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Full Paper

Investigating woolly apple aphid (*Eriosoma lanigerum*) (Hausmann, 1802) migration dynamics and parameters in a *Fuji* apple tree orchard during the 2023 and 2024 spring seasons

Untersuchungen zur Dynamik der Migration von *Eriosoma lanigerum* (Hausmann, 1802) in einer Apfelanlage der Sorte *Fuji* während der Frühjahrssaisonen 2023 und 2024

Studio sulle dinamiche e dei parametri di migrazione dell'Afide lanigero (*Eriosoma lanigerum*) (Hausmann, 1802) in un impianto melo cv. *Fuji* durante le stagioni primaverili 2023 e 2024

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ABSTRACT

Migration data obtained by applying sticky bands on individual trees for two years were pooled into replicates to strengthen statistical analyses and to derive N1 population migration parameters. Destructive shoot sampling was omitted in this study and replaced by non-destructive measurements of shoot occupation, expressed as the percentage of occupied internodes. Although this approach reduced detailed information on colony size, it preserved canopy integrity and provided a sufficiently precise and representative assessment at plant and plot level. Woolly apple aphid (WAA) upward migration intensity alone does not determine canopy infestation by *Eriosoma lanigerum* (Hausmann, 1802)(Hemiptera: Aphididae). Downward counter-migration, before and during the migration peak, must be considered to estimate true canopy infestation pressure. Results indicate that changes in migration direction after the migration peak cannot be explained solely by temperature. Downward migration of older nymphal instars was confirmed using adhesive bands. Data possibly indicates a relationship between these stages on trunks and the subsequent flight activity of *Aphelinus mali* (Haldemann, 1851) (Hymenoptera: Aphelinidae). Ongoing studies are examining this phenomenon in other apple-growing regions of South Tyrol.

KEYWORDS

Eriosoma lanigerum; woolly apple aphid (WAA); methods; *Aphelinus mali*

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INTRODUCTION

Eriosoma lanigerum (Hausmann, 1802) (Hemiptera: Aphididae), commonly known as the Woolly Apple Aphid (WAA), is becoming one of the most important insect pests in South Tyrolean apple production. WAA pressure saw increases in the period from 2022 to 2024 due to various abiotic factors and to a reduced portfolio of synthetic insecticides, with limited effective alternatives available [1]. This has made it more challenging for field technicians and advisory services to manage WAA infestations. In view of this development, we have created an experimental field combining different types of WAA-resistant rootstocks with the cv *Royal Gala* and *Fuji*. Work on this project began in 2023 and has been completed in spring 2026 with the final plantings [2] [3].

In our previous trials (2021-2022), we made a definite number of observations and collected different data from samplings by applying simple survey techniques with easily observable robust parameters (modified protocols based on EPPO 2022 [4]). Due to their frequent repetition on the same plant or on groups of plants together with other parameters (migration dynamic surveys), these observations should help us provide a risk assessment for the distribution of WAA canopy infestation on tree groups in plots and rows of the experimental field, we established [3]or help us predict the WAA presence on the aerial plant parts during the resettlement period in spring [5]. For completeness, we also recorded the WAA presence/absence on the grafting area

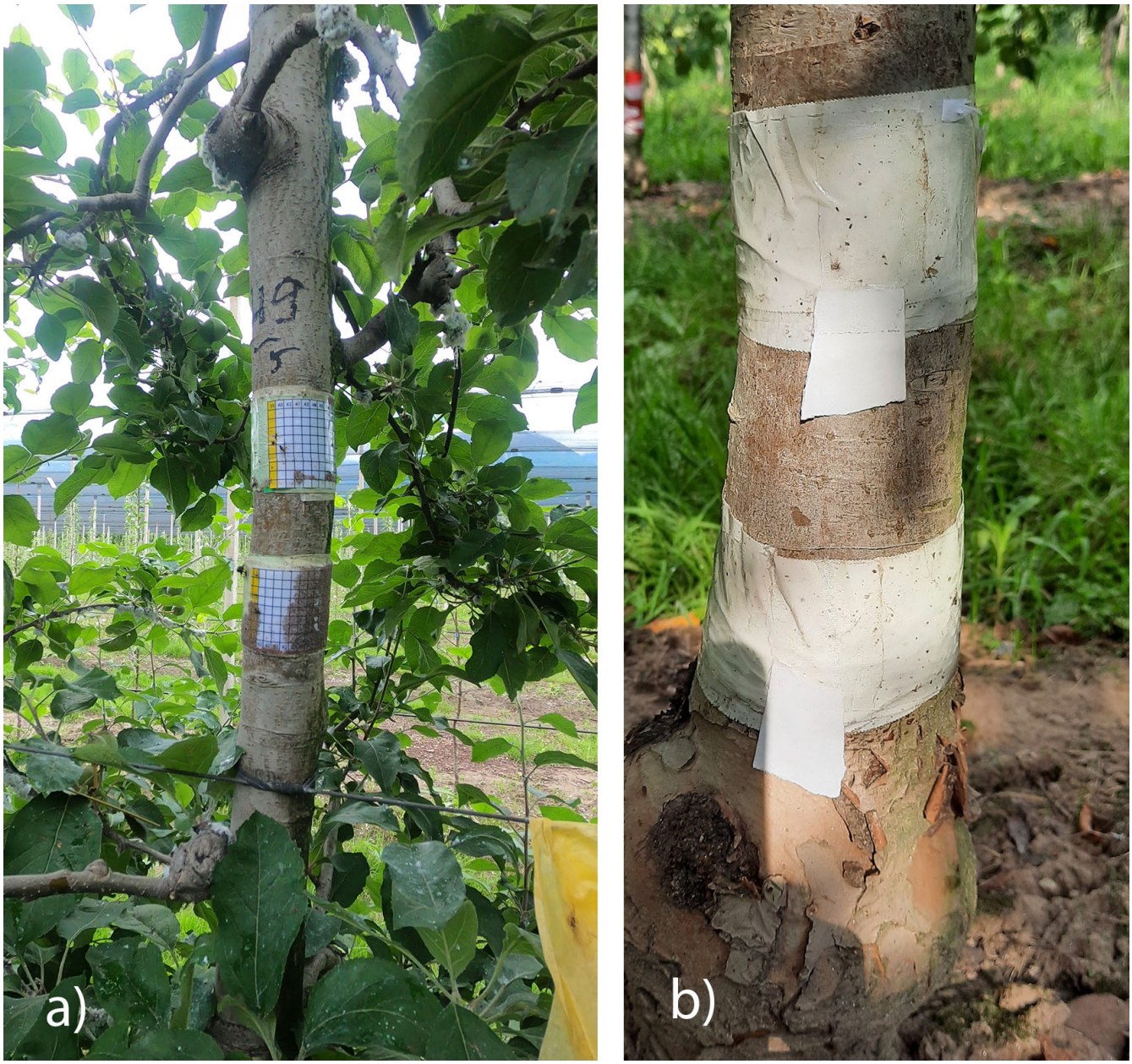

Fig. 1: Both transparent ‘sticky bands’ (1a) affixed on the white sticky base at 1.5 m above the ground, with a grid fitted under the transparent sticky band; the picture (1b) shows the transparent sticky bands (without a counting grid included) mounted on the sticky white base above the graft position between the rootstock and the *Fuji* cv (picture from the 2021-2022 experiments).

and active WAA settlement on older wood including stem tissues.

After further adjusting the methodology already implemented in previous work, we were able to investigate specific population parameters and dynamics concerning upward and downward migration during the spring period in 2023 and 2024. Part of the data are presented here, part of the raw data are reported in the article as tables. Part of the data are available in the online repository, which we refer to as [6].

In the present work, we continued to investigate WAA presence on wooden plant tissues other than annual shoots recording the presence/absence of WAA on selected points on the observational trees. These data will be published in a separate article (article currently in preparation), together with permanent upper and lower rootstock settlements of WAA, recorded after clearing the observational trees of the actual and the previous experimental field [5]. The article will include also the summer - fall migration periods and the data on the overwintering success of aerial WAA colonies in the canopy.

MATERIALS AND METHODS

N1 MIGRATION AND *A. MALI* ADULTS SURVEY METHODS

In these studies, we aimed to integrate adjusted protocols to facilitate future introduction of automated WAA surveillance using AI-driven monitoring devices [7] (Fig. 1a). For general information on the topic, see [8].

The data presented here refer to observations in a delimited experimental field (rows 49-57) (Fig. 2), which covers the southern part of a 3000-m² *Fuji* orchard. The entire *Fuji* orchard (2.2 ha in total) was severely affected by WAA. Minimal insecticide treatment was carried out in this part of the field dur-

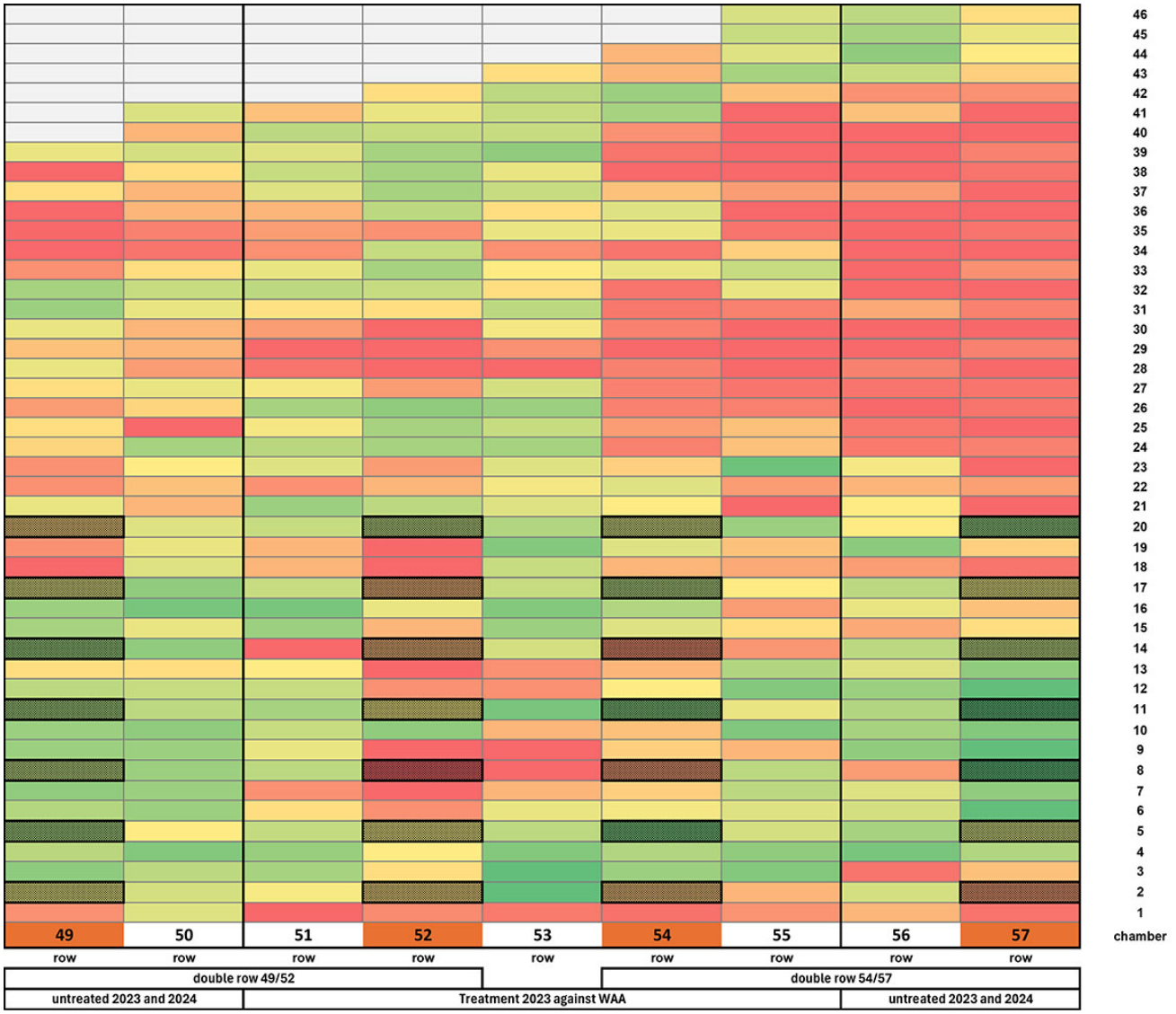

Fig. 2: The rows (49, 52, 54, 57) and the “chambers” 1-9 (plot 1) and 12-21 (plot 3) forming two plots (1, 3), each with a respective number of 3 observational trees inside. The series had been performed alternatively in the rows 49 and 52 or 54 and 57.

