Positive ratios denote economic viability of treatments relative to the control (Aziz et al. 2012). Cost: benefit ratios in this study were higher than those obtained in similar studies, e.g., between 1:4 and 1:29 were obtained in cabbage pest management with aqueous plant extracts (Amoabeng et al. 2014). Patel et al. (1997) obtained cost: benefit ratios between 1:12.6 and 1:14.1 when neem extract was compared with endosulfan in pigeon pea pest management. These studies analysed only the cost of plant protection, and the calculated cost: benefit ratio was based on incomes.

In the present study, cost: benefit ratios were higher in season one and declined in seasons two and further in season three. This was due to a reduction in damaged yield in the control. It is possible that numbers of natural enemies were concentrated in the manipulated treatments in season one but moved across all treatments including the control as their numbers increased given the relatively small separation between treatments. Griffiths et al. (2008) reported that natural enemies have the capacity to disperse across habitats with habitat boundaries doing little to prevent their movement.

Table 2: Evaluation yield parameters in three seasons for economic analysis of habitat manipulation for conservation biological control of cabbage pests in Kumasi, Ghana.

Treatment	Yield/plant (kg)			Undamaged yield (t/ha)			Damaged yield (t/ha)	
	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3	Season 1	Season 2
Ageratum	0.71 ± 0.11a	0.70 ± 0.01a	0.90± 0.02ab	21.10 ± 0.55b	19.88 ± 0.63c	31.50 ± 0.40a	3.73 ± 0.15bc	4.62 ± 0.86ab
Crotalaria	0.55 ± 0.02b	0.83 ± 0.05a	0.90 ± 0.02ab	15.37 ± 0.27c	22.15 ± 0.95bc	31.50 ± 0.31a	3.88 ± 0.86b	6.90 ±0.43a
Cymbopogon	0.73 ± 0.10a	0.76 ± 0.04a	0.81 ± 0.01bc	21.71 ± 0.22b	23.55 ± 0.80bc	28.35 ± 0.34c	3.84 ± 0.23bc	3.05 ± 0.65b
Lantana	0.77 ± 0.02a	0.69 ± 0.04a	0.86 ± 0.02abc	24.11 ± 0.40a	20.55 ± 0.29c	30.10 ± 0.47b	2.84 ± 0.22c	3.60 ± 0.13b
Talinum	0.70 ± 0.01a	0.76 ± 0.01a	0.93 ± 0.03a	20.74 ± 0.47b	24.66 ± 0.78ab	32.55 ± 1.40a	3.76 ± 0.17bc	1.94 ± 0.17b
Tridax	0.58 ± 0.01b	0.91 ± 0.04a	0.85 ± 0.02abc	16.48 ± 0.63c	27.23 ± 1.56a	29.75 ± 0.37bc	3.82 ± 0.36bc	4.62 ± 0.37ab
Control	0.51 ± 0.04b	0.64 ± 0.03a	0.77 ± 0.01c	12.61 ± 0.61d	15. 92 ± 0.54d	27.33 ± 0.47d	5.50 ± 0.25a	6.8 ± 0.97a
P< 0.05	0.001	0.048	0.004	0.001	0.001	0.001	0.001	0.001
F	22.53	1.08	6.82	12.75	21.65	15.34	84.00	9.55
df	6, 21	6, 21	6, 21	6, 21	6,21	6, 21	6, 21	6, 21

Means within a column with different letters differ significantly (P < 0.05). Note: No damaged yield in season three. Yield per hectare = head weight per plant x plant population per hectare.

Table 3: Evaluation of cost and benefit of habitat manipulation for conservation biological control of cabbage pests in three seasons in Kumasi, Ghana.

