Intercropping Potato with Citrus Trees as Ecologically-Based Insect Pest Management

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Intercropping Potato with Citrus Trees as Ecologically–Based Insect Pest Management

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Potato can be cultivated on various environments in different seasons, which makes it vulnerable to numerous insect pests. The presence of various types of insect pests may hinder the pest management with pesticides. Intercropping system provides an alternative nonchemical option for controlling insect pests. This study was carried out to evaluate the usefulness of intercropping potato under sweet orange *Citrus sinensis* trees. For this purpose, densities of four main sap–sucking insect pests and their natural enemy predators were examined in two cultivation seasons. The results indicated that the intercropping system could be a useful technique for using space under citrus trees. The intercropping system significantly reduced the infestation of whitefly *Bemicia tabaci* though the density of green peach aphid *Myzus persicae* rather increased. Planting systems also had a significant but minor impact on potato leafhopper *Empoasca fabae* and green sink bug *Nezara viridula*. Beside, the pest occurrence differed markedly between summer and winter potato fields. Natural enemies such as ladybeetle *Coccinella undecimpunctata* densities were greater on intercropping than mono–cropping potato in both winter and summer seasons but *Orius insidiosus* was rather fewer in intercropping systems. Our study suggests that the intercropping system is useful in pest management of potato.

Key words: IPM, ground cover plants, piercing–sucking insect pests, *Orius insidiosus*, horticulture trees, *Macrolophus caliginous*, *Scymnus interruptus*

INTRODUCTION

Potato, *Solanum tuberosum* L., is an important non–cereal food crop, coming in the fourth rank after rice, wheat and maize grown in the world (Zhang *et al*., 2017). Since the crop had been introduced to Europe in the 16th Century from its origin in southern Peru (Spooner *et al*., 2010), several herbivorous pests have become responsible for hampering potato growth. Piercing–sucking insects often lead to considerable damage on potatoes. Furthermore, such insects are able to transmit the majority of the described plant viruses, causing a significant yield loss (Radcliffe *et al*., 1993; Oliveira *et al*., 2001; Hogenhout *et al*., 2008). Thus, management of such piercing–sucking pests is crucial to stable production of potato.

Among the insects assemblage, whiteflies, aphids and leafhoppers are the most common and widespread piercing–sucking insect pests in potato fields (Anonymous, 2008). Although the management of these pests is of particular importance in potato production, they have often developed insecticide resistance, making it difficult to control them solely by insecticides (Radcliffe *et al*., 1993; Anonymous, 2008). It is therefore desirable to incorporate other control measures to reduce damage caused by them (Mousa *et al*., 2013; Elsharkawy and Mousa, 2015). The occurrence and population dynamics of such insect pests fundamentally depend on climatic factors (Yumamura *et al*., 2006; Curnutte *et al*., 2014) and on natural enemies (Yamamura and Kiritani, 1998; Hirose, 2006; Sayed and Teilep, 2013, Ueno and Tran, 2015). Hence, use of natural enemies could be an option. On the other side, cultivation systems including tillage (Hatten *et al*., 2007), crop rotation (Chilcutt and Matocha, 2007) and planting spaces (Mohamed, 2012) also influence the pest populations. Establishment of cropping system to minimize pest severity may hence be possible.

Many studies have revealed that intercropping is an important alternative cultural control technique to protect the crop from insect pests (e.g., Landis *et al*., 2000; Vaiyapuri *et al*., 2010; Degri *et al*., 2014). Intercropping can safeguard the crop because the non–host crop can (1) work as a physical barrier to insect pests searching their host plant (Parker *et al*., 2013); (2) emanate confusing chemical volatiles which mask the presence of the host crop for specialist insect pests (Sulvai *et al*., 2016); and (3) release repellent chemicals to pest insects or chemicals that attract their natural enemies (Letourneau *et al*., 2011; Degri *et al*., 2014).