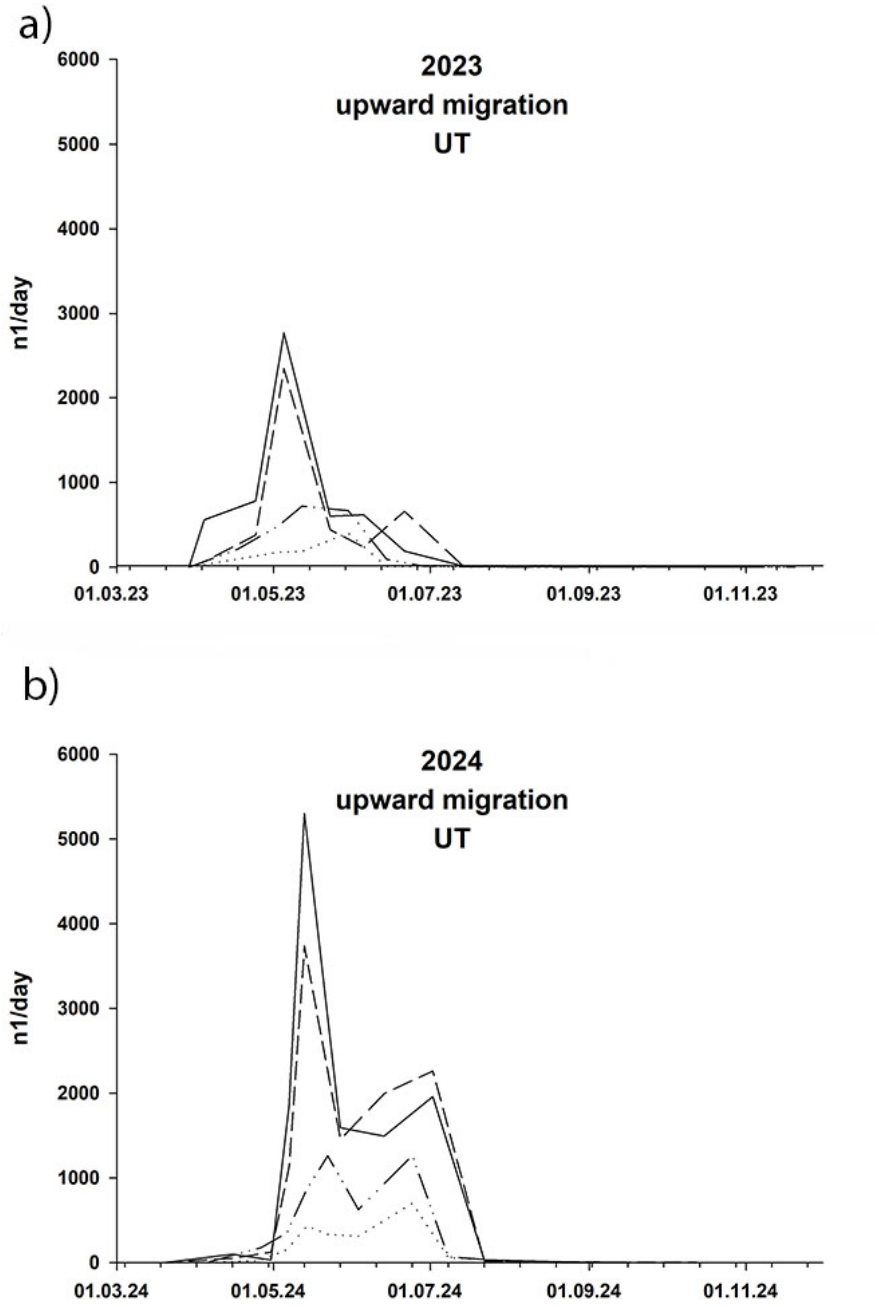

Fig. 3: The N1 migration expressed as nymphae/d collected on the testimonial trees in the different untreated plots (UT) during the entire season (lower sticky band; 2023 and 2024).

ing 2020-2024 (except for WAA in 2023; see below). Within this area, we selected observational trees within rows comprising two plots (1 and 3) of nine chambers each, and three observational trees within the nine chambers forming each a single plot. Plot 1 was in the southern part (chambers 1-9), and plot 3 (chambers 13-21) was located in the northern part of the four rows (Fig. 2).

The local meteorological station had recorded the relevant meteorological conditions for development, and the thresholds for the migration and activity behavior, of both *E. lanigerum* and *A. mali* at a height of 2 m. We recorded the *Aphelinus mali* (Haldemann, 1851) (Hymenoptera: Aphelinidae) flight on both of the sticky bands directly.

According to previous work (for the migration survey method, refer to [5]), we limited exposure of sticky bands to two out of four rows for a number of days, while covering the remaining two rows with non-sticky bands to allow free migration in both directions. The migration data are expressed as N1 individuals/observational tree by extrapolating the counting on the grids to the tree diameter dividing by the days of exposure of the sticky bands. We defined the N1 spring migration start data, applying preliminary test series using 'sticky bands', which indicated absolute no migration prior to both March dates (29 March 2023 and 19 March 2024) and the upward migration start (N1/day/tree >=0) during the following survey periods.

For practical reasons, we chose to apply a moderate insecticide treatment strategy against WAA on part of the experimental field in 2023 containing 50% of the observational trees applying the a.i. Pirimicarb (Aphos 50®) twice in the first and the last decade of may. Furthermore, in 2023 we applied a general insecticide (Neem-Azal®; marginal side effects on WAA) and IPM-fungicide strategy across the entire field, excluding active ingredients like sulfur, acting directly or indirectly on *E. lanigerum*. The respective WAA treatments are labelled UT (untreated) and TM (treated). In 2024, the entire experimental field remained untreated against WAA, apart from the standard insecticide (Neem-Azal®) and IPM-fungicide sprays. We performed basic statistical analyses on the mean and maximum values observed for the year, row and plot effects for the migration part and for the *A. mali* flight activity recording adults on the same 'sticky bands' used for migration studies.

The study began in spring 2023 and continued until December 2024. In January 2025, the entire orchard was cleared. After this the creation of the new experimental orchard was started [3].

METHODS FOR INVESTIGATING SHOOT COLONIZATION AND WAA PRESENCE ON TREES

Similarly to previous investigations [5], 5-10 shoots per observational tree from the top of older fruiting wood bearing fruitlets were visually selected and inspected. Contrary to the original protocols [4], we excluded quantitative estimates of colony strength (e.g. classes or cm² of wax surface area) from our records. Our method considered the most distal internode position occupied by an active WAA individual. Since N1 individuals migrating upwards start to form colonies from the proximal part of shoots (i.e., the oldest and lowest leaf and internode), we assumed that the internodes below had already been colonized. In this article, we present shoot-colonization data from 2023 and 2024, analyzing the settlement process until the end of the spring season in both treated and untreated areas. We performed basic statistical analyses on the mean and maximum values observed for the year, row and plot effects on shoot colonization.

RESULTS

THE N1 UP- AND DOWNWARD MIGRATION DYNAMIC AND STRENGTH DURING THE SPRING SEASON IN PLOTS AND ROWS AND THE *A. MALI* FLIGHT RECORDED ON THE STICKY BANDS

As shown in [7], we further modified the classical method ([9] [10] [11]) by mounting the sticky bands at a minimum of 1.5 m above the ground (Fig. 1a). We observed upward migration in surveys from the 29th of March 2023 and from the 19th March 2024 on. We continued recording over the spring maximum until the end of the spring season and the end of the vegetation period in November, covering 246 days in 2023 and 237 days in 2024. Only the 'spring season data' are reported in this article (for the 'spring season' definition see [5]). As explained earlier the summer-fall migration data are presented an discussed in a separate article together with other supplemental observations and recordings, e.g. the overwintering of WAA in the aerial parts of the apple plants.

As we had done previously [5], we calculated the standard mean and maximum values that characterize the spring season (2023 and 2024), and we also considered pivotal points in the upward and downward migration dynamics to derive additional migration parameters (see the following chapter). We included mean and maximum data for *A. mali* calculated from the catches on the sticky bands in table 1, table 2, table 3, and table 4. Due to insufficient chemical treatment quality in 2023, we present and discuss the observational data for trees in untreated and treated rows separately for upward- and downward-migrating N1 individuals focusing prevalently on data of the untreated part. Figure 3, figure 4, figure 5, and figure 6 show the upward and downward migration activity of N1 individ-

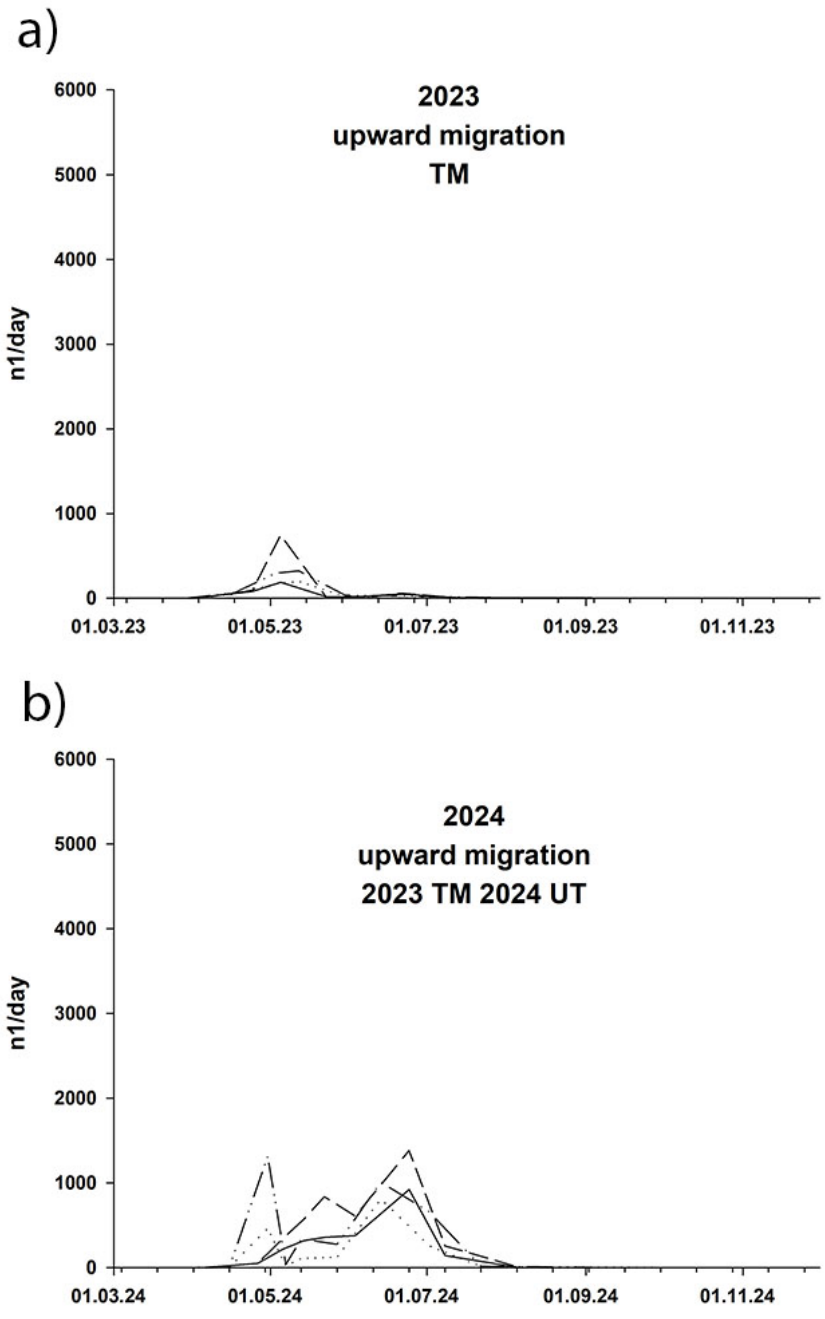

Fig. 4: N1 migration expressed as nymphae/d collected on the testimonial trees in the different treated plots (untreated UT; treated TM) during the entire season (lower sticky band; 2023 and 2024).

uals in both 2023 and 2024. The figures for the treated group are shown in figure 4 and figure 6. A proper statistical analysis is reported in the repository section [6].

Spring migration started during the exposition period from 29 March 2023 to 4 April 2023. In 2023, towards the spring maximum), was followed by a second increase in upward migration (after a brief drop) until 30 May 2023. This marked a data point at which there was a subsequent decrease in upward migration, which continued to drop until 5 June 2023. In 2023, the switch

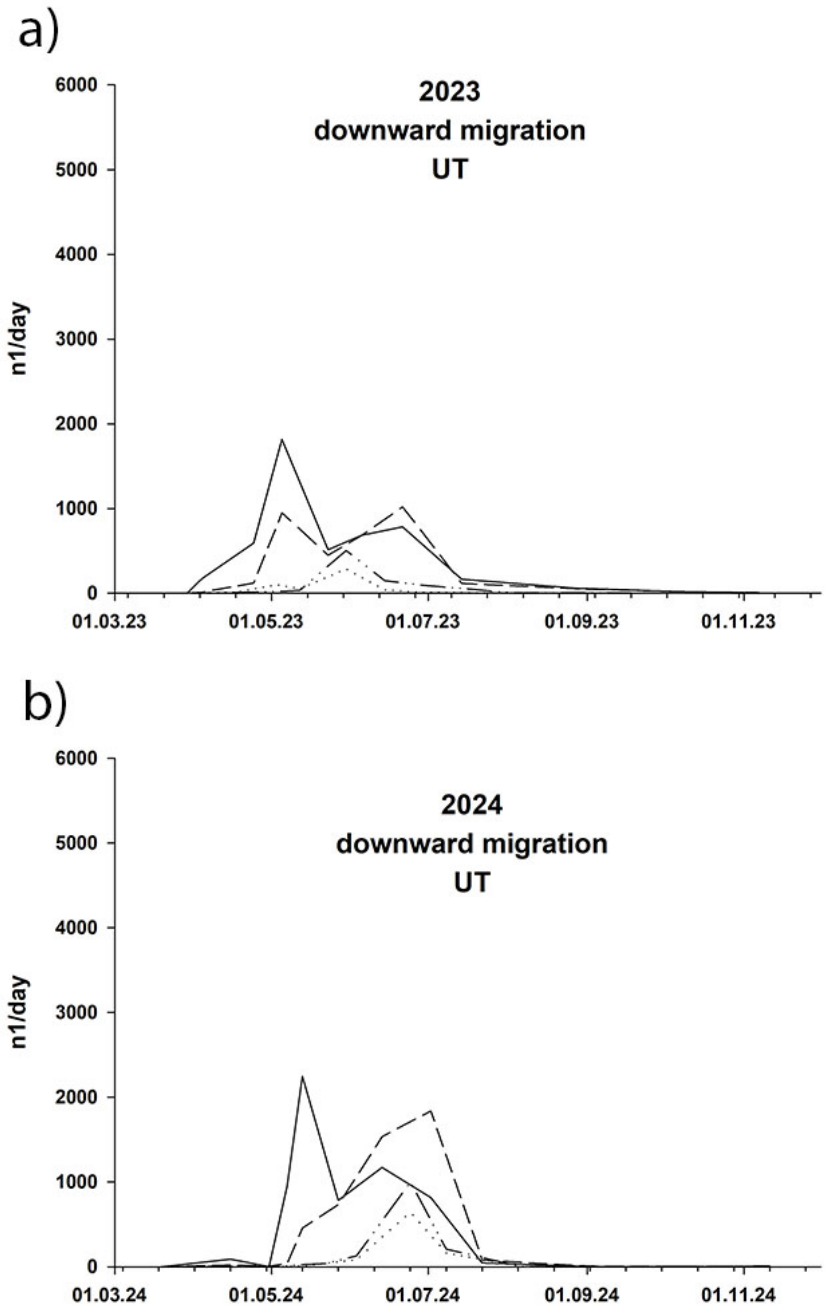

Fig. 5: N1 migration expressed as nymphae/d collected on the testimonial trees in the untreated (UT) plots during the entire season (upper sticky band; 2023 and 2024).

spring migration lasted 121 days, and in 2024 it lasted 123 days.

