# Session 9B

# Neonicotinoid Insecticides

# Present Status and Future Challenges

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| Platform Papers: | 9B-1 to 9B-4 |
| Poster Presentations: | P9B-5 to P9B-6 |

# Nicotinic acetylcholine receptors as target sites for neonicotinoid insecticides

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Nicotinic acetylcholine receptors (nAChRs) are major excitatory neurotransmitter receptors in both vertebrates and invertebrates. In humans, nAChRs mediate the effects of nicotine associated with tobacco smoking and have also been implicated in several neurological and neuromuscular disorders. In insects, nAChRs are expressed abundantly in the nervous system and are the site of action of commercially important insecticides (Millar & Denholm, 2007). Of particular practical and commercial importance are the neonicotinoid insecticides which are used extensively for both crop protection and animal health applications.

Nicotinic receptors are pentameric cell-surface complexes containing five co-assembled subunit proteins. In all species examined to date, a large number of nAChR subunits have been identified that can co-assemble in various combinations to generate a diverse population of distinct nAChR subtypes. In the fruit fly (*Drosophila melanogaster*), an extensively studied model insect species, ten nAChR subunits (Dα1-Dα7 and Dβ1-Dβ3) have been identified by molecular cloning. A similar number of nAChR subunits have been identified in other insect species which have been examined. Studies of both native and recombinant insect nAChRs are now beginning to identify which subunits co-assemble with one another and to establish the influence of subunit composition upon pharmacological properties. Such information is however, still far from complete. In part, this is a consequence of difficulties encountered in the expression of recombinant nAChRs from insect species in heterologous expression systems (Millar, 1999). Strategies which have been employed successfully to circumvent some of these difficulties include the expression of hybrid receptors containing both insect and vertebrate nAChR subunits (Lansdell *et al.*, 1997), expression of artificial subunit chimeras (Lansdell & Millar, 2004) and the use of native (insect) cell expression systems (Lansdell *et al.*, 1997). An important goal of such work is to determine the influence of nAChR subunit composition upon the physiological and functional properties of insect nAChRs.

Heterologous expression studies with cloned nAChR subunits have provided evidence that Dα1-Dα3 (and the homologous subunits from other insect species) are targets for neonicotinoid insecticides (Lansdell *et al.*, 2000), whereas other recent studies have implicated the Dα6 subunit as a component of the receptor for the widely used insecticide spinosad (Perry *et al.*, 2007).

Since the introduction of the first neonicotinoid insecticide imidacloprid in 1991, resistance has been slow to develop, but is now established in some insect field populations and is a major worldwide threat to the effective control of insect pests. Although it appears that resistance may primarily be due to metabolic changes (Millar & Denholm, 2007), recent work has identified a resistance-associated target-site mutation (Y151S) within two nAChR subunits from the brown planthopper (*Nilaparvata lugens*), a major rice pest in many parts of Asia (Liu *et al.*, 2005). Radioligand binding studies with recombinant nAChRs have provided direct evidence that the Y151S mutation is responsible for the loss of specific [$^3$H]imidacloprid binding (Liu *et al.*, 2005).

To examine the influence of the Y151S mutation upon the functional properties of nAChRs, further studies were performed with recombinant nAChRs expressed in *Xenopus* oocytes, using two-electrode voltage clamp recording (Liu *et al.*, 2006). The agonist potency of several nicotinic agonists has been examined, including all of the neonicotinoid insecticides which are currently licensed for either crop protection or animal health applications. The Y151S mutation was found to have no significant effect on the maximal current observed with the endogenous nAChR agonist acetylcholine. In contrast, a significant reduction in maximal current and a rightward shift in agonist dose-response curves was observed for all neonicotinoid insecticides. Interestingly, differences were observed in the magnitude of these effects with different neonicotinoid compounds examined.

