Short range dispersal of western flower thrips in field-grown French beans in Kenya

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Abstract. The short-range diurnal dispersal pattern of adult western flower thrips *Frankliniella occidentalis* (Pergande), in relation to spatial distribution of French beans, was determined in the field. A total of 1200 adult female *F. occidentalis* were released on 60 French bean plants with 20 adult thrips per plant at the central release point of 3.14 m². Dispersal was determined in terms of the number of thrips recorded on French beans planted on concentric circles at 0.9, 1.8, 3.6, 7.2 and 14.4 m radii from a circular central release point for five days. Results indicated that there was a steady increase in the proportion of dispersing adult *F. occidentalis* from the first to the fourth day in the first planting season, and from the first to the third day in the second planting season. The peak hour for dispersal was 10.15 h in the first season while it was 13.15 h in the second season. Temperature and wind speed were positively associated with the dispersal activity of adult *F. occidentalis*. Minimal flight activity was at temperatures below 15 °C and peak flight activity was at 19 °C. The prevailing wind direction did not influence the dispersal pattern of adult *F. occidentalis* in both seasons. Adult *F. occidentalis* moved up to 7.2 m on French beans on the first day. In both seasons, the mean direction of thrips dispersal was mostly uniformly distributed (not oriented to a particular compass direction) around the central release point. The results provide an insight into developing integrated management strategies against the pest based on isolation of farm fields, management of alterative hosts around French bean fields and insecticide application.

Key words: colonization, *Frankliniella occidentalis*, *Phaseolus vulgaris*, circular statistics

Introduction

The western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) is a major worldwide pest of ornamental and horticultural crops (Kirk, 2002). The species causes considerable damage to a wide range of plants through feeding, oviposition and transmission of tospoviruses (Kirk and Terry, 2003). In Kenya, for instance, *F. occidentalis*

is an important pest of French bean, *Phaseolus vulgaris* L. (Fabaceae) (Nderitu *et al.,* 2009; Nyasani *et al.,* 2012, 2013*a,b*). Adult *F. occidentalis* are small (1–2 mm in length), and have slender wings fringed with cilia with both males and females being capable of flight (Lewis, 1997). For dispersal, adult thrips take off by simultaneously flexing their abdomen, flapping their wings and jumping with their hind legs (Lewis, 1997). Their patterns of flight behaviour have not been as widely studied as that of other insects, such as aphids or locusts (Pearsall, 2002).

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Since adult *F. occidentalis* have a limited dispersal capacity, they often colonize the first (nearest) plant they encounter (Rhainds and Shipp, 2004). It is believed that previous colonization of host plants by conspecifics enhances the incidence of adult dispersal (Agrawal and Colfer, 2000; Rhainds and Shipp, 2003), and dispersal may generate a relatively uniform distribution of thrips among plants (Rhainds and Shipp, 2004). For small-winged insects, such as thrips, it is reasonable to hypothesize that wind direction and intensity play a role in their movement and dispersal. However, a previous study has indicated that the mean direction of dispersal of adult *F. occidentalis* into orchards located adjacent to wild land was found to be primarily from these source areas, regardless of the dominant wind flow patterns (Pearsall and Myers, 2001).

Invasion of field crops by thrips is usually due to either infested nursery transplants or immigration of adults from neighbouring fields, but little inform-ation is available on how thrips populations colonize and disperse within a field crop. Knowledge about the movement pattern of thrips into, out of, and within a particular crop is important in under-standing and predicting its population dynamics in space and time, and in providing information for possible sampling schemes and management strategies (Pearsall and Myers, 2001). In Kenya, land holding is small in areas of high agricultural potential that often results in French beans of a dif-ferent phenology being grown adjacent (0.5–10 m) to one another (Kimenye, 2002). The growing of young French beans in the vicinity of old crop fields or other alternative hosts that harbour thrips poses a serious problem, as old fields may act as a 'green bridge' for carryover of thrips to the newly planted fields. Previous studies have indicated that there is a sudden influx of *F. occidentalis* to new French bean fields at flowering stage (Nyasani *et al.*, 2013b). However, few studies have rigorously investigated the short-range dispersal pattern of adult *F. occidentalis* on field-grown crops such as French bean. Thus, the objective of the present study was to determine the short-range diurnal dispersal pattern of adult *F. occidentalis* in relation to the spatial distribution of French bean, to predict its relative dispersal capacity and ability to infest new fields in an agroecosystem.