In intercropping systems, many locative combinations are possible, e.g., different crops planting in the same or alternating rows, planting a non–main crop as a fence surrounding the main one or, in our case, planting the main crop under sustainable horticulture trees. Although many previous studies investigated the usefulness of intercropping two different vegetable crop species (Potts, 1991; Baidoo, 2012) or vegetable crops with cereals (Nwanze, 1989; Chabi–Olaye, 2005) to control insect pests, few studies have been focusing on intercropping systems with horticulture tree crops.

Accordingly, in the present study, we address the

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usefulness of intercropping vegetable crops under horticulture trees. Pest management success in intercropping systems can depend on the choice of non–main crops. Here, we choose citrus trees to incorporate into an intercropping system with potato. As the first step to establish the intercropping system, we examine how the intercropping system could influence the occurrence and density of piercing–sucking pests and their natural enemy predators in order to evaluate how the system could affect pest–natural enemy dynamics. Basing on the results, we discuss the usefulness of citrus trees in intercropping systems.

MATERIALS AND METHODS

Sites and experimental designs

The experiment was carried out during the period from November 2015 till May 2016, which covered two potato cultivation seasons, i.e., late winter and early summer seasons. The first study field was located at the horticultural experimental farm of the Faculty of Agriculture, Kafrelsheikh University, Kafr El–Sheikh, Egypt, where citrus trees were grown in order to evaluate the effect of intercropping potato under citrus trees. The second field was used as a control and was at the experimental farm of the Agricultural Research Center, Sakha, Kafr El–Sheikh. The two study fields were located in the same area within 5 km apart from each other. Both fields were the same in terms of atmospheric conditions, soil structure and the surrounding vegetation. In our study, we used the variety Cara, a high yield potential variety with good foliage cover, which had been imported from UK. In the first field, one row of potato was alternately planted with one raw of eight years old sweet orange trees *Citrus sinensis* (L.). Four plots were set up, each of which contained six rows of potato and five rows of citrus trees, and each row contained 16 potato tubers or five trees. In the second field, a plot size of 25 m^2 was used and replicated four times. Potato tubers in both fields were planted at the distance of 30 cm within the row and 60 cm apart between rows and/or trees. Each plot was separated from each other by at least 1.5 m. The plots were uniformly fertilized with the recommended values of N–P–K. No insecticides were applied in the two study fields.

Data collection

The field sampling was initiated from the incipient–leaf growing stage of potato plants, and was continued once per week till the harvest. Thus, sampling dates were from 12 November 2015 to 21 January 2016 and from 28 March 2016 to 30 May 2016 in the winter and summer planting seasons, respectively. From each field, a cross diameter method was used, and 30 randomly–selected plants in each plot were directly inspected to monitor the densities of the potato pests, i.e., sweet potato whitefly (=Cotton whitefly) *Bemisia tabaci* (Gennadius) adults, potato leafhopper *Empoasca fabae* Harris, green peach aphid *Myzus persicae* (Sulzer) and southern green stink bug *Nezara viridula* (L.). The densities of immature whiteflies were measured by collecting 30 leafs per plot and examining them in the labo-