As yet there has been no work to establish the prevalence of the Y151S mutation in field populations of *N. lugens*; however this is being investigated in conjunction with ongoing surveys of neonicotinoid resistance in several countries. An important next step in understanding the practical significance of the mutation is to relate data reported here with the phenotypic expression of resistance in laboratory bioassays and under field treatment regimes.

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## Applied aspects of neonicotinoid uses

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### State of the art

Neonicotinoids are among the most effective insecticides for the control of sucking insects such as aphids, whiteflies, leaf- and planthoppers, thrips, some micro lepidoptera and a number of coleopteran pests. Their broad spectrum of efficacy together with systemic, translaminar, pronounced residual activity and the unique mode of action make the neonicotinoids the most rapidly expanding insecticidal class since the launch of the first product, imidacloprid (Bayer CropScience, 1991). In the ten years that followed six other neonicotinoid insecticides were launched: acetamiprid (Nippon Soda, 1995), nitenpyram (Sumitomo Chemical Takeda Agro Company, 1995), thiamethoxam (Syngenta, 1998), thiacloprid (Bayer CropScience, 2000), clothianidin (SumiTake, Bayer CropScience, 2001), dinotefuran (Mitsui Chemicals, 2002). Their biological profiles and main differences are summarised. The outstanding development of neonicotinoid insecticides for crop protection, consumer / professional products and animal health markets between 1990 and today reflect the unique success of this chemical class. The technical profile and multiple uses of neonicotinoid insecticides are described using imidacloprid, the forerunner and most successful molecule from this chemical class, as an example.

### Application technology

On the basis of their systemic properties manifold application technologies have been developed for neonicotinoids. Methods such as drench, overhead drench, drip, in-furrow, float, soil injection, trunk application and injection and seed treatment will be presented.

New horizons for crop protection have been made available by the development of seed treatment with neonicotinoid insecticides. Seed dressing, film coating, pelleting or multilayer coating permitting for environmentally safe and highest protection of young plants against attacking insects: aphid and vector control in cereals and sugar beet, cut- and wireworms in a range of different crops, corn rootworm in maize, aphids, whiteflies, selected thrips species in cotton and leaf- and planthoppers in rice to mention just a few. Neonicotinoids are usually very safe for all crops mentioned. Compared with former soil insecticides neonicotinoids have a broader spectrum, lower mammalian toxicity, lower operator exposure and allow a better handling ‘on the seed / in the bag’.

### Life cycle management

Bayer CropScience has developed the new formulation technology O-TEQ (oil dispersion, OD) for foliar applications of its neonicotinoid insecticides Confidor (imidacloprid) and Calypso (thiacloprid). With O-TEQ formulations, the systemicity and the rain stability of neonicotinoids, e.g. on pome fruit, reaches a level never before achieved and in consequence supplying a superior bioavailability for systemic active ingredients:

excellent overall biological performance, better knock-down effect, improved residual efficacy and, in some instances, reduced dose rates compared with former SL, SC or SE formulated products.

In addition, a broad range of neonicotinoid combinations with other active ingredients have been developed in the past and will be in the future. These innovative products (e.g. imidacloprid & pyrethroids) cover a broad range of sucking and chewing pests or act complementary (e.g. imidacloprid & spirotetramat) against a given pest species. In optimized formulations, the active ingredients display their full biological potential, furthermore, they are safe and easy to handle for the farmer.

Resistance management of neonicotinoid insecticides is an extremely important and valuable constituent to prolong the life span of this chemical class. It is interesting to note that neonicotinoids have proved to be relatively resilient to the development of resistance, particularly in pest aphid species.

**The stress shield story**

A major proportion of yield losses in crop plants is due to abiotic stress factors such as drought, flooding, heat, cold etc. Continuous evaluation of field trial data indicated that applications of imidacloprid resulted in increased growth and higher yields even in the absence of damaging pest species. To investigate how treated plants respond and adapt to pure abiotic stress conditions, drought stress tests with barley plants were developed.

