入侵紅火蟻
防治技術研討會專刊

Proceedings of the Symposium on the Control of Red Imported Fire Ant

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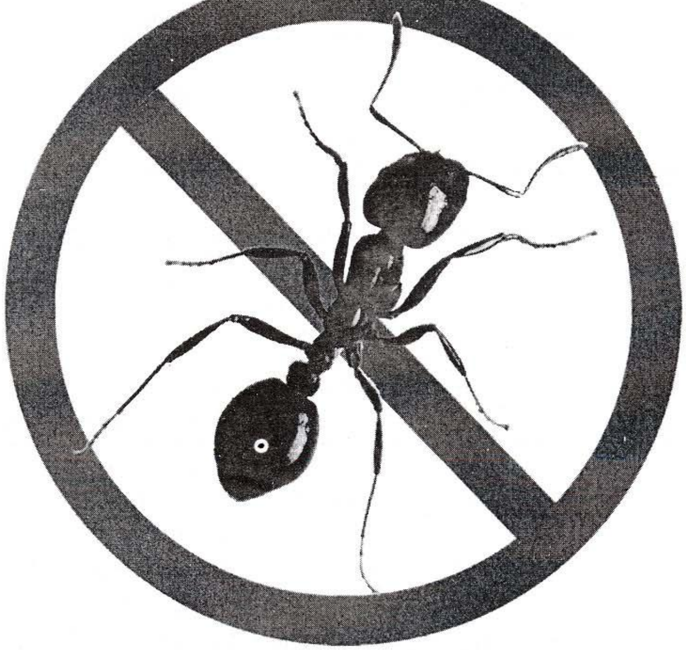

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Towards a Successful Control of the Red Imported Fire Ant - The Texas Experience

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I wish to thank Bureau of Animal and Plant Health Inspection and Quarantine, Council of Agriculture, Taipei, Taiwan, for this opportunity to visit this new incursion of the red imported fire ant, and to be able to provide any assistance I can in helping your country address this formidable challenge.

The red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), is an exotic invader species from South America. It was accidentally introduced into the Southern United States (Mobile, Alabama) around the 1930's and spread into Texas during the 1950's. Movement occurred through mating flights and natural spread, and by the movement of articles infested with recently-mated queen ants or ant colonies such as bales of hay, nursery stock, turf grass (sod), and equipment transporting infested soil or other suitable media.

Biology. *S. invicta* is a social insect that commonly develops colonies in nests of soil formed into hills or mounds. Inside, many tunnels form "galleries" in which the ants reside (Vinson, 1997). Ants move within these tunnels, seeking optimum conditions for survival and production of developing ants. In cool weather or when soil is saturated, the ants may occur just under the mounds' surface. During hot, dry weather, ants reside deep in the soil and may not construct mounds. Nests have no central opening and ants leave the mound to forage for food through shallow subterranean tunnels.

The colony is initiated when winged male and female ants, called "reproductives," leave the colony on a nuptial or mating flight. This event generally occurs on the first sunny day following periods of rain, in mid-morning to afternoon. Flights can occur at any time of the year when temperatures are favorable; generally in the spring and fall in Texas. Coupling occurs in midair and male ants die soon thereafter. Females, containing enough sperm from the mating to produce hundreds of eggs daily throughout their 5 to 7 year life span, land and dig a shallow burrow or seek a suitable crevice in which to start a colony. The newly-mated queen ant produces eggs that hatch into larvae that are fed by the queen from energy obtained from the digestion of flight muscles, metabolized fat reserves and ingestion of sterile (trophic) eggs. Larvae develop between molts through 4 stages or instars before pupating. Small sterile female worker ants emerge in a month or two. Thereafter, queen ants are fed and cared for by worker ants while laying eggs.

Regardless of size, the youngest worker ants initially care for the queen and help develop and defend the nest or mound, while the oldest worker ants become foragers that leave the nest in search of food. After a period of months, or in the absence (or insect growth regulator treatment) of a queen, colonies begin producing winged reproductive male and female ants. Winged reproductive ants do not work to assist in the maintenance of the colony and cannot sting.

Two forms of *S. invicta* colonies are recognized: 1) single queen or monogyne colonies containing one reproductively-active queen and worker ants that are defensive towards worker ants of neighboring colonies; and, 2) multiple queen or polygyne ants that can contain many queens and workers that display no territorial behavior and often produce higher nest numbers in areas where they occur.

Worker ants range in size, but are uniform in proportion of body parts. Worker ants of many other ant species are uniform in size or major worker ants have larger or uniquely-shaped heads. Nests produced by *S. invicta* generally are found in open, sunny areas, but can occur underground, next to or underneath cement slabs or other objects, or inside homes or utility housings. Colonies migrate to new, more suitable nesting sites regularly. They can develop a new nest or mound in a day or two far from the initial nest location. During flooding conditions, *S. invicta* colonies containing all colony members and developing stages, float and form "rafts" that can persist until a dry suitable nest location is reached.

Impact. *S. invicta* is a pest in both urban and agricultural areas. Although omnivorous, they are predominantly predaceous on other arthropods, particularly on caterpillars and beetles. However, like some other ant species, they encourage populations of certain sucking insects such as aphids, mealybugs, and scale insects (Homoptera), that produce the sugary liquid, called honeydew, when prompted by foraging worker ants. Imported fire ants have an affinity for electrical equipment, often nesting in utility housings during cooler weather. When shocked, foraging ants release chemicals (pheromones) that attract other ants to electrical switches and circuits, causing equipment failure. The ants are capable of stinging man and domestic animals causing serious injury and occasionally death. Treatment of this pest by the general public results in the greatest impact, economically. Overuse and misuse of insecticide treatments has resulted in surface runoff water contamination, particularly where high numbers of ant mounds occur. In areas infested with the multiple queen or polygyne form of these ants, ant nest numbers can exceed 200 mounds per acre.

In agricultural areas, *S. invicta* also affects other arthropod pest populations in either positive or negative ways. However, the foraging ants also affect plants as they feed on germinating seeds of many crops (corn, sorghum, soybeans and others), or other plant parts such as okra buds and potato tubers. In hay production, their tall mounds cause cutting equipment damage. During hot, dry weather, foraging ants are rapidly recruited to soft, moist tissues of newly born or hatching animals. Multiple stings can cause temporary or permanent blindness to calves and reduce survival of ground nesting birds, wildlife and other animals.

In Texas, recent economic surveys conducted by Dr. Curtis Lard, Agricultural Economist, documented an annual impact of $1.2 billion per year. Most of this impact is in residential areas, where about half of the cost is due to the purchase and application of insecticides in an attempt to control this species. In agricultural areas, the impact is about $90 million annually. Although the medical cost of *S. invicta* is not dramatic statewide, it can be devastating to individuals. About 1 percent of the population is hypersensitive to arthropod venom and even one sting can cause serious medical complications or occasionally death. Most people, however, can tolerate numerous stings. The ants bite with their mouthparts, called mandibles, and then sting many times with the stinger on the abdomen connected to a venom gland. Stings burn "like fire" and in a day or so form a fluid-filled whitish pustule characteristic of this species.

Some people react with extreme anger when stung, and often carry out treatments with extreme emotions using "home remedies" that are possibly ineffective or even dangerous.

Management. Like with other pests, the system's approach or philosophy of integrated pest management (IPM) has relatively recently been applied to *S. invicta* (Drees and Gold, 2003). Where suppression is warranted, a program approach using the most cost-effective economically-sound combination of non-chemical cultural practices, biological control agents (parasites, predators, and pathogens), and selected chemical treatments can be designed and implemented. In the United States, attempts to eradicate this species were made for several decades using primitive insecticides until the early 1980's. These efforts were unsuccessful, and the large area of land currently infested makes eradication uneconomical. Thus, programs in the southeastern U.S. aim to eliminate the problems caused by the ants and prevent further spread. Eradication, however, could be thought of as a goal within the context of IPM. For instance, even with the use of large-scale intensive chemical treatments, preservation or re-establishment of native ant species (as biological control agents) is likely to be crucial to the ultimate success of a *S. invicta* eradication program. Efforts must be implemented to monitor native ant species populations throughout this undertaking.

In the U.S., a number of organizations are involved in imported fire ant research, regulatory and educational programs. Eradication is ongoing in California around Los Angeles by the California Department of Food and Agriculture. Like Texas, other states (South Carolina, Georgia, Alabama, Arkansas, Louisiana, Oklahoma) conduct some type of fire ant program at universities and agricultural departments. The United States Department of Agriculture's Animal and Plant Health Inspection Service (USDA-APHIS), located in Gulfport, Mississippi, develops treatment programs to support the federal fire ant quartantine regulations, and the USDA's Agricultural Research Service (USDA-ARS), located in Gainesville, Florida, and Stoneville, Mississippi, develops management methods and focuses largely on classical biological control.