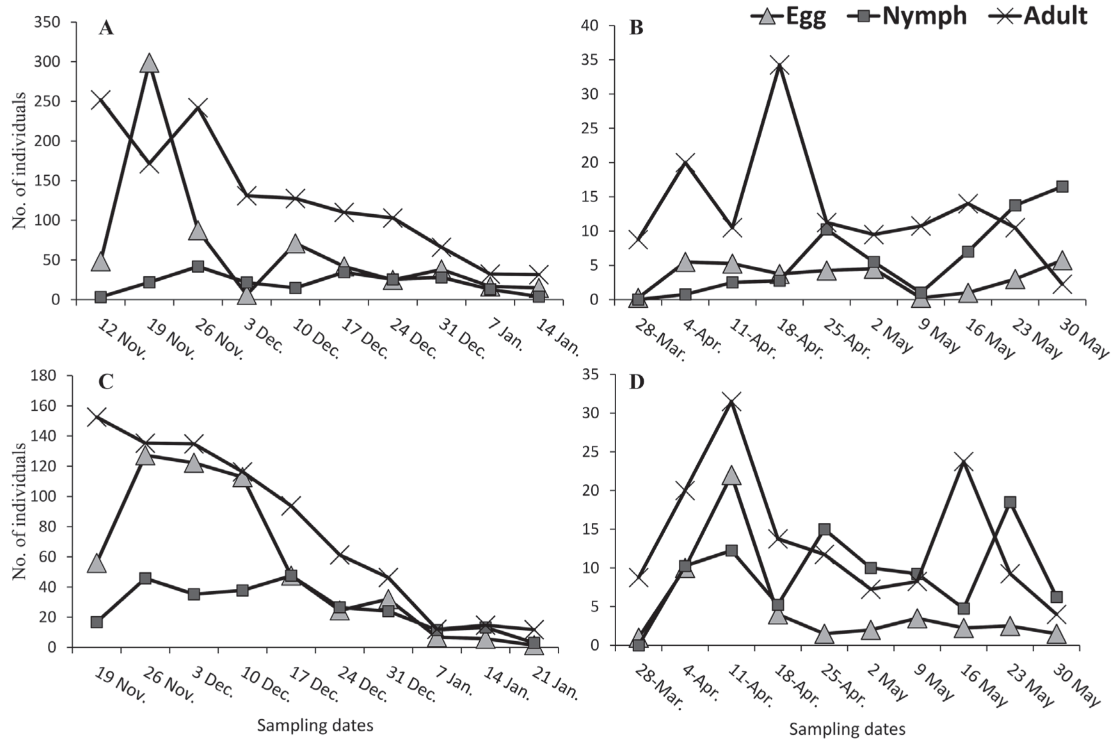

Fig. 1. Mean weekly abundance of *B. tabaci* during the period between Nov. 2015 to May 2016. (A) winter mono–cropping potato; (B) summer mono–cropping potato; (C) winter intercropping potato; (D) summer intercropping potato.

ratory. In addition, the numbers of the associated predators were counted. Five insect predators, *Orius insidiosus* Say, *Macrolophus caliginosus* Wagner, *Coccinella undecimpunctata* L., *Scymnus interruptus* (Goeze) and true spiders, were considered as the most dominant species.

Statistical analyses

The collected data were subjected to GLM with a link function, log, assuming a Poisson distribution. When necessary, the means were compared by analysis of variance (ANOVA) or Tukey–Kramer HSD test. Significance value was set at α=0.05. In addition, relationships between the densities of insect pests and their associated predators were analyzed. Statistical analyses were done using COSTAT software version 6.4 and JMP version 8.0.

Table 1. Statistical summary for the effects of cropping system and season on whitefly abundance

Factors	Adults	Nymphs	Eggs
System	4.76 *	8.06	0.95 NS
Season	612.2	115.3	1189.1
Interaction	7.11	NS	7.11

* Chi–squared values estimated with GLM are shown; all values indicate a statistical significance. The interaction term indicated with NS is statistically not significant, and, hence, is excluded from the whole model.

RESULTS AND DISCUSSION

Pest occurrence

In our study fields, we detected four main piercing–sucking insect pests, i.e., whitefly *B. tabaci*, potato leafhopper *E. fabae*, green peach aphid *M. persicae* and green bug *N. viridula*, throughout the growing stages of potato in winter and summer seasons. These pest species were often abundant in the study fields but the densities of the four pest species differed greatly depending on the species and cropping season.

