Ecological Characteristics and Causes of the Occurrence of the Soybean Aphid, Aphis Glycines.

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The soybean aphid, *Aphis glycines* Matsumura, is distributed in tropical and subtropical regions such as Southeast Asia and parts of Africa as well as temperate zones such as northern China and Japan. The soybean aphid is an important pest of the soybean plant, causing not only direct damage by feeding but also indirect damage from its heavy secretion of honeydew on the plants, which serves as a growing medium for sooty mold fungus. The soybean aphid is also an important vector of viral diseases.

Although the soybean aphid has long been known as a soybean pest, few studies have been carried out on the mechanism involved in its population fluctuations. This review describes host plants, transmitted viruses, natural enemies, ecological properties, and seasonal abundance. We also describe the dynamics for high-density occurrence of the species in relation to crop production.

I   Host plant and damaged plant parts

In China it was confirmed that the soybean aphid has a complete life cycle (Wang et al., 1962). It has also been confirmed that ovipara, fundatrix and winged males were observed on primary host plants in Tochigi and Ibaraki prefectures, Japan (Takahashi, 1993).

Primary host (winter host):   There were some reports that *Rhamnus dahurica* Pall and *R. japonica* Maxim were found as winter hosts in Japan (Takahashi et al., 1993). *R. dahurica* Pall was also found as a winter host in China (Wang et al., 1962).

Secondary host (summer host): *Glycine soja* Sieb. Et Zucc, an ancestor to the soybean, was also known as a secondary host (Sakai, 1950). *Pueraria lobata* Ohwi in Korea and *P. javanica* Benth in the Philippines were reported as secondary hosts (Tanaka, 1976, Takahashi, 1996). The soybean aphid also resides on *Desmodium intortum* (Blackman and Eastop, 1984).

Damaged parts: The soybean aphid resides on different parts of plants at different stages. In the case of soybeans, it first resides on soft and young leaves. When they populate on soybeans, the young leaves and shoots from branches are occasionally dwarfed. After blooming and young pods appear, the aphid resides on whole plants, especially young and

mature leaves, petioles, shoots, and young pods.   When the aphid resides on young pods, it causes significant damage to the quality and yield of soybeans (Sakai, 1950; Kajino, 1979).

II   Transmitted viruses.

Table. 1 shows a list of viruses transmitted by the soybean aphid and infected plants.   The winged aphid searches host plants by inserting its mouthparts into plants randomly, sometimes transmitting viruses to non-host plants and non-preferred plants.   Because of this, there is some probability for soybean aphids transmission of viruses to non-host plants such as mung bean, peanut, cucumber, sugar beet, abaca, and tabacco.

A new strain of soybean dwarf virus (SDV) was discovered to be transmitted by *Acyrthosiphon pisum* (Harris) and soybean aphids at the National Agricultural Research Center for Tohoku region (Mikoshiba et al., 1991).   The SDV has been thought to be transmitted only by *Aulacorthum solani* (Kaltenbach), and the spread of soybean SDV disease was studied in relation to *A. solani* incidence. The differences among SDV transmission by *A. solani*, *A. pisum* and *A. glycines* must be studied.

III   Natural enemies.

There are many kinds of natural enemies for aphids, and most of them are poluphagy insects. It is known that predatory insects for aphids are the lady beetle, green lacewing, *Epistrophe* sp, and *Aphidoletes* sp (for example, Dixon, 1973).   But there are few studies on what kinds of natural enemies effectively suppress population density of soybean aphids. Oku and Kobayashi indicated predation by *Orius* sp is effective to suppress populations of soybean aphid. For hymenopterous parasitoids, Gao (1985) reported from four years of Chinese field studies (1979 – 83) that an average 56%, maximum 76% of aphids were parasitized by *Lysiphlebus japonicus*.

IV   Comparison of ecological properties among aphid species.

In this chapter, I describe ecological properties of the soybean aphid compared to foxglove aphid, *Aulacorthum solani* (Kaltenbach). This insect is known to be a pest of soybean in East Asia, like Japan, Korea and China (Kogan and Turnispeed, 1989).   The average body size of egg-laying wingless females of this insect was 2.1mm (Okada and Nakazuji, 1980), larger than the soybean aphid, which is 1.6mm on average (Takahashi, 1966).

