Intercropping Kale with Culinary Herbs Alters Arthropod Diversity and Hinders Population Growth in Aphids

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Abstract. The aim of this work was to evaluate arthropod diversity and levels of population growth in *Myzus persicae* (Sulzer) under kale (*Brassica oleracea* L. var. *acephala* DC) intercropped with green onion (*Allium fistulosum* L.), coriander (*Coriandrum sativum* L.), basil (*Ocimum basilicum* L.), and parsley [*Petroselinum crispum* (Mill.) Nym.]. The following characteristics were evaluated under both monocrop and intercrop systems: 1) arthropod diversity and abundance, 2) population growth rate in the *M. persicae* aphid, 3) average number of aphids per kale leaf, and 4) total fresh weight of produced kale. The experiment was carried out in Fortaleza, in the state of Ceará, Brazil, in a design of randomized blocks, with five treatments and five replications. The family Aphididae was the most abundant, represented by *M. persicae*. Thirty-nine spiders were the most abundant predators. The intercrop with basil gave the greatest diversity of arthropods. The aphid population showed slower growth under the intercrop systems with cilantro and with parsley. Fresh weight production in the kale was inversely proportional to the number of aphids on the plants. The results suggest that intercropping kale with culinary herbs is a promising strategy to reduce aphid populations and losses occasioned by them.

Kale (*B. oleracea* L. var. *acephala*) is one of the most widespread vegetables of the Brassicaceae family found worldwide (Fernandes et al., 2009). In Brazil, it represents a major share of vegetable production (Silva et al., 2012) and is of great economic interest, especially for family farmers.

Kale cultivation is considered a high-risk activity because of severe phytosanitary problems, especially with pests (Marcolini et al., 2005; Silva et al., 2012). In areas cultivated with kale, there are frequent infestations by the cabbage aphid [*Brevicoryne brassicae* L. (Hemiptera: Aphididae)], green peach aphid [*M. persicae* Sulzer (Hemiptera: Aphididae)], diamondback moth [*Plutella xylostella* L. (Lepidoptera: Plutellidae)], kale leafworm [*Ascia monuste orseis* Latrielle (Lepidoptera: Pieridae)], cabbage looper [*Trichoplusia ni* Hübner (Lepidoptera: Noctuidae)], and whitefly [*Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae)] (Filgueira, 2008; Gallo et al., 2002).

The aphids attack not only kale, but also numerous other species, being considered an

important pest in these crops throughout the world (Blackman and Eastop, 2000; Collier and Finch, 2007; Gallo et al., 2002). The damage caused by the insects is because of the continuous sucking of sap from the phloem tissue and the transmission of plant viruses. The most visible damage from such an attack is shriveling and chlorosis of the leaves and shoots (Blackman and Eastop, 2000; Collier and Finch, 2007; Gallo et al., 2002; Saethre et al., 2011).

In general, the control of aphids in kale crops has mainly been through the use of insecticides (Bass et al., 2014). However, aphids exhibit a great ability to develop resistance mechanisms that allow them to survive exposure to insecticides at concentrations normally considered toxic (Bass et al., 2014; Georgiou and Lagunes-Tejada, 1991). In these situations, some producers assume that the survivors did not receive a lethal dose and may react by increasing the pesticide dosage or the frequency of application.

Continuous spraying during the harvest period, where the kale leaves are periodically removed over short periods of time, has resulted in the presence of insecticide residue above acceptable levels (ANVISA, 2011). Chemical control has, therefore, become problematic, making it necessary to search for new management strategies for the aphid populations.

One alternative to the use of agrochemicals is control by intercropping. In intercrop systems, two or more species grow

simultaneously in the same area throughout all or part of their cycle (Albuquerque et al., 2012), bringing benefits to agricultural production. In a recent and thorough review (which evaluated more than 500 experiments in 45 studies), the benefits of intercropping were clearly demonstrated (Letourneau et al., 2011). Among such benefits, increases in the diversity and abundance of natural enemies and the suppression of pest populations were detailed. Thus, crop diversification can be used as a strategy for optimizing pest management in crops with serious phytosanitary problems, such as kale.