Seasonal prevalence of the whitefly is shown in Fig. 1. *Bemisia tabaci* was the most abundant pest in our study fields. The whitefly densities were much higher in winter than in summer, and GLM showed that all stages of whiteflies were significantly greater in density on winter potato plants (Table 1). In winter season, this pest continually damaged potato plants, except the latest growth stage of potato. The adult whiteflies were detected from the earliest stage of potato, i.e., the incipient–leaf growing stage, when the densities of adults were highest; thereafter, adult densities gradually decreased (Fig. 1). The densities of whitefly nymphs and eggs increased following the adult density, and, then, decreased.

The aphid *M. persicae* were also found abundant in our fields, in particular, in winter. GLM detected a high level of statistical significant on the season difference in aphid density (Table 2). In winter season, this aphid was detected in large number in both types of fields but was rather rare in summer (Fig. 2). In summer, the aphid was found relatively abundant, though much fewer than in winter, at the earliest growth stage of potato plants but decreased quickly thereafter, remaining very scarce until the harvest stage. In contrast, the density of *M. persicae* in winter season was high at the earliest plant stage then gradually increased until middle growth stage, and decreased thereafter. Control of the aphid therefore can be important in winter but seems not necessary in summer. The presence of a relatively great number of the aphids at the earliest growing stage of potato may suggests that there are other close–by habitats around the potato fields, from which they migrate into the field immediately after planting.

Table 2. Statistical summary for the effects of cropping system and season on pest insects

Factors	*Myzus* aphids	Potato leafhoppers	Stink bugs
System	10.73 *	4.10	15.23
Season	249.7	811.5	563.2
Interaction	NS	NS	NS

* Chi–squared values estimated with GLM are shown; all values indicate a statistical significance. The interaction terms indicated with NS are statistically not significant, and, hence, are excluded from the whole model.

Curiously, the potato leafhopper *E. fabae* showed an opposite trend of occurrence, being markedly abundant in summer whereas its population densities were much lower in winter (Fig. 2). GLM showed that the seasonal difference in leafhopper density was highly significant (Table 2). The leafhopper *E. fabae* is widely known as one of the most important piercing–sucking pests infesting over 500 plant species belonging to 74 families through different geographical regions (Greathead, 1986; Ellsworth *et al.*, 1999; Oliveira *et al.*, 2001). Management of this pest is important in Egyptian potato fields, particularly, in summer.

Similarly, the southern green stink bug *N. viridula* was found mostly in summer season and was very scarce in winter season (Fig. 2). Again, the seasonal difference in the abundance was highly significant (Table 2). These leafhopper and stink bug pests were rather few in the earliest growing stage of potato but gradually increased their population size, suggesting that they migrated from outside of the field and increased the density by reproducing quickly in the field. Thus, both pest species seems negligible in winter season but the management will be required in summer season when they become abundant.

Cropping effect

The effects of cropping systems, *i.e.*, mono–cropping versus intercropping with citrus tree, were examined for the 4 main pest species observed in our fields. All pest individuals detected were summed for each sampling plot across each growing season, and the summed data were used to analyze the effect of intercropping on

