Distribution, host plants, and seasonal occurrence of the maize orange leafhopper, *Cicadulina bipunctata* (Melichar) (Homoptera: Cicadellidae), in Japan

Keiichiro Matsukura,1,* Masaya Matsumura,1 Hiroaki Takeuchi,1 Nobuyuki Endo1 and Makoto Tokuda2

1 Research Team for Insect and Nematode Management, National Agricultural Research Center for Kyushu Okinawa Region; Koshi, Kumamoto 861–1192, Japan
2 Growth Regulation Research Group, RIKEN Plant Science Center; Yokohama 230–0045, Japan

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Abstract

The maize orange leafhopper, *Cicadulina bipunctata*, is a serious pest of second crops of forage maize in Kyushu, Japan, because it induces maize wallaby ear symptom (MWES), characterized by stunted growth and severe swelling of leaves. We investigated the seasonal occurrence, host plants, and distribution of *C. bipunctata* in Kyushu from 2004 to 2007. Population densities of *C. bipunctata* rapidly increased from late July, and generally peaked between September and October. *Cicadulina bipunctata* fed mainly on *Eleusine indica*, *Digitaria ciliaris*, and *Setaria viridis* from summer to autumn, and overwintered as adults mostly on *Sasa* spp., followed by wheat and Italian ryegrass. In early spring, the first generation seemed to grow largely on wheat. These results suggest that earlier planting of the second crop of forage maize and management of *Sasa* spp. in early winter are likely to be effective strategies for reducing the infestation of forage maize by *C. bipunctata*. Field surveys in 2005 and 2007 revealed that *C. bipunctata* was distributed at 34 of 54 sites, including Fukuoka, Saga, Kumamoto, Miyazaki, and Kagoshima prefectures. Because such a wide distribution has not been reported in previous studies, *C. bipunctata* is considered to have expanded its range in recent years.

Key words: *Cicadulina bipunctata*; maize wallaby ear symptom; forage maize; poaceous plants; distribution

INTRODUCTION

The maize orange leafhopper *Cicadulina bipunctata* (Melichar) (Homoptera: Cicadellidae) is a sucking insect that feeds on various crops and weeds of the Poaceae (Maramorosch et al., 1961; Catindig et al., 1996; Li et al., 2004). This species is a serious pest of maize, because it induces galls characterized by the stunted growth of leaves and severe swelling of leaf veins on maize, as well as on other poaceous plants. The gall symptom was previously suspected to be caused by a viral disease referred to as maize wallaby ear disease (Maramorosch et al., 1961; Grylls, 1975); however, the galls are now regarded as insect galls produced in response to the injection of chemicals by *C. bipunctata* during feeding (e.g. Ofori and Francki, 1983). The condition is therefore now called “maize wallaby ear symptom” (MWES) (Matsumura and Tokuda, 2004).

The genus *Cicadulina* is distributed in tropical and subtropical regions of the Old World (Webb, 1987). Among species belonging to this genus, *C. bipunctata* is the most widespread, inhabiting North and East Africa, Asia, and the Pacific (Webb, 1987). The occurrence of MWES on crops was first reported in Australia (Tryon, 1910; Grylls, 1975) and then in the Philippines (Agati and Calica, 1949; Maramorosch et al., 1961).

In Japan, *C. bipunctata* was first recorded in Kumamoto Prefecture (Matsumura, 1914), but damage by MWES to crops was not recognized until 1986, when it was found on sweet corn in Okinawa Prefecture (Kawano, 1994; Hayashi, 2002). Fur-
thermore, MWES was reported on young seedlings of second crops of forage maize from 1987 onward in Kumamoto, Miyazaki, and Nagasaki prefectures in Kyushu, Japan (Ohata, 1993). The damage has gradually become more serious since 2000, and it currently occurs over a wide area of central Kyushu (Matsumura et al., 2005).

To establish effective control methods to accompany the use of cultivars resistant to MWES (Ohata, 1993), information on the ecology of *C. bipunctata* in the field—especially seasonal changes in population density and host-use pattern—is needed. Even though *C. bipunctata* also feeds on various poaceous plants other than maize, marked damage occurs only on young seedlings of the second maize crop in summer. This suggests that *C. bipunctata* migrates from other Poaceae into the second crop of maize. We therefore investigated the seasonal occurrence and host plants of *C. bipunctata* on various poaceous plants growing around maize fields in central Kyushu.

Moreover, we investigated the current distribution range of *C. bipunctata* in Kyushu, because *C. bipunctata* is suggested to have gradually expanded its distribution in recent years (Matsumura et al., 2006). This investigation should not only help clarify the need for *C. bipunctata* control around maize fields in various localities, but should also help predict the future expansion of distribution and the global warming-related agricultural damage that may be caused by this species.