From this perspective, the aims of the present study were 1) to evaluate whether intercropping kale with condiment crops [green onion (*A. fistulosum*), coriander (*C. sativum*), basil (*O. basilicum*), and parsley (*P. crispum*)] could promote changes in the structure of the arthropod community (diversity and abundance); 2) to analyze whether intercropping could reduce populations of the *M. persicae* aphid; and 3) to evaluate the economic benefits of intercropping by the total fresh weight of kale produced under the different cropping systems (monocrop and intercrop).

Material and Methods

Characterization of the study area. The study was carried out between Aug. and Nov. 2015 in an experimental area in Fortaleza, in the state of Ceará, Brazil (03°44'S, 38°34'W, at an altitude of 21 m). According to the Köppen classification, the climate in the region is tropical with dry summers (Alvares et al., 2014).

During the study, the average air temperature was around 28.1 °C, with the minimum air temperature varying between 21.4 and 23.6 °C and the maximum air temperature between 29.0 and 32.4 °C. The relative humidity ranged from 57.7% to 80.7%, with an average value of 66.6%. The accumulated rainfall in the period was 11 mm. We obtained the data from the meteorological station of the Universidade Federal de Ceará.

Experimental design and experimental unit. We used a randomized block design with five treatments and five replications. The treatments consisted of kale grown as a monocrop and intercropped with culinary herbs: monocrop of kale, kale intercropped with coriander, kale intercropped with green onion, kale intercropped with parsley, and kale intercropped with basil.

One experimental unit comprised a total area of 2.88 m². We grow the kale at a spacing of 0.6 × 0.6 m. For the intercropped treatments, the culinary herbs were arranged between the rows of kale. The spacing of the green onion was 0.2 × 0.10 m. We grew the coriander and parsley in rows spaced 0.20 m apart and at a seeding density of 4 g of seed per linear meter. With the basil, we adopted a spacing of 0.6 × 0.25 m. The working area consisted of the four central kale plants, including the rows of culinary herbs between them in the intercropped treatments.

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Setting up and conducting the experiment.

We used the cultivars Manteiga da Georgia (kale), Verdão (coriander), Todo Ano (green onion), Graúda Portuguesa (parsley), and Italiano (basil). We sowed the kale and the basil in plastic trays of 162 cells filled with a substrate of earthworm humus and vermiculite (4:1 v/v). We transplanted the seedlings at 20 and 23 d after sowing (DAS), respectively, for the basil and kale. We planted the green onion, coriander, and parsley in grooves made directly in the soil 8 d before transplanting the kale seedlings. Two consecutive crops of coriander were grown by virtue of their shorter cycle in comparison with the other crops.

Before planting, the soil was fertilized with 12 kg·m⁻² of organic compost (locally produced). We carried out cover fertilization with organic compost every 2 weeks, beginning 15 d after transplanting (DAT) the kale seedlings. The doses were 0.3 kg/plant for the kale and basil and 1.5 kg·m⁻² for the remaining crops. We irrigated the plants by using a micro sprinkler twice a day. We controlled the weeds periodically and applied no crop defenses during the experiment.

Harvesting followed the marketing standards for each crop in the growing region. We harvested the kale at 41, 56, and 70 DAT; the basil at 36, 51, and 70 DAT; the parsley at 55 DAS; the green onion at 70 DAS; and the coriander at 35 and 36 DAS for the first and second crops, respectively. The kale leaves harvested throughout the production cycle were weighed to obtain the total fresh weight (g/plant).

Arthropod collection and identification.

We carried out a weekly population survey of the arthropods on both the kale and condiment crops, starting at 7 DAT of the kale seedlings and continuing until the final harvest.

For the kale crop, the number of aphids was quantified by direct count on one leaf per plant, preferably from the middle leaf (fully expanded, adult leaf). We collected and stored a few specimens weekly for species confirmation. For the remaining arthropods (other pests, natural enemies, or both), we inspected the whole plant, with minimal disturbance to avoid dispersal, and collected all the arthropods present. Where there were caterpillars, these were counted, isolated, and kept in petri dishes under environmental conditions with a feeding substrate (pieces of kale leaf), to control for the emergence of parasitoid adults, none of which were later found.

We also sampled the condiment crops to verify the possibility of arthropods being shared between these and the kale crop. For the green onions, coriander, and parsley, four points were chosen at random, whereas for the basil, we analyzed the four plants in the central working area. Inspection was by beating the plant leaves over a tray with a white background.