It was shown that the leaf area of drought-stressed barley plants treated with imidacloprid increased as opposed to the untreated. Subsequent gene analysis in barley revealed a delayed production of drought stress marker genes. Plants from the same tests showed longer lasting energy production-related gene activity (photosynthesis), supplying plants with more energy during drought stress. These and other findings i.e. increased root development in tomato plants and more efficient energy production (photosynthesis) in cotton plants following seed treatment confirmed the field observations. In addition to the abiotic stress mitigation, imidacloprid applications supported plants against biotic stresses. Gene expression analysis revealed a significant overexpression of specific pathogenesis-related proteins associated with the plant's own defense mechanism against pathogens.

The 6-chloronicotinic acid, a major decomposition product of imidacloprid, is suggested as being responsible for the physiological changes in the plant which aid in-plant and stress protection. The interaction of imidacloprid with plants to moderate abiotic and biotic stress points to a second mode of action on top of the well known direct activity against insect pests supporting plants to achieve higher yields and better quality under adverse growing conditions.

**Outlook**

Despite a slightly smaller crop protection market a steady increase in the sales of neonicotinoid insecticides is predicted for the next 10 years. This is attributed to their broad insecticidal activity, the unique mode of action, high selectivity to mammals and versatile application forms for foliar, soil uses and seed treatment. A successful life cycle management with innovative new formulations, combinations with other well fitting products and an active resistance management will make neonicotinoid insecticides a class of their own in future crop protection markets.

# Resistance to neonicotinoids in *Myzus persicae* in the UK: good news, bad news and challenges ahead

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One of the most prominent aphid crop pests in the UK is the peach-potato aphid, *Myzus persicae* (Sulzer). Control measures have focused on the application of synthetic chemical insecticides which has lead to the evolution of several insecticide resistance mechanisms (Foster *et al.*, 2002) whose existence reinforces the importance of having access to alternative chemistry for aphid control. One valuable class of insecticides are the neonicotinoids (Millar & Denholm, 2007) as they circumvent all existing forms of resistance in this species. However, the increasing use of these compounds, including the forerunner imidacloprid, on a growing number of *M. persicae* hosts, is placing these compounds at increasing risk from the evolution of resistance; a process which may capitalise upon current limited, but consistent, variation (~ 10 fold) in response to these compounds. This finding was seen in laboratory-based bioassays on *M. persicae* clones collected from the UK and around the world (Foster *et al.*, 2003) and supports a widespread view that resistance management strategies should currently treat all neonicotinoids as belonging to the same cross-resistance grouping.

The mechanism conferring the limited, broad-based slight reduction in susceptibility in response to neonicotinoids remains unknown. However, it could represent the first signs of the evolution and subsequent selection of significant resistance capable of causing neonicotinoid control failures similar to that existing in cotton whitefly (*Bemisia tabaci*), Colorado potato beetle (*Leptinotarsa decemlineata*) and brown planthopper (*Nilaparvata lugens*) (Nauen & Denholm, 2005). The extent to which imidacloprid and newer neonicotinoids are rapidly being adopted on a widening range of UK crops as seed treatments, foliar sprays, soil drenches and compost additives is leading to accumulating risks of the evolution of neonicotinoid resistance in *M. persicae* and other aphid pests. Furthermore, it is notable that the most recent approvals include potatoes and brassica crops which, due to their predominance as aphid hosts, are likely to exert particularly strong selection for resistance phenotypes.