Materials and methods

Experimental site

Field experiments to determine the short-range diurnal dispersal pattern of adult *F. occidentalis* on French bean were conducted at the Kenya Agricultural and Livestock Research Organization (KALRO), Embu Centre, Kenya. KALRO-Embu is located in the Upper Midlands 2 (UM2) agroeco-logical zone at an altitude of 1480 m (0.501291°S, 37.458664°E). It is characterized by a fairly flat and structurally good landscape. Its soils are classified as Humic Nitisols. It receives an annual rainfall of 1238 mm (Jaetzold *et al.*, 2007). The experiments were conducted in two planting seasons: March to April and June to July 2011.

Experimental design

Empirical models assessing variations of popula-tion density as a function of the distance from a point source have been used to quantify the dispersal ranges of several insect species (Roslin, 2000; Cronin *et al.,* 2000; Cronin *et al.,* 2001). Additionally, since dispersal range of an organism is understood as the numerical variation in a population density due to the natural movement of its individuals over time (Ricklefs and Miller, 2000; Nathan, 2001), we used a concentric circle design as outlined by Darrouzet-Nardi *et al.* (2006) (Fig. 1) to study the dispersal pattern of adult *F. occidentalis* in French bean fields. The experiment was conducted at the centre of the field. To prevent infestation from the surroundings, a buffer zone of 30 m around the experimental fields was kept weed free before and during the experiments. The same experimental design was used in the two planting seasons: March to April and June to July 2011. The experiment was replicated twice in each season.

Crop

A total of 60 French bean plants *Phaseolus vulgaris* L. (cv Serengeti) were planted on a flat bed in an open field at the central release point of 3.14 m^2 to simulate a 'source' plot for thrips infestation (Fig. 1). To determine the dispersal pattern of adult *F. occidentalis* from the central release point, French beans were also planted at a spacing of 15 cm between plants on con-centric circles of 0.9, 1.8, 3.6, 7.2 and 14.4 m radii from the 'source' plot (Fig. 1). The distances (radii) from the central release point were chosen based on the real farmer situations as observed during the survey studies on the seasonality of *F. occidentalis* on French bean under farmers' fields (Nyasani *et al.*, 2013b). At planting, diammonium phosphate (DAP) fertilizer was applied at the rate of 10 g per hole and mixed well with the soil. Two French bean seeds were planted per hole and later thinned to one per hole. A total of 38, 75, 150, 300 and 600 plants were planted at 0.9, 1.8, 3.6, 7.2 and 14.4 m radii, respectively. The buffer zones between concentric circles and the surroundings of the experimental fields (30 m all round) were kept weed free before and during the experiments to prevent
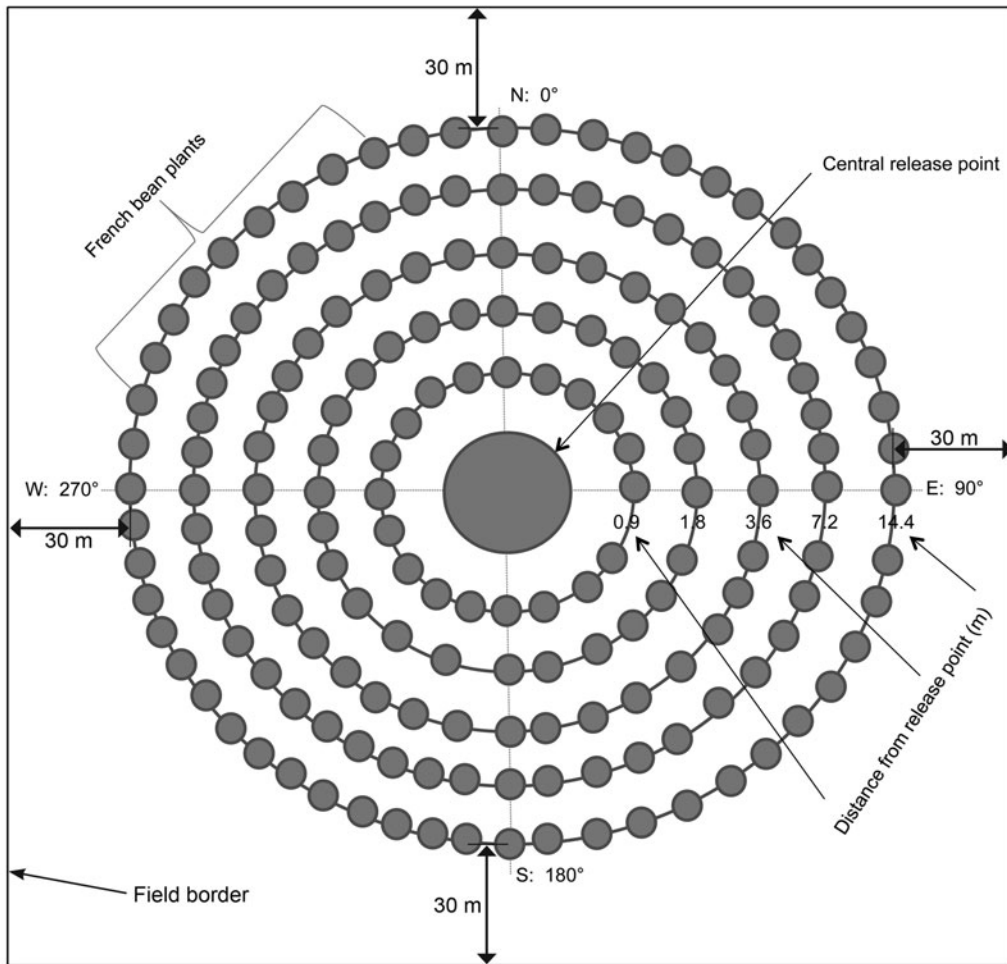
Fig. 1. Experimental design to determine the dispersal pattern of adult western flower thrips (WFT) *Frankliniella occidentalis*. The solid circle at the centre represents the point where 1200 adult WFT were released, and the smaller circles represent the French bean plants planted in different concentric circles depicting various radii from the release point.