The captured arthropods were stored in Eppendorf tubes containing a preservative solution (hydrated alcohol—70%) for later

identification. Arthropods were observed using a Zeiss stereomicroscope and identified at least to the family level based on the literature (Fujihara et al., 2011; Triplehorn and Johnson, 2011).

Data analysis. Data from the arthropod sampling were used for a faunistic analysis and for a study of the population fluctuation of the aphids throughout the kale crop cycle. The faunistic analysis was carried out based on the average number of arthropods sampled in each treatment on each collection date, and through such ecological parameters as relative abundance and diversity. Relative abundance represented the percentage participation of the number of individuals of each taxon in relation to the total number of individuals sampled. Diversity relates the number of taxa to the distribution of individuals among them. Diversity was calculated using the Shannon–Wiener index (H') (Shannon and Weaver, 1949), according to the formula $H' = -\sum pi(\ln pi)$, where H' = species richness component, pi = relative frequency of species i given by ni/N , ni = number of individuals of species i , N = total number of individuals, and $\ln$ = Napierian logarithm. The diversity indices found for each cropping system (monocrop or intercrop) were compared by their respective confidence intervals (95% probability), such that the overlap between intervals characterized them as statistically similar.

The fluctuation in the number of aphids/leaf over time for each cropping system was analyzed graphically through regression analysis, and trend curves were elaborated using the Table Curve 2D 5.01 statistical software (TableCurve 2D, 2002). A single regression model was selected for all cropping systems; the model was chosen for the highest values for R^2 and the lowest values for P . The mean number of aphids/leaf over time for each cropping system was submitted to the nonparametric Wilcoxon rank test (SAS Institute, 2002) as the data did not present a normal distribution. Finally, the influence of the aphid populations on the total fresh weight produced by using each kale plant in the three harvests was analyzed by linear regression (SAS Institute, 2002).

Results

The relative abundance of arthropods in the different kale cropping systems (monocrop or intercrop) displayed a similar pattern, where the family Aphididae represented over 98% of the individuals collected (Table 1). Individuals of the family Aphididae were all identified as *M. persicae*. The family Pieridae was the second most abundant taxon, except in the intercrop with basil (Table 1).

The remaining taxa were observed in lesser abundance (Table 1), being represented by predators, most of them polyphagous. Among them, spiders (Araneae) were the most abundant, occurring in greater numbers in the intercrop with basil and less in the monocrop. Attention should also be

given to ladybugs (Coccinellidae) which had the highest abundance in the intercrop with basil, followed by the intercrop with coriander. No coccinellids were seen in the monocrop.

In general, the cropping systems influenced arthropod diversity (Table 1). The intercrop of kale and basil had the highest number of taxa (15), whereas the monocrop of kale and the intercrop with green onion were the least diverse (five and six taxa, respectively). Intermediate values were seen for the intercrops with coriander and parsley (10 and 8 taxa, respectively). These results are supported by the Shannon–Wiener indices (H'), which indicate greater diversity associated with the intercropped kale and basil (0.092), differing from the other cropping systems, especially the monocrop (Table 1). Despite the observed differences, it is possible that these are underestimated because of the sampling techniques used in the present study. The sampling techniques used are limited by the observation period (compared with other methods such as sticky panels) and also because of potential disturbance by insects that could fly away at the sampling moment.

Fluctuations in the aphid populations were similar among treatments. Irrespective of the cropping system, the incidence of aphids started at 14 DAT, reaching peaks in the population between 42 and 56 DAT, as shown in Fig. 1A. However, in the intercrops with coriander and parsley, the population grew at slower rates, and consequently presented delayed peaks. At 35 DAT, the sharing of aphids between crops (kale and companion) was noted, and it was possible to see the presence of aphids in the culinary herbs, especially in the parsley. Population declines were seen notably after 49 DAT, being greater in the intercrop with coriander.

Fluctuations in the mean number of aphids over time were adjusted to the polynomial growth model ($y = cx^4 + bx^2 + a$), explaining at least 69% of the observed variations ($R^2 > 0.69$) (Table 2). As shown in Fig. 1B, the mean number of aphids observed with the different cropping systems did not differ ($\chi^2 < 6.16$; gl = 4; $P > 0.18$).

As for the effects of the aphid infestation on the performance of the kale crop, the total fresh biomass produced was inversely proportional to the mean number of aphids/leaf observed on the plants in the different cropping systems, as shown in Fig. 2. That is, the cropping systems that presented a lower mean value for aphids per leaf also obtained higher values for fresh weight produced per plant, especially the intercrop with parsley. The data fit the linear model ($y = -0.54x + 152.86$), explaining 66% ($R^2 = 0.66$) of the observed variations ($P = 0.0069$).