The good news is that a detailed survey of *M. persicae*, collected as live samples over the last several years from field and glasshouse crops over a wide geographical area of England, has shown neither an overall upward trend (based on date of collection) in the frequency of aphids expressing the known reduced susceptibility to neonicotinoids (low resistance) nor the existence of aphids expressing increased resistance factors higher than those already recorded in the UK. There is therefore still no evidence for imidacloprid resistance greater than ~10-fold. There is also no evidence of any associations between the proportions of these types of *M. persicae* in the samples with crop or latitude or longitude of collection site. These findings imply that neonicotinoids applied either as seed treatments or foliar sprays should currently remain fully effective for controlling aphids. This has been supported by laboratory-based experiments, done under simulated field conditions in field chambers, using standard *M. persicae* clones showing full susceptibility and low resistance to neonicotinoids which have demonstrated excellent efficacy when these compounds are applied at commercial rates aimed at controlling aphids. As a result, neonicotinoids, used in conjunction with alternatives from other chemical classes, continue to be vital components of resistance management strategies for *M. persicae*. The bad news is that the field simulator experiments revealed that *M. persicae* carrying low resistance gain subtle, but significant, fitness advantages in the form of being more likely to feed and reproduce when the concentration of these compounds is reduced over time. These periods may provide 'windows of selection' that could lead to the evolution of more potent resistance to neonicotinoids.

The recent registration of a foliar neonicotinoid application (thiacloprid) for use on potatoes and brassicas has diversified the range of applications available to growers for controlling *M. persicae* carrying the well-characterised, established resistance to organophosphates (OPs), carbamates and pyrethroids. Against this backdrop, the challenge of continuing to manage aphids carrying these forms of resistance, and potential future resistance to neonicotinoids, requires close cooperation between researchers, regulators, agrochemical companies and representatives of the different commodities affected by *M. persicae* and the plant virus diseases it transmits. Such partnerships exist in the form of the Insecticide Resistance Action Group (IRAG-UK) and the Steering Panel for an SA-Link project (LK 0953), both of which are working to anticipate resistance risks and potential management recommendations for the future.

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## Resistance management for the neonicotinoid insecticides: a coordinated agrochemical industry approach

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The neonicotinoid insecticides are a crucially important group of compounds with a key mode of action in the toolbox of insecticides for the control of a broad range of sucking pests and other species of agricultural importance. Their excellent potency and spectrum coupled with a range of other desirable properties led to a rapid adoption for the control of key pests such as the tobacco whitefly (*Bemisia tabaci*) and Colorado potato beetle (*Leptinotarsa decemlineata*). As agonists of the nicotinic acetylcholine receptor (Insecticide Resistance Action Committee mode of action Group 4A), the neonicotinoids brought a new mode of action to the portfolio of chemistries to control many pests that had previously been hard to control, and where resistance to previously used modes of action was common. As the neonicotinoid group has grown from the original compound, imidacloprid, to now include seven commercialised compounds, the use of this chemical group has expanded enormously such that the neonicotinoids represented 16.2% of the total insecticide market in 2005 (Phillips McDougal, 2006). Given this scale of use, it is clear that selection pressures on many pest populations are extremely high. Preventing the evolution of resistance to the neonicotinoids in target pests and maintaining their effectiveness is clearly essential if this valuable mode of action is not to be lost.

To effectively combat the development of resistance, or to solve already developed resistance problems, requires an organised approach in which all the major producers are actively involved, and in which strategies and solutions are agreed and implemented in a concerted, sustainable manner. Only by adopting such a coordinated biologically-relevant approach it is possible to combat the development of resistance to a key insecticide group like the neonicotinoids. Accordingly, with the great majority of the combined share of the neonicotinoid market, Bayer CropScience and Syngenta have together tackled this problem.

Over a period of 3 years, technical specialists from both companies with expertise in resistance management have met and successfully collaborated to understand the nature of problems where over-use or mis-use of neonicotinoids has already led to the development of resistance and to identify potential at-risk pests. Common, global insecticide resistance management (IRM) recommendations were first agreed and these provided a framework for the development of locally applicable IRM strategies. Implementation of these at a local country level then followed. Working contacts between nominated representatives from each company have been established in key countries, and guidelines for local IRM strategies for neonicotinoids have been agreed taking into account the general guidelines of both companies. Where possible, the development of these guidelines has involved local authorities, regulators and influencers as well as local IRAC groups and local companies selling neonicotinoids. These guidelines provide clear advice for the timing and positioning of neonicotinoid applications and advice on the use of alternative modes of action that together form a sustainable IRM strategy for all insecticides.