Figure 1 shows the relationship between developmental period and temperature for the soybean aphid and foxglove aphid.   Although at less than 13 °C the developmental period for the foxglove aphid was shorter than for the soybean aphid, at higher temperature that of

the soybean aphid was shorter than the foxglove aphid. For example, average developmental time from first instar wingless females to adults of soybean aphid was 4.5 days at 22 °C and 3.3 days at 27 °C (Hirano et al., 1996). On the other hand, the time for the foxglove aphid was 9.3 days at 20 °C and 7.3 days at 25 °C (Kajino, 1971).

The gross fecundities of both insects at 22 °C and 23 °C were not significantly different (table 2). The intrinsic rate of increase (r_m) of soybean aphid was twice as high as the other (table 2). As a result, the developmental period (from first instar wingless female to adult), pre-reproductive period, and reproductive period of soybean aphid were shorter than that of foxglove aphid. It was thought that higher r_m of soybean aphid than that of foxglove aphid was due to developmental day and other factors being significantly shorter.

V   Seasonal prevalence of occurrence.

Although there is as yet no detailed report investigating seasonal prevalence of soybean aphids, their occurrence in soybean fields in Japan is described below. The occurrence and growth of winged aphids was observed in May to June in fields where soybean had been planted in spring. The number of insects reached a peak in August (Sakai, 1950; Oku and Kobayashi, 1966; Kajino, 1979; Inoue, 1981; Takahashi, et al, 1993).

The winged aphid appeared in soybean fields in mid-May and late June in Utsunomiya and Kyoto. Moreover, sexual generation was observed in mid-October (Sakai, 1950; Takahashi, et al, 1993). The effective cumulative temperature for completion of the nymphal stage of soybean aphid was calculated. The limiting temperature of development was 9.5 C (fig. 1). From first instar larvae to first reproduction at 22 C took 5.2 days, and at 27 C took 3.9 days (Hirano et al., 1996). Based on the regression line for these conditions, the effective cumulative temperature was extrapolated to be 67.1 degree-days. Based on the temperature limits that affect development, it can be estimated that if winged aphids appear in soybean fields and egg-laying wingless females continue reproducing, there will be 26 generations per year in Utsunomiya and 25 generations in Kyoto.

VI   Factors for high-density occurrence.

As Dixon (1985a) indicated, most studies about population dynamics of aphids were done for small numbers of host plants in a small test field. Moreover, detailed studies were done for small sections of the population. In the case of soybean aphid, mechanism of population dynamics has not studied in a wide area considering the relationship of transmitted viruses and forecasting of occurrence dynamics.

It is known that changing weather often significantly affects the population of aphids (For example, Shiga, 1970; Dixon, 1985). Moreover, the natural enemies often influenced variations in the aphid population (Shiga, 1970). Seasonal and spatial distributions of host

plants also significantly effect the population. I describe the relationship between seasonal and spatial distributions of host and aphid populations below.

4,000 kinds of aphid species are reported worldwide, and most are found in temperate zones. The number of aphid species tends to be less in tropical regions where the number of species of plants is large. On the other hand, the number of insect species is larger than that in the temperate zones (Dixon et al., 1987). Dixon and others (1987) created a new model to solve this problem and proposed a theory based on the model. In tropical regions where many kinds of plants exist, the shared area ratio by each plant species (covered area), decreases. As the area covered by host plants decreases, the frequency of success of herbivores migration among host plants would be decreasing. Therefore, if the ecological properties for the insect are narrowly host-specific, and with low frequency of migration success, the numbers of species of insects with these properties decrease in regions where the number of species of plants is large.

The aphid has three ecological properties. 1: narrow host specificity (Eastop, 1973). 2: low ability of finding hosts, showed experimentally by Kennedy et al. (1959 a, b; 1961). 3: host-searching period is short because the insect cannot survive for a long period without host plants (Dixon, 1985 a, b). Because of features 2 and 3 i.e. low host finding capacity and the maximum host plant covered area, the probability of extinction of the aphids is high. Moreover, adding condition 1, the number of species of aphid is very small in tropical region where many plant species exist.