Discussion

The species *M. persicae* is considered cosmopolitan and one of the most adaptable among aphids, alternating its populations

Table 1. Mean number of individuals ($\bar{X}$), relative abundance of arthropod taxa collected in monocrop kale plants and intercropped with coriander, green onion, parsley and basil, between Sept. and Nov. 2015, and the Shannon-Wiener diversity index (H').

Order/family	Monocrop		Intercrop coriander		Intercrop green onion		Intercrop parsley		Intercrop basil	
	$\bar{X}$	Abundance	$\bar{X}$	Abundance	$\bar{X}$	Abundance	$\bar{X}$	Abundance	$\bar{X}$	Abundance
Aphididae	150.86	99.86	118.62	99.41	140.83	99.79	136.48	99.43	152.91	98.63
Araneae	0.03	0.02	0.16	0.13	0.11	0.08	0.21	0.15	1.19	0.77
Chrysomelidae	—	—	0.01	0.01	—	—	—	—	0.01	<0.01
Cicadellidae	—	—	0.01	0.01	—	—	—	—	0.03	0.02
Coccinellidae	—	—	0.13	0.11	0.01	<0.01	0.09	0.07	0.26	0.17
Culicidae	—	—	—	—	—	—	0.02	0.01	0.34	0.22
Dolichopodidae	0.01	0.01	0.02	0.02	0.04	0.03	0.05	0.04	0.11	0.07
Formicidae	—	—	—	—	—	—	—	—	0.01	<0.01
Lygaeidae	—	—	—	—	—	—	—	—	0.04	0.02
Mantodea	—	—	0.04	0.03	—	—	—	—	0.01	0.01
Membracidae	—	—	—	—	—	—	—	—	0.01	<0.01
Pieridae	0.13	0.09	0.25	0.21	0.12	0.08	0.34	0.25	0.09	0.06
Plutellidae	0.03	0.02	0.08	0.06	0.03	0.02	0.02	0.01	0.02	0.01
Reduviidae	—	—	—	—	—	—	—	—	0.03	0.02
Syrphidae	—	—	0.01	0.01	—	—	0.04	0.03	0.01	<0.01
Total	151.07	100	119.32	100	141.13	100	137.26	100	155.04	100
H'	0.011 c (0.008–0.015)		0.045 b (0.03–0.05)		0.017 c (0.013–0.022)		0.043 b (0.036–0.050)		0.092 a^z (0.084–0.101)	

^zMean values followed by the same letter do not differ by overlap of the confidence interval at 95% probability ($P \leq 0.05$).

The bold formatting indicates the arthropod diversity index for the cropping system.

Fig. 1. Aphid dynamics in monocrop kale and intercropped with condiment species. (A) Aphid population fluctuation. (B) Aphid abundance per kale leaf.

among its various hosts, and remaining more or less active throughout the year depending on temperature conditions (Kasprowicz et al., 2008; Van Emden et al., 1969). Similarly, among the several representatives of the family Pieridae, some are important pests of the Brassicaceae (Gallo et al., 2002).

Concerning the presence of spiders and ladybugs, the results of this study are similar to those observed by Souza (2014), who obtained a greater abundance of arachnids and coccinellids in an intercrop of sweet pepper (*Capsicum annuum* L.) and basil, when compared with a monocrop of sweet

pepper. Spiders are recognized as important generalist predators (Charlet et al., 2002) and are present in most terrestrial habitats, including less disturbed agricultural systems (Souza, 2014). When gathered into species groups, spiders can contribute to a reduction in the population of several pest (Sunderland, 1999), such as aphids.

Resende et al. (2010), also studying an intercrop of kale and coriander, found a greater abundance of coccinellids in the intercropped kale in relation to the monocrop. Furthermore, other researchers have seen a greater presence of coccinellids in sweet pepper intercropped with basil (Souza, 2014), and tomato (*Solanum lycopersicum* L.) intercropped with coriander (Togni et al., 2010), when compared with their respective monocrops. These results underline the superiority of intercropping systems as regards phytosanitary problems, as coccinellids are important in pest regulation, feeding preferentially on aphids, cochineals, mites, and whiteflies (Silva, 2013).