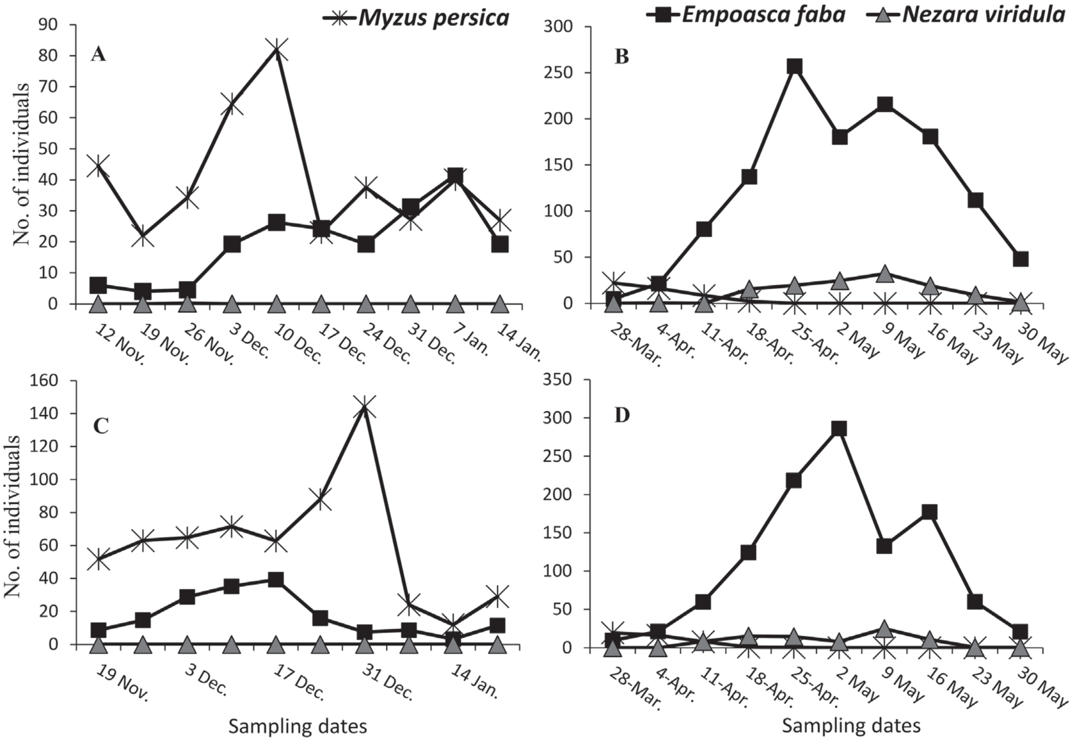

Fig. 2. Mean weekly abundance of *M. persicae, E. fabae* and *N. viridula* during the period between Nov. 2015 till May 2016. (A) winter mono–cropping potato; (B) summer mono–cropping potato; (C) winter intercropping potato; (D) summer intercropping potato.

their occurrence. The mean sums of whitefly eggs, nymphs and adults are presented in Fig. 3. The observed numbers of whitefly adults differed significantly (Table 1; $P < 0.0001$) between the mono–cropped and intercropped potato fields in winter while there was no difference in the summer season (Fig. 3). A striking difference was that the intercropping system decreased whitefly adult density almost in half when compared with the mono–cropping system (Fig. 3). Also, egg and nymph densities were affected significantly by the cropping systems (Table 1) though the effect of the systems depended on the season (Fig. 3).

It is known that whiteflies and aphids are highly migratory insects (Taylor, 1977; Reynolds *et al*., 2006; Riis and Nachman, 2006) and are capable of continuously flight for more than 2 h (Blackmer and Byrne, 1993). This may explain why both *B. tabaci* and *M. persicae* are scarce in summer potato; in summer, there are many alternative host plants that both species prefer, such as cotton and other vegetable crops. Because of this, a dilution–like effect may be present. Also, high temperature and low rainfall condition during summer season in Egypt may not be suitable for whitefly and aphid reproduction. Because a variety of biotic and abiotic factors can influence insect abundance (Wolda, 1988; Marchioro and Foerster, 2016), factors influencing the population trends of the above mentioned 4 pest insects remain to be investigated in the potato fields of Egypt.

In the present study, we also recorded the densities of *M. persica*, *E. faba* and *N. viridula*; the mean numbers and population fluctuation during the summer and winter seasons are summarized in Fig. 3. Stink bug *N. viridula* was a rather scarce pest regardless of the seasons and cropping system though both factors had significant influences (Table 2).

Contrariwise, the green peach aphid *M. persica* occurred on winter potato in high numbers for both inter– and mono–cropping potato fields; the densities of the aphid was significantly much lower on mono– than on inter–cropping potatoes (Table 2; $p < 0.0001$). The reason for this is unclear. Lebbal and Laamari (2016) have reported that *M. persicae* is rather a very rare aphid species detected on citrus trees. Although this aphid has a wide range of host plants, we could find any evidence or literature that *M. persicae* uses citrus trees as an important host plant. We thus believe that the aphid increases on intercropping potato not because citrus trees are its source of reproduction. Future studies should focus on the process of how the aphid density is affected by mono– versus inter–cropping systems.