infestation from the surroundings. No fungicide, foliar feed or insecticide was applied on the French bean plants during the entire experimental period. Cultural practices as recommended by the Ministry of Agriculture were adopted (Jaetzold *et al.*, 2007).

Experimental insects

Initial cultures of *F. occidentalis* were field collected from French beans at Thika, Kenya, in January 2011. Sample specimens were further processed in the laboratory to confirm identity of the thrips using LucID key (Moritz *et al.*, 2004). The *F. occidentalis* were reared in ventilated plastic jars (9 cm × 15 cm × 8 cm). A hole was cut on the lid and covered with thrips-proof organdy cloth (mesh openings of 95 μm) to allow ventilation. The thrips were reared at the International Centre of Insect Physiology and Ecology (*icipe*)'s insectary at 25 ± 1 °C, 50–

60% relative humidity (RH) with a 12 h L:12 h D photoperiod as described by Nyasani *et al.* (2013a). French bean pods, surface coated with sugar and honey solution, were used as a food supplement. To determine the sex of newly hatched thrips (2 days old), 5 thrips were placed in a 6 cm diameter Petri dish and classified under a stereomicroscope based on external morphological differences. Adult female and male *F. occidentalis* were aspirated separately and transferred into individual ventilated plastic jars.

We only used adult females, since sex ratios of *F. occidentalis* from field samples are often biased towards one sex (Reitz, 2009). Furthermore, it is the females that pose the greatest challenge, because they are responsible for reproduction, both asexually and sexually, hence perpetuating their population density. At the six leaf stage, baseline sampling for thrips on the French bean plants was

done and no thrips were observed on the plants in both planting seasons. Newly hatched (3 days old) adult female *F. occidentalis* were subsequently released onto the middle leaves of French beans using a modified straw with 20 thrips per plant and left to acclimatize for two hours before the start of data collection. All the 60 French bean plants at the central release point were infested with *F. occidentalis*. The releases were made at 06:00 h when thrips are known to be inactive and at the six leaf stage to avoid attraction of thrips into flowers, thus limiting dispersal.

Sampling and quantifying thrips movement

Two hours after release, approximately 10% of the plants in each concentric ring up to a maximum of 20 plants (i.e. 5, 10, 15, 20 and 20 French bean plants at 0.9, 1.8, 3.6, 7.2 and 14.4 m radii, respectively) were observed for thrips colonization every hour during the day for five days. At each field observation, the plants sampled for thrips were tagged to allow other plants to be sampled in the next field observation. The thrips detected on the French bean plants were carefully collected using a fine bristle brush and placed in plastic vials containing 70% ethyl alcohol. The thrips specimens were further processed in the laboratory and identified to species level using the LucID key (Moritz *et al.*, 2004; Moritz *et al.*, 2013). During the field observations, plants at the central release point were not observed for thrips infestation so as not to influence dispersal of thrips to neighbouring plants. However, at the end of the experiment, the number of thrips observed on all the 60 French bean plants at the central release point were counted and recorded.