Given the intensity of use, the neonicotinoids have proved remarkably resilient to the development of resistance. Nevertheless, some problems have occurred and these have resulted from the clear mis-use or over-use of the compounds. The most frequently encountered resistance problems have occurred in the whitefly *B. tabaci*, especially where spray thresholds are extremely low because of the potential of this species to transmit viruses. Whilst this problem first arose in the Almeria region of SE Spain, other areas are now affected. The team's work has focused on developing local IRM strategies to counter this resistance in whiteflies, or the threat of it, in vegetable crops in Mexico, melons and tomatoes in Guatemala, beans in Brazil and covered vegetables in Morocco, Italy and Turkey. More recently the team has focused on countering new concerns of resistance to neonicotinoids in thrips in Japan, and the team is developing counter-measure to recommend to deal with this situation.

The most recent problems have concerned the evolution of resistance to neonicotinoids in the brown planthopper (*Nilaparvata lugens*) in rice in the Indian sub-continent and Asia. Significant resistance has developed in this species in a number of countries including China, India, Thailand, Bangladesh, Vietnam, Indonesia and Malaysia. The companies are cooperating to undertake monitoring to assess the extent of the problem and the degree to which various countries are affected by this problem. Resistance experts are collaborating to understand the nature of this resistance. Accordingly, cross-resistance studies have confirmed resistance to the neonicotinoid group and have established viable alternative chemistries that circumvent the resistance that has developed. Biochemical and molecular studies are being undertaken to understand the resistance mechanism involved in this resistance, and to determine the presence of other mechanisms that would compromise the use of alternative insecticides.

The team works closely with IRAC, and in developing appropriate IRM strategies it takes full account of the best practice of IRM as endorsed and promoted by IRAC. The availability of local IRAC country groups aids greatly in helping to implement effective IRM strategies and wherever possible these groups are involved in developing appropriate locally acceptable solutions. The recent formation of an IRAC SE Asia group provides an additional body of influence with which the team can help to promote sustainable use of the neonicotinoids.

A major factor in more recent resistance issues with the neonicotinoids has been the uncontrolled use of generic imidacloprid from small local producers. In the case of resistance to neonicotinoids in the brown planthopper this has been pivotal in the evolution of this problem. A good number of the larger producers of off-patent insecticides are interested in effective IRM, and it is now essential that a way is found to involve these responsible generic companies in the activities outlined above. Clearly, the many, sometimes hundreds of local producers remain a problem but it is essential that the leading global brand leaders and larger generics show the way: cooperative and effective IRM is essential for the sustainable use of the neonicotinoids.

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# Recent status of insecticide resistance of the rice planthoppers in East and Southeast Asia

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## Introduction

The brown planthopper (BPH), *Nilaparvata lugens* (Stål), and the whitebacked planthopper (WBPH), *Sogatella furcifera* (Horváth) (Homoptera: Delphacidae), are the two serious pests of rice throughout Asia. To control these pests, neonicotinoid and phenylpyrazole insecticides such as imidacloprid (IMI) and fipronil have been used since middle 1990s in East Asian countries. In 2003 the development of insecticide resistance against neonicotinoids in BPH was first observed in Thailand and has quickly spread to other neighbouring countries such as Vietnam, India, and China (Harris, 2006).

From 2005 the BPH and WBPH immigrating into Japan have developed insecticide resistance against imidacloprid and fipronil, respectively (Matsumura *et al.*, unpublished). However, until now the $LD_{50}$-values of BPH and WBPH against both neonicotinoid and phenylpyrazole insecticides have been poorly reported in many Asian countries. Therefore, we determined and compared the insecticide susceptibility of BPH and WBPH which were collected from East and Southeast Asian countries.