Texas Cooperative Extension within the Texas A&M University System at

College Station has focused on developing IPM approaches, implementing large-scale community-wide fire ant management programs, conducting applied research to develop new products and approaches, and conducting aggressive outreach educational programs such as the development of the web site, http://fireant.tamu.edu. The approach heavily promoted by this effort is the "Two-Step Method" of fire ant control. This program relies on the broadcast application of a bait-formulated fire ant insecticide once or twice per year. Treatment of individual ant nests or mounds is minimized by relying on bait treatments to eliminate 80 to 90 percent of the colonies initially present. Remaining "nuisance" mounds can be quickly eliminated using dust, granular, liquid or aerosol treatments or home remedies such as use of boiling water. Use of this method in larger areas such as neighborhoods or communities, provides dramatic reduction of *S. invicta* population levels, insecticide use and associated cost, while increasing numbers of other ant species (Riggs *et al.*, 2002). These programs rely on residents to work together to treat their neighborhoods in a coordinated manner, using volunteers to broadcast-apply bait to common areas, vacant lots, and for residents unable to make their own treatments.

New technology. Much progress has been made over the last decade to bring new products for imported fire ant control to market in the U.S. Applied laboratory and field trials have resulted in bait formulations of methoprene (Extinguish®) and pyriproxyfen (Distance®, Esteem®), which are insect growth regulator (IGR) insecticides now available and registered for many use sites. Extinguish® is registered for use on cropland, pastures and urban areas. Baits containing spinosad are fast acting but perform somewhat inconsistently. Together with a d-limonene mound drench product, this combination constitutes a Two-Step program using products certified by the Organic Materials Review Institute (OMRI). Fipronil products are now available as a bait formulation (Ceasefire™) and as granular products (Over 'N Out® and Chipco®Chioce). The bait performs similar to traditional metabolic inhibitor hydramethylnon baits (Amdro®Pro, Probait®, and others) that provide 80 to 90 percent control 3 to 6 weeks following treatment. Granular fipronil formulations, through more expensive, provide nearly absolute control after about four weeks of application that lasts for many months following treatment.

Product performance differs according to formulation and active ingredients. IGR products provide slow suppression, requiring 1-2 months when applied in the spring and up to 6 months following treatment in the fall. The level of control attained is similar to faster acting bait products like hydramethylnon (Amdro®Pro), but lasts far longer because queen ants are incapable of producing worker ants for an extended period of time (i.e., queen ants have reduced or dysfunctional ovaries). Blending hydramethylnon and insect growth regulator baits, like methoprene, and applying them at half rates of each product can provide a performance profile with the best characteristics of both ingredients: fast acting and long lasting suppression. This "hopper blend" combination (Amdro®Pro plus Extinguish®) is now available in the U.S. for use in pastureland under federal labels, and has been introduced as a pre-blended product as Extinguish®Plus for use in non-agricultural lands. Another new bait product containing indoxacarb (Advion™) provides elimination of imported fire ant foraging and colonies in a few days after application. Label expansions and new product development continue to improve IPM programs for *S. invicta*.

Application technology has also been improving. Conventionally-formulated bait products are usually applied at a rate of 1 to 1.5 lbs. per acre using a hand-held or vehicle-mounted applicator or aerially, using a helicopter or airplane such as a crop duster. Industrial vehicle-mounted applicators using fans or blowers to provide an air stream to broadcast ant bait products have been developed to more rapidly treat larger areas. The air-assisted modification of the GT-77 model Herd Seeder was introduced in 2004. Based on concepts of the prototype developed at Texas A&M University, this adaptation uses a leaf blower and a directional shoot to distribute bait to one side of a vehicle moving up to 20 miles per hour. A combination of application methods was used to apply the hopper blend treatment in a demonstration conducted in a 100 acre community, Lago Santa Fe in Galveston County, Texas, where fire ant suppression has been maintained to over 3 years.

Biological control. Research efforts at the University of Texas under the direction of Dr. Larry Gilbert, and with the USDA-ARS (Gainesville, Florida) by Dr. Sanford Porter, have resulted in releases of several parasitic fly species for the red imported fire ant. These flies (Diptera: Phoridae), primarily *Pseudacteon* *tricuspis* and *P. curvatis*, have been released at over 20 locations in Texas. *P. tricuspis* has survived the winters and begun to spread at about 6 release sites. The flies suppress fire ant foraging behavior during the daytime allowing native ant species to better compete with this exotic invader, and thereby potentially providing sustainable suppression. A disease of *S. invicta,* called *Thelohania solenopsae* (Microsporidia) has also been detected across much of the infested parts of state. It is known to cause a slow decline of fire ant colonies (Williams *et al.*, 1999). Biological control of this social insect is expected to result from the introduction, establishment and preservation of a number of the ant's natural enemies, similar to the situation in South America where *S. invicta* is not considered to be an important pest ant species. However, biological control will not result in *S. invicta* eradication.

Area-Wide Suppression Program. Texas Cooperative Extension has collaborated in a multiple state effort organized by the USDA-ARS researchers (Gainesville, Florida) involving South Carolina, Mississippi, Florida and Oklahoma. The goal of this effort is the demonstration of the integration of chemical and biological methods to suppress *S. invicta* in improved pastures. In each state, at least two large areas of pastureland (generally 300 acres each) have been chosen. These areas receive aerial or ground treatments of the hopper blend (Amdro® Pro plus Extinguish®) to provide 80 to 90 percent control. Around one of each pair of sites, parasitic phorid flies and *Thelohania* are released and monitored. By using a treatment threshold (i.e., 20 mounds per acre) to trigger re-treatment with the bait combination, collaborators hope to demonstrate that the introduction and establishment of biological control agents will increase the interval of needed chemical treatments by suppressing resurgence to the fire ant population using biological control agents.

Eradication Considerations. As the Bureau of Animal and Plant Health Inspection and Quarantine (Council of Agriculture, Taipei, Taiwan) contemplates potential actions to combat this new pest ant invader, I wish you the best for a successful effort, whether the goal becomes eradication, containment or suppression using IPM approaches. I must note that, to date, no eradication effort has been a documented success. The history of eradication efforts in the U.S.

using the first broadcast-applied bait product, Mirex, was unsuccessful. National efforts in the U.S. today focus on containment by regulating, through treatments and inspection, the movement of high-risk articles by the USDA-APHIS and implemented by departments of agriculture in each state.

I have been honored to have served on the Science Advisory Panel for the California Department of Food and Agriculture, currently conducting an eradication program in the Los Angeles area. Their program has been ongoing since 1999, has had limited success, and recently experienced serious state funding problems. In 2001, I made my first trip to Brisbane, Australia, and have been a member of the Science Review Team since that time. Their effort has shown great promise, but the program is still ongoing. I wish both of these programs the best and hope for ultimate success. However, even if these monumental efforts fail to achieve eradication in historical time, these programs' accomplishments remain noteworthy. They both will have prevented an even more rapid infestation of much larger areas of suitable imported fire ant habitat, along with serious negative impacts fire ants cause to native fauna, flora and the economies of infested areas.

The potential range of *S. invicta*, as analyzed by Morrison et al. 2004 (http://cmave.usda.ufl.edu/ifahi/ifarange_global.html), shows Taiwan to be likely to become fully infested should eradication or containment efforts not be implemented or successful. Following my visit to California in late 1998, my colleagues, Dr. Dave Williams, Mr. Homer Collins and Dr. Awinash Bhatkar, developed a fact sheet entitled, "Considerations for Planning, Implementing, and Evaluating a Spot-Eradication Program for Imported Fire Ants" (FAPFS030, http://fireant.tamu.edu/materials/factsheets). This document discusses a number of concepts for agencies or organizations contemplating to attempt an eradication effort. The concept of spot-eradication rests on the biology of *S. invicta* and its ability to spread by ground or mating flights into previously-treated areas. There will always remain a need of increasing surveillance and regulation of high-risk articles constituting human-assisted movement of this species, capable of reintroducing the species to previously-eradicated areas.

Eradication efforts currently rely on available insecticide products registered for use sites in your country. Acquiring registrations and access to product and application equipment is urgently needed so that treatment can commence in a timely manner and before further spread occurs. Treatment regimes discussed in the fact sheet are theoretical and effectiveness/efficacy of treatments needs to be verified locally. All land areas known to be infested must be treated, including a "buffer" area of land surrounding the infested area where low populations of newly-established undetectable colonies may reside. Treatments must be timely using the most thorough application equipment, with aerial treatment being preferred. As treatments provide only a percent control (roughly 80 to 90 percent per treatment), multiple applications improve performance within a year and over several years. Mathematically, however 100 percent control is not achievable. Success can be verifiable only through intensive monitoring or survey efforts.