Upon identification, 100% of the thrips collected were *F. occidentalis*. Voucher specimens of slide-mounted thrips from this study are maintained in the thrips IPM programme lab at *icipe*, Nairobi, Kenya. Dispersal of adult *F. occidentalis* was measured by the number of thrips recorded on French bean at each concentric circle. The prevailing daily weather conditions (rainfall, RH, wind and temperature) were recorded at a neighbouring weather station (150 m away) at KALRO, Embu.

Data analysis

All circular data were first transformed into radians before analyses. The analyses were performed using R v2.13.1 (R Development Core Team, 2010). The circular statistics were obtained using the CirStats package (Claudio, 2009) as described by Jammalamadaka and SenGupta (2001). The results on a circular scale were presented using 'rose' diagrams, which depict frequencies (as the area of the wedge) and dispersion of the measured angle

(Wells, 2000). The rose diagrams were constructed using Oriana v4 (Kovach, 2011).

The sample mean resultant length (r − rho) and the angular deviation (s) characterized thrips dispersal such that the angular variance s^2 was as defined by Batschelet (1981). The measure of concentration was given by the value ρ, which varies from 0 (when there is so much dispersion that a mean angle cannot be described) to 1 (when all the data are concentrated at the same direction). Directionality in the distribution of adult *F. occidentalis* at each radius and day was tested for significance using the Rayleigh test (Batschelet, 1981). Rao's test for homogeneity was used to compare the distribution of thrips (i.e. to test for differences in mean directions and/or differences in concentrations at different radii/distances from the release point) (Rao, 1967).

A circular−linear correlation was used to determine the correlation between prevailing weather parameters (wind speed and temperature) and the dispersal activity of adult *F. occidentalis* (daily catches). The correlation analyses were performed using Oriana v4 (Kovach, 2011). Rainfall and RH were not included in the correlation analysis, because there were only two rainfall events in both planting periods. Wind direction was computed in terms of degrees. To understand the influence of wind direction on thrips captures, the numbers of adult *F. occidentalis* recorded at each sampling point corresponding with the prevailing wind direction were subjected to ANOVA using package circular statistics in Oriana v4. All tests were performed at the 5% significance level.

Results

Differences in the number of thrips dispersing by distance and time

The recapture rate of adult *F. occidentalis* in the first season was 93.7% and 35.1% in the second season. At the end of the experiment (five days after thrips release), 3.6% of adult *F. occidentalis* remained at the central release point in the first season, while 46.8% of the thrips remained at the central release point in the second planting season. In the first season, there was a steady increase in the proportion of dispersing adult *F. occidentalis* from the first to the fourth day, and this remained constant thereafter (Fig. 2). In the second season, there was a slight increase in the proportion of dispersing adult *F. occidentalis* from the first to the third day and from the fourth to the fifth day. A decline in the proportion of dispersing adult *F. occidentalis* was seen on the fourth day (Fig. 2).

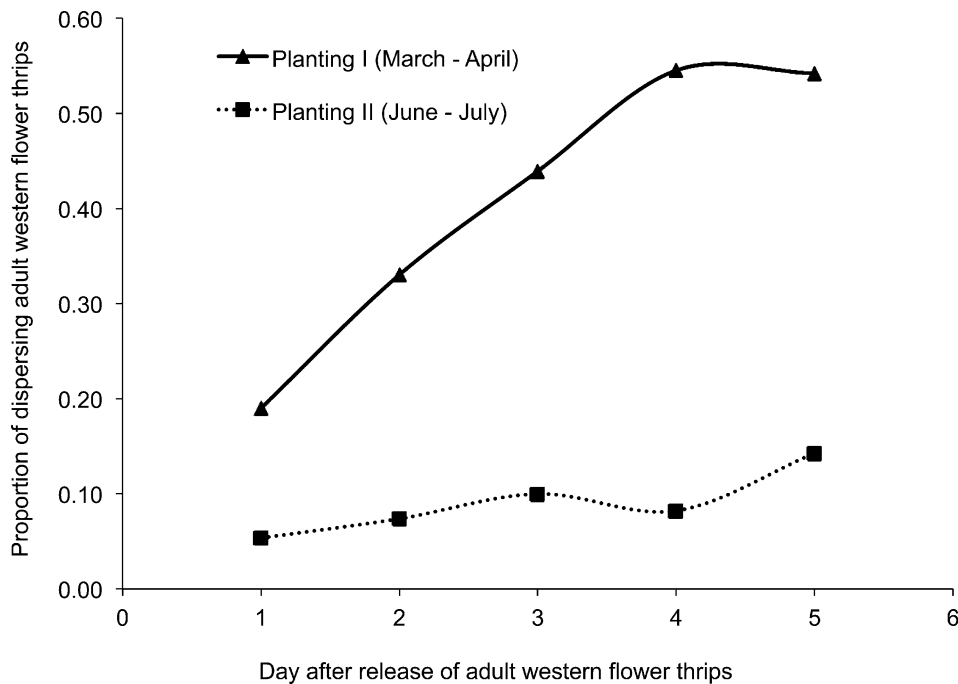The results indicate that the peak hour for dispersal was at 10:15 h in the first season while it