**MATERIALS AND METHODS**

**Census fields.** The seasonal occurrence and host plants of *C. bipunctata* were investigated at two sites in Kumamoto prefecture: Kyokushi, in the city of Kikuchi (32.57°N, 130.50°E), and Kuro-matsu, in the city of Koshi (32.55°N, 130.44°E). These are dry fields where most farmers practice double-cropping of forage maize (first crop: April to mid-July; second crop: late July to November). Some farmers cultivate wheat (*Triticum aestivum*) or Italian ryegrass (*Lolium multiflorum*) between autumn and spring, instead of a second maize crop. At both census sites, several species of poaceous weeds were growing in fallow fields and on the surrounding levees during summer, with cypress groves in which bamboo grasses, *Sasa* spp., grew throughout the year.

The distribution of *C. bipunctata* was investigated in grassy fields, comprising mainly southern crabgrass (*Digitaria ciliaris*) and goosegrass (*Eleusine indica*), in 51 localities in Kagoshima, Miyazaki, Kumamoto, Saga, and Fukuoka prefectures in 2005, and additionally in three localities on Amakusa Island, Kumamoto, in 2007.

**Seasonal occurrence.** Seasonal occurrence was investigated for 4 years (2004 to 2007) in Kyokushin, and for 3 years (2005 to 2007) in Kuro-matsu. Insects inhabiting grassy fields adjacent to forage maize fields were collected with a 36-cm-diameter sweep net in 2004 and 2005, and with a suction machine with an 11.5-cm-diameter inlet (Pro Force, Tanaka, Japan) from 2005 to 2007. In this survey, one sample consisted of 10 sweeps or 10 one-second suctions from the top through to the bottom of grasses. Collected insects were dried at 50°C for 1 day and the numbers of adults and nymphs counted under a binocular microscope.

Samples were collected almost monthly throughout the year in 2004 and every 2 weeks (mainly from June to November) between 2005 and 2007. The number of samples varied among collection dates, from 4 to 20, with an average of 8.0.

To compare population density and seasonal occurrence among census years, data obtained by the sweeping method were adjusted to match those obtained by the suction method. Major axis regression with a fixed intercept of 0 (see Snedecor, 1952; Sokal and Rohlf, 1995) was applied to the 2005 sweeping method data against the suction method data for the same year. The regression was applied separately to data for adults and nymphs. From these regressions, coefficients for the conversion of adult and nymph data from the suction method to the sweeping method were determined. Furthermore, the data were converted into densities per square meter. Because the diameter of the suction machine inlet was 11.5 cm, the density of adults or nymphs per square meter, *D*, was calculated by the following equation:

\[ D = \frac{N}{(\pi \times (0.115/2)^2 \times 10)} \]

where *N* is the number of catches per sample.

**Host plants from summer to autumn.** Host plants of *C. bipunctata* were investigated weekly
from July 25 to November 25, 2006 in a fallow field and its neighboring levee in Kyokushi. Adults and nymphs inhabiting southern crabgrass, goosegrass, foxtail grass (*Setaria viridis*), barnyardgrass (*Echinochloa crus-galli*), and Johnson grass (*Sorghum halepense*) were collected by the suction method. Five samples were collected in each weed species, and the numbers of adults and nymphs were counted after a 1-day drying period at 50°C. The density per square meter was calculated for each plant species by the method mentioned above.

**Host plants during overwintering period.** Host plants of *C. bipunctata* during the overwintering period (December to May) were investigated in Kyokushi from 2006 to 2008, and in Kuromatsu from 2005 to 2008. *Cicadulina bipunctata* was collected by the suction method every 1 or 2 months from December to May. Five or 10 samples were collected from cultivated wheat and Italian ryegrass, as well as from bamboo grasses growing near the fields. The numbers of adults and nymphs were counted after a 1-day drying period at 50°C. Density per square meter was calculated for each plant species by the method mentioned above.

**Geographical distribution.** The distribution of *C. bipunctata* in Kyushu was investigated by sweeping with a 36-cm-diameter net in autumn, when adult density was highest for the year (Fig. 2). The investigation was conducted on September 28 and October 14, 2005 in 13 northern localities (Saga and Fukuoka prefectures); from October 9 to 11, 2005 in 10 southern localities (Kagoshima and Miyazaki prefectures); on September 29 and October 27, 2005 in 28 central localities (Kumamoto prefecture); and on October 14, 2007 in three localities on Amakusa Island. In this survey, one sample consisted of 5 sweeps, and 4 or 5 samples were taken in each locality. The number of adults was counted after a 1-day drying period at 50°C.

**RESULTS**

**Seasonal occurrence**

There was a high positive correlation between the number of catches by the sweeping method and that by the suction method (Fig. 1). Because catch trends in the two census fields were similar, we pooled these data in the regression analysis. The slope of the regression line was 1.46 ($r=0.947$) and 3.14 ($r=0.972$) for adults and nymphs, respectively. The data collected by the sweeping method (in 2004 and 2005) were adjusted to those by the suction method using these conversion coefficients.