The fact sheet, "Survey-Based Management of Red Imported Fire Ants" (FAPFS007), provides a discussion of fire ant monitoring methods used in Texas. Techniques described can be useful in developing methods for surveying land areas in and around fire ant infestations. Visual inspections are the least labor-intensive, but in some areas or during certain times of the season, environmental conditions cause *S. invicta* not to develop their characteristic mounds. Thus, additional methods, such as use of food lures placed alone or in some type of container to attract foraging worker ants, is a valuable addition. Pitfall traps are very labor intensive but have the advantage of being in place for longer periods, sampling many ant species.

Ant mound monitoring can be accomplished in sub-sample areas to provide data to document changes in population levels in terms of number of mounds per unit area. For field research, permanent circular plots are often established. A string or tape of a certain length constitutes the radius of a circle of known area. Counting ant mounds as surveyors walk around the circle provides the number of mounds in that area. Similarly, transect plots can be used where surveyors walk a certain distance counting ant mounds encountered along the width. Baited vials containing food lures placed in these plots can add to results of ant mound numbers obtained with little extra investment in time or effort.

Almost every "ant expert" can discuss their favorite food lure to attract foraging worker ants. Pieces of cardboard, soaked in vegetable oil (e.g., peanut oil, olive oil, soybean oil) and pierced with a field flag make quick and easy monitoring stations. Similarly, condiment cups containing a piece of hotdog or other processed meat (tuna fish or pet food) can be used to attract foraging ants within 30 to 60 minutes of placement. Many designs of pitfall traps have been used to monitor ants successfully. Drilling holes in the vertical sides can allow ants to enter from below the soil surface to monitor subterranean species. As stated earlier, monitoring native ant species should be a serious concern in treatment programs because some bait products can eliminate species which otherwise would help compete with *S. invicta* for resources, raid small colonies or prey on newly-mated queens.

Successful eradication, or lack thereof, will be evident during years to come. However, within a short time period where resources are available and dedicated to an eradication effort, plans for the program must include an intention to document success. Because total elimination of a species constitutes eradication, planning intensive surveillance efforts in and around previously infested and treated areas, as well as buffer areas around the treated areas, will be the required documentation for success. These efforts should be initiated directly following termination of the treatment regime and optimally continued for at least two years. Graphic depiction of survey efforts made where no *S. invicta* were detected using suitable methods, would constitute a documented success. Conducting the treatment phase of an eradication effort for this or any other exotic pest without committing to and completing the verification phase using intensive sampling would result in a failure to document a return from this investment.

I cannot predict success for any eradication program attempted. I can only approach this subject theoretically because the reality and liability of implementation rests with those organizations that commit to undertaking this challenge. However, it is my hope that the experience gained through my research and education efforts, focused on managing red imported fire ants in Texas, can be helpful to those making decisions and allocating resources to support such efforts in Taiwan and possibly elsewhere. Having witnessed the efforts in Australia, however, I am encouraged that with sufficient resources and determination, eradication may be possible. In Brisbane, the Department of Primary Industries estimates that they have achieved 99.4 percent control. The low level of ant colonies remaining provides a technical challenge no one has faced before: How does one design and implement a survey program to detect and treat the last few colonies? Perhaps, this is one aspect of eradication that leaves many in the scientific community skeptical that successful eradication of *S. invicta* is achievable.

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由德州經驗談成功防治入侵紅火蟻之道

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首先我想感謝中華民國行政院農業委員會動植物防疫檢疫局的邀請，使我有機會來參訪並瞭解此地入侵紅火蟻之最新疫情，也讓我有榮幸能提供協助以幫助貴國面對此艱鉅挑戰。

入侵紅火蟻學名 *Solenopsis invicta* Buren，屬膜翅目蟻科昆蟲，為源自南美洲之外來入侵種。1930 年代紅火蟻在偶然機會侵入美國(於 Alabama 州 Mobile 郡)，於 1950 年代間已擴散至德州，其移動係經由交尾後飛行與自然擴散，或是經由乾草、苗圃植物、草皮、附著感染土壤機具與其他可夾帶新交尾蟻后或火蟻族群之物品移動所傳播。

生物學特性

入侵紅火蟻為社會性昆蟲，其族群通常於土壤內構築蟻巢而於土表形成山丘狀，蟻丘內部佈滿多孔廊道，火蟻於其間活動以找尋最適合生存與繁殖之位置。當溫度涼爽或土壤過濕時，火蟻可能近在蟻丘表面下活動；而當天氣炎熱乾燥時，火蟻則可深居土內，並不形成蟻丘。成熟紅火蟻之蟻丘外部並不具中央開口，其覓食路徑係採多條淺層之地下蟻道。

火蟻族群之繁衍係源自有翅型雄蟻及雌蟻(即生殖型)在離巢後之交配飛行，發生時間多為連續陰雨後第一個晴天的近午至下午，此交尾飛行可於一年中氣溫適宜的任何時間發生，以德州而言則為春季與秋季。交配行為於空中進行，雄蟻於交尾後不久死亡，雌蟻則於飄落至地面後挖掘淺穴或覓尋土縫，藉其所獲足量精子於隨後的五至七年壽命中，每日生產數百粒計之蟻卵以繁衍族群。剛交尾過的蟻后產下的首批卵孵化的幼蟲，經蟻后以獲自分解飛行筋肉、代謝蓄積的脂肪及取食營養卵等能量加以餵育，幼蟲經四個齡期後蛻化成蛹，不孕性小型雌性工蟻遂於一或二個月內開始發生。此後，蟻后在產卵期間即由工蟻負責照顧與餵食。

無論體型大小，年輕工蟻之任務為照顧蟻后及構築與保衛蟻巢，年長工蟻則轉變為覓食蟻，離開巢穴在外尋食。經過數個月或當蟻巢中沒有蟻后(或以昆蟲生長調節劑處理)時，族群內開始產生有翅生殖型之雄蟻與雌蟻，此等生殖型無需協助族群的維持工作，亦無叮咬能力。

入侵紅火蟻區分為二種類型：(一)單蟻后型：即蟻巢中僅有一隻具生殖活性的蟻后，本巢工蟻對附近蟻巢之它巢火蟻具防禦行為；及(二)多蟻后型：指一巢中有多隻蟻后，本巢工蟻並不表現領域性行為，通常於發生區域內可產生數量較多的蟻巢。

雖然入侵紅火蟻之工蟻體型差異甚大，惟各體節維持固定比例，有別於其他螞蟻具有均一體型或是主要工蟻群具較大或特殊頭型之特性。紅火蟻喜於開闊的晴照地區築巢，惟其亦能於水泥板或其它物品的鄰接地底，甚至居家或電器機箱中發生。火蟻族群會經常遷移至新的適宜築巢點，可於一或二天內於離巢甚遠處另起家園，在淹水情況下，包括幼蟲在內之蟻群尚可聚集形成蟻筏，藉由流水飄浮至乾燥的適宜築巢點。

危害與影響

入侵紅火蟻為危害都市地區及農業產區的有害生物。雖然紅火蟻為雜食性昆蟲，卻以節肢動物為主食，特別是毛蟲與甲蟲類，而如同其他螞蟻，火蟻的存在亦可增加蚜蟲、介殼蟲等同翅目刺吸性昆蟲之族群數量，藉由催取蜜露互利。在冷涼氣候下，紅火蟻喜於電器機箱中取暖築巢，當覓食蟻遭到電擊時，散發之化學物質(費洛蒙類)可吸引其它火蟻至電路點，進而造成短路跳電。由於紅火蟻具有叮咬人類與家畜禽之能力，可能造成嚴重傷害甚至死亡，因此大眾要求防治紅火蟻之期許導致了最主要的經濟衝擊。此外，滅蟻藥劑的過度與不當使用已造成了表層逕流水質的污染，尤其在高密度蟻丘發生地區特別嚴重，以多蟻后型紅火蟻而言，每英畝的發生蟻丘數目可達200 個以上。

如同前述，入侵紅火蟻在農業產區可以正向或是反向地影響其他節肢動物的族群數量，此外覓食火蟻亦可危害作物生產，例如取食玉米、高粱、大豆等萌芽種子，或是食用秋葵蕾芽、馬鈴薯塊莖等其他植物部位，而在乾草生產上，高凸蟻丘易造成割收機具之毀損。另當氣候炎熱乾燥時，覓食蟻可迅速聚集於新生幼獸或破殼雛禽的濕軟組織部位，經連續叮咬後可造成雛牛暫時性或永久性失明，並降低地巢性鳥類、野生動物與其他幼獸的存活率。