Fig. 2. Cumulative proportion of dispersing adult western flower thrips (WFT) *Frankliniella occidentalis* on French beans five days after release of 1200 adult WFT at the central release point in experimental fields.

was 13:15 h in the second season (Fig. 3). The peak period for dispersal mainly depended on prevailing weather conditions. Temperature and wind speed were positively correlated with the dispersal activity of adult *F. occidentalis* (r = 0.711, d.f. = 8, $P = 0.021$ and r = 0.548, d.f. = 8, $P = 0.030$, respectively). It was observed that flight was minimal at temperatures below 15 °C, whereas the peak flight activity was at 19 °C (Fig. 3). In the first season, the number of adult *F. occidentalis* catches remained unchanged at temperatures of 21−24 °C (Fig. 3). In the second season, the numbers of adult *F. occidentalis* catches recovered on French bean were relatively lower compared with those in the first planting season (Fig. 3). Adult *F. occidentalis* were only able to disperse from the central release point up to 7.2 m on the first day and no thrips were observed on French bean at 14.4.m from the central release point on the first day (Fig. 4) in both planting seasons. The peak period for dispersal was on the third day after release of adult *F. occidentalis* (Fig. 4). On the third day (peak period for dispersal), the least number of adult *F. occidentalis* per plant (3.9 ± 0.7) was recorded at 0.9 m while the numbers of adult *F. occidentalis* per plant recorded at 1.8, 3.6, 7.2 and 14.4 m were 1.9, 3.2, 3.7 and 2.4 times higher than those at 0.9 m, respectively (Fig. 4). A decline in the density of dispersing adult *F. occidentalis* was observed from the third to the fifth day for all distances (Fig. 4).

Dispersal direction of adult western flower thrips

In the first planting season the prevailing wind direction did not influence the dispersal pattern of adult *F. occidentalis* ($F_{6, 17} = 1.664$, $P = 0.191$) and mean direction of dispersal for adult *F. occidentalis* varied among the five days. Out of the five days, the mean direction of thrips dispersal was uniformly distributed (not oriented to a particular compass direction) around the central release point on the first, third, fourth, and fifth days (ā = 193.0°, r = 0.044, $P = 0.632$; ā = 252.7°, r = 0.033, $P = 0.718$; ā = 267.3°, r = 0.112, $P = 0.080$; and ā = 80.5°, r = 0.954, $P = 0.768$, respectively) (Fig. 5). The only exception was on the second day, where adult *F. occidentalis* were oriented (non-uniformly distributed) towards the NW direction (ā = 279.1°, r = 0.112, $P = 0.017$) (Fig. 5).