The conclusion of Dixon (Dixon, et al., 1987) was that presence of food resources significantly affects the persistence of an insect population. Hirano and others arrived at the same conclusions from field research data on soybean pest, herbivores, and lady beetles (Hirano and Fujii, 1993; Hirano et al., 1995). Furthermore, it was inferred that successful insect migration was a function of a change in the habitat area of host plants or the insects. (Hirano and Fujii, 1993; Hirano et al., 1995). The aphid has a short generation span and low frequency of successful migration, so it seemed that length of growth period of the host and seasonal change of host covered area strongly affect aphid population dynamics.

Talekar and Chen (Talekar and Chan, 1983) investigated the number of soybean aphids every two weeks in a soybean test field for six years (1975 – 80) in Taiwan. In general, the occurrence of soybean aphids was high from November to February and was maximum in December. However, this was not observed from May to September. The authors discussed the reason, because aphid occurrence was high when temperatures were low, and suitable temperatures for growth occurred in the cool season (November to February). But in 1978, the same aphid occurrence was seen in July to September, when the temperatures were the highest in the year. In Java Island in Indonesia, where the same temperatures occur as during summer in Taiwan, the seasonal change in ratio of damaged area (damaged area /

total area of soybean field) by soybean aphid was positively correlated with changes in total area. On the other hand, it was suggested that weather changes affected the damaged area relatively less.   The reasons for the damaged area increasing with   increasing total soybean field area were believed to be as follows.   First, the increase of soybean fields for investigation; second, the frequency of success of migration was increasing; third, the increasing rate of individual insects reproduced, then the increased average population density of at area might cause an expansion in areas of damage (Hirano and Fujii, 1993).   In Taiwan, the soybean is cultivated in the fall (after October), after secondary rice harvesting. Generally, the time of high occurrence of soybean aphids in test fields was consistent with the time when cultivated areas of soybeans near the test fields was large.

How should we interpret the seasonal prevalence of occurrence for soybean aphid at the test field of Talekar and Chen in relationship to seasonal changing soybean field areas in the region?   The changes in population density of soybean aphid in test fields would be effected by mortality factors, for example, weather conditions or natural enemies that affect migration of insects from other fields.   When the soybean fields are large, average density of the soybean aphid population would be high.   So if the population in the test fields dramatically decreased by factors that affect population, it is most likely that the population would be recovered by migration of aphids from outside of the test fields.   When the fields are small, the average density would also be small, and distances between the test fields and the surrounding fields should be far.   In this case, if the population would dramatically decrease by these factors, the probability of population recovery in the test fields would be small.   For these reasons, when the area of soybean field was large (Nov. to Feb.), it was thought that the population density in the test field had been at the same level as in the same season of different years.   On the other hand, when the soybean fields outside of the test fields were small in a year (May to Sep.), the population density was high when the effect of mortality factor was less, and the density was low when the factor was large.   In the case of Taiwan, Talekar and Chen described (Talekar and Chen, 1983) seasonal changes in field areas, (like expanding areas in in the fall) having a seemingly significantly affect on seasonal population dynamics.

Focusing on seasonal and spatial changes in host plants, if the area in Japan meets the following four conditions to increase successful migration of soybean aphids, then the ratio of soybean fields with high density occurrence (the area of soybean fields observed high density occurrence / total area of soybean fields) would increase.   These four conditions are : 1. Presence of winter hosts. 2. Widespread cultivation of soybean. 3. Suitably long term of growth for a host in the region, due to no adjustment in seeding time. 4. Continuous cropping of summer and winter soybean.   In particular, if reproduced soybean aphids from summer soybeans migrate to fall soybeans and reproduce, then high density occurrence is likely to

happen.

Conclusions

Soybean aphids as vectors of a virus have been relatively well investigated. The life cycle and ecological property of soybean aphids have been gradually defined. However, the mechanism of population dynamics related to forecasting of occurrence and virus disease transmission has been not fully understood.

As I described in Chapter VI, to consider the relation between food supply and chronological and spatial change is important for insect population dynamics research. In order to study the mechanism of soybean aphid population dynamics, the crop system of the subjected area and the influence of chronological and spatial changes of other host plants in summer and winter to insect population dynamics should be investigated, besides the factors of natural enemies and weather. Namely, the following information would contribute enormously to the development of a more elaborate forecast of occurrence model for the insect. 1. Detection of winter and summer host plants as sources of occurrence in the field and levels of migration to the field. 2. Spatial relationships of host plants (for instance, the distance of winter and summer host plants and the distance of soybean fields) 3. The time of year for soybean aphids to proliferate in host plants, and the amount of host plants (for instance, seeding date, harvest date and crop area). If suitable conditions for growth are dependent on the variety of soybean, describe in detail for each variety.