The leafhopper *E. fabae* was quite few in winter season, showing two peaks in both cropping systems, the first in April and the second in May. The density of this leafhopper marginally differed between the intercropping and mono–cropping potato fields (Table 2); when the population trends were compared, the difference seemed very small (Fig. 2), suggesting that the effect of cropping systems was small on the leafhopper, at least, in the present study.

Many authors suggested that intercropping systems are an alternative practicable solution for pest manage-

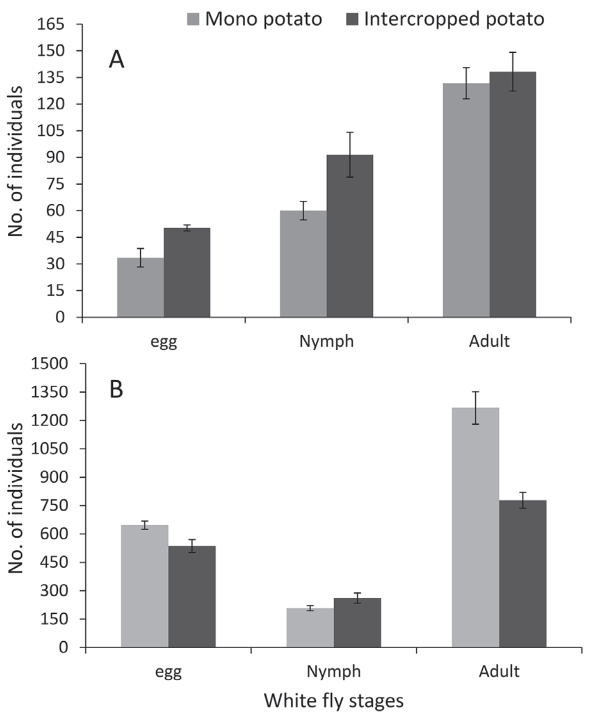

Fig. 3. Mean numbers of whitefly eggs, nymphs and adults occurred in mono– versus inter–cropping potato fields (A: summer season; B: winter season). Lines above bars indicate standard errors.

ment (Zhou *et al*., 2013; Sharaby *et al*., 2015; Sulvai, 2016). Although, in our study, the green peach aphid was rather increased on intercropped potato, we believe that the intercropping system with citrus trees is useful because it can lead to a reduction of the other main pests, as discussed above.

Natural enemies

A variety of arthropod predators were detected in our study fields, and at least several species or groups were associated with sucking insect pests on potato plants. Amongst them, the most frequently observed predators were *Orius insidiosus*, *Coccinella undecimpunctata*, *Macrolophus caliginosus*, *Scymunus interruptus* and true spiders. The occurrence and density of the latter three predators did not notably differ between the two planting systems.

However, the anthocorid *O. insidiosus* was more frequently detected in the mono cropping than the intercropping systems (Fig. 4). In the mono–cropping fields of the winter growing season, *Orius* predators increased the density very quickly after planting potato and decreased as the season went, reaching finally to zero, probably because they dispersed from the field to search an overwintering site (Fig. 4). In the summer growing season, again, *Orius* predators increased the density after planting but remained high (Fig. 4). However, in the intercropping potato fields, in both seasons, the density remained much lower.