依據農業經濟學家 Curtis Lard 博士近年來進行經濟調查結果顯示，每年

入侵紅火蟻於德州造成的危害金額為 12 億美元，主要損失來自住宅地區，其中約有半數費用花費在購買與施用火蟻防治藥劑上，至於農業產區，每年危害金額約為 9,000 萬美元。整體而言，雖然德州花費在火蟻叮咬處置的醫療費用並不高，但火蟻叮咬可以對個人造成嚴重危害，據統計有 1%的人會對節肢動物的毒液過敏，這些人即使僅被火蟻叮咬一次也可能導致嚴重的併發症甚至喪命，惟對大多數人而言，其身體仍可承受多次叮咬。火蟻叮咬時，係先以口器緊咬皮膚，再由連接腹內毒囊的腹尾毒針連續叮刺，痛如火灼，約於一日後於該部位長出特有的白色膿泡，因此有些人在受到叮咬後萬分氣憤，常於盛怒下採取可能無效甚至具有危險性的自我療法。

防治與管理

如同其他有害生物，研究人員於近年來已開始將系統性方式或有害生物綜合管理(IPM)的觀念應用在入侵紅火蟻防治上(Drees and Gold, 2003)，如要抑制火蟻族群，則可選取非化學性栽培技術、生物防治劑(如寄生者、捕食者、病原菌)及選擇性化學藥劑等處理，設計符合經濟效益並可行的處理組合後據以執行。美國曾於 1980 年代前的數十年間，多次嘗試以傳統殺蟲劑撲滅紅火蟻，這些努力並未成功，而且目前火蟻發生面積過大也使得撲滅計畫不具經濟性，因此現在美國東南部地區係將防治目標設定為消除火蟻危害所產生問題，以及防止入侵紅火蟻繼續蔓延的務實作法。然就 IPM 領域而言，執行上仍可將撲滅火蟻列入工作目標，例如在進行大規模密集化學藥劑撒佈後，仍應考慮本土螞蟻族群(具生物防治性)的保存與復育可能為最終撲滅紅火蟻之重要關鍵，因此在整體防治計畫內仍應進行本土螞蟻種類與數量的監測。

目前美國有部分機構正推動與入侵紅火蟻相關之研究、防治管理與教育計畫，例如加州政府農業廳現正於洛杉磯週邊地區進行火蟻撲滅計畫，而包括德州、南卡洛萊納、喬治亞、阿拉巴馬、阿肯色、路易斯安那、奧克拉荷馬等州則由各州農業廳及大學進行各個火蟻防治計畫。在聯邦部分，分設於密西西比州 Gulfport 市的美國農部動植物健康檢查署持續為聯邦政府火蟻檢疫規定開發處理技術，而位於佛羅里達州 Gainsville 市及密西西比州 Stoneville 市的美國農部農業研究署則以開發入侵紅火蟻生物防治技術為主。

德州農工大學主校區內德州合作推廣中心之研發重點包括：發展紅火蟻 IPM、執行大範圍社區火蟻管理計畫、開發新產品與防治技術之應用研究、

積極推動相關教育推廣計畫等。在推廣努力上，德州合作推廣中心用心經營 http://fireant.tamu.edu 火蟻網站，全力推廣入侵紅火蟻二階段防治法，第一階段防治係於每年進行一至二次的殺蟲餌劑撒佈，先行去除 80%~90%的蟻丘，第二階段再針對剩餘少數的蟻丘個別施予粉劑、粒劑、液體澆灌、氣霧式等化學藥劑，甚或使用沸水等家用方法予以快速滅除。二階段防治法適用於鄰里或社區等大範圍的防治計畫，能夠迅速降低紅火蟻族群數量，並減少殺蟲劑之使用及相關費用，同時亦可增加本土螞蟻的數量(Riggs*et al*., 2002)。本法之推動有賴於社區居民的志願參與，相互協調於鄰里公共區域及空地等處共同施藥，以及協助未能自行施藥之鄰居進行防治。

防治新技術

在過去十年間，紅火蟻防治藥劑之研發已獲得長足進步，並有多種新藥上市。餌劑配方的美賜平(Extinguish®)與百利普芬(Distance®, Esteem®)為應用實驗室研發與通過田間試驗之昆蟲生長調節劑(IGR)，並經註冊可於許多場所使用，例如 Extinguish®之註冊範圍即包括農地、牧場及都市地區。含賜諾殺成份之餌劑藥效較快，但表現有些不穩，其配合 d-檸檬油精進行蟻丘澆灌之二階段處理組合，已通過有機物質評論研究所(OMRI)之認證許可。另外在市面上取得之芬普尼藥劑包括餌劑配方(Ceasefire™)與粒劑產品(Over 'N Out® 及 Chipco®Choice)兩類，其餌劑表現與傳統代謝抑制劑愛美松餌劑(Amdro®Pro, Probait®等)相近，可在處理後三至六週內達到 80%~90%的控制；芬普尼粒劑雖然較貴，卻能於處理約四週後具有幾近完全控制效果達數月之久。

防治藥劑之有效性係由劑型及有效成份共同決定，例如 IGR 產品之抑制效果較緩，需於春天施用後一至二月或秋季施用約六個月後方見具體成效，減蟻效果則與愛美松(Amdro®Pro)等速效性餌劑相近，但 IGR 藥劑能有較長的防治效期，因其係影響蟻后產卵及有效卵數以持續抑制工蟻發生。事實上將愛美松與美賜平等 IGR 餌劑各取半量混合施用後，可兼具二者之優：速效性與長效期，此種"料斗拌合"(hopper blend)組合(Amdro®Pro plus Extinguish®)已獲聯邦政府註冊上市為牧場防治火蟻用藥，而於非農業用地則有 Extinguish® Plus 預拌藥劑。此外尚有一種含有因得克成份的新餌劑(AdvionTM)，可於施用數日內即消除火蟻覓食及蟻群，這些藥劑的註冊擴充及新一代產品的研發均將持續改良入侵紅火蟻 IPM。

再者，防治藥劑的施用技術也在持續進步中。以傳統配方的餌劑言，過

去常採手持式、車用式撒佈器或以直昇機或噴藥飛機以每英畝 1 至 1.5 磅用量進行撒佈，為能大面積快速施藥，新近發展之工程車用式撒佈器則使用風扇或吹動器製造氣流來噴撒餌劑。例如 Herd Seeder 公司甫於 2004 年上市之 GT-77 改裝吹動型，即為採用德州農工大學設計之原型機概念，利用架設於車上之吹葉機及導向管以每小時 20 英哩側向快速噴撒餌劑。德州使用此種噴佈方式配合上述料斗拌合餌劑進行廣達 100 英畝的社區防治示範，已於 Galveston 郡 Lago Santa Fe 地區有效抑制火蟻族群達三年以上。

生物防治

經過德州大學 Larry Gilbert 博士的研究團隊以及美國農部農業研究署(佛州 Gainsville 市)Sanford Porter 博士的多年研究，目前已完成多種紅火蟻寄生蠅類之野放，這些寄生蠅(雙翅目蚤蠅科)類主要為 *Pseudacteon tricuspis* 及 *P. curvatis* 等，已於德州超過 20 個處所進行測試，*P. tricuspis* 並於其中 6 處成功越冬並開始蔓延。蚤蠅之作用機制係於日間抑制紅火蟻的覓食行為，使得本土螞蟻群有機會與入侵火蟻競爭，盼以持續抑制。另外在德州各火蟻發生地所偵測到的小芽苞真菌(*Thelohania solenopsae*)病原，亦可造成火蟻族群的逐漸衰弱(Williams *et al*., 1999)。未來研究人員仍將藉助天敵之引進、立足與保育等努力來推動火蟻生物防治，使其如同處於南美洲原產地面臨生物制衡而無法造成嚴重危害，惟應注意利用生物防治並無法達成撲滅紅火蟻的目標。

區域火蟻抑制計畫

在美國農部農業研究署(佛州 Gainsville 市)的組織下，德州合作推廣中心與南卡洛萊納、密西西比、佛羅里達及奧克拉荷馬等州共同執行了結合化學防治與生物防治的牧場火蟻防治示範計畫。此計畫係由各州選定至少兩區改良式牧場(通常每區 300 英畝)，區內先採空中或地面方式撒佈料斗拌合餌劑(Amdro®Pro plus Extinguish®)以完成 80%至 90%的防治，再於其中一區釋放寄生蚤蠅與小芽苞真菌進行生物防治為實驗組，並採當每英畝發生 20 蟻丘時為再次施用餌劑之處理基準。研究人員希望證明利用生物防治劑之釋放與立足後，能夠抑制火蟻的再度發生以延長所需施藥時間。