In the second planting season, the prevailing wind direction did not influence the dispersal pattern of adult *F. occidentalis* ($F_{7,16} = 0.765$, $P = 0.624$). Similar to the first planting season, the mean direction of dispersal for adult *F. occidentalis* varied among the five days. Adult *F. occidentalis* were uniformly distributed around the central release point on the second and fourth days (ā = 224.4°, r = 0.157, $P = 0.147$; and ā = 262.2°, r = 0.183, $P = 0.085$). Conversely, the mean direction of thrips dispersal was non-uniformly distributed around the central release point on the first, third and fifth
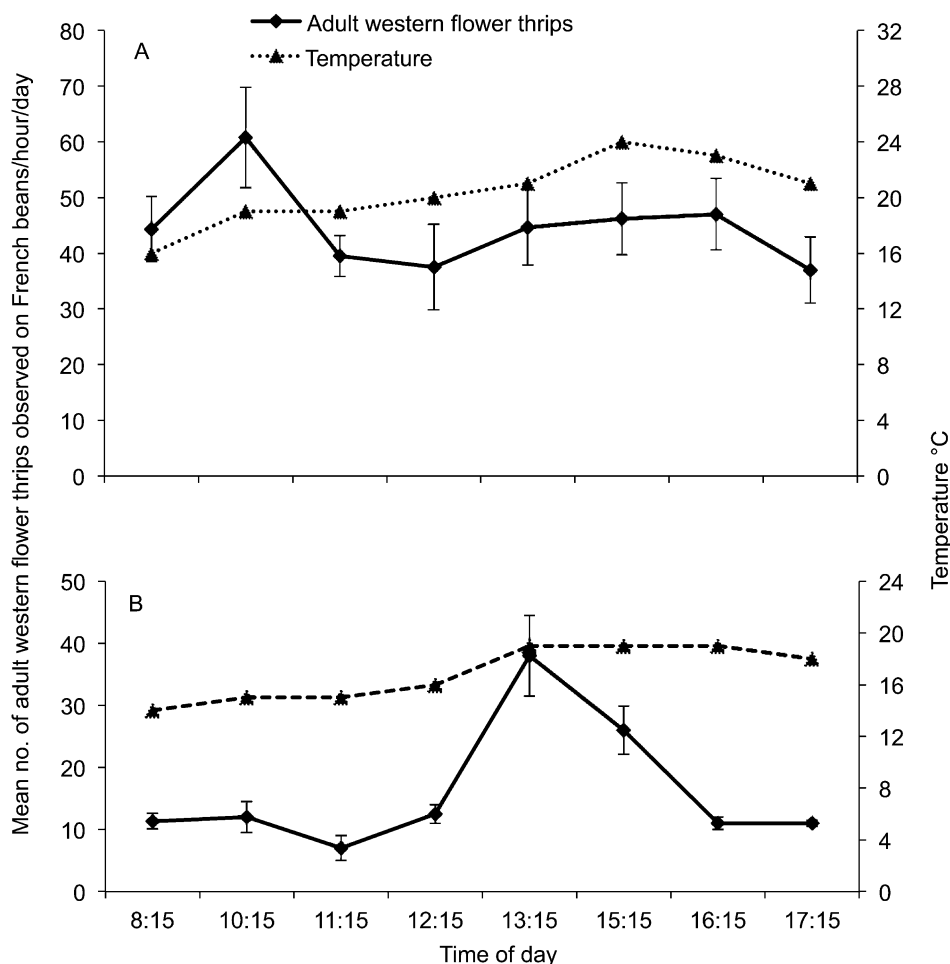
Fig. 3. Hourly patterns of flight of adult western flower thrips (WFT) *Frankliniella occidentalis* on French beans at KALRO-Embu in: (A) March–April and (B) June–July 2011. Mean number (± SEM) of adult WFT per hour per day was calculated from total hourly catches after release of 1200 adult WFT at the centre of experimental fields.

days ($\bar{a} = 224.0^0$, r = 0.315, $P = 0.001$; $\bar{a} = 265.1^0$, r = 0.312, $P < 0.001$; and $\bar{a} = 261.8^0$, r = 0.293, $P < 0.001$, respectively) (Fig. 5). In general, mean direction of thrips dispersal varied among the five days and between planting seasons, suggesting that other factors other than the major wind flow were responsible for the direction of dispersal for the thrips.

Discussion

Adult *F. occidentalis* were only capable of colonizing French bean grown at 0.9, 1.8, 3.6 and 7.2 m on the first day after release. However, dispersal increased over time and adult *F. occidentalis* were able to colonize French bean plants grown at 14.4 m from the central release point. This indicates that French bean grown closer to the release point