The first significant increase in migration occurred from 24 April 2023 to 05 May 2023 (noticed as increase of the main migration direction occurred on 5 June 2023, 31 days after the first upward migration maximum (on 5 May 2023) (Fig. 3), and 62 days after the start of the main upward migration. After this data, the downward migration exceeded the upward migration. Migration in both directions dropped on 3 August 2023 below ten individuals/tree/day, 121 days after the start of migration. By this time, the spring migration period had ended in untreated plots.

In 2024, the upward migration began on 5 April, with a significant increase in the upward movement of the N1 instars. A further increasing migration activity in the early days of May 2024 led to the spring maximum on 13 May 2024 (also considered the first seasonal maximum of upward migration), 38 days after the start of upward migration on 5 April 2024. A distinctive second migration maximum was observed in both directions following a temporary drop after the first spring migration maximum at 13 May 2024, between 27 May and 24 June 2024, when the number of N1 surpassed the threshold of 2,000 individuals/tree/day. The main migration direction (upward and downward migration in /day) switched from predominantly upward to downward between 2 July 2024 and 8 July 2024, 56 days after the first spring season maximum and 94 days after the beginning of the upward migration on 5 April 2024. 6 August 2024 must be considered the end of the spring migration period, when the number of N1 individuals migrating upwards and downwards daily fell below the ten N1/tree/day threshold. In both years, upward and downward migration prevailed during the same period of the spring migration season (Fig. 7).

In both years the lower minimum temperature conditions (15 °C) required for N1 migration activity (Fig. 8) were met from the first days of April on. The respective upper limiting temperature threshold (32 °C), which supposedly inhibits WAA development [12], was exceeded at different times in 2023 and 2024. Figure 8 reports the daily temperature amplitude and the lower and upper ‘cut-off’, expressed as days with hours > 0 exceeding the thresholds. Figure 8 indicates periods with temperatures allowing

migration (> 15 °C) for 5.33 h/day during the entire period prior to the beginning of the upward migration on 5 April 2023 [13]. Pessimal temperature conditions (> 32 °C; [12]) occurred from 5 June 2023 onwards, with a constant increase in the number of hours exceeding 32 °C per day until 28 June 2023 (Fig. 8, upper graph, red line). These conditions persisted beyond the end of the spring migration season (3 August 2023). The climatic conditions in 2024 (Fig. 8, bottom graph), with minimum temperature conditions for N1 migration occurring before the beginning of the upward migration on 5 April 2024, with 5.33 h/day exceeding 15 °C from 29 March 2024 onwards (blue graph). Days with a higher number of hours with pessimal temperatures exceeding 32 °C (n > 2 h/d; red graph) occurred at the end of spring-season migration, after 6 August 2024.

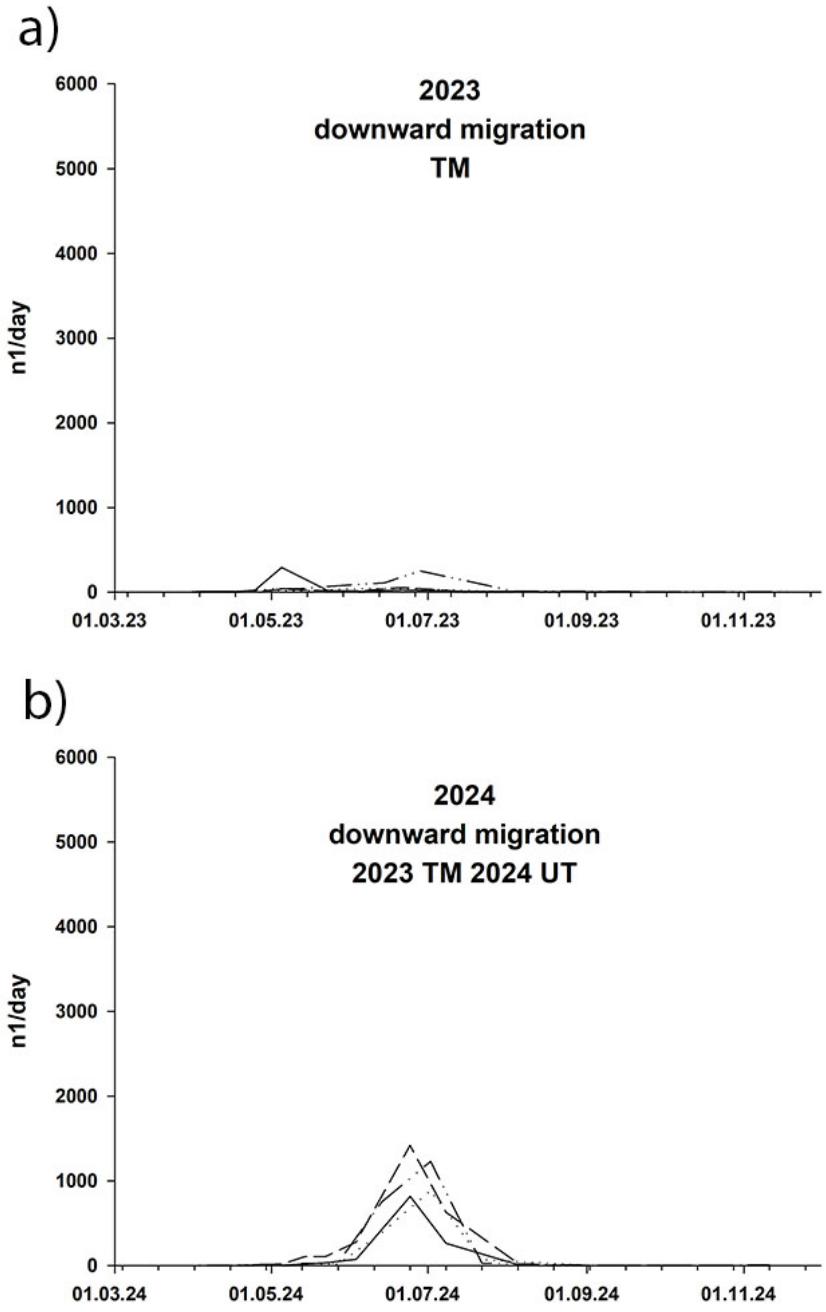

Fig. 6: N1 migration expressed as nymphae/d collected on the testimonial trees in the different treated plots (untreated UT; treated TM) during the entire season (upper sticky band; 2023 and 2024).

Marked differences appeared between the results for the WAA related treatments in spring 2023 only (rows and plots; see fig. 3, fig. 4, fig. 5, fig. 6).We considered the treated and the untreated plots differently for comparison purposes specifically for up and downward migration activities in both years. For data on untreated observational trees, refer to table 1 and table 2. For the treated part, see table 3 and table 4 (see the previous chapter). Since we were unable to provide an accurate statistical analysis of the parameters (upward and downward migration) including all factors (year, treatment, row) due to unequal variances ($p>0.05$), we analyzed the dataset separately for treated and untreated observational trees. The statistics are included in the repository [6].

For all the parameters (untreated observational trees only), the daily N1 up- and downwards migration, and the activity of adult *A. mali* were all significantly affected by the factor row ($p<0.0001$) when considering the mean values of both years (Tab. 1). The situation was similar when considering the maximum values (Tab. 2). Regarding the up- and downwards migration on observational trees inside the treated area, no significant results were obtained for the factor row, but the two years were found to be significantly different ($p<0.05$). This accounts also for the maximum data (Tab. 2, tab. 4).

As shown in table 2 and table 4, differences regarding maxima were found in adult *A. mali* numbers between years and rows. The statistics mentioned previously revealed significant effects depending on year and row, but these differed by treatment status. In the untreated group, *A. mali* differed between rows ($p<0.05$). There were also marginal differences for year (n.s.). For maximum values in the untreated part, both year and row showed significant effects ($p<0.05$). For treated observational trees, only year had a significant effect ($p<0.05$), not row (Fig. 9b, fig. 10b).

RESULTS: SHORTENING THE EXPOSURE OF STICKY BANDS ALTERNATING OBSERVATIONAL TREE CONDUCTANCE AND SURVEILLANCE ACCURACY

We observed the actual intensity (i.e. the WAA crawler coverage) of the upward migration (lower sticky band) in the field in the first days after starting a new series and based on this observation, we decided for how long the series had to be conducted. We categorized the upward migration densities, expressed as N1/day per observational tree, into classes according to the relative exposure periods for both years. Consequently, at the peak of the upward migration, the number of days of exposure has been reduced; see table 5.

RESULTS: *A. MALI* FLIGHT ACTIVITY 2023 AND 2024

We recorded the flight activity of *A. mali* under treated and untreated conditions (Fig. 9, fig. 10). The effects of the WAA treatments, as well as row- and plot effects, were partly significant when considering the mean and maximum number of adult *A. mali* individuals caught per day on both the upper and lower sticky bands, depending on treatment status. The discussion section presents a relative percentage distribution of *A. mali* catches for both years, reporting data from the untreated part of the plots (Tab. 6, tab. 7). The relevant statistics for both years for the data on *A. mali* adults recorded on both sticky surfaces were reported in previous chapters.

In 2023 the *A. mali* flight started in the untreated area between 4 April and 17 April, depending on the rows and plots. Although precipitation occurred frequently in April and May 2023, the *A. mali* flight increased continuously. The 2023 flight maximum occurred between 30 May and 21 June, depending on the row and plot, and was calculated from 1 January as day 163.

In 2024, from the start of the sticky band exposure period on 19 March, the *A. mali* flight activity was reduced until the end of June. The temperature conditions in April 2024 were favorable at the beginning of the month, with a sharp drop in the middle, followed by an increase at the end. May 2024 was particularly rainy, with frequent precipitation events until mid-May, followed by two weeks of suitable temperatures for the period [14]. June 2024 saw periods of rain and low temperatures until the second half of the month, when temperatures increased. Prior to this, *A. mali* flight was at a minimum, until between 13 June and 24 it increased 40-fold. Finally, during the period 8th and 22 July (depending on the rows and plots), we observed the seasonal maximum of the *A. mali* flight, 196 days counting from the 1th January.

RESULTS REGARDING SHOOT COLONISATION DYNAMICS IN 2023 AND 2024

Table 8 and table 9 show the relative percentage distribution of WAA presence over the spring season for both years, reporting only the untreated part. Tab. 10 and tab. 11 show the respective data for the treated observational trees. The dataset containing the absolute percentage is reported in the discussion section.

Because of the poor effectiveness of the WAA treatments (consider map in Fig. 2 for WAA treated rows) carried out in 2023, there was an undesirable variability in the shoot colonization and the number of upward-migrating N1 individuals in some of the treated rows (Tab. 10, tab. 11). For this reason, our comments and discussions focus primarily on the untreated observational trees.

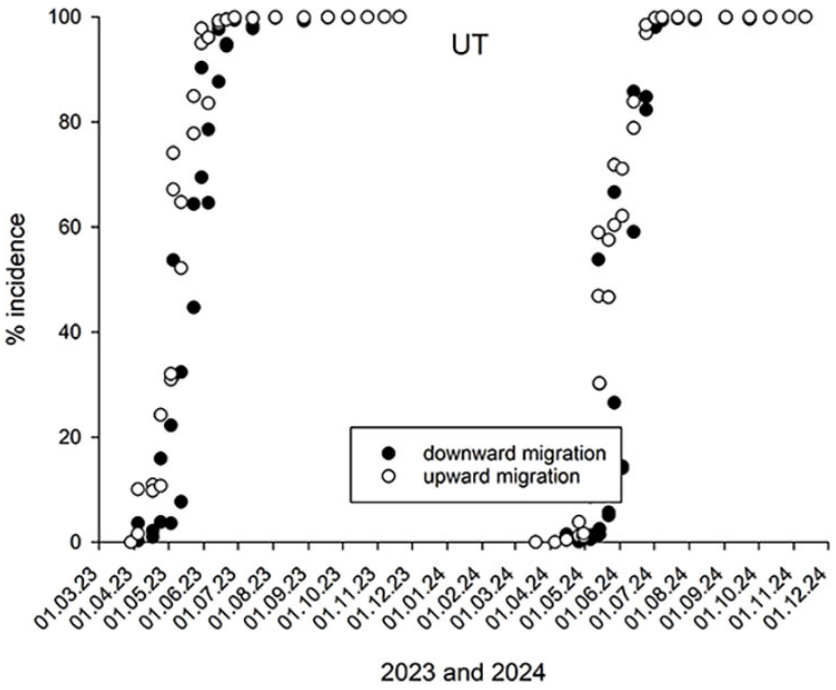

Fig. 7: N1 migration expressed as the cumulative % (nymphae/d) f, collected on the observational trees in the untreated plots (UT) during both seasons (upper and lower sticky band).