採行撲滅目標之考量

目前行政院農業委員會動植物防疫檢疫局正細擬對入侵紅火蟻之相關作為，無論未來防治目標訂為撲滅、防堵或採 IPM 方式抑制火蟻，個人均

衷心祝福該目標能順利達成，而在此我必須提醒目前全球尚無成功撲滅入侵紅火蟻的記錄。美國在過去曾經嘗試利用首次發展的撒佈式滅蟻樂 (Mirex) 餌劑來進行火蟻撲滅，結果並未成功，今日的美國已將防治目標設定為火蟻的防堵，即由美國農部動植物健康檢查署訂定高風險物品之處理及與檢查等移動管制規定，而由各州農業廳來負責執行。

本人有幸受邀為加州農業廳科學諮議委員，現於洛杉磯地區推動火蟻撲滅計畫，該計畫自 1999 年開始推動，撲滅成果有限，最近更發生經費不足之窘境。本人另於 2001 年首度受邀訪問澳洲布里斯本並擔任科學評議委員至今，雖然澳洲政府的火蟻撲滅目標有望達成，惟該項計畫尚仍進行中。我希望這二項計畫最後都能圓滿成功，即便將來是以失敗收場，該等計畫獲致成就仍然值得推崇，因其已防止了入侵紅火蟻以更快速度進行更大範圍的蔓延，大大的降低了對自然生態的衝擊以及發生地區的經濟損失。

依據 Morrison 等人在 2004 年對全球紅火蟻可能發生區域之分析結果（http://cmave.usda.ufl.edu/ifahi/ifarange_global.html），未來倘台灣採取撲滅計畫或防堵措施的努力未能成功，則全台各地將可能淪為入侵紅火蟻疫區。我在 1998 年底訪問加州後，與同事 Dave Williams 博士、 Homer Collins 及 Awinash Bhatkar 等人共同撰寫了「規劃、執行及評估入侵紅火蟻單點撲滅計畫之考量因素」乙篇簡介(FASPS030, http://fireant.tamu.edu/materials/factsheets)，該份文件述及防治主管機關在採行火蟻撲滅計畫時所應具備觀念。單點撲滅的觀念考量了紅火蟻的生物特性以及其於地面擴散或交尾飛行之入侵能力，因此防治者在完成藥劑處理後仍須持續加強火蟻監測，並執行高風險物品移動管制措施，以防止紅火蟻再度入侵已撲滅地區。

目前貴國之火蟻撲滅努力仰賴各類施用地點之藥劑取得，必須儘早完成用藥註冊並備妥足量藥劑與適宜施用機具，方能在火蟻蔓延前及時進行防治。簡介中之藥劑處理結果係以理論值推算，實際執行成效尚待實地驗證，依據單點撲滅計畫，應對所有已發生區域及周邊可能無法偵測到的低密度緩衝區全予施藥，施藥必須及時並應使用最能徹底施藥的撒佈機具，尤以空中施藥為佳。由於各次施藥僅能達到某種比例的效果(每次處理約 80%至 90%)，因此採行一年多次施用與多年連續施用會有較佳結果。惟由數學面計算，100%的完全滅除是無法達成的，只有經由密集的監視或調查後，方能確認撲滅已完成。

另份「以調查結果進行入侵紅火蟻管理」簡介資料(FAPFS007)係討論在德州採行的火蟻監視方法，善用該等技術有助於進行火蟻發生地區及鄰近區

域之面積調查。目視檢查法為最簡便，但應注意某些地區在特定季節時，紅火蟻族群未必會在該環境中產生典型的蟻丘，因此尚須考慮以食物誘餌(可直接放置或置於容器中以吸引覓食蟻)等其他監視法補強。掉落陷阱之設置雖較費工，惟其具有長時監視及同時進行多種螞蟻調查等優點。

調查蟻丘數目時，可採次級樣品(sub-sample)取樣法來調查單位面積內的蟻丘數以記載蟻群變化。在田間調查上，常以固定長度的線帶為直徑劃出固定的圓形採樣區，再點算區內的蟻丘數。同樣地，調查人員亦可於設定的寬度內行走固定距離，以點算出矩形採樣區內的蟻丘數變化。配合於採樣區內放置食餌瓶，可以少量投資獲取附加成果。

幾乎每位“螞蟻專家”均有其吸引覓食螞蟻的最適食餌，可簡單利用田間標誌旗插上一小片經植物油(如花生油、橄欖油、沙拉油)浸泡過的厚紙板以快速製作簡易的監視點，同樣地，利用盛裝熱狗碎屑或其他加工肉品(鮪魚或寵物食品)之佐料罐亦可在設置後 30 至 60 分鐘內吸引到覓食蟻。另外掉落陷阱的多項設計亦能成功進行監視，例如於陷阱側面開孔便可監視土壤中的螞蟻種類。如前所述，進行藥劑處理時應考慮對本土螞蟻族群進行監視作業，因為本土蟻群可參與資源競爭、攻擊未成熟火蟻群及捕食新交尾蟻后，某些種類的餌劑施用可能消滅這些相互抗衡的本土蟻群。

無論能否完成撲滅目標，結果將於來年時漸趨明朗，執行撲滅計畫時仍須企圖於每隔資源允許的短暫期間時展開調查並記錄藥劑處理結果，以全心全力投入。由於某種物種的完全消除謂之撲滅，因此應規劃於先前火蟻發生區內部及鄰近地區、藥劑處理區併同藥劑處理區週邊之緩衝區等區域進行密集的監測作業，方為成功之必要條件。這些監測作業應於藥劑處理結束後隨即進行，最好持續兩年，經採適當偵測法均不再察覺火蟻發生時，則圖示結果即為成功撲滅火蟻之驗證。當執行入侵紅火蟻或其他外來有害生物等撲滅計畫時，倘於完成藥劑處理階段後未於驗證階段再予密集抽樣確認，將會造成是項計畫投資失敗。

我無法預期任何火蟻撲滅計畫的成敗，僅能由理論面來進行探討，因為撲滅計畫的實際執行及成敗責任取決於執行任務的機關本身。然而，我謹衷心期望我所提供多年來於德州進行紅火蟻防治研究與教育推廣工作所獲經驗，能對決策者與資源分配者有所幫助，以支援台灣及其他地區的火蟻防治工作。就在見證了澳洲的努力後，我被入侵紅火蟻能在充分資源與決心情況下被成功撲滅的想法所深深激勵。依據昆士蘭州政府初級產業部的估計，目前在布里斯本地區的撲滅目標已達 99.4%，但再繼續撲滅剩餘的低密度火蟻

群，真是無人所曾面臨之技術挑戰：要如何來設計及執行調查計畫以偵測並處理最後少數的火蟻呢？或許，這就是讓許多科學家對成功撲滅紅火蟻始終抱持懷疑態度的一面。

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Comments and Considerations for Addressing the Incursion of *Solenopsis invicta* Buren (Hymenoptera: Formicidae) in Taiwan

November 2004

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Areas infested with the red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicide), were visited from 7 to 10 November 2004. I greatly appreciated assistance from all who provided me with background information, served as guides, and with whom I discussed the possibilities of (and limitations for) addressing the approximately 7,000 ha infested in three locations. These areas included 1) National Taipei University grounds; 2) the area near Chiang Kai-Shek International Airport; and 3) agricultural areas near Jungpu, Chiai County, in central Taiwan. During my visit, I observed land use patterns that differ dramatically from infested areas in the southeastern United States and Australia that will pose a challenge to thorough treatment of *S. invicta* infestations, such as farm plots of less than 1 ha, rotation of farm land that includes flooding fields, and intermixed agriculture and urban areas.

Comments and considerations made herein are presented as part of my role as member of the Fire Ant Advisory Board. Together with comments from other members of this newly created Board, I hope my suggestions are received in a constructive manner and considered for implementation by appropriate policy makers and leaders involved in developing a plan by Taiwan's agencies and scientists to address this island country's serious threat.