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Table-1 Plants infected by virus, which is carried by soybean aphid

Name of virus	Host plants	Type of transmission	References
Soybean mosaic virus	Soybean	Nonpersistent transmission	Kosinaga and Iizuka (1963), Tuchizaki et. al. (1982)
Soybean stunt virus	Soybean	Nonpersistent transmission	Kosinaga and Iizuka (1963), Roechan et al. (1975), Iwaki (1979), Takahashi et al. (1980) Iwaki, (1979)
Soybean yellow mosaic virus	Soybean	Persistent transmission	Iwaki (1979)
Indonesian soybean dwarf virus	Soybean	Persistent transmission	Iwaki (1979), Iwaki (1980), Honda et al. (1986)
Bean common mosaic virus	Soybean	Nonpersistent transmission	Nakano, et al. (1983)
Bean yellow mosaic virus	Soybean	Nonpersistent transmission	Roechan Et al. (1978 a), Iwaki (1979), Takahashi et al. (1980)
Mungbean mosaic virus	Mungbean	Nonpersistent transmission	Iwaki (1979)
Peanut mottle virus	Peanut	Nonpersistent transmission	Roechan et al. (1978 b), Iwaki (1979),)
Watermelon mosaic virus	Cucumber	Nonpersistent transmission	Kawagoe and Okada (1984)
Abaca mosaic virus	Abaca	Nonpersistent transmission	Kennedy et al. (1962)
Beat mosaic virus	Sugar beat	Nonpersistent transmission	Fukushi and Sikata (1953), Kennedy et al. (1952)
Tabacco veinbanding mosaic virus	Tabacco	Nonpersistent	Fang et al. (1985), Kubo (1977)

	transmission	

Table-2 Comparison of population parameter of egg-laying wingless females of soybean and potato aphids

	Soybean Aphid[a]		Foxglove aphid[b]
	22°C	27°C	23°C
Pre─reproductive period (day)	0.7	0.6	1.4$\pm$0.2[c]
Reproductive period (day)	9.6$\pm$0.9	6.5$\pm$0.7	18.6$\pm$1.1
Total number of eggs per a female aphid	60.3$\pm$5.2	45.0$\pm$4.8	58.1$\pm$2.9
Intrinsic rate of increase (r_{am})	0.45	0.53	0.21

a): Hirano et al. (1996), b): Okada, Nakasuji (1980), c):Average $\pm$ standard error
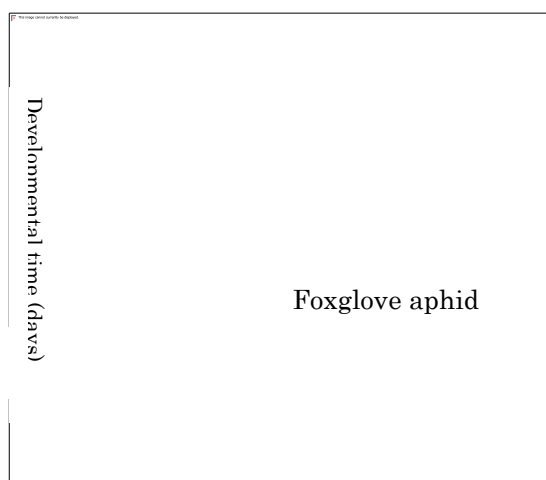

Fig-1 The relation between the developmental time of soybean and foxglove aphid and temperature.   The growth is determined with the days for aphid to grow from first instar larvae to adult.   (The figure is prepared based on the effective accumulate temperature and growth limit temperature)

Data from Hirano, et al. (1996) (effective accumulate temperature: 57.1 degree-days, growth limit temperature 9.5oC) was used for soybean aphid and data from Kahjino (1971) (effective accumulate temperature: 159.1 degree-days, growth limit temperature 3.2oC) was used for foxglove aphid.