We started our shoot surveys on 2 May 2023, when we observed an average of 8.5 fully developed leaves per shoot; see repository [6]. From 2 May to 9 May 2023, we observed the first nymphal instars settling on the lower internodes of the shoot. This presence increased, leading to a first maximum on 31 May 2023. From this point onwards, shoot colonization decreased slightly until 21 June, before increasing again in response to a second spring-season maximum. During the period from the end of May to mid-June, colonization decreased due to periods of high temperatures reaching 36 °C. After this, active presence decreased in differ-

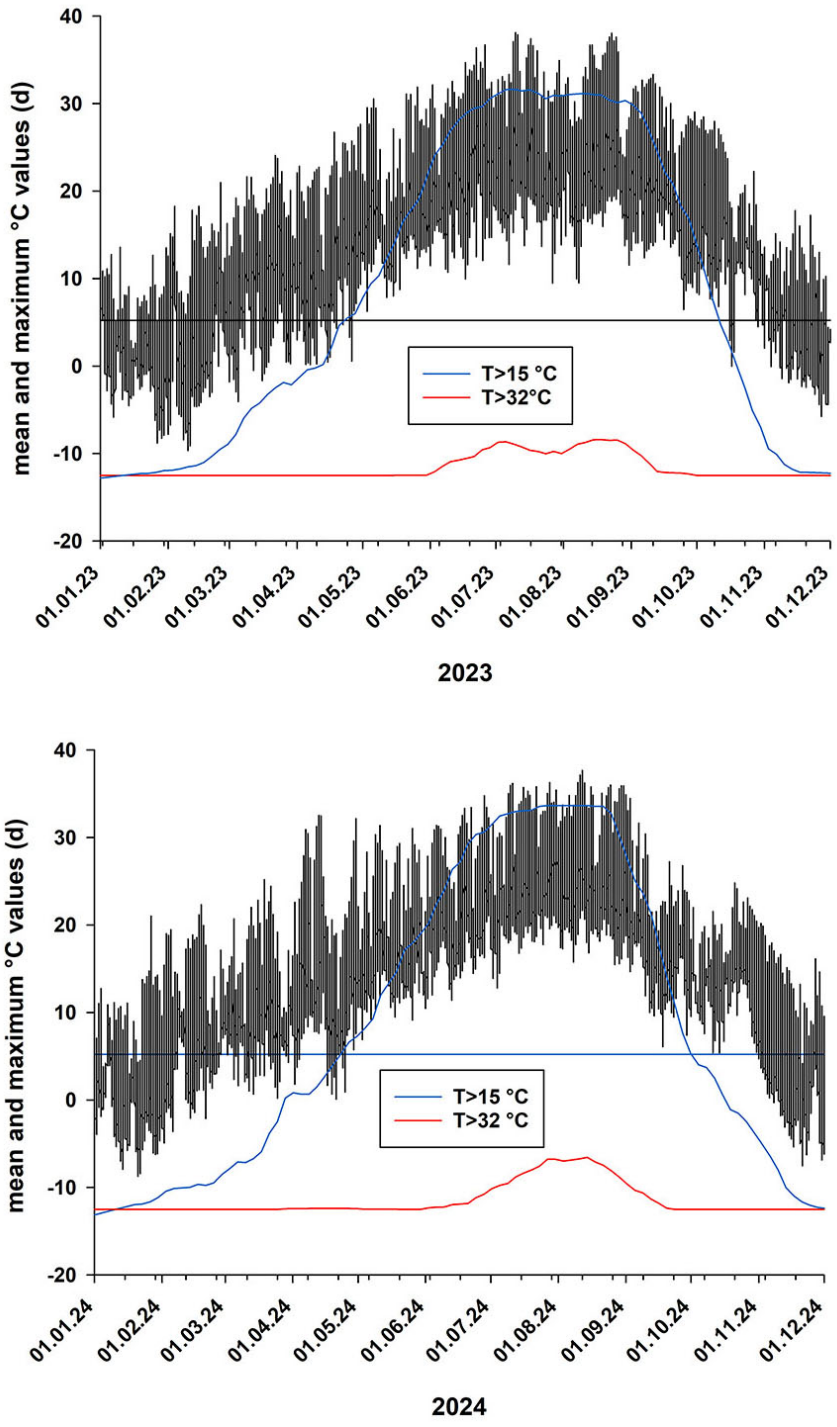

Fig. 8: The meteorological conditions reporting the daily minimum values, mean values, and maximum values (black graph) during the two seasons. The periods of the season during which the temperature exceeded 15 °C (blue graph) or 32 °C (red graph) are indicated. The horizontal line indicates the 15 °C threshold.

ent ways across rows, leading to a minimum on 5 July 2023 and a final decrease in WAA colony activity on 25 July 2023.

On 5 April 2024, we started visual inspections of a fixed number of shoots per testimonial tree. On 17 April 2024, we visually recorded an average of 7.8 fully developed leaves per shoot and observed the first WAA settlements on the growing shoots [6]. After its initial appearance, shoot colonization by WAA increased rapidly between 6 and 10 May 2024. During a second period, from 22 to 27 May 2024, shoot colonization increased again, reaching a second peak on 24 June 2024. Following this, the number of WAA colonies on shoots began to decrease. When daily maximum temperature increased to above 32 °C for a few days, with peaks of 36 °C, the general upward migration on the sticky bands decreased between 2 and 8 July 2024. This decrease was also evident in the reduced colony settlement activity on the shoots, as observed between 9 July and 1 August.

RESULTS REGARDING SHOOT COLONIZATION MEAN AND MAXIMUM VALUES IN BOTH YEARS IN PLOTS AND ROWS

Table 12 and table 13 show the mean and maximum percentage of shoot colonization, as determined by visually counting internodes over the spring season for both years, with the untreated and treated parts reported separately. The statistics are reported in the Discussion section. Mean shoot colonization in 2023 (referring to the untreated part) during the spring season was 11.55% (maximum 26.51% of internodes). The respective mean values for 2024 were 28.83% (maximum 73.97% of internodes occupied by WAA instars). The plots with treated observational trees showed a mean shoot colonization percentage of 1.65% and 10.95% in 2023 and 2024, with respective maximum values of 8% and 44%.

When analyzed separately, comparing untreated and treated observational trees (untreated in both years versus treated in 2023 and untreated in 2024), the mean shoot colonization percentage was affected by the location of the testimonial tree within the rows ($p<0.05$) and the year (n.s.). The statistics are included in the repository [6]. For maximum values, year had a clear effect ($p=0.002$) on the percentage of occupied internodes. When comparing effects inside the treated part (TM in 2023 but not in 2024), the effect of year prevailed over row and plot factors. Some variability was observed between observational trees across

plots and rows in the untreated part. The possible origins of this variability are commented in the Discussion section (Fig. 11, fig. 12).

RESULTS: 'OLDER' WAA INSTARS MIGRATING DOWNWARD

As in our previous investigations (done in 2021 and 2022; [5]), we checked the upper sticky band for 'older' nymphal instars. We refer to these morphs as 'darkened' older nymphal instars, considering them to be already parasitized when they are leaving the upper parts of the tree. Table 14 shows the relative activity of these morphs in the untreated part of the experimental field in 2023. The sticky bands were exposed in the WAA untreated rows (49 and 57) by conducting the process alternating trees between the two rows. Table 15 shows the relative activity of these morphs in the untreated part of the experimental field in 2024. Due to the alternating conduction, whereby the sticky bands were exposed in alternating rows 49 and 57, some calculations were normalized by interpolation (Fig. 13, fig. 14). For the treated part data for 2024, we refer to the repository [6]. To compare the data with the relative percentage activity of adult *A. mali* individuals on both sticky bands during the entire season we report the *A. mali* data in the corresponding chapter in the discussion part (Tab. 6, tab. 7).

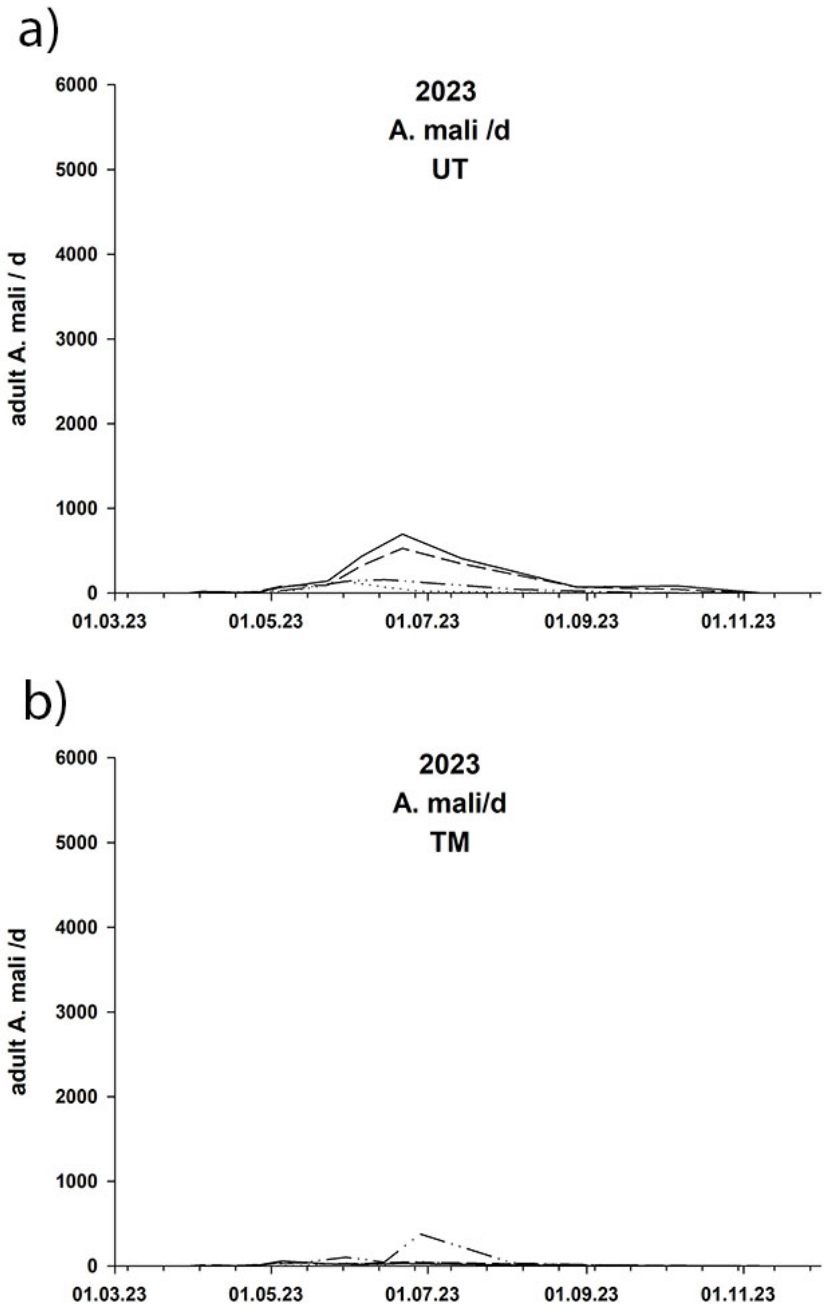

Fig. 9: The *A. mali* flight expressed as adults/d collected on the testimonial trees in the different plots (untreated and treated plots) during the entire season 2023 (mean number of lower and upper sticky bands).

DISCUSSION

DISCUSSION: ADAPTATIONS OF THE STICKY BAND METHOD

Grouping the migration data into classes shows that 2024 had a higher number of periods with higher upward migration rates. Consequently, there were more shorter exposure periods in 2024 than in 2023 (Tab. 5). As in our previous work, we conducted surveys by alternating sticky band exposure periods between different rows and observation trees within the two plots. This probably ensured that N1 migration remained uninhibited, allowing free movement in both directions during intermittent 'non-sticky' periods applying modifications (see below). Permanent conduction, involving continuous exposure and replacement of barriers, can lead to deviated migration via nearby plants connected by lateral wooden parts.

From a practical perspective, the year 2024 exhibited higher mean and maximum N1 migration values than 2023 (Tab. 2, tab. 3). However, the statistics applied to the upward migration data show no significant differences between the two years with regard to upward migration [6]. A similar trend was observed in the downward migration data, with no significant differences in mean and maximum values expressed in N1/tree/day ($p>0.05$) for the factor year. However, a significant difference was observed between the two rows (49 and 57) in the untreated part regarding upward and downward migration for mean and maxima ($p\leq0.01$). Figure 3 illustrates this. Differences between the years were evident ($p<0.05$)

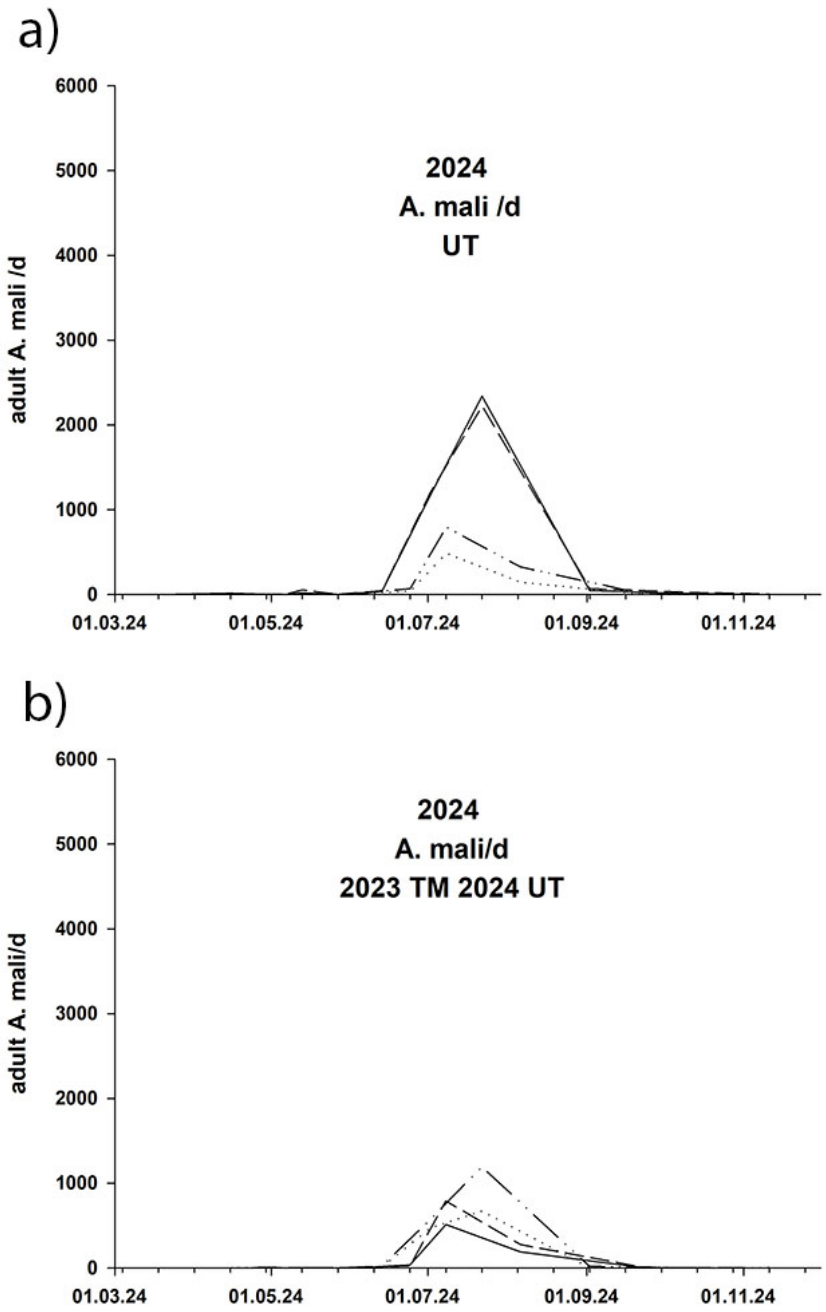

Fig. 10: The *A. mali* flight expressed as adults/d collected on the testimonial trees in the untreated (UT) and treated (TM) plots during the entire season 2024 (mean number of lower and upper sticky bands).

for the treated part because the treatment applied in 2023 affected migration in 2023 but not in 2024, when the observational trees remained untreated against WAA. This also applies to the maximum values [6].