The first efforts towards designing a program to address the *S. invicta* incursion in Taiwan need to focus on learning more about the strain(s) of this species that occur, and on conducting an active survey(s) to better delineate the extent of the infestations. The size of infested land is likely to be greater than is currently known; and the cost of the treatment and surveillance program efforts required will be directly proportional to land area involved. Securing collaborative relationships with appropriate agencies and scientists in areas where *S. invicta* already occurs is essential. The fire ant researchers at the USDA-ARS laboratory in Gainesville, Florida, can help instruct Taiwan personnel to collect and send specimens to determine: 1) whether populations are monogyne or polygyne or a mixture of both (Dr. Stephen Valles); 2) determine characteristics of cuticular hydrocarbone characteristic of certain strains in different geographical areas worldwide (Dr. Robert Vandermeer); and 3) determine if local populations of any of the locally occurring polygyne form of this species is infected with *Thelohania solenopsae* (Dr. David Oi). Fire ant quarantine program personnel at the USDA-APHIS laboratory in Gulfport, Mississippi (Ms. Anne-Marie Callcott) can provide assistance and guidelines for developing inspection and treatment protocols for Taiwan to help prevent further movement of this species in high risk articles such as nursery stock, hay and other materials capable of transporting mated queen ants or ant colonies. Regulation of high risk articles would be essential to prevent further man-assisted long-distance spread of this exotic invader.

Insecticide products and their registration by Taiwan's regulatory agencies such as the EPA must proceed with urgency to assure that appropriate tools are available to treat all suitable habitats. Although this species most commonly occurs in open sunny areas, they can occur underneath and inside buildings and even on rooftops where decomposing leaves and debris accumulates. Any soil is suitable habitat wherever it occurs including medians in roadways, forests, and sanitation dump sites. If all suitable and potential habitats are incapable of being uniformly treated, an eradication effort is unfeasible and the goal of efforts to address this incursion should be modified to that of containment or suppression using integrated pest management (IPM) approaches.

Commitment to eradication. In consideration of the options for addressing the currently known areas of infestation (e.g., integrated pest management or suppression, containment, or eradication attempt), only an intensive program aimed at eradicating this species from the island country of Taiwan will prevent this exotic pest ant invader from spreading to all areas of the country. Failure will quickly result in dramatic changes in the ecology (flora and fauna), economy and behavior of people working and living in infested areas (e.g., land use practices and ability to enjoy of the outdoors).

A commitment to eradication will require that all land areas currently infested, plus a 2 km area surrounding infested areas that may be in early stages of colonization by newly mated queen ants from mating flights, must be treated three to four times per year, with two treatments consisting of insect growth regulator products (e.g., pyriproxyfen, methoprene, or fenoxycarb) for a period of three years. Areass beyond the treatment area(s) should be actively surveyed for incipient or yet undetected infested land. Documentation of success should optimally include two years of intensive survey efforts following the three year treatment program to assure that no further *S. invicta* colonies are detected.

All agencies involved in managing or regulating land use practices (e.g., agricultural areas, urban areas, university grounds, parks, etc.) would be required to approve and commit to implement a uniform treatment plan and assure timely application of each treatment within the shortest possible time frame. Coordination of treatment and surveillance efforts must be managed and monitored by a central unit such as a Fire Ant Control Center. Sufficient resources must be committed to this effort, including, 1) funding over the course of the multi-year program; 2) personnel; 3) application equipment; and 4) ant control products.

Failure to eradicate the *S. invicta* from currently infested lands will occur if all infested areas are not treated. Viable ant colonies will remain in these areas to re-infest lands where the ants have been previously eliminated and the ant will continue the spread by mating flights or ground migration, spreading the infestation. This situation can occur when: 1) site use restrictions for ant control products prevent all infested land from being thoroughly treated; or 2) access to any infested land prevents thorough treatment. Application using a combination of ground application methods (e.g., hand-held seeders or vehicle mounted applicators) are less efficient and more costly than using aerial application. Serious consideration should be given to developing and using aerial application at least to agricultural lands and inaccessible or heavily vegetated areas.

Application of bait-formulated fire ant products requires training to evenly spread extremely low volumes of product to large areas of land. People involved in application must thoroughly understand the proper use of bait products and application. This requires training followed up with quality assurance. Use of volunteer labor or attempts to merely give bait products and equipment to land managers will most likely in result in failure to properly treat all infested lands. Use of a limited number of highly trained applicators is encouraged for ground application, including licensed professional pest control operators dedicated to implementing the *S. invicta* treatment program regime in urban and mixed agricultural areas.

Outreach education and public relations. Through active, aggressive public relations (PR) program efforts, everyone (including policy makers, leaders, and residents of agricultural and urban communities within and surrounding the treatment and surveillance area) must be engaged and informed of eradication program activities and be provided with realistic expectations (e.g., insect growth regulator treatments provide slow suppression and ultimately elimination while preventing further spread). Their support and participation by reporting suspect *S. invicta* colonies is essential to the success of this effort. This effort will enjoy a high level of accountability, not only in Taiwan but also in the rest of the world.

Product selection and treatment program. Although investments into introducing and establishing potential biological control agents (e.g., phorid flies, *Thelohania*) should be considered and initiated early, use of these agents would not result in eradication. However, they may offer long-term suppression and may be valuable to have available for release as soon as possible should eradication efforts fail. Contacts with U.S. scientists and regulators (Dr. David Oi and Ms. Anne-Marie Callcott) and utilization of local expertise such as Dr. Johnny Chen could help more quickly develop approval and provide inoculations of diseased ants for establishment in Taiwan's polygynous *S. invicta* populations. Eradication efforts in Queensland, Australia seem to be progressing successfully, although post-treatment surveillance efforts are only now beginning and some lands are continuing to be treated. Adopting applicable program elements from this example of an eradication program seem the best course of action.

A single broadcast application of an insect growth regulator (IGR) product at the recommended rate can provide slow suppression of a *S. invicta* population by reducing mound or colony numbers within the treatment area and number of foraging ants as assessed by food lures or pitfall traps. Colonies are eliminated because the queen ant(s) can no longer produce (sterile female) worker ants and their ovaries become reduced or non-functional for 12 to 18 months or more following ingestion of the active ingredient. Furthermore, winged reproductive female ants produced in IGR-affected colonies are reportedly sterile and any newly-mated healthy queen ant adopted by an IGR-treated colony also is affected through communal feeding (trophalaxis). Thus, IGR treatments, maintained over a sustained period both eliminate ant colonies slowly and prevent further spread or re-invasion of treated lands.

Two treatments per year will maintain colonies, with the active ingredient persisting in the bodies of surviving worker ants, not in the environment (IGR chemicals decompose within 7 to 14 days in the environment). These effects of IGR treatments observed elsewhere should be verified in Taiwan. Choice of the IGR product will depend mostly on label and use restrictions, cost, and availability, than active ingredients as they all have similar modes of action as juvenile hormone (JH) mimics or analogs (sometimes called "juvenoids"). Methoprene (e.g., Extinguish®) has the least use restrictions and could potentially be used beyond the edges of bodies of water); pyreproxyfen (e.g., Distance®, Esteem®) have urban and some agricultural site use clearance on U. S. product labels, but can not be applied to water. Fenoxycarb (Award®) use is somewhat restricted to urban areas, non-producing orchards and non-food horse pastures.

Other bait products are available that can provide faster suppression of *S. invicta* colonies and ant mound numbers in treated areas. In the southern U.S., broadcast-applied bait products offer 80 to 90 percent control per treatment within days (i.e., indoxacarb), weeks (i.e., spinosad, hydramethylnon, fipronil) that may last for months depending upon re-invasion pressure from untreated colonies occurring in surrounding untreated lands. However, colonies surviving treatment can contain reproductively healthy winged female reproductive ants capable of spreading the infestation or re-infesting previously-treated lands. For the third annual treatment in an attempted eradication program effort, any of these products may prove to be useful in increasing the rate of population reduction *when applied after an initial IGR treatment*, whether applied alone or as a "hopper blend" with an IGR, such as hydramethylnon plus methoprene or other suitable combination.

Contact surface-applied insecticides (e.g., fipronil), can provide maximum control 4 weeks after treatment for 12 to 18 months, but cost and site-use restrictions such as use around water edges will limit usefulness as a large-scale treatment. Such a treatment can also qualify for the third annual treatment in selected areas within an eradication effort. However, use of such a contact insecticide surface treatment should not be made until after an IGR treatment has been applied. Use of labor-intensive insecticide individual mound treatments (IMT's such as carbaryl drench, acephate 75% SP dust applications) should be minimized or possibly eliminated. Effectiveness of these products should also be verified in Taiwan and only proven practices incorporated into a treatment regime.

Further research within infested areas of Taiwan could help develop other treatment options before area-wide bait applications take effect and ant mounds become scarce. Although most of these research efforts should be dedicated to verifying performance of products proven to be effective elsewhere, new treatments options may include assessment of 0.3% fipronil and formulated insecticide as a *S. invicta* treatment for selected agricultural land areas. Furthermore, a conventional processed corn grit formulation of fipronil ant bait (Bayer's product, CeaseFire™), could be requested and tested to make it suitable for application with calibrated application equipment and as a possible substitute for hydramethylnon bait in a "hopper blend" treatment.