As many natural enemies (i.e., syrphids, lacewings, coccinellids, and aphid parasitoids) are anthophilous, their establishment and performance are improved when flowering herbaceous plants are placed within cropping systems (Hagen, 1962; Hodek, 1967; Jervis and Kidd, 1996). Flowers provide not only nutrients (pollen and nectar) which support metabolism and gamete development, but also provide mating sites and shelter (Aguiar-Menezes and Silva, 2011; Altieri and Leptourneau, 1982; Altieri and Whitcomb, 1979; Jervis and Kidd, 1996). In the present study, some crops (coriander, green onion, and parsley) were harvested before flowering which may have contributed to the lower number of natural enemies in the experimental area.

The greater diversity of arthropods associated with basil, was also reported by Souza (2014) when grown with sweet pepper. However, the diversity pattern obtained by the researcher was better ($H' = 1.716$) than that in the present study ($H' = 0.092$). Analyzing

Table 2. Important parameters of the regression analysis for fluctuation in the number of aphids per kale leaf over time in each cropping system.

Cropping system	Model	Coefficient			R^2	P
		(a)	(b)	(c)		
Monocrop	$y = cx^4 + bx^2 + a$	-31.25	0.20	-3.3e-05	0.69	<0.0001
Intercrop coriander		-65.95	0.21	-4.1e-05	0.70	<0.0001
Intercrop green onion		-70.67	0.30	-7.8e-05	0.72	<0.0001
Intercrop parsley		-53.15	0.18	-2.8e-05	0.87	<0.0001
Intercrop basil		-45.07	0.21	-3.9e-05	0.73	<0.0001

Fig. 2. Relationship between total fresh matter (g/plant) and mean number of aphids per leaf of monocrop kale and intercropped with culinary herbs.

diversity patterns, the values observed in this study were overly low. This fact may be related to the greater dominance of aphids (less diverse arthropod population) and to a shorter sampling period because of the severe damages caused by the attack of aphids that weakened the kale plants. This restricted the number of observations and limited the estimate of the arthropods mainly in the composition of predator taxa.

The aphid population dynamics were similar to the pattern described by Wellings and Dixon (1987). According to these researchers, the colonies of aphids display a period of steady growth followed by a period of decline. This is because the aphids locate and colonize the host plants more quickly, and initially their populations tend to grow in number, whereas, their natural enemies begin to colonize the plants later, attracted by the greater supply of prey (period with the highest aphid population density). From then on, because of the greater intraspecific competition for food, the aphids begin a process of dispersal due to the detriment of the plant from the continuous sucking of sap or from natural enemies, explaining the subsequent decline in population.

When considering the high population level of aphids, this study corroborates the results

found by Stoetzer (2013), who highlighted mid-October as the period most favorable to heavy aphid infestation due to higher temperatures and an absence of rainfall. Although not distinctive, it is worth noting that the average numbers of aphids observed in kale plants consorted with Apiaceae were the lowest among cultivation systems, maybe due to a greater abundance, and/or diversity, of natural enemies.

In fact, in this study, the greater presence of natural enemies in response to the diversity of the intercropping systems did not guarantee a noteworthy reduction in the number of aphids. One possible explanation for these results may be related to the insect sampling technique used in this study. Removal of natural enemies at each sampling date may have contributed to a lower impact of these organisms on the aphid population. Anyway, Letourneau et al. (2011) demonstrated that diversification practices cannot always be translated into pest suppression. According to Heemsbergen et al. (2004) it is not the species number but the degree of functional differences between species that enhance overall ecological functions. Thus, the screening of key plants is of crucial importance to shape agricultural systems to specifically reduce pest pressure and enhance production.

Intercropping alone was not enough to solve the problem of pest management in the area of kale production. However, it represents an important tool to be explored in integrated pest management programs designed to fight against this pest. Additional studies should be conducted to establish better designs for achieving even lower populations of aphids (such as placement of culinary herb plants between the kale plants inside the row). Also, agronomic aspects (labor involved water and nutrient usage, etc.) and economic aspects (profitability and mostly land equivalent ratio) should be assessed. Although some intercropping systems have hindered population growth in aphids, high population levels were reached. Thus, the compatibility of intercropping with other non-aggressive aphid control strategies should also be investigated. These studies are necessary before widespread recommendation of this approach to growers.

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