Due to experimental requirements the original method [9] [10] [11] was adapted by elevating the point to a minimum of 1.5 m from the soil, where the sticky bands were placed [7]. This change in the protocols may have influenced the efficiency of the migration surveys e.g. the respective maxima. In the present work, the spring season maxima, referring to the maximum number of individuals on observational trees /day per plot, varied similar with regard to upward migration between the two years, compared to the data from 2021 and 2022 [5]. In 2021 and 2022, we recorded N1 activity values that exceeded any published data on parafs obtained using a similar sticky barrier approach at 50 cm from the ground [9] [10] [11]. During the previous work, in 2021, the maximum data for some groups of trees reached 6,878 N1 individuals/day on 30 June. In 2022, values were lower, with 2,015 N1 individuals/day recorded on 26 May [5]. In the current experiments, 2,766 N1 individuals/tree/day were recorded on 5 May 2023, and 5,302 N1 individuals were observed migrating upwards on 13 May 2024. Although we changed the former protocols, the actual values we recorded, are comparable to those of previous work [5].

DISCUSSION: N1 STEM MIGRATION DYNAMICS IN 2023 AND 2024

In this study, the 'spring season' migration lasted 121 days in 2023 and 123 days in 2024. In both years, the upward migration began on or after April 4th. The maximum migration occurred at similar data in both years on 5 May 2023 and on 13 May 2024 despite the earlier vegetation start in 2024. The spring season ended at a similar date in both years: 3 August 2023 and 6 August 2024. Excluding the mean and maximum values these data give us the impression that, apart from the absolute values, which differed (n.s.) the two years were similar regarding the population dynamics. When discussing the consequences of migration, we consider 'pressure' to be a synonym for abundance or population strength. As shown in table 1 and table 2; we consider the mean N1/day/tree for the upward migration far more high in 2024 than in 2023.

In the present work we continued to investigate the migrating activity of WAA individuals by some of the parameters we had developed: e.g. establishing the moment of the migration direction 'switch' [5]. Apart from the numerical differences in mean and maximum migration population, to discuss annual population strength more accurately, we must take into account that in 2023, the switch in migration direc-

tion from upward to downward occurred at 155 days after 1 January, one month after the maximum of the upward migration (which was at 6th May 2023; 124 days after 1st January). In 2024, the 'switch' of the prevalent migration direction occurred on 8 July, at day 189, which was two months after the annual maximum of the upward migration on 13 May (day 133 after 1st January). From this, it can be assumed that the N1 population present in the canopy accounted for a higher proportion of nymphal presence and for a longer period in 2024 than in 2023.

The mean cumulative migration recorded on the untreated observational trees reached 99.97% of the total seasonal upward migration per year until the end of the spring season, as observed on 3 August in 2023. In 2024, a cumulative 99.98% of the total annual upward migration was reached on 6 August. The respective downward migration was 99.84% in 2023 (3 August) and 99.64% in 2024 (6 August) (Fig. 15, fig. 16). Taking into account the previous findings [5] and the current results, we can conclude that the majority of up- and downward migrating N1 individuals in this orchard were strictly correlated during the restricted spring migration period. In previous investigations in the former experimental field in the same orchard (in 2021 and 2022; [5]), the mean cumulative spring season upward migration on all the testimonial trees reached 99.5% of the total annual migration. This was observed until 26 July 2021 (97.05% in 2021 downwards). In 2022, 92.3% of the upward migration was observed on 13 July (95.71% in 2022 downwards).

In fact, 'older' bibliographic references do not properly mention this observation. Theobald [15] was one of the first authors to address a seasonal migration-direction preference. On the contrary, Dumbleton and Jeffreys [16] observed no root-directed migration in autumn and winter in New Zealand. Other authors observed downward migration in autumn and a co-occurrent

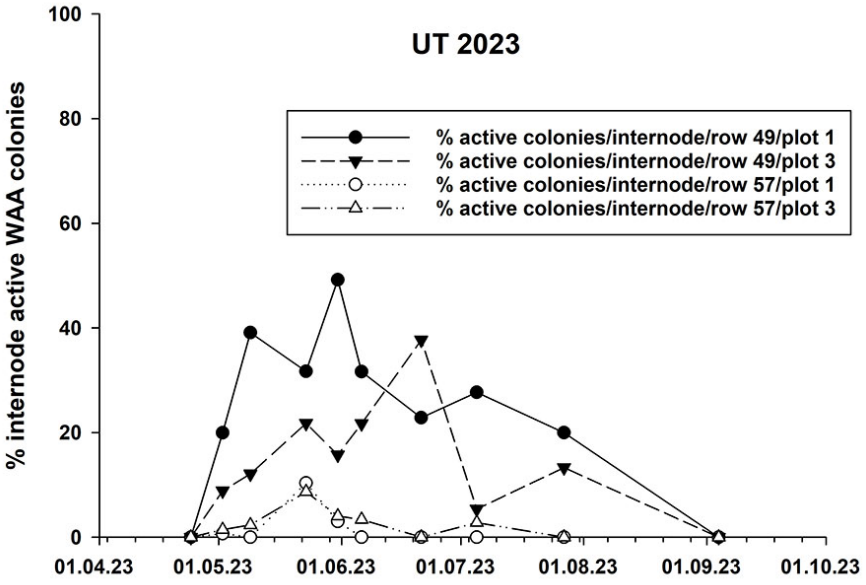

Fig. 11: The spring season internode colonization percentage by WAA and the respective rows and plots. The data refer to the untreated (UT) observational trees grouped in rows and plots.

up and downward migration during spring [13]. Despite differing statements, the hypothesis of a prevalence of downward migration in autumn is consistently repeated and cited [10]. More recently published works confirm our observations, a temporal collinearity of the main part of the up-and downward migration during the spring migration period without a specific discussion on the nature of this behavior, but affirming that the relative migration activity from autumn to spring is not consistent in numbers compared to the spring migration [11].

In agreement with some authors [11], we discovered only limited time periods with predominantly downward migration (article in preparation). Compared to the percentage of individuals accumulated during the spring period(s) in our research, less than 4% of N1 population migration during the entire season took place in the pre-winter period. Based on these findings, we must assume that in this experimental field individuals moving downwards from canopy WAA colonies in spring (including those starting from the shoot colonies) are directed towards lower plant parts, including the grafting point and roots. This spring activity may have contributed to the permanent colonization of plant tissues other than shoots by WAA. It is unclear if the N1 nymphal instars successfully settle on different woody tissues including the grafting point and roots during the spring season. Further investigations are needed to answer this question.

DISCUSSION: WAA ON SHOOTS 2023 AND 2024

The goal of the current study and previous research [5] was to develop methods that are less time-consuming for long-term investigations in an extended randomized experimental field with different susceptible rootstocks and two susceptible apple cultivars [3]. As already mentioned, we adapted protocols simplifying the methods in a way that allowed us the future use of A.I. driven imaging technologies [7]. In the previous work [5], we learned, through proper validation, that visually inspecting the shoots of selected observation trees can provide reasonable insight into the ongoing settlement process on the shoots of apple trees in a plot or apple field. In the current experiments, we only applied the non-

destructive method to observe testimonial trees instead of repeated sampling destructively on plants inside a plot in both years.

Table 8 and table 9 show the relative percentage distribution of WAA on shoots over the spring season for both years, reporting only the untreated parts. Table 12 (UT 2023 and 2024) and table 13 (TM, 2023 only) show the mean and maximum values for the percentage of actual internodes present on the shoots of the testimonial trees, for rows, plots and years. Table 16 and table 17 display the absolute percentage of WAA presence on shoots

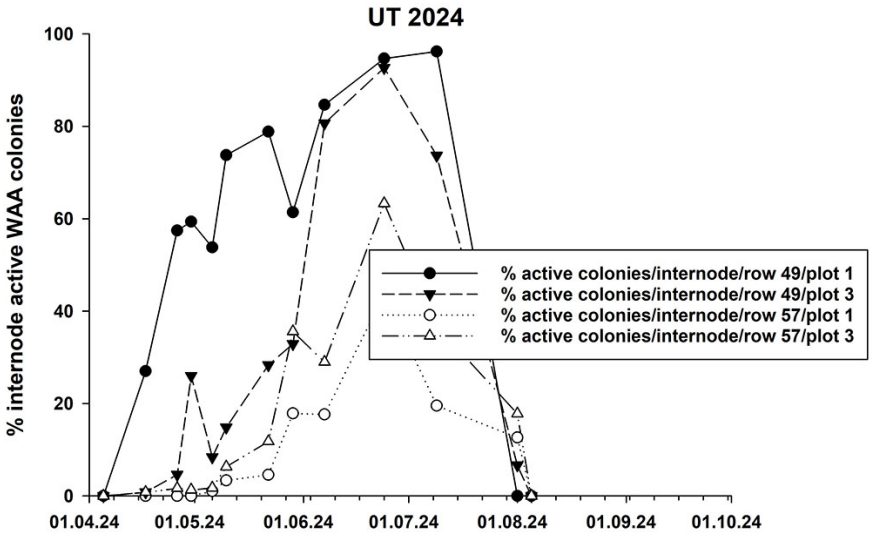

Fig. 12: The spring season internode colonization percentage by WAA and the respective rows and plots. The data refer to the untreated (UT) observational trees grouped in rows and plots.

in tabular form reporting only the untreated part of the experimental field. The respective data on the number of developed internodes on shoots are reported in the repository section [6]. Figure 11 and figure 12 show the percentage presence of active WAA colonies on the internodes of the shoots on the observational trees.

The first observations were made at a phenological point assuming, that the shoots had reached approximately 20% of their final length. We then started our visual surveys later on 2 May 2023, when we observed eight and a half fully developed leaves per shoot [6]. In 2024, we proceeded in the same way, but earlier due to the early beginning of the spring season, with the first shoots bearing WAA colonies forming on the lower internodes from 17 April 2024 onwards.

Despite the phenological differences between both years several factors have probably influenced the dynamics of WAA activities on the shoots, causing local variability between observational trees within individual rows and plots. The pressure from invading, upward-migrating individuals seemed to be one of the main driving factors (Tab. 16, tab. 17). Considering the annual upward migration dynamics recorded on the stem for both years (graphically shown in figure 3, 2023 UT and 2024 UT), we observed also a more intense activity on shoots (and on the stem) in plots of row 49 than in row 57 plots during the spring colonization process in 2024 compared to 2023 (2023: Fig. 11; 2024: Fig. 12).

A significant presence of multicolored Asian lady beetle, *Harmonia axyridis Pallas* (Coleoptera: Coccinellidae), a voracious predator of aphids including also all WAA instars [17] present on the observational trees, particularly on the observational trees in row 57, may have contributed to the high degree of variability of the data collected on the trees within the untreated rows. This needs to be considered when interpreting the lack of significance regarding the treatment effects observed on the shoots in 2023 ($p>0.05$). *Harmonia axyridis* as an occasional predator on apple, in 2023 probably was "attracted" to some of the trees in the rows (WAA treated and untreated part) where the Azadirachtin (NeemAzal) sprays during bloom had failed to regulate *Dysaphis plantaginea Passerini* (Hemiptera: Aphididae). The spot like presence of *H. axyridis* on RAA colonies had also a predatory effect on WAA colonies. Data on % of active colonies on shoots for observational trees exposed to treatment in 2023 are not shown graphically for both years. Instead, we have reported the relative percentage data for the treated testimonial trees (Tab. 12, tab. 13).

From the percentage distribution in table 8 and table 9 (untreated trees in 2023 and 2024), we can see that, as shown in figure 11 and figure 12, the colonization process on shoots experienced ups and downs prior to reaching its spring maximum. This dynamic must be considered in the context of weather conditions, particularly higher limiting temperatures (see below), and the influence of *A. mali*. As we prefer not to consider the limited sampling data on the degree of *A. mali* presence on internodes here, we cannot discuss direct effects of *A. mali* on the shoot-colonization process in spring. These data will be included in a separate article (in preparation) dealing with overwintering of WAA on the observational trees. Instead we comment the topic in the next chapters (see below).

Based on our visual inspections of different apple plant tissues on observational trees (article in preparation), we must presume that, at the beginning of shoot growth and the subsequent WAA colonization process, most of the basic (older) fruitwood on the observational trees had already been actively colonized by WAA individuals (results to be published; article in preparation). This suggests that a not readily es-

timable portion of the N1 population colonizing shoots did not start spring migration exclusively from rootstock colonies or those permanently formed beneath the grafting point. Alternatively, they could have started migration from already colonized 'old wood' tissues at the base of the growing shoot after their successful overwintering in the canopy. Specially this issue will be discussed in an article a part.

Independent of the source of migration, intermittent inhibitory effects of high temperatures probably caused the discontinuous settlement process on shoots in both years, as shown by figure 11 and figure 12. Investigations conducted in the past century revealed that temperatures up to 30 °C stopped embryonal development of larvae inside the 'virginoparae female' [18]; Bodenheimer [19] observed a drop in reproduction at these temperatures. Current observations and temperature recordings [5] suggest that the upper temperature threshold limiting WAA reproduction must be higher.

We would argue that the increase in downward migration from the shoots versus the upper sticky bands in 2023 promoting the migration 'switch' was also partly due to critical temperature conditions. Pessimal temperature conditions increased constantly from 5 June to 28 June 2023 with peaks of 36 °C (Fig. 8, upper graph, red line), covering more daily hours and exceeding 32 °C. Absolute data on active settlement of the shoots are provided in table 16 and table 17. For the treated part data, we refer to the repository [6]. The 2023 data shows that a general decline in WAA percentage on internodes after 31 May 2023, a calendar data that coincides with the change in migration direction from upward to downward.