The abundance of *C. bipunctata* varied greatly among census years. The maximum adult density was highest in 2005 (687.5 and 1,161.1 adults/m² in Kyokushi and Kuromatsu, respectively) and lowest in 2006 (123.3 and 79.0 adults/m², respectively) (Fig. 2). The maximum nymphal density was highest in 2005 (537.4 and 3,643 nymphs/m², respectively), and lowest in 2007 in Kyokushi (150.3 nymphs/m²) and in 2006 in Kuromatsu (186.9 nymphs/m²) (Fig. 3).

Adults of *C. bipunctata* exhibited similar patterns of seasonal occurrence among census years, except in 2006, when the population density was very low (Fig. 2). Although there were very few adults from January to mid-July, numbers began to increase from late July or early August and peaked from September to October, except in 2006. Nymphal density increased rapidly in August or September (Fig. 3), although its peak varied among census years, especially in Kyokushi (Fig. 3a).

**Host plants from summer to autumn**

The densities of *C. bipunctata* differed among the 5 species of poaceous weeds, particularly after late September (Fig. 4). The density of *C. bipunctata* was highest on goose grass (maximum 331.1 adults/m² and 631.0 nymphs/m²), followed by
southern crabgrass and foxtail grass. The density on barnyardgrass was relatively low (maximum 42.7 adults/m² and 52.5 nymphs/m²), and that on Johnson grass (maximum 28.0 adults/m² and no nymphs) was the lowest.

Host plants during overwintering period

Densities of adults during the overwintering period varied among poaceous plants (Fig. 5). In December, more than 100 adults/m² were present on bamboo grasses every census year. Adult densities were smaller on wheat and Italian ryegrass than on bamboo grasses, although those on Italian ryegrass were relatively high in winter 2007–2008. Densities on these plants greatly decreased from January to February to fewer than 10 adults/m² after March. No adults were observed on Italian ryegrass in April.

Nymphs of *C. bipunctata* were rarely found during the overwintering period (Fig. 6). Although fewer nymphs (approximately 10 nymphs/m², or fewer) were often observed on bamboo grasses from November to December, no nymphs were found on wheat and Italian ryegrass in these months or on any census plants from January to April. A few nymphs were observed frequently on wheat in late May and in one census period on bamboo grasses (Fig. 6b).

Geographical distribution in Kyushu

*Cicadulina bipunctata* was found in 34 of 54 lo-
Ten or more adults were collected per sample from central Kyushu and part of northern Kyushu (in one locality in Fukuoka prefecture). In contrast, *C. bipunctata* was not collected from other localities in northern Kyushu. In southern Kyushu and Amakusa Island, *C. bipunctata* was found in several localities, but the density was relatively low (less than 10 adults per sample).

**DISCUSSION**

Our field surveys revealed the annual life cycle of *C. bipunctata* in Kyushu, Japan. The population density of *C. bipunctata* remains low from spring to early summer, increases rapidly from late July, and peaks between September and October (Figs. 2 and 3). As *C. bipunctata* is distributed largely in

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**Fig. 5.** Densities of *C. bipunctata* adults on three poaceae plants growing in or around maize-cropping fields during overwintering of *C. bipunctata* in Kumamoto prefecture. Bamboo grasses were growing in a cypress grove neighboring the field throughout the year. Wheat and Italian ryegrass were usually cultivated in these census areas from autumn to early spring; however, in Kuromatsu, there were no investigable wheat fields in 2005–2006 and 2006–2007, and no Italian ryegrass fields in 2007–2008. Densities were calculated from an equation using the number collected by the suction method (see Materials and Methods). Vertical bars indicate SEM.

**Fig. 6.** Densities of *C. bipunctata* nymphs on three poaceae plants growing in or around a maize-cropping field during the overwintering period of *C. bipunctata* in Kumamoto prefecture. See legend to Fig. 5 for details.

**Fig. 7.** Distribution of *C. bipunctata* in Kyushu. Investigations were conducted in three localities on Amakusa Island in 2007 (in dashed circle), and at 50 other localities in Kyushu in 2005. The number of catches per sample was calculated as the mean of 4 or 5 samples. One sample consisted of 5 sweeps.
tropical and subtropical regions rather than temperate regions (Webb, 1987), the temperature from winter to spring in Kyushu may be too severe for the survival and propagation of this species. Southern crabgrass, goosegrass, and foxtail grass are the main host plants from summer to autumn (Fig. 4). In December, when these poaceous weeds have died, adults and some nymphs seem to migrate to other hosts, such as wheat, Italian ryegrass, and bamboo grasses, for overwintering (Fig. 5). The adult density was much higher on bamboo grasses than on the other two hosts (Fig. 5), and these grasses are therefore probably more suitable hosts for *C. bipunctata* in winter. Nymphal density of *C. bipunctata* was much lower than the adult density throughout the overwintering period, and no nymphs were observed from January to April in all census years (Fig. 6), so it was considered that *C. bipunctata* overwinter as adults in Kyushu. After the overwintering period, newly emerged nymphs were frequently observed on wheat and sometimes on bamboo grasses, but not on Italian ryegrass (Fig. 6). This suggests that most overwintered females migrate from their overwintering sites to wheat fields, and lay their eggs on wheat.