## Materials and methods

The 16 and 17 populations for BPH and WBPH, respectively, were collected from East Asia (Japan, China, Taiwan, northern and southern Vietnam) and Southeast Asia (Philippines) from May to October in 2006. The insecticide susceptibility of these populations was monitored by a standard topical application method (Fukuda & Nagata, 1969) on neonicotinoid (IMI and thiamethoxam (THIAM)), phenylpyrazole (fipronil), and O-*sec*-butylphenyl methylcarbamate (BPMC) insecticides.

The long-winged female adults were treated topically within seven days after emergence with a hand micro applicator (Burkard, UK) with acetone droplet of 0.08 μl. Mortality was determined 24 hours after treatment at 25°C and the $LD_{50}$–value was calculated by the Bliss's probit method. The tests were conducted on two to five generations after collection.

## Results

We found a species-specific changes in insecticide susceptibility in Asian rice planthoppers i.e. BPH for IMI and WBPH for fipronil). In case of IMI the $LD_{50}$-values for BPH collected from Japan, China, Taiwan, and Vietnam were 3.9-24.2 μg/g and were (remarkably higher than those collected before 2001 in Japan, China, and Vietnam (ranged from 0.1 to 2 μg/g) (Endo & Tsurumachi, 2001; Nagata *et al.*, 2002, Liu *et al.*, 2003). In contrast, the BPH populations in the Philippines had smaller $LD_{50}$-values (0.14-0.36 μg/g) for IMI. Although the $LD_{50}$-values for THIAM were not so large (0.18-2.2 μg/g), the BPH populations indicated a positive cross-resistance between IMI and THIAM. On the other hand, all the BPH populations had much smaller $LD_{50}$-values (0.09-0.93 μg/g) for fipronil. In WBPH, almost all the populations from Japan, Taiwan, China, Vietnam and the Philippines had extremely larger $LD_{50}$-values (12.2-278.1 μg/g) for fipronil except a few populations from the Philippines (0.66-5.89 μg/g). However, in case of IMI all the WBPH populations collected showed much smaller $LD_{50}$-values (0.09-0.93 μg/g). In case of BPMC the $LD_{50}$-values for BPH and WBPH ranged from 4.7-43.3 μg/g and 6.1-25.2 μg/g, respectively. No significant differences were detected among countries.

**Discussion**

A major reason for the development of insecticide resistance of BPH against IMI and WBPH against fipronil is due to the tremendous use of these insecticides in China (especially from the 2000s) (Xia, 2006) and Vietnam. Fipronil has been used commonly to control the rice leaffolder, *Cnaphalocrocis medinalis* (Guenée) and the rice stem borers in early stage of rice in Vietnam and China. Spraying fipronil in early season could also be more affected on WBPH than on BPH, because WBPH increases earlier than BPH in the rice growing season. This could be a possible reason why insecticide resistance against fipronil occurred only on the WBPH species.

Further comparative studies on the mode of action of neonicotinoid and phenylpyrazole insecticides against BPH and WBPH should be needed to explain the species-specific development of insecticide resistance against neonicotinoid and phenylpyrazole insecticides as well.

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## Variable efficacy of neonicotinoids against mealybug species under greenhouse conditions

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### Introduction

The mealybugs, *Planococcus citri* (Risso) and *Phenacoccus madeirensis* (Green) are difficult pests to control in greenhouse ornamental production in the southeastern United States. The Madeira mealybug is the most difficult mealybug pest to manage in the region. A life history study of this pest has provided a better understanding of its biology and how to manage it on crops (Chong *et al.*, 2003). On the other hand the Citrus mealybug is the most common mealybug in greenhouses in this area. In the late 90s Madeira mealybug became a major pest of greenhouse crops and early trials were conducted to determine a management strategy. This insect can be managed with insecticides but it is essential that good coverage and proper timing be achieved (Townsend *et al.*, 2000). The neonicotinoid imidacloprid had been used successfully against other mealybugs; however this insecticide was not as effective against this new pest. The objective of these experiments was to evaluate insecticides that have a good potential to be efficacious against Madeira mealybugs and fit into rotational programs against this pest as well.