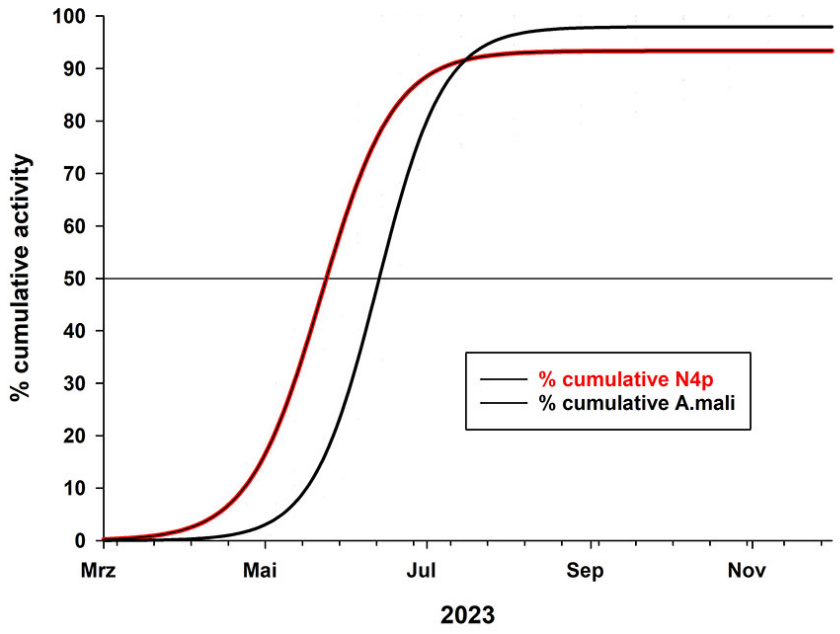

Fig. 13: The seasonal dynamic of the cumulative percentage of N4 instars activity and the *A. mali* flight (cumulative annual) for 2023 on the untreated observational trees (UT).

After this point, upward migration on the stem also decreased slowly.

In general, the WAA presence on internodes dropped first in row 57 in June 2023 (Fig. 11). After a temporary gain of colonies strengths, the presence of the WAA percentage on shoots regained intensity starting after June 2023 for a short time depending on the row, followed by a general decline. Despite the 'detrimental' effects of temperature, migration continued to progress slowly, with subsequent ups and downs, compared to the shoots in row 49. Figure 3a, figure 5a and table 16 show the differences between the rows and the observational trees inside the plots. At this time *Harmonia axyridis* had already disappeared permitting the WAA colonies to grow. The data concerning the observational trees in the 'treated' part are reported in the repository [6].

Due to the earlier start of apple phenology in 2024 (bud break data at 28 February 2024), the growing process of shoots was more advanced compared to the previous year. As well as the phenological earliness of 2024, the differences compared to 2023 included more intense migration of individuals in both directions, with two distinct migration peaks and a longer-lasting upward migration of N1 instars in 2024, with a late switch in migration direction on 8 July 2024. In 2024, the general change in migration direction was not triggered solely by suboptimal temperatures. From 2 July to 2 September, days with temperatures above 30 °C occurred frequently, with peaks of 32 °C lasting a minimum of two hours a day. The shoot growth process also ceased at this time. Specific observations must be done in the future to investigate, if the combination of both factors, stop of the shoot growing process and maximum temperatures entering the pessimal range for WAA are important for the colony establishment.

After the maximum of the first annual upward migration on 13 May 2024 (day 133), we observed the 'switch' in the direction of stem migration on 7 July 2024 (day 189), two months later. This coincided with a drastic drop in shoot colonization. At this time, we observed a decreasing presence of active WAA colonies on the shoots, which is consistent with the increased prevalence of downward migration observed on the upper sticky band. As shown in table 14 and table 15, part of the decolonization of shoots could be due to the downward migration of 'older' nymphs 'emptying' the colonies of preimaginal

instars. This phenomenon may also have indirectly affected subsequent N1 reproductive dynamics because older instars were excluded from reproducing on internodes and, ultimately, from reproducing successfully subsequent WAA generations. From table 15 reporting the 2024 data, we observed that the downward migration process of 'older' nymphs began later, starting on 22 May 2024 (row 54/57) and 05 June 2024 (row 49/57). It is difficult to quantify the extent to which this contributed to the decline in shoot colonization by WAA prior to 8 July 2024, when the N1 migration switch occurred (see subsequent chapter).

sticky bands mounted at a minimum of 1.5 mt high and discontinuously activated yields quantitative data comparable to those obtained using sticky bands placed near the grafting point of the apple tree (Fig. 1). This accounts for the N1 counting and the surveys on the *A. mali* flight. A direct comparison of our method with the normally used yellow sticky traps for *A. mali* surveillance was not included in the experimental settings.

The strength of the mean flight of *A. mali*/d and tree differed between 2023 and 2024. Considering the observational trees in the untreated rows, we counted a mean of 97 *A. mali* individuals/day from March to November in 2023. In 2024, we

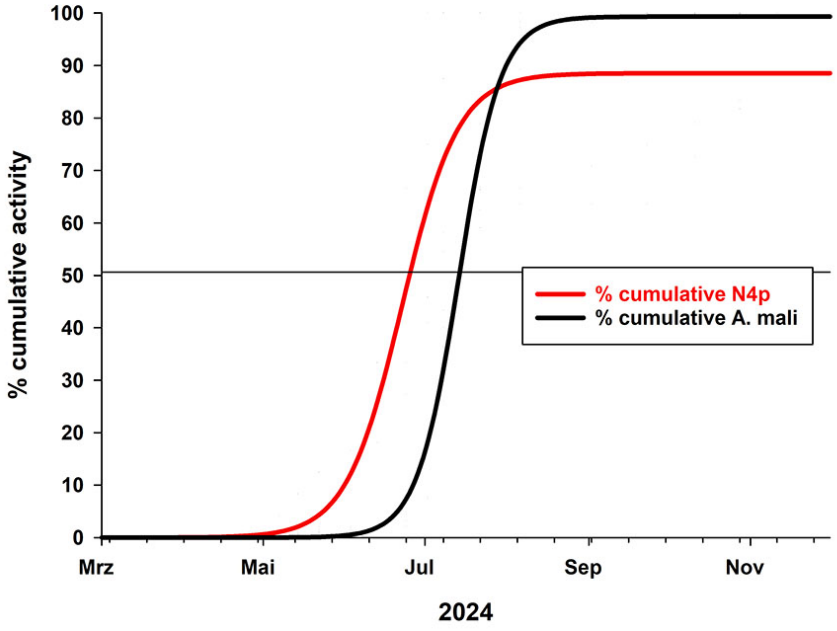

Fig. 14: The seasonal dynamic of the cumulative percentage of N4 instars activity and the *A. mali* flight (cumulative annual) for 2024 on the untreated observational trees (UT).

DISCUSSION: *A. MALI* FLIGHT DYNAMICS AND WAA PRESENCE ON SHOOTS

Mounting the 'sticky bands' at a higher level probably enhances the visual attraction range for *A. mali* and the access by A.I. driven automatic visual recording systems, thereby eliminating frequent contamination with soil or mud particles. From our comparisons with results of the former investigations [5], we can conclude that using

counted a mean of 191.7 *A. mali* individuals/tree/day over the same period, covering the entire annual season. The data are shown in table 6 and table 7. For the treated part data, we refer to the repository [6]. The total number of *A. mali* caught and counted was different in both years. When we totaled the respective mean catches for each exposition period on both sticky bands, we counted 4,278 *A. mali* individuals/tree/day in 2023 and 9,205 in 2024. The data for 2023 and 2024 refer to untreated observational trees. In 2021, we calculated a mean daily value of 102 *A. mali* individuals/tree/day for the whole year. In 2022, we counted 95 *A. mali* individuals/tree/day. Totaling the catches on the sticky bands in 2021 and 2022 revealed differences between the two years. 8,573 *A. mali* individuals were caught in 2021, compared to 6,908 in 2022. This summary reflects the data from the untreated observational trees of former investigations [5]. During both experiments, the range of the 'totals' per observational trees where similar for the *A. mali* countings.

As stated in the results section, the minimum temperature conditions for *A. mali* hatch and flight [20] were given in both years, starting from 13 April 2023 and 15 April 2024. Taking into account the *A. mali* flight (Fig. 9, fig. 10), which refers to the shape of the flight development curve from the start until the spring flight maximum, we must discuss how good the presence of *A. mali* females fitted with viable prey individuals during the spring migration periods in both years affecting the parasitoid performance.

Our former experiences [5], practical experiences of technicians (advisory services) and findings of some authors reveals similar thoughts and/or research approaches to investigate or solve the problem of a poor synchronization between host and parasite. Hetebrügge et al. [21] initiated a project to rear *A. mali* and release a fixed number of individuals in early spring, thereby preventing the parasitoid's absence when the WAA population typically increased the most during spring. Mols and Boers [22] conducted specific investigations from a genetic perspective, based on the assumption that *A. mali* is poorly synchronized with the Central European WAA populations during their spring development. Some authors have reported similar phenomena involving desynchronized parasitoid flight in relation to WAA activity. Jancke [23], Evenhuis [24] and Castellari

[25] noted the absence of *A. mali* flights under certain conditions specially in summer and put forward various hypotheses.

Due to the limited data on *A. mali* dynamics we have collected, a general discussion on this topic is not possible. Instead, we will focus on observations relating to some of the 'simple' population parameters that we recorded at various times over the course of two years. From our limited recordings and observations, we must presume that the earlier annual presence of *A. mali* and the expected parasitisation activity covered the 'prey' on the shoots better in 2023 than in 2024. Conversely, in 2024, we observed a different situation during the main spring flight

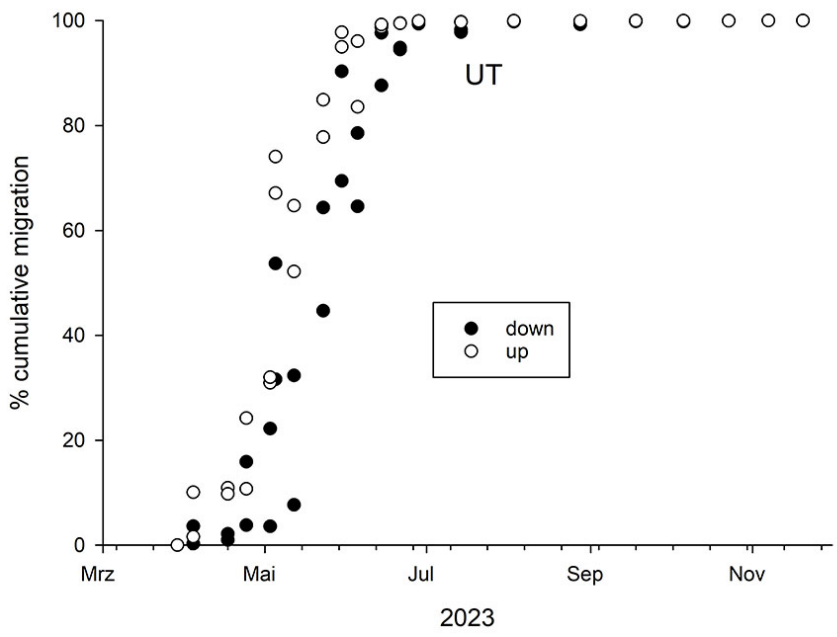

Fig. 15: The N1 migration expressed as the cumulative % (nymphae/d) for 2023, collected on the untreated observational trees (UT) in the different plots during the entire season (upper and lower sticky band).

period of *A. mali*. The maximum number of *A. mali* catches/tree/day in 2024 occurred with delay compared to 2023, and at a different point in relation to the (higher) WAA maximum on shoots in the spring of 2024. During spring 2024, the delayed *A. mali* flight progressed but increased slowly and the late annual flight maximum failed to cover the more intense earlier and enduring WAA presence in the upper parts of the trees. As in 2021 [5], the main part of the *A. mali* flight was delayed until the end of the upward migration period in 2024 (Tab. 7).

Speaking about the WAA active presence in the canopy parts, the point when the downward N1 migration increases (compared to the upward migration) marks a critical point also for the *A. mali* activity on shoot colonies. Beside the positive fact, that the net presence and the 'pressure' of WAA on aerial colonies is lowered by the moving N1 instars, emptying the shoot and canopy colonies, there is a second aspect. N1 instars in movement are not liable hosts for *A. mali* females until they settle on a viable tissue. The effect of this situation on the *A. mali* reproduction is unclear; *A. mali* adults probably had to rely on the permanent WAA colonies on "alternative" wooden tissues, other than shoots(for the 'switch' effect see relative previous chapters).

When it comes to the viable prey for *A. mali*, we are referring to the WAA population present on shoots and other wooden tissues. It is important to note that nymphal instars and apterous adults also colonize stem and rootstock parts, as well as old wood bark crevices. Further, only the N2-N3 instars that have already settled are suitable for the successful reproduction of *A. mali*, which leads to predominantly female offspring ([26] [20]).

In 2023, we observed an early spring N1 migration maximum, followed by an imminent switch in the direction of N1 migration, leading to an earlier decrease in the presence of the WAA population in the apple canopy compared to 2024. After this data, we observed a continuous increase in the relative annual flight activity of *A. mali* in 2023, reaching 50.19% on 14 June (Tab. 6). At this time 30% of the internodes on the shoots beared active WAA colonies.

From our recordings on both sticky bands, we can see that, compared to the data of the first upward migration maximum in 2024 (13 May), in this year, we recorded only 0.89% of the total annual *A. mali* flight. At the migration switch point on 8 July 2024, 38.5% of the annual *A. mali* flight was observed (Tab. 7). According to the data (9th July 2024) in table 17, the percentage of WAA presence on shoots was 84.95% (row 49) and 28.19% (row 57).

DARKENED INSTARS MIGRATING DOWNWARDS DURING THE ACTUAL EXPERIMENTS

Starting from our observations and investigations, we have evidence, that darkened instars ultimately hatch into adult *A. mali* individuals after final development. These adults may have contributed to spring adult flight activity, which for many authors [20] [21] [22] is pivotal for containing the WAA on shoots and various stem and upper rootstock parts. Thanks to the modified survey protocol that we applied, we can assume that the instars must already be parasitized prior to the start of their migration. We recorded this type of morphea exclusively at the border of the upper sticky band. We observed the phenomenon in the field, on stems, where the sticky band border fits with the wooden tissues on the circumference of the stem. The wooden tissues on the stem circumference bearing the darkened in-

stars, never showed signs of necrosis or wooden gall tissue. So we can exclude nymphal development and parasitation at this sites.

In general, in the '*Eriosomatinae* group' only larvae (N1) migrate [13]. Patch [27] stated that 'older' nymphal instars can migrate from crowded colonies. The effect of the colony density on the incidence of this particular behavior has not been studied in this work. Starting from the 'banding method' we applied and considering the resulting implications and our observations, we have to assume that migration behavior of this 'older' nymphal morphs is probably induced by a endogenous host manipulation ([28] [29]) by *A. mali* larvae already inside the nymphs, when downward migration hasn't started. Former visual inspections and documented observations in the field (pictures in figure 17 and figure 18) are in accordance with our assumptions. Based on the actual results, we can now interpret some former observations in the hope that the current assumptions, which are supported by more experience, can explain the nature of the behavior (and some consequences) documented in some pictures.