(source) is likely to receive the highest adult *F. occidentalis* infestation rates and can serve as a 'green bridge' for infestation of French bean at longer distances from the 'source' field. Previous studies on dispersal of adult *F. occidentalis* in greenhouse crops have shown that the thrips have a limited dispersal capacity on cucumber (*Cucumis sativus* L. (Cucurbitaceae)) or chrysanthemum (*Dendranthema grandiflora* (Tzelev) (Asteraceae)), and often colonize the first (nearest) plants they encounter (Rhainds and Shipp, 2004). Our results also support those of Kareiva (1982) working on the dispersal pattern of two crucifer-feeding flea beetles, *Phyllotreta cruciferae* and *Phyllotreta striolata* under field conditions and Rhainds and Shipp (2004) working on the dispersal pattern of adult *F. occidentalis* in greenhouse crops, who reported that over time insect dispersal can happen over a relatively wide spatial scale with each adjacent
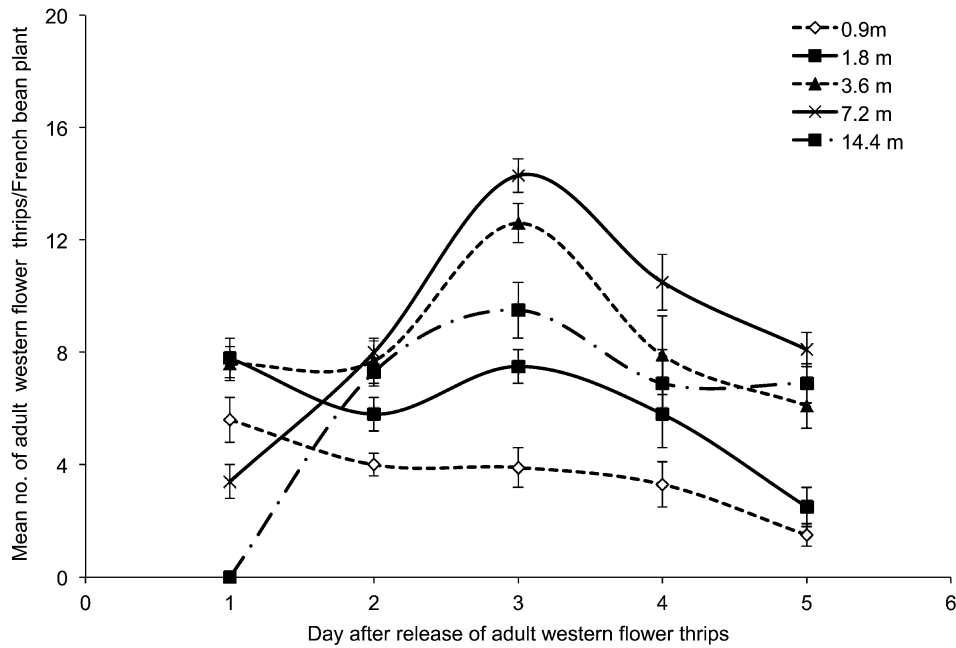
Fig. 4. Mean number (± SEM) of adult western flower thrips (WFT) *Frankliniella occidentalis* recorded per French bean plant at different distances (radii) from the central release point for five days. A total of 1200 adult WFT were released at the centre of the experimental fields and their movement monitored for five days.
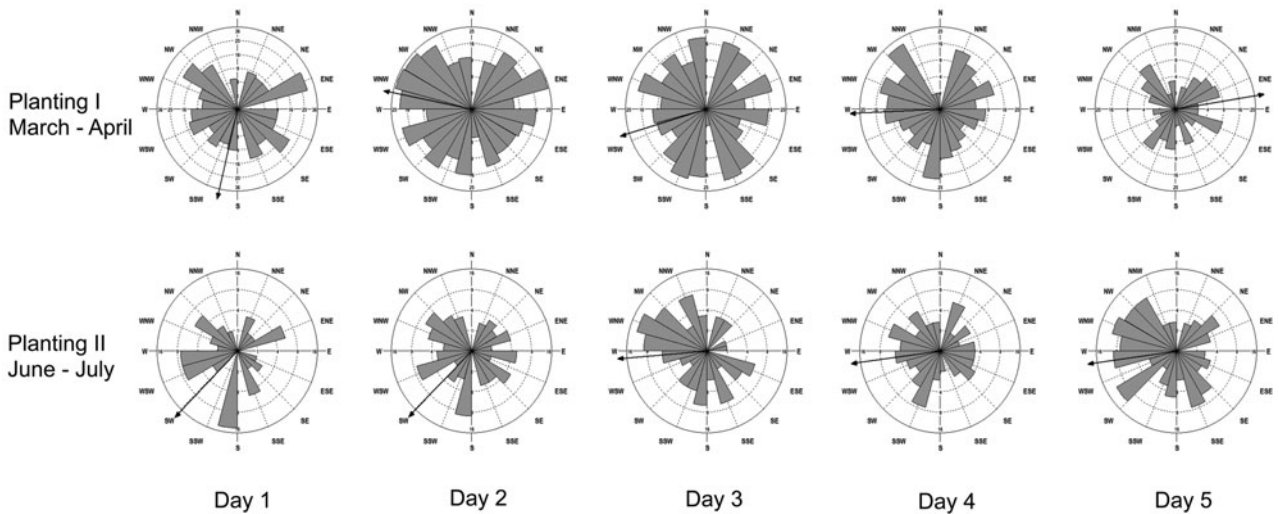