### Materials and methods

Plants were maintained on raised benches and fertilized with Peter Lite 20/10/20 used in the irrigation at 200 ppm ad needed. Coleus was used as the host plant in all experiments except the first 2007 Madeira mealybug experiment where egg plant was used. Spray treatments were applied with a hand held compressed air sprayer at 2.46 kg/cm$^2$ twice 14 days apart. A single application of drenches was applied to the potting medium surface. Ten replications were used in each experiment.

To estimate populations plants were sampled every seven or 14 days and the mortality presented below was from the forth or fifth week after the initial application. One drench application was made and two foliar sprays at 14 day intervals. Several experiments for Madeira mealybug efficacy were conducted from 2000 to 2006 and a mean for the results for each compound are presented. In 2007 we evaluated three neonicotinoids (acetamiprid, dinotefuran and thiamethoxam), flonicamid, two insect growth regulators (IGRs) (buprofezin and novaluron), an oil (Facin), and two standards (acephate and biphenthrin) for efficacy against these problematic mealybugs.

### Results

During the earlier experiments the neonicotinoids split out into two groups based on percent mortality. The most effective compounds were: dinotefuran drench with 80% and foliar with 75%, and thiamethoxam foliar with 74% mortality. The mortality increased with each of these compounds after the fourth or fifth week. The compounds that did not provide as good a mortality level were: thiamethoxam drench with 47%, clothianidin foliar with 40%, imidacloprid drench with 3% and foliar with 32%, and acetamiprid with 22% mortality. These treatments did not always provide increased mortality after the fourth or fifth week.

In 2007, we evaluated three neonicotinoid type insecticides, flonicamid, buprofezin, and an oil against citrus mealybugs in the first experiment. All treatments were very effective with better than 60% mortality at four weeks. The acetamiprid foliar, dinotefuran drench, thiamethoxam, flonicamid and buprofezin foliar, treatments had good residual activity through the eight weeks of the experiment. The population was suppressed but then increased with oil and dinotefuran foliar treatments. All of these treatments compared favorable with the standards and could be used in a management program against citrus mealybugs.

In the second and third experiments insecticides were evaluated for control of Madeira mealybugs. As broad spectrum insecticides, the standards acephate and biphenthrin have been the most effective insecticides in many experiments. We have a concern about whether they will be available for many more years and they are very hard on natural enemies and prevent the use of a biological control program. Most of the insecticides tested are not as hard on natural enemies of mealybugs or other pest species. The second experiment was all foliar sprays except for a dinotefuran drench. Novaluron was the least efficacious with 70% mortality but this was still good suppression. However the population in the novaluron treatment started to increase after week four. The other treatments were very effective: flonicamid (100%), biphenthrin standard (100%), buprofezin (99%), dinotefuran (97%), and its drench (95%). This was the only experiment on a host other than coleus. The host in this experiment was egg plant and the efficacy was improved because of less foliage and better spray coverage.

In the third experiment the population did not increase as much as in other experiments and the reduction in population, compared to the check, was not as evident. All of the treatments were foliar sprays and the treatments did result in significant reduction in the population with an exception of one acetamiprid treatment. A low rate of acetamiprid was not significant but the high rate was and there was an increase in mortality by adding a surfactant to acetamiprid. There was also an indication that the addition of a surfactant improved the efficacy of dinotefuran (from 43% to 79%). Buprofezin (96% mortality) and acephate (100%) were very effective and continued to hold until the end of the experiment.

**Discussion**

The commercial neonicotinoids are very effective against citrus mealybugs and all active ingredients can be used against this pest. However not all neonicotinoids are effective against Madeira mealybugs, especially on hosts that have dense foliage and good coverage is difficult. The IGR buprofezin is very effective against Madeira mealybugs. Dinotefuran used as a drench, thiamethoxam, and acetamiprid plus a spreader sticker are effective and can be used in a management program for Madeira mealybugs. These insecticides compare very favourable to the standard insecticides, acephate and biphenthrin.

**References**

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