Treatment	Income from undamaged yield (US$)			Income from damaged yield (US$)		Cost of protection	Net income (US$)			Cost: benefit ratio		
	Season 1	Season 2	Season 3	Season 1	Season 2	(US$)	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3
Ageratum	9,284.00	6,560.40	10,395.00	820.60	1,016.40	70.40	10,034.20	7,506.40	10,324.60	1: 46.6	1: 10.8	1: 18.5
Crotalaria	6,762.80	7,309.50	10,395.00	853.60	1,518.00	88.00	7,528.40	8,739.50	10,307.00	1: 8.8	1: 22.6	1: 14.6
Cymbopogon	9,552.40	7,771.50	9,355.50	844.80	671.00	88.00	10,291.20	8,354.50	9267.50	1: 40.1	1: 18.2	1: 2.8
Lantana	10,608.40	6,781.50	9,933.00	624.80	792.00	96.80	11,136.40	7,476.70	9,836.20	1: 45.3	1: 7.5	1: 8.4
Talinum	9,125.60	8,137.80	10,741.50	827.20	426.80	79.20	9,873.60	8,485.40	10,662.30	1: 39.4	1: 21.9	1: 20.7
Tridax	7,251.20	8,985.90	9,817.50	840.00	1,016.40	70.40	8,021.20	9,931.90	9,747.10	1:18.0	1: 45.2	1: 10.3
Control	5,548.40	5,253.60	9,020.55	1,210	1,496.00	0.00	6,756.20	6,749.60	9,020.55			

Income from undamaged yield = total weight of undamaged yield x price (kg) undamaged yield. Income from damaged yield = total weight of damaged yield x price (kg) damaged yield. Total income = income from undamaged yield + income from damaged yield. Net benefit = Total income – cost of protection (for each treatment). Benefit over control treatment = Net income for each treatment – income from control. Cost: benefit ratio = Benefit over control for each treatment ÷ cost of protection for each treatment. Economic analysis followed in procedure in Amoabeng et al. (2014).

3.4 Indirect benefits and constraints of habitat manipulation for conservation biological control

Benefits associated with the use of conservation biological control may be categorized into those that directly accrue to the grower and those that benefit society. Reflecting on both benefits should determine the adoption of the pest management tactic (Griffiths et al. 2008). Conservation biological control may contribute to higher yield and quality of crop produce and profitability as seen in this study and it offers the potential for food commodities with reduced risk of insecticide residues which may attract a price premium, thus enhancing profit margins. Globally, consumers will offer premium prices for food commodities without pesticide (Cullen et al. 2008). Overall, conservation biological control may increase profitability by providing economically valuable levels of pest suppression without the use of insecticides and the attendant risks of these chemical inputs (Wyckhuys et al. 2013).

Notwithstanding the numerous benefits that habitat manipulation for conservation biological control may offer, there are potential barriers to their adoption. For instance, natural enemies may not be available in sufficient numbers especially during the early stages of the program, and pest damage may go beyond economic threshold levels (Hajek and Eilenberg 2018). Some plants that are intended to provide floral resources to natural enemies may rather favour pests (Gurr et al. 2017). The land area devoted to the manipulation plants is an opportunity cost, as they reduce the total land area for the crop (Collins et al. 2003). In the current study, the control treatment had 500 cabbage stands more than the habitat manipulation treatments, thus resulting a shortfall in the plant stand of the economic crop. Despite the reduced plant population of the manipulation treatments, they produced higher yields per hectare compared with the control as a result of reduced stress from pest attack and thus, compensating for the shortfall in plant population.

4 Conclusions

The high cost: benefit ratios obtained in this study show the potential of habitat manipulation using these non-crop plant species for sustainable pest management in cabbage. More generally, this study provides motivation for studies in a wider range of geographical locations and crop systems to assess the utility of habitat manipulation for conservation biological control of insect pests. Whilst many such studies have reported benefits to natural enemy density and pest incidence, there is a need for more research to provide cost: benefit evidence to spur uptake.

Acknowledgement

This manuscript emerged from the doctoral fellowship awarded to ABW by Charles Sturt University, Australia, through the International Postgraduate Research Scholarship (IPRS) and International Tuition Payment (ITP) programs. Thanks to Mrs AC Johnson for reviewing and editing the manuscript.

Competing interest

The authors declare that no competing interest exist for this work

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