Fig. 5. Daily dispersal patterns of adult western flower thrips (WFT) *Frankliniella occidentalis* on field-grown French beans at KALRO-Embu, Kenya in March–April and June–July 2011. The bigger the wedge of the 'rose' diagram, the bigger the number of adult WFT recorded at that angle. An arrow pointing outwards shows the daily mean flight direction. The significance of the mean direction of flight of WFT on each day was tested by Rayleigh test at $P < 0.05$.

host plant potentially acting as a stepping stone. The results have implications on management of *F. occidentalis* on French bean in terms of isolating old fields from new ones, managing alternative hosts within French bean fields, applying insecticide, and devising crop rotation schemes.

Dispersal of adult *F. occidentalis* was at the peak at 10:15 h and 13:15 h in the first and second planting seasons, respectively. Our results corroborate those of Kasina *et al.* (2006), who reported that dispersal of adult *F. occidentalis* on field-grown French bean was at peak at 10:00–13:00 h. Dispersal of adult

F. occidentalis was dependent on temperature with minimal dispersal activity at temperatures below 15 °C and maximum activity at 19 °C. However, at temperatures of 21–24 °C, there was a decline in dispersal activity of adult *F. occidentalis* in the first planting season. Our results are in agreement with those of Pearsall (2002), who reported that the dispersal activity of adult *F. occidentalis* on nectarine orchards was rare at 15 °C and most common between 15 and 30 °C. Similarly, temperature has been reported as the major environmental factor that affects thrips dispersal (Pearsall and Myers, 2001; Morsello *et al.,* 2008; Morsello *et al.,* 2010). It has been reported that once temperature increases above the flight threshold (*c.* 17−21 °C), thrips dispersal may occur *en masse* (Lewis, 1997; Morsello *et al.,* 2008). In our study, wind speed was positively correlated with dispersal activity of *F. occidentalis*. According to Lewis (1973) and Pearsall and Myers (2001), it is unlikely for thrips to direct their direction of flight at higher wind speeds, because they can be blown upwards and away from their breeding or overwintering sites, hence increasing their dispersal distance.

In the first and second planting seasons, *F. occidentalis* were mostly uniform (not oriented to a particular compass direction) around the central release point. The results indicate that dispersal of adult *F. occidentalis* is mainly uniform and therefore, the density of thrips among French bean plants within a limited spatial scale may be uniform, due to between and within plant dispersal. The lack of orientation of adult *F. occidentalis* towards a particular compass direction might be because of the wind forming eddies around the thrips; thus the thrips originating from one direction may be thrust to another direction on French bean. It is also believed that thrips are unable to direct the course of their flight (Pearsall and Myers, 2001); however, it is possible that they may be able to control their direction at very low wind speeds (Pearsall and Myers, 2001). Nevertheless, directed movements in response to olfactory and visual stimuli can modify distribution patterns of insects (Pasek, 1988). Our results support those of Pearsall and Myers (2001) and Rhainds *et al.* (2005), who reported uniform distribution of adult *F. occidentalis* in nectarine orchards and Chrysanthemum, respectively.

The daily dispersal activity of adult *F. occidentalis* on French bean was lower on the first, second, fourth and fifth days, whereas the daily dispersal activity was higher on the third day. The lower dispersal activity of *F. occidentalis* on the first day might have been because lab-reared adult *F. occidentalis* released on French bean were acclimatizing to the new environment. The lower catches of *F. occidentalis* recorded on the fifth day were due to the high capture rates recorded on the third

day. Additionally, the population at source was reducing over time and the willingness of the thrips to disperse might have been reduced.

Our results suggest that dispersal pattern of adult *F. occidentalis* on French bean is mainly not oriented towards a specific compass direction. We also show that adult *F. occidentalis* are capable of dispersing up to 7.2 m on French bean in a day. An understanding of the dispersal pattern of adult *F. occidentalis* is important in developing sustainable management options against the pest based on the isolation of farm fields in a rotation scheme and management of alternative hosts within French bean fields. To extrapolate the results to a wider scale, further studies are recommended to understand the role of landscape features, cropping patterns, weather conditions, and pest management strategies on dispersal of adult *F. occidentalis*.

Acknowledgements

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