<u>Surveillance practices</u>.

Using visual, bait lure and pitfall trap methods as appropriate, active surveys of *S. invicta* population levels can be documented. As in Queensland, Australia, a sub-sample of land parcels (called infested properties of IPs) can be periodically monitored (i.e., quarterly) within infested treated areas to verify the impact of control measures implemented for each type of treatment regime and product combination applied. Additional assessment methods, such as examination of brood or larval type (i.e., worker versus reproductive brood) and condition of ovaries in queen ants extracted from IGR treated colonies can provide further evidence of treatment success. Furthermore, a sub-sample of properties within a treated 2 km "buffer area" around the known area of infestation, but not known to be infested, should be surveyed to document that additional spread has not occurred. Finally, active and passive surveys undertaken beyond the treated area will be useful to search for any additional areas of infestation currently not known. Use of a habitat model to select survey sites may be useful to search in the most likely habitats to make these efforts more efficient. Training swimming pool maintenance personnel to collect and submit any winged ant samples collected when cleaning pools can help document the occurrence of *S. invicta* mating flights. Informing construction company workers of symptoms of this ant can help increase awareness and detection.

Plans to implement an eradication effort should include funding support for personnel and equipment to continue active survey efforts for two years following termination of the treatment regime to provide documentation that no *S. invicta* are detected. Documentation of success is critical to the completion of any eradication program efforts.

Dedicated personnel (e.g., staff, volunteers or professional pest control operators) recruited to conduct surveillance must be properly trained and quality assurance efforts are needed to verify efficiency of these activities. Surveying areas where few, if any, *S. invicta* occur is challenging to almost anyone because of the nature of looking for the ants at length and finding nothing. Documentation of native ant species during this process can not only provide some rewards for participants, but also increase knowledge about native species, as well as their abundance and distributions. These data are also a critical part of any eradication program effort due to the importance of other ant species and competitors to *S. invicta*.

Mapping and data management. Due to the complexity of the infested environment infested by *S. invicta* in Taiwan, a data management system will be required to coordinate survey and treatment activities. Maps depicting infested properties, surveyed properties by surveillance method and treatment regime will provide documentation of program design, implementation and assessment. The system developed in Australia can serve as a successful model for the development of such a management system.

Regulation of high risk articles. There seems to be some hesitation to regulate the movement of nursery stock (e.g., potted plants, potting media or soil, mulch) in

Taiwan. However, the inspection and treatment of those items produced within infested areas and to be moved to locations outside of those areas is essential to: 1) prevent man-assisted movement of this invading ant species; and, 2) the success of any eradication program or containment effort. Movement of soil moving equipment or transport of any soil on pallets and other items in contact with soil in infested areas is capable of transporting queen ants or colonies. Regulatory procedures developed in the U.S. (USDA-APHIS) and Australia (DPI, FAC) can serve as models for developing similar procedures and practices in Taiwan.

Developing Taiwanese expertise. Should Taiwan elect to conduct an eradication program effort, sufficient resources and commitment should be provided or promised at the onset to personnel involved in order for them to complete the task. This commitment should allow for development of the program over the duration of at least a 3 year treatment phase plus a 2 year survey component for completing this effort. In addition, scientists involved in developing and implementing this program should be provided opportunities to visit other successful programs, particularly the ongoing effort in Queensland, Australia. Participation in the Annual Imported Fire Ant Research Conference in the U.S. would also be beneficial to establish personal working relationships with other scientists addressing this species.

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對台灣入侵紅火蟻疫情之防治建議書

2004 年 11 月

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我在 2004 年 11 月 7 至 10 日應邀前往台灣訪查入侵紅火蟻發生地區，個人在此特別感謝其間提供協助的所有熱心人士，他們提供了疫情背景、地區嚮導，同時和我在火蟻發生面積約 7000 公頃的三個重要地點共同討論防治計畫的可行性(及其限制因子)，這三個地點分別為(1)國立台北大學校區，(2)中正國際機場鄰近地區，及(3)中台灣嘉義縣的中埔鄉農業區。在本次旅程中，我觀察到和美國東南部及澳洲截然不同的土地利用形式，例如耕作面積小於 1 公頃的農地區劃、水田淹灌的輪作制度、都市與農業區域交錯的土地型態等，均為在火蟻發生區進行徹底藥劑處理的重大挑戰。

我在此處所作建議，部分係基於個人擔任紅火蟻防治諮議委員所扮演角色，希望在結合諮議委員會其他成員的建議後，能夠有建設性地被接納採用，以提供決策者與相關政府機關與研究單位人員在執行火蟻防治計畫時之參考，以有效因應島國面臨的重大威脅。

台灣在規劃紅火蟻防治計畫時，首先應進行的工作為確認目前本地發生的紅火蟻為何種品系(strain，未必為單一品系)，同時應進行主動調查(active survey)以界定發生範圍。依個人推測，實際發生紅火蟻面積可能大於目前所知區域，而進行藥劑處理及監測作業所需經費又與火蟻發生面積成正比。目前如何獲取和其他紅火蟻發生國家相關機關與研究單位科學家的合作關係非常重要，例如位於 Florida 州 Gainsville 市的 USDA-ARS 實驗室能協助與指導台灣人員採集與寄送火蟻樣品，以：(1)瞭解台灣發生的紅火蟻為單蟻后型、多蟻后型或是二者混合發生(可聯絡 Dr. Stephen Valles)；(2)鑑定表皮碳氫化合物特徵以與其他發生地區之火蟻品系進行比較(可請 Dr. Robert Vandermeer 協助)；瞭解本土所發生的多蟻后型族群是否已被微孢子病原 *Thelohania solenopsae* 所寄生(Dr. David Oi 協助) 。此外，位於 Mississippi 州 Gulfport 市的 USDA-APHIS 實驗室的檢疫人員(Ms. Anne-Marie Callcott)則能協助與引導台灣訂定適宜的火蟻檢查與檢疫處理方法，以防範紅火蟻藉

由苗圃植物、稻草或其他可夾帶交尾蟻后或蟻群的高風險物品向外蔓延。對高風險物品進行移動管制為推動防治計畫的重要基本措施，能避免火蟻以人為方式進行長距離的蔓延。

台灣必須迅速備妥處理藥劑及完成其於相關主管機關的註冊作業，以確保在所有的紅火蟻發生棲所都能有適用的處理藥劑。雖然紅火蟻發生地點多於開闊的晴照地區，但亦可在地底、建築物內部、甚至於落葉腐積的屋頂上發生，而無論在道路分隔島、森林或垃圾場的土壤皆為其合適棲所，如果可選擇的藥劑無法在上述所有可能棲所完成均勻處理(uniform treatment)，則撲滅計畫便不可行，必需將防治目標修正為採行綜合有害生物管理(IPM)的疫區圍堵或族群抑制。

撲滅計畫之成功要件

經考量在現有發生地區可能採取的選擇方案(如 IPM、族群抑制、疫區圍堵或進行撲滅)，惟有採行密集的撲滅計畫方為避免紅火蟻向全島擴散的唯一方案，倘撲滅目標於未來未能達成，入侵紅火蟻將造成本地環境生態、經濟活動及工作起居行為的重大改變(如農地耕作方式與戶外活動享受等)。

為使撲滅計畫奏效，藥劑處理區域必須包括現在<u>所有的</u>火蟻發生區，同時應向外涵蓋 2 公里環帶以將新交尾蟻后飛行蔓延的可能風險納入，藥劑處理須以三年為期，每年處理三至四次，其中二次係以昆蟲生長調節劑(IGRs)進行防治(如百利普芬、美賜平、芬諾克)，而在藥劑處理區外，尚應主動進行調查以找出初期發生或尚未查覺的火蟻發生點。此外，為能確認撲滅目標已達成，在進行三年的藥劑處理後仍宜持續為期兩年的密集監測作業，以確認紅火蟻不再發生。

所有涉及土地利用的主管機關(無論其管轄範圍為農業區域、都市地區、學校、公園等)，皆應批准與執行其防治計畫，俾於各該次藥劑處理的最短時間內及時將處理區內所有土地通通處理完成。而為能整合與協調各火蟻發生地區所進行的藥劑處理與監測作業，必須交付如國家紅火蟻防治中心的專責單位來負責統籌，同時亦須確保各項資源均可充分取得，包括：(1) 多年計畫經費編列；(2)人力資源；(3)施用機具；(4)滅蟻藥劑種類與數量。