According to Li and Liu (2004), *C. bipunctata* spend the winter on wheat in Sichuan Province, China, and migrate in early April to the first maize crop, which is not seriously damaged. The first generation of *C. bipunctata*, appearing from May to June, induces serious MWES on the second maize crop (Li and Liu, 2004). This infestation pattern by *C. bipunctata* in Sichuan is similar to that in Kyushu (Ohata, 1993; Matsumura et al., 2005). In Sichuan, a second generation appears from early July and feeds mainly on poaceous weeds.

The observed seasonal occurrence of *C. bipunctata* is consistent with empirical phenomena already known. Firstly, MWES occurrence was lowest in 2006 among the last 5 years (2004–2008) (Ohata, personal communication). This coincides with the low occurrence of *C. bipunctata* in 2006 (Figs. 2 and 3), which was probably due to the harsh winter and low July temperatures in that year (Ohata, personal communication; Matsukura et al., unpublished data). Secondly, in Kyushu, MWES occurs not on first cropping maize but also on second cropping maize, which is seeded from late July to mid-August. The seasonal occurrence of *C. bipunctata* (Figs. 2 and 3) synchronizes with this

effect.

These findings on *C. bipunctata* and MWES occurrence will contribute to improve culture control of MWES. As mentioned above, the synchrony of the cropping season and *C. bipunctata* results in MWES in second cropping maize. Furthermore, few MWES symptoms appear in older maize, even if *C. bipunctata* feeds on it (Matsukura et al., unpublished). Thus, earlier planting of the second maize crop could suppress damage, since it would allow maize plants to mature enough to avoid the severe MWES damage that comes with the increase in *C. bipunctata* populations.

In addition, weed control during overwintering of *C. bipunctata* may be effective to reduce MWES damage the following summer. In central Kyushu, severe MWES damage occurs only in areas where bamboo grasses are closely distributed (K. Matsukura et al., personal observation) and bamboo grasses are used as the main hosts of overwintering *C. bipunctata* (Fig. 5). This suggests that the presence of bamboo grasses near maize fields is a key trigger of local outbreaks of *C. bipunctata* in central Kyushu; therefore, control of bamboo grasses between November and December would be effective to reduce MWES damage the following summer. In contrast, weed control during summer (i.e., control of weeds, such as goosegrass, southern crabgrass, and foxtail grass) may not be effective, because *C. bipunctata* can feed not only on these weeds but also on cultivated maize from late spring to early summer. In addition, exhaustive control of these weeds is difficult because of their scattered distribution. The relative abundance of *C. bipunctata* on the first maize crop and on these weeds from late spring to early summer should be clarified in the future.

In Kyushu, *C. bipunctata* was previously recorded only in several localities in Kumamoto, Nagasaki, and Miyazaki prefectures (Matsumura, 1914; Ohata, 1993); however, in this study we revealed the wide-ranging distribution of *C. bipunctata* across 5 prefectures in central and southern Kyushu (Fig. 7). The recent outbreaks and distribution range expansion of *C. bipunctata* may be related to the warm climate in recent years, which may be associated with global warming, as suggested by Matsumura et al. (2005). Tokuda and Matsumura (2005) have revealed that *C. bipunctata* does not exhibit growth retardation even at high
temperatures, such as 30 and 34°C. This suggests that further global warming would enhance the occurrence of MWES in line with the population increase and distribution range expansion of C. bipunctata. To control C. bipunctata populations and to reduce the damage caused by MWES, it is important to clarify the environmental factors affecting the distribution of C. bipunctata.

In addition, the cold hardiness of C. bipunctata should be examined in the near future because, as well as diapause during winter, it is a well-known key trait for the survival of insects inhabiting temperate and cold regions (reviewed by Tauber et al., 1986; Lee, 1991). In particular, data on the survival rates of C. bipunctata under various low-temperature conditions will be critical to estimate the overwintering population dynamics of C. bipunctata and this pest’s distribution expansion in the future.

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REFERENCES


Tryon, H. (1910) In *Report of the Department of Agriculture and Stock, Queensland for 1909–10* (Queensland Dept. of Agriculture and Stock, ed.). Department of Brisbane,