These pictures (Fig. 17) were taken in spring 2023 before the former experimental field [5] was cleared, and work in the current field (2023-2024) had just begun. Banded observational trees, surveyed during 2021 and 2022 were used for a final investigation between 13 and 21 March 2023. During winter 2022/2023 , the sticky white base was covered with a paper band to protect it and allow free migration in both directions. From the pictures taken during the exposure period on paper bands affixed in the position above and near to the grafting point (Fig. 18), we learned that, below the former 'darker nymphal instars' that had accumulated (the exit holes of which indicated a successful hatch of *A. mali*), we observed an accumulation of hatched *A. mali* individuals on the upper edge of the upper sticky band. This suggests that this morphea that have already migrated downwards can contribute to the local presence of *A. mali* in spring after overwintering. Therefore, we cannot deny the possibility that the strength of the *A. mali* population and the incidence of 'older' nymph population are 'somehow' related. As the recordings of the appearance of these particular instars are qualitative (i.e. we recorded their presence or absence), we cannot consider the precise contribution of these morphs to the total *A. mali* flight during the different periods.

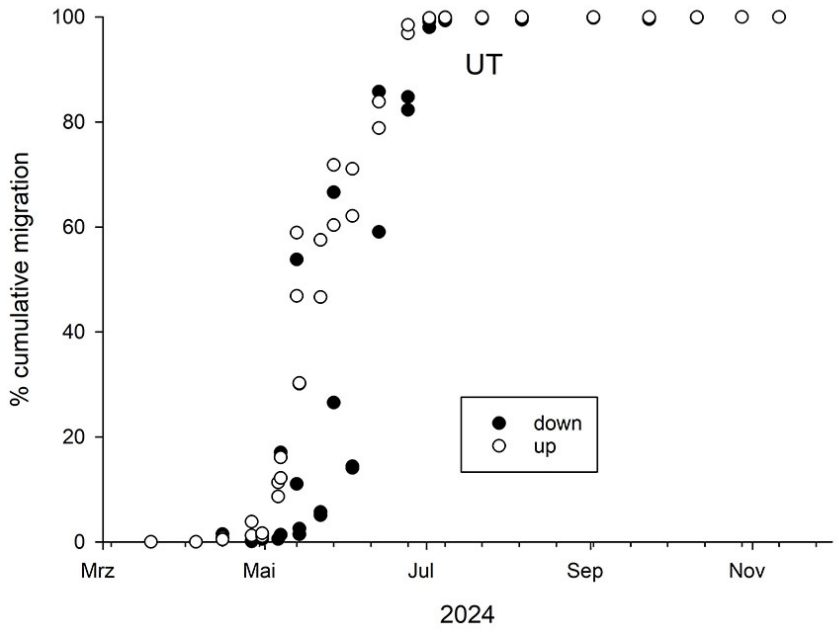

Fig. 16: The N1 migration expressed as the cumulative % (nymphae/d) for 2024, collected on the untreated observational trees (UT) in the different plots during the entire season (upper and lower sticky band).

The fact, that the 'darkened older nymphal instars' are those who have migrated downwards during selected periods accumulating on the upper sticky bands bears some unexpected 'practical' consequences. These instars were not only excluded from WAA reproduction on shoots or stem colonies, but they also contributed to an direct increase of the adult *A. mali* population during the spring migration season. Further, the recordings on the WAA 'mummy' presence on shoots to quantify the actual *A. mali* efficiency are biased, because in the visual but also in the destructive samplings part of the parasitized WAA population (because moving downward) is absent. For this reason the actual percentage of *A. mali* activity could be larger than expected from the counting on shoots. These assumptions and conclusions accounts for the WAA populations studied in the actual and the former experimental field [5] in the same *Fuji* orchard. Studies have been started in different locations in the South Tyrol Apple growing areas to confirm or deny the particular behavior of these WAA morphs.

We further must keep in mind that, considering the visual inspections from 2023 and the investigations on the observational trees also the dynamic of the spring flight of *A. mali* and the WAA strength itself could possibly be influenced by the unpredictable activity of these migrating morphs through the years.

As discussed earlier, the suitable WAA prey in the aerial environment were better covered by the adult flight activity of *A. mali* in 2023 than in 2024. This accounts for the early increase in *A. mali* flight and the data on the maximum flight inten-

Fig. 17: The white sticky base under the transparent single sticky band (absent) in spring 2023 after the overwintering period applied at 1.5 m; from November 2022 until the end of February 2023 it was covered by a “non-sticky” paper band, allowing free migration. In the picture the paper band has been removed.

sity of the adult population in 2023, which matched the early presence of an active WAA population. Conversely, in 2024, after restrained and delayed flight evolution of *A. mali*, a late flight maximum was observed which neither did adequately cover the early first spring WAA migration maximum on 13 May 2024 nor the second WAA maximum between 27 May and 24 June 2024 including the contemporary shoot settlement process. As mentioned in the previous chapter, this kind of 'mismatch' (between migration activities and colony establishment, and *A. mali* activities recorded on sticky bands) and the shoot colonization process, likely led to poor containment of the WAA population on shoots and in the canopy in 2024.

From the data presented in figure 13 and figure 14, it can be seen that, similar to the delayed increase in *A. mali*, the appearance and percentage increase of 'darkened nymphal morphs' activity has also shifted backwards in 2024, when compared to 2023. Increasing activities for both morphs were observed starting from the end of June 2024 on (Tab. 15, tab. 7). Considering this, we can hypothesize that the early appearance of this particular morphs in 2023 supported the early increase of the *A. mali* flight in this year, fitting optimally with the WAA nymphs development in the canopy. The opposite is true for the 2024 year, when both 'darkened older nymphal instars' and the *A. mali* adults occurred 'too late' to cover the nymphal population. Ongoing research on WAA in apple orchards in different locations will provide some new evidence on the importance of this phenomena.

SUMMARY

In these field investigations, we omitted repeated destructive shoot surveys of trees within experimental fields, in favor of repeated non-destructive observations on a defined number of selected trees. Instead, we present data on visually recorded active WAA settlement on shoots of selected observational trees, expressed as the percentage of occupied internodes. Although this simplified protocol resulted in loss of information usually obtained through laboratory counting and dissection of samples, such as colony size and intensity, it enabled us to preserve the integrity of the entire canopy-colony system. By avoiding artefacts associated with intensive destructive wood-sample collection and focusing on individual observational trees, this approach provides

Fig. 18: The observational tree in early March, with upper and lower sticky bands; around the edge of the upper sticky band we notice former *A. mali* "mummies" showing exit holes, and nearby on the edge of the sticky band some hatched A. mali individuals.

a more rapid, representative depiction of population dynamics, particularly at a single plant or plot level.

This approach included deriving population parameters for the migrating N1 population in view of future implementation of AI-driven technologies. To enable more robust statistical analyses, data from three individual trees were pooled into groups, treated as replicates and assigned to rows. Considering the actual results and previous experiences, there remains a need to explain the timing and triggers responsible for migration start and changes in the migration direction of the N1 population following the migration maximum. Pessimal temperature conditions explain part of the seasonal dynamics.

If the intensity of upward migration determines the degree of canopy infestation, it is evident that the continuous decolonization caused by counter-migration up to the seasonal migration maximum must be taken into account for estimating the annual pest pressure. What can be stated with certainty is that the number of upward-migrating N1 nymphs must be adjusted to account for the proportion of the population migrating downwards during the same period. Only in this way can actual infestation pressure or active canopy presence of WAA be determined. Accordingly, the development of this balance - from the data of the onset of migration, through the maximum, to the moment of mass directional reversal and end of migration - must be considered.

In this study, the downward migration of larger dark nymphal stages was observed, interpreted and documented. During both years, a relationship was observed between the presence of these developmental stages on the trunk and the subsequent increase in flight activity of *A. mali* on the adhesive surfaces. This observation agrees with the recordings during the previous work. Apart from a direct decolonizing effect in the canopy compartment, these morphs probably can contribute to the *A. mali* flight after they finished development and hatching. Ongoing research in a dedicated project should further investigate the presence of this phenomenon and the consequences in other apple-growing areas of South Tyrol.

ZUSAMMENFASSUNG

In dieser Studie wurde auf destruktive Erhebungen am Fruchttrieb verzichtet und stattdessen eine wiederholte nicht-destruktive Erhebung der Triebbesiedlung vorgenommen, ausgedrückt als Prozentsatz der besiedelten Internodien. Obwohl dieser Ansatz detaillierte Informationen über die Größe und Intensität der Kolonien ausblendet, wurde eine zeitsparende repräsentative Bewertung der Befallsstärke durch die Apfelblutlaus auf Einzelbaum- und Parzellenebene ermöglicht. Außerdem blieb die Integrität der Baumkrone erhalten.

Die Daten zum Frühjahrs-Migrationsverhalten der Apfelblutlaus an einzelnen Bäumen wurden zu Wiederholungen zusammengefasst, um die statistischen Analysen zu ermöglichen und Migrationsparameter der „crawler“ (N1)-Population abzuleiten. Weitere Ergebnisse deuten darauf hin, dass Veränderungen in der Migrationsrichtung nach dem Migrationshöhepunkt nicht allein durch die Temperatur erklärt werden können. Die Intensität der Aufwärtswanderung allein bestimmt nicht ausschließlich die aktuelle Befallstärke in der Baumkrone durch die Apfelblutlaus *Eriosoma lanigerum* (Hausmann, 1802) (Hemiptera: Aphididae). Um den tatsächlichen Befallsdruck durch die Apfelblutlaus abzuschätzen, muss auch die Gegenwanderung nach unten vor, während und nach dem Migrationsmaximum berücksichtigt werden.

Die Abwärtswanderung größerer Nymphenstadien wurde wiederum bestätigt. Daten aus beiden Jahren deuten auf einen Zusammenhang zwischen dieser vorwiegend durch *A. mali* parasitierten Stadien am Stamm und der anschließenden Flugaktivität von *Aphelinus mali* (Haldemann, 1851) (Hymenoptera: Aphelinidae) hin. Laufende Studien untersuchen dieses Phänomen in anderen Apfelanbaugebieten Südtirols.

RIASSUNTO

In questo studio il campionamento distruttivo dei germogli in campo è stato omesso e sostituito da indagini visuali non distruttive sulla colonizzazione dei germogli su un numero di piante scelte, espresse come percentuale di internodi di germoglio da frutto occupati. Sebbene questo approccio riduca le informazioni dettagliate sulla dimensione e sull'intensità delle colonie, esso preserva l'integrità della chioma e fornisce una valutazione rappresentativa a livello di pianta e di appezzamento fornendo informazioni sufficientemente valide sull'andamento della popolazione e sull'infestazione della chioma.

I dati riguardanti la migrazione primaverile dell'*Eriosoma* raccolti su singoli alberi spia sono stati aggregati in repliche a livello di filare e parcella per rafforzare le analisi statistiche e per derivare i parametri di migrazione della popolazione N1. L'intensità della migrazione verso l'alto, da sola, non determina esclusivamente l'infestazione della chioma. La contro-migrazione verso il basso, prima e durante il picco migratorio, deve essere considerata per stimare la reale pressione d'infestazione da parte dell'afide lanigero *Eriosoma lanigerum* (Hausmann, 1802) (Hemiptera: Aphididae).

I risultati indicano che i cambiamenti nella direzione della migrazione dopo il picco migratorio non possono essere spiegati esclusivamente da fenomeni legati alle temperature, ma probabilmente dipendono da altri fattori, ancora da studiare.

La migrazione verso il basso degli stadi ninfali più sviluppati è stata nuovamente confermata mediante l'uso di strisce adesive. I dati raccolti negli due anni suggeriscono una relazione tra la presenza di questi stadi sui tronchi e la successiva attività di volo di *Aphelinus mali* (Haldemann, 1851) (Hymenoptera: Aphelinidae). Studi in corso stanno esaminando l'importanza di questo fenomeno in altre aree frutticole dell'Alto Adige.

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APPENDIX: TABLES

Tab. 1: The values for both years and the respective rows and plots show the mean values for the spring season downward and upward N1 migration/d, and the mean catches of *A. mali*/d. The data refer to the untreated part of the observational trees.

Parameter/UT	Year	Row/row	Plot	mean N1 downward/d	mean N1 upward/d	mean *A. mali*/d
Spring mean	2023	49/52	1	675.94	791.14	252.75
Spring mean	2023	49/52	3	477.64	592.94	198.20
Spring mean	2023	54/57	1	70.19	127.39	41.12
Spring mean	2023	54/57	3	116.00	315.67	78.82
Spring mean	2024	49/52	1	762.62	1547.34	449.21
Spring mean	2024	49/52	3	587.43	1346.96	444.30
Spring mean	2024	54/57	1	104.77	223.50	75.81
Spring mean	2024	54/57	3	156.60	513.74	134.10

Tab. 2: The values for both years, the respective rows and plots show the spring season maximum for downward and upward N1 migration, and maximum *A. mali* catches/d. The data refer to the untreated part of the observational trees.

Parameter/UT	Year	Row/row	Plot	max N1 downward/d	max N1 upward/d	max. *A. mali*/d
Spring max	2023	49/52	1	1818.85	2766.85	698.22
Spring max	2023	49/52	3	1021.42	2346.73	526.18
Spring max	2023	54/57	1	285.08	406.80	136.17
Spring max	2023	54/57	3	502.79	722.94	156.44
Spring max	2024	49/52	1	2246.65	5302.27	2338.90
Spring max	2024	49/52	3	1837.57	3738.27	2223.46
Spring max	2024	54/57	1	642.79	700.01	486.40
Spring max	2024	54/57	3	1001.19	1266.75	793.53

Tab. 3: The values for both years and the respective rows and plots show the mean for the spring season downward and upward N1 migration/d, and the mean catches of A. mali/d. The data refer to the treated part of the observational trees.