如果無法完全處理火蟻發生區內的每塊土地，則區域內尚未處理區塊中的火蟻群仍將活存，進而感染已完成藥劑處理的區塊，或可繼續經由交尾飛行或地面遷移等方式蔓延，因此在該發生地區進行撲滅的防治努力將會失

敗。上述情況的可能發生原因為：(1)因為藥劑註冊尚未完成，因此無法處理<u>所有的</u>發生場所；或是(2)因為無法接近<u>**任何的**</u>發生地點，致無法處理完全。以後者而言，倘僅使用地面撒佈機具(如手動式或車架式撒佈器)較之空中撒佈效率低而費用高，因此台灣仍應嚴肅考慮針對農田、無法接近地點或高度覆蓋植被地區採行空中撒佈。

撒佈滅蟻餌劑應施以訓練，方能於大面積範圍內均勻施用極低用量的餌劑。由於操作人員須能充分瞭解正確使用餌劑方式並進行撒佈，因此在訓練後尚須接受撒佈作業品質確認(quality assurance)，倘僅囑付志工人員或逕將餌劑與撒佈器具交付相關單位自行施用，極可能無法於所有發生地點進行適當處理，因此建議進行地面撒佈時，應採精兵政策使用經高度訓練之專業操作人員，包括可委請持有執照的害蟲專業防治人員來參與都市地區或農地的火蟻防治計畫。

教育宣導與公關動員

應積極主動地進行公關宣導作為，以動員所有人(包括相關決策者、主導者、藥劑處理區及其周邊與監測區內的農民、社區民眾等)來全力參與火蟻防治計畫，並應宣導火蟻撲滅計畫的執行內容、過程與預期結果(如採行IGRs 處理之初期抑制效果較緩，但可有效防止蔓延並於最終達到撲滅效果)。而民眾發現與回報可疑蟻蹤的支持，更為獲致撲滅目標的基本要件，無論在台灣或世界各地均能可靠地享有這些公關動員後的回饋。

藥劑選擇與處理計畫

雖然在計畫初期便應有引進並建立火蟻天敵 (如蚤蠅、微孢子病原等)族群的規劃，但是利用這些生物防治體並無法達成撲滅目標。由於這些天敵具有長期抑制火蟻族群的效果，當撲滅目標無法達成時倘能儘速釋放天敵來進行抑制，亦將有其價值，因此台灣可考慮連絡相關的美國科學家與負責官員(Dr. David Oi 及 Ms. Anne-Marie Callcott)，並利用陳守中博士等本地專家以協助完成天敵審核作業，屆時方得及時釋放寄生物於多蟻后族群中立足寄生。雖然澳洲昆士蘭省火蟻撲滅計畫在藥劑處理後的監測作業伊始，甚至目前尚有少部分地區仍以藥劑處理，但由於現階段該火蟻撲滅計畫已見成功曙光，直接採用該撲滅計畫的可行架構似為當前台灣最佳行動策略。

以推薦用量的 IGRs 於藥劑處理區中進行單次撒佈，能夠逐步減少蟻丘

數目、火蟻族群與覓食蟻數量，這些慢速抑制效果可由進行食物誘餌與掉落陷阱監測得知。有關 IGR 處理後蟻群數量減少原因，係由於蟻后於攝入有效成分後可造成卵巢退化或失效達 12 至 18 個月以上，致無法再生產職蟻；甚者，報導指出經 IGR 處理蟻群所產生的有翅型雌蟻為不孕性，而新交尾蟻后在 IGR 處理蟻群中亦因分食作用(trophalaxis)而影響其生殖能力。因此，IGR 藥劑遂能以上述慢性消滅蟻群，及防止火蟻蔓延或再發生等二種作用方式，來維持其族群抑制效果。

一年兩次的 IGR 處理，可使藥劑有效成分存於殘活職蟻蟲體中持續作用，但不致造成農藥環境殘留(因 IGR 藥劑在環境中 7 至 14 天內分解)，這些作用方式應該也會在台灣驗證。選擇 IGR 產品時，因其作用機制均屬青春激素類似物(juvenoids)類之處理效果，使用上較少考慮有效成分種類，主要選擇考量為藥劑品牌、使用場所限制、價格高低及可取得性等。在 IGRs 中，以美賜平(如 Extinguish®)的使用限制最小，甚至可於水域的邊緣地帶使用；百利普芬(如 Distance®, Esteem®)依美國商標標示，可使用於都市地區及部分農業用地，但不能用於水域；至芬諾克(如 Award®)的使用則受限於都市地區、停產果園及畜養馬匹等非食用牧場等場所。

除 IGR 藥劑外，尚有多種餌劑可於藥劑處理區內快速達成火蟻抑制效果，例如在美國南部，施用撒佈型餌劑可於處理後數日內(如因得克)或數週內(如賜諾殺、愛美松、芬普尼)達到 80 至 90%的控制效果，效期約持續數月，維持時間端視火蟻族群由鄰近地點再次入侵的潛勢而定。但應注意，這類藥劑處理因非 IGR 作用，在處理區內逃過一劫的蟻群可產生具有繁殖力的有翅型雌蟻進行蔓延或於處理區內再度發生，因此在進行撲滅計畫時，仍***應先施以 IGR 餌劑處理後***再採用這類藥劑進行年度的第三次處理，如此即可加速降低火蟻密度。施用這類餌劑時，可以單獨處理或是採取與 IGR 藥劑混合之料斗拌合處理(hopper blend，如美賜平拌合愛美松)等適當組合。

另外其他尚有施於地面的觸殺型藥劑(如芬普尼粒劑)，能在施用 4 週後提供 12 至 18 個月的最佳控制，但經考量其價格及於無法於水域施用等限制因素，將影響其大面積的施用，惟仍可配合於撲滅計畫的特定範圍內進行第三次處理，但應注意此類觸殺式藥劑須配合於 IGR 處理後施用。此外，撲滅計畫中亦應儘可能減少或避免採用太過費工之個別蟻丘處理(如以加保利澆灌、施用 75%毆殺松可溶性粉劑等)，尤應先驗證各項藥劑處理之效能，有效者方能納入處理組合中。

在大面積餌劑奏效及蟻丘數量減少前，台灣仍應繼續研究各種可能的火

蟻防治藥劑，這些研究多為驗證已在其他地區使用過的藥劑種類，但仍可評估於選擇農地上施用 0.3%芬普尼粒劑與滅蟻劑型等本土配方。此外，亦可要求將傳統芬普尼玉米屑餌劑(拜耳公司產品 CeaseFire™)配方進行試驗，以調整於校準撒佈機具中使用，及作為在料斗拌合處理中愛美松餌劑的可能替代。

監測作業

適當地運用目視法、食物誘餌及掉落陷阱等方法，可主動掌握紅火蟻發生密度，例如在澳洲昆士蘭省，每季均定期在火蟻發生地點之地表採取子樣本(land parcels)進行監測，以驗證各種藥劑處理之執行成效。其他尚有包括檢視蟻群幼蟻形態(即比較職蟻與生殖型幼期)及檢測 IGR 處理後蟻后卵巢狀態等監測方法，亦能作為藥劑處理有效與否之佐證。此外，雖然在火蟻發生區周圍 2 公里的環帶區應無火蟻疫情，但仍應進行子樣本監測以確認紅火蟻並未蔓延。最後，亦應針對處理區外的其他地區進行各種主動與被動的調查，以找出其他未知的火蟻發生點，此時即可利用棲地模式先行分析找出最可能發生火蟻的地點，將使調查作業事半功倍。訓練游泳池維護人員在清理時收集及寄送有翅型蟻樣，有助於追蹤火蟻交尾飛行的情況；而對營建工程人員加強認識紅火蟻之教育宣導，亦有助於提高疫情警覺與強化監視作業。

在撲滅計畫中，應於執行三年藥劑處理後，再納入兩年執行主動監測調查的人員與設備經費，以確保紅火蟻真正滅絕，此為完成撲滅計畫的重要關鍵。

對於招募參與監測作業的專責人員(如職員、志工或害蟲專業防治公司人員)，亦應給予充分訓練，同樣採行品管查核措施以驗證其作業成效。在撲滅計畫後期中，針對極低密度發生區之調查作業極為辛苦，因為在該段期間火蟻行蹤難覓，此時可賦予監測人員調查本土螞蟻之任務，如此不僅可對工作有所報償，同時亦能增加研究人員對這些螞蟻的瞭解及其分布及數量。這些資料對撲滅計畫亦屬重要，因為部分本土螞蟻具備與入侵紅火蟻競爭的重要性。

地理資訊與數化管理

由於紅火蟻發生地區的環境複雜性，台灣將需要一個數化管理系統以整合各項調查情況與藥劑處理紀錄。此套地圖管理系統應能索引各火蟻發生地