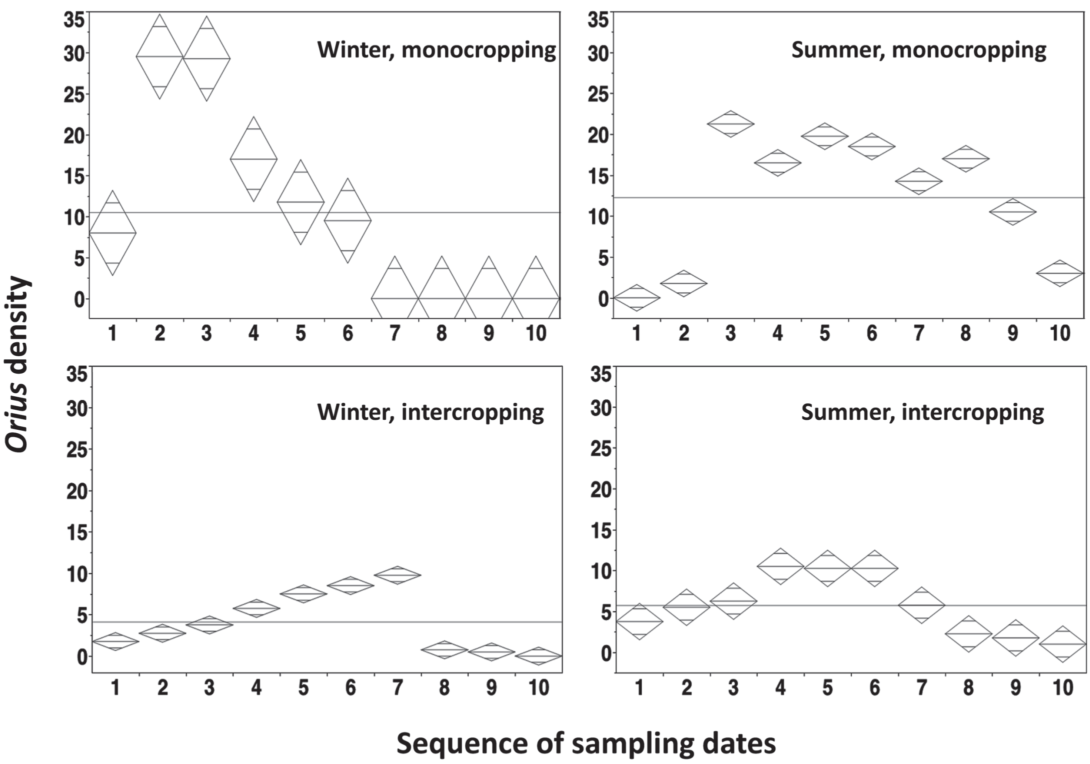

Fig. 4. Population trends of *Orius insidiosus* in potato fields during the period between Nov. 2015 till May 2016. Sampling sequences instead of the dates are used in the x–axis. Grand means are shown as a horizontal line on each figure, and mean diamonds illustrate a sample mean and ±95% confidence intervals.