Parameter/TM	Year	Row/row	Plot	mean N1 downward/d	mean N1 upward/d	mean A. mali/d
Spring mean	2023	49/52	1	23.02	67.25	16.78
Spring mean	2023	49/52	3	77.35	115.10	89.87
Spring mean	2023	54/57	1	53.68	55.19	24.09
Spring mean	2023	54/57	3	20.13	133.43	27.94
Spring mean	2024	49/52	1	136.27	266.49	82.82
Spring mean	2024	49/52	3	286.77	450.73	123.33
Spring mean	2024	54/57	1	176.10	224.62	145.49
Spring mean	2024	54/57	3	261.75	456.46	225.48

Tab. 4: The values for both years, the respective rows and plots show the spring season maximum for downward and upward N1 migration/d, and maximum A. mali catches/d. The data refer to the treated part of the observational trees.

Parameter/TM	Year	Row/row	Plot	max N1 downward/d	max N1 upward/d	max A. mali/d
Spring max	2023	49/52	1	44.58	201.94	50.39
Spring max	2023	49/52	3	249.44	327.94	376.70
Spring max	2023	54/57	1	292.44	190.90	60.14
Spring max	2023	54/57	3	56.81	747.88	45.91
Spring max	2024	49/52	1	818.81	922.32	512.22
Spring max	2024	49/52	3	1420.07	1382.52	790.53
Spring max	2024	54/57	1	888.27	807.78	668.24
Spring max	2024	54/57	3	1229.93	1313.35	1193.34

Tab. 5: Number of exposure periods in days of the upper and lower sticky band on the untreated observational trees in the years 2023 and 2024 depending on the intensity of the upward migration (classes of N1 individuals/day).

	Upward migration UT			
Days per period	1-4	5-8	9-12	13-17
N1 individuals/day				
Number of series (2023)				
2400-3000	1.00			
1800-2400	1.00			
600-1200	1.00	5.00		
0-600		13.00	8.00	14.00
Number of series (2024)				
4800-5400	1.00			
3600-4200	1.00			
1800-2400	2.00	2.00		
1200-1800		4.00	1.00	
600-1200	1.00	1.00	2.00	
0-600	3.00	11.00	9.00	10.00

Tab. 6: The relative activity of the adult *A. mali* in the untreated part of the experimental field in 2023. Due to the alternated conduction, exposing the sticky bands alternating between double rows (49/52) and (54/57), the flight data are not in line.

Treatment	UT			
Parameter	% mean A. mali/d			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
29.03.2023	0.00	0.00	0.00	0.00
04.04.2023	0.99	1.14		
17.04.2023			1.30	1.02
24.04.2023	0.07	0.33		
03.05.2023			5.78	4.64
05.05.2023	3.47	5.37		
12.05.2023			12.33	9.70
23.05.2023	7.46	6.28		
30.05.2023			46.75	24.84
05.06.2023	22.45	21.38		
14.06.2023			23.00	27.92
21.06.2023	36.25	35.06		
28.06.2023			6.96	22.57
14.07.2023	21.16	22.90		
03.08.2023			2.70	7.79
28.08.2023	3.63	4.68		
18.09.2023			0.64	1.04
06.10.2023	4.32	2.76		
23.10.2023			0.54	0.48
07.11.2023	0.21	0.11		
20.11.2023			0.00	0.00
Total	**100**	**100**	**100**	**100**

Tab. 7: The relative activity of the adult A. mali in the untreated part of the experimental field in 2024. Due to the alternated conduction, exposing the sticky bands alternating between double rows (49/55) and (52/57) the flight data are not in line.

Treatment	UT			
Parameter	% mean A. mali/d			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
19.03.2024	0.00	0.00	0.00	0.00
05.04.2024			0.06	0.08
15.04.2024	0.40	0.36		
26.04.2024			0.00	0.00
30.04.2024	0.02	0.06		
07.05.2024	0.05	0.14	0.40	0.19
14.05.2024	0.57	1.48	0.95	0.63
22.05.2024	0.04	0.03	0.18	0.37
03.06.2024			0.45	0.40
13.06.2024	1.03	1.19		
24.06.2024			5.73	5.74
02.07.2024	32.24	33.16		
08.07.2024			71.10	65.38
22.07.2024	64.00	60.87		
06.08.2024			20.86	26.66
02.09.2024	1.29	1.91		
23.09.2024			0.25	0.48
11.10.2024	0.31	0.67		
28.10.2024			0.01	0.08
11.11.2024	0.05	0.12		
Total	**100**	**100**	**100**	**100**

Tab. 8: Relative % values for the respective rows and plots recorded by non-destructive surveys on trees in the plots during "spring season" showing the relative WAA presence, in terms of percentage, on internodes on shoots at several days, including some of the surveys in late summer 2023. The total internode % presence is set to 100% for the spring season period 2023.

Treatment	UT			
Parameter	% Internode WAA			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
24.04.2023	0.00	0.00	0.00	0.00
02.05.2023	8.25	5.93	4.75	6.35
09.05.2023	16.15	8.07	0.00	10.29
23.05.2023	13.09	14.53	73.87	38.43
31.05.2023	20.32	10.50	21.38	17.76
06.06.2023	13.06	14.48	0.00	14.91
21.06.2023	9.44	25.13	0.00	0.00
05.07.2023	11.43	3.59	0.00	12.26
27.07.2023	8.26	8.88	0.00	0.00
04.09.2023	0.00	8.88	0.00	0.00
Total % spring	**100**	**100**	**100**	**100**

Tab. 9: Relative % values for the respective rows and plots recorded by non-destructive surveys on trees in the plots during "spring season" showing the relative WAA presence, in terms of percentage, on internodes on shoots at several days, including some of the surveys in late summer. The total internode % presence is set to 100% for the spring season period 2024.

Treatment	UT			
Parameter	% Internode WAA			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
05.04.2024	0.00	0.00	0.00	0.00
17.04.2024	3.93	0.23	0.00	0.40
26.04.2024	8.36	1.26	0.00	0.81
30.04.2024	8.64	7.03	0.00	0.65
06.05.2024	7.83	2.28	0.89	0.85
10.05.2024	10.73	4.02	2.81	3.08
22.05.2024	11.47	7.67	3.82	5.72
29.05.2024	8.94	8.90	14.85	17.25
07.06.2024	12.32	21.82	14.66	14.05
24.06.2024	13.78	25.06	36.24	30.69
09.07.2024	14.00	19.93	16.21	17.86
01.08.2024	0.00	1.80	10.51	8.64
05.08.2024	0.00	0.00	0.00	0.00
Total % spring	**100**	**100**	**100**	**100**

Tab. 10: The relative % values for the respective rows and plots recorded by non destructive surveys on trees in the plots during "spring season" show the relative WAA presence, in percentage terms, on internodes on shoots at several days, including some of the surveys in late summer. The total internode % presence is set to 100% for the spring season period 2023.

Treatment	23 TM			
Parameter	% Internode WAA			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
24.04.2023	0.00	0.00	0.00	0.00
02.05.2023	16.47	4.18	0.00	0.00
09.05.2023	58.52	8.42	68.65	31.31
23.05.2023	3.05	11.18	5.77	21.47
31.05.2023	0.00	0.00	0.00	0.00
06.06.2023	0.00	0.00	4.14	0.00
21.06.2023	16.47	30.06	13.10	34.69
05.07.2023	5.49	46.17	8.35	12.53
27.07.2023	0.00	0.00	0.00	0.00
04.09.2023	0.00	0.00	0.00	0.00
Total % spring	**100**	**100**	**100**	**100**

Tab. 11: Relevant % values for the respective rows and plots recorded by non-destructive surveys on trees in the plots during “spring season” show the relative WAA presence, in terms of percentage, on internodes on shoots at several days, including some of the surveys in late summer. The total of internode % presence is set to 100% for the spring season period 2024.

Treatment	23 TM 24 UT			
Parameter	% Internode WAA			
Row	52	52	54	54
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
05.04.2024	0.00	0.00	0.00	0.00
17.04.2024	0.00	0.00	0.00	0.00
26.04.2024	0.44	0.00	0.00	0.51
30.04.2024	2.43	0.40	1.23	0.00
06.05.2024	1.61	6.04	0.57	0.00
10.05.2024	1.21	2.95	0.53	0.00
22.05.2024	7.11	3.24	6.51	2.42
29.05.2024	14.42	16.76	12.48	8.67
07.06.2024	18.37	9.29	15.95	12.97
24.06.2024	29.02	25.31	43.06	40.44
09.07.2024	19.27	30.08	18.87	22.28
01.08.2024	6.12	5.93	0.80	12.72
05.08.2024	0.00	0.00	0.00	0.00
Total % spring	**100**	**100**	**100**	**100**

Tab. 12: The values for both years and the respective rows and plots show the mean for the spring season internode colonization by WAA. The data refer to the untreated part of the observational trees grouped in rows and plots.

Treatment	Year	Parameter	Row	Row/row	Plot	mean spring	max spring
UT 23 and 24	2023	% Internode WAA	49.00	49/52	1	26.91	49.21
UT 23 and 24	2023	% Internode WAA	49.00	49/52	3	15.20	37.74
UT 23 and 24	2023	% Internode WAA	57.00	54/57	1	1.56	10.36
UT 23 and 24	2023	% Internode WAA	57.00	54/57	3	2.52	8.71
UT 23 and 24	2024	% Internode WAA	49.00	49/52	1	57.27	96.22
UT 23 and 24	2024	% Internode WAA	49.00	49/52	3	30.81	92.67
UT 23 and 24	2024	% Internode WAA	57.00	54/57	1	10.04	43.67
UT 23 and 24	2024	% Internode WAA	57.00	54/57	3	17.20	63.33

Tab. 13: The values for both years and the respective rows and plots show the mean for the spring season internode colonization by WAA. The data refers to the treated part (2023 only) of the observational trees grouped in rows and plots.

Treatment	Year	Parameter	Row	Row/row	Plot	mean spring	max spring
23 TM 24 UT	2023	% Internode WAA	52.00	49/52	1	1.35	7.11
23 TM 24 UT	2023	% Internode WAA	52.00	49/52	3	2.96	12.29
23 TM 24 UT	2023	% Internode WAA	54.00	54/57	1	1.79	11.06
23 TM 24 UT	2023	% Internode WAA	54.00	54/57	3	0.49	1.54
23 TM 24 UT	2024	% Internode WAA	52.00	49/52	1	10.43	36.33
23 TM 24 UT	2024	% Internode WAA	52.00	49/52	3	14.05	50.70
23 TM 24 UT	2024	% Internode WAA	54.00	54/57	1	6.97	36.00
23 TM 24 UT	2024	% Internode WAA	54.00	54/57	3	10.92	53.00

Tab. 14: The percentage of presence of the “darkened” older instars; the percentage expresses the relative activity of this particular morph during the different exposition periods on the observational trees in 2023 in the untreated part.

Treatment	UT			
Parameter	single %N4P			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
29.03.2023	0.00	0.00	0.00	0.00
04.04.2023	0.00	7.32		
17.04.2023			20.00	16.67
24.04.2023	13.64	14.63		
03.05.2023			20.00	16.67
05.05.2023	9.09	14.63		
12.05.2023			20.00	33.33
23.05.2023	27.27	14.63		
30.05.2023			40.00	33.33
05.06.2023	13.64	14.63		
14.06.2023			0.00	0.00
21.06.2023	9.09	4.88		
28.06.2023			0.00	0.00
14.07.2023	4.55	9.76		
03.08.2023			0.00	0.00
28.08.2023	4.55	4.88		
18.09.2023			0.00	0.00
06.10.2023	4.55	4.88		
23.10.2023			0.00	0.00
07.11.2023	13.64	9.76		
20.11.2023			0.00	0.00
Total % spring	**100**	**100**	**100**	**100**

Tab. 15: The percentage of presence of the “darkened” older instars; the percentage expresses the relative activity of this particular morph during the different exposition periods on the observational trees in 2024 in the untreated part.

Treatment	UT			
Parameter	single %N4P			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
19.03.2024	0.00	0.00	0.00	0.00
05.04.2024			0.00	0.00
15.04.2024	0.00	0.00		
26.04.2024			0.00	0.00
30.04.2024	0.00	0.00		
07.05.2024	8.33	0.00	0.00	0.00
14.05.2024	0.00	0.00	0.00	0.00
22.05.2024	8.33	9.09	0.00	0.00
03.06.2024			25.00	33.33
13.06.2024	16.67	18.18		
24.06.2024			50.00	66.67
02.07.2024	25.00	27.27		
08.07.2024			25.00	0.00
22.07.2024	8.33	9.09		
06.08.2024			0.00	0.00
02.09.2024	8.33	0.00		
23.09.2024			0.00	0.00
11.10.2024	8.33	18.18		
28.10.2024			0.00	0.00
11.11.2024	16.67	18.18		
Total % spring	**100**	**100**	**100**	**100**

Tab. 16: Actual percentage of internodes occupied by WAA on shoots on the untreated observational tree; we randomly selected a number of 10 shoots at every control data.

Treatment	UT			
Parameter	% Internode WAA			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
24.04.2023	0.00	0.00	0.00	0.00
02.05.2023	19.97	8.90	0.67	1.44
09.05.2023	39.11	12.11	0.00	2.33
23.05.2023	31.71	21.82	10.36	8.71
31.05.2023	49.21	15.76	3.00	4.03
06.06.2023	31.64	21.74	0.00	3.38
21.06.2023	22.86	37.74	0.00	0.00
05.07.2023	27.69	5.39	0.00	2.78
27.07.2023	20.00	13.33	0.00	0.00
Total % spring	**100**	**100**	**100**	**100**

Tab. 17: Actual percentage of internodes occupied by WAA on shoots on the untreated observational tree; we randomly selected a number of 10 shoots at every control data.

Treatment	UT			
Parameter	% Internode WAA			
Row	49	49	57	57
Row/row	49/52	49/52	54/57	54/57
Plot	1	3	1	3
05.04.2024	0.00	0.00	0.00	0.00
17.04.2024	27.02	0.83	0.00	0.83
26.04.2024	57.44	4.65	0.00	1.67
30.04.2024	59.38	26.01	0.00	1.35
06.05.2024	53.80	8.42	1.07	1.75
10.05.2024	73.76	14.85	3.39	6.35
22.05.2024	78.86	28.36	4.60	11.81
29.05.2024	61.41	32.91	17.89	35.61
07.06.2024	84.67	80.67	17.67	29.00
24.06.2024	94.67	92.67	43.67	63.33
09.07.2024	96.22	73.69	19.54	36.85
01.08.2024	0.00	6.67	12.67	17.83
Total % spring	**100**	**100**	**100**	**100**