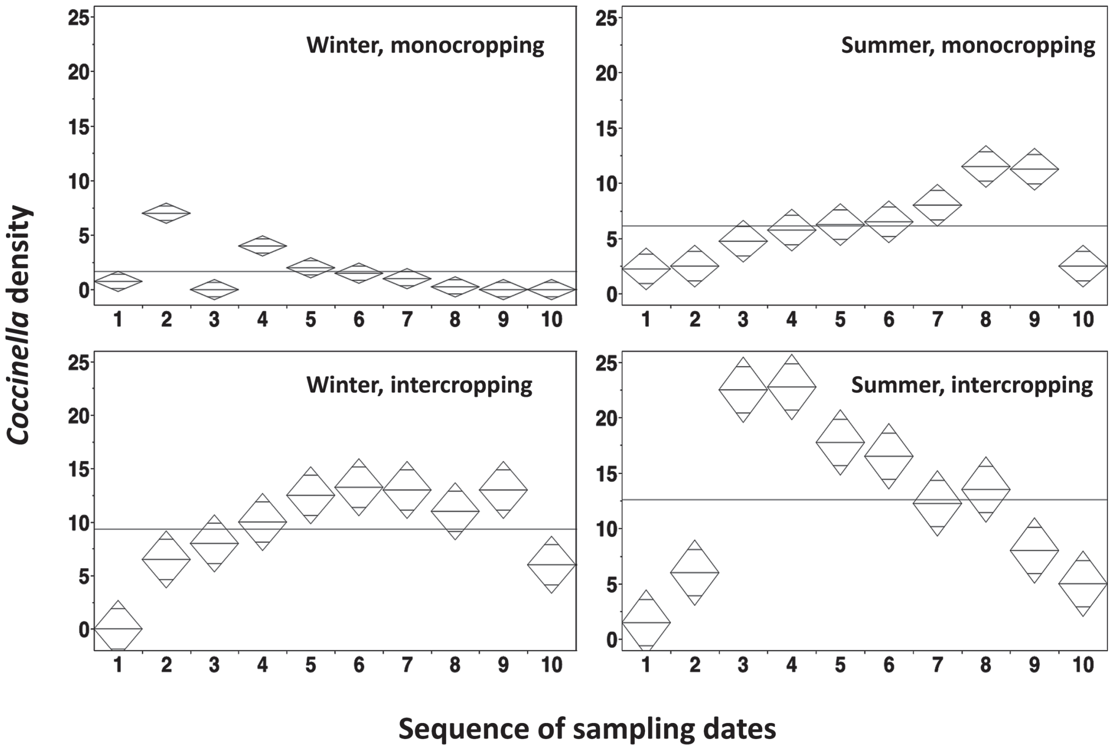

Fig. 5. Population trends of *Coccinella* predators in potato fields during the period between Nov. 2015 till May 2016. Sampling sequences instead of the dates are used in the x axis. Grand means are shown as a horizontal line on each figure, and mean diamonds illustrate a sample mean and ±95% confidence intervals.

The density difference in two cropping systems might be due to the fact that citrus trees are a host for various thrips and spider mites (Hare *et al.*, 1989), which are preferred prey for *Orius* predators. The presence of preferred prey on citrus trees may thus prevent the predators from moving to potato plants, causing the relative low density of *Orius* predators on intercropped potato plants.

In contrast, the eleven–spotted lady beetle *Coccinella undecimpunctata* was more abundant and remarkably increased in the intercropped potato fields of both seasons (Fig. 5). As we showed, the density of green peach aphid in winter was much greater in intercropped than in mono–cropped potatoes. This fact may be a reason because the lady beetle prefers the aphid as prey. However, the aphid was scarce in summer, and the difference in the summer lady beetle density was not explained in that way. The process of how intercropping can affect lady beetles remains unclear. It is well known that lady beetles are polyphagous voracious predators (Hodek, 1996), and *C. undecimpunctata* may prey on insects other than aphids on summer potato plants.

The other predators, i.e., *Macrolophus caliginosus, Scymunus interruptus* and true spiders, were more abundant in summer than in winter. Their overall densities, however, were fairly low, regardless of the seasons. In addition, there were no significant differences in their densities between the cropping systems. Therefore, those predators may not play a major role in intercropping potato fields.

Natural enemies such as insect predators and parasitoids play an important role in suppressing pest insects. Although chemical control is often a main measure to combat insect pests (Tran *et al.*, 2007; Ho *et al.*, 2013), a sole reliance on pesticides can cause the emergence of resistant pests and the destruction of native natural enemy complex, which may eventually lead to an outbreak of the pests (Ueno, 2006; Ueno and Tran, 2015). Enhancing their activity can promote suppression of the pests. Intercropping can work by enhancing biological control with native natural enemies (Landis *et al.*, 2000). Indeed, we have found in our intercropping systems that some main natural enemies increase their density though we do not know how intercropping can positively influence them. Again, we recommend intercropping systems for effective pest management in potato fields in Egypt.

AUTHOR CONTRIBUTIONS

K. M. Mousa designed the study, conducted the field experiment, analyzed the data, and prepared the manuscript. T. Ueno participated in the discussion and polished up the research concept and the manuscript. Both authors read and approved the final manuscript.

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