# 1990-1992 PROJECT REPORT FOR THE VERO BEACH RESEARCH STATION

Robert C. Adair, Jr.

Vero Beach Research Station
of the
Kerr Center for Sustainable Agriculture
7055 33rd Street
Vero Beach, FL 32966

**As of January 2004 the Kerr Center's VBRS became the Florida Research Center For Agricultural Sustainability, Inc.**

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## STORY IN BRIEF

The primary activities of the Vero Beach Research Station (VBRS) are centered on developing and demonstrating innovative practices for Sustainable Agriculture. Great strides have been achieved in foliar feeding techniques and demonstration of a successful low-input management program for citrus production. As a result of these developments, the U.S. Fish and Wildlife Service has funded the VBRS to develop an IPM program for the citrus groves at the Merritt Island National Wildlife Refuge. Additional research funding was received from a company that produces a seaweed product for agricultural use. Areas where progress has been made is in improvements in the use of spray oils for pest control, evaluations of foliar fertilizers, and the agricultural benefits of seaweed. There have been significant challenges in using natural and nontoxic methods to control citrus pests, along with coping with a damaging freeze, a new insect pest, and lower fruit prices. It has also been a real test for us to maintain economical production levels in our groves while both meeting the agronomic needs of these growing trees with limited resources and conducting research on them. These limitations however, have required us to be creative and therefore helped to stimulate development of low-input practices out of necessity.

## INTRODUCTION

Continued progress has been made in the development of sustainable methods for citrus production, despite adverse weather conditions and challenges in the area of pest control. The VBRS experienced a 100 year freeze in December 1989 that delayed research efforts for a short period. In May 1990, the Apopka Root Weevil (*Diaprepes abbreviatus*) was found in the VBRS groves by the research station manager. This is the most destructive species of root weevil affecting citrus and was believed to be found in only a few isolated areas in Florida. Since the viability of the research station's 30 acres of citrus trees as well as groves in the state were at risk, research efforts were directed at controlling this lethal pest. Fortunately, a new company had just developed a new biological control product for root weevils using parasitic nematodes. By networking with the USDA, University of Florida, and the company's scientists, the latest and most promising biological control methods for controlling this insect are being applied to our grove as well as our cooperator's groves.

The efficiency of the nontoxic spray program to control the typical insect pests to citrus has received significant improvements since 1989. While it has proven to be almost impossible to control insect pests in our groves solely with natural and biological pest control strategies, spray oil has afforded us with an excellent non-toxic material for insect and fungus control while not affecting beneficial insect populations. Refinements have been made in the selection, timing, and application of spray materials. The nontoxic spray program was developed to address several compelling reasons to reduce the use of toxic insecticides in citrus groves. These include: increased restriction and regulation of the use of pesticides, development of resistance to pesticides, cost and energy savings, incompatibility with natural pest control measures due to disruption of beneficial insects populations, and the potential liability for pesticide use facing growers i.e. worker safety, effects on wildlife, and costly environmental clean up(Haney). Other regulatory concerns affecting growers is the issue of agricultural surface water runoff into the nearby Indian River Estuary meeting EPA standards. In an attempt to address this, we evaluated the possibility of using low-rate applications of foliar fertilizers to help reduce the amount of ground applied fertilizers. We are using composted horse and chicken manure in our groves and are looking at the economical feasibility for its continued use.

Our demonstration grove gives visitors an opportunity to see first hand, an actual economically productive citrus grove using low input management programs developed here at the VBRS. Nearby is the popular multispecies tree planting which features a variety of subtropical fruit trees including three species of banana trees, lychee, sapote, Persian limes, Robinson tangerine, Orlando tangelo, and Puerto Rican Red Papayas trees. Perhaps the interest here lies in the sampling of the tasty fruit that ripens throughout the year. Interplanted among the fruit trees are the resourceful neem trees also known as the toothbrush tree, Margosa tree, *Azadirachta indica*. The neem tree produces a powerful insect growth regulator (IGR) in the oil of its seed called Azadirachtin. Azadirachtin can be extracted from the neem seed oil with ethanol to produce Neem Seed Extract (NSE). Two companies currently are using the NSE as the basis for their insecticide product. There are two pesticidal aspects of this tree that are being studied here. Firstly, to determine the effectiveness of NSE as a insecticide for citrus. And second, to explore the possibility of interplanting Neem trees within our citrus grove as a potential double crop for Citrus (or other subtropical fruit trees or crops) that would serve as an insecticide source. This is frequently the missing link in most sustainable farming models. That is, for an insecticide to be sustainable, it must not only be effective, safe for the environment and man, and not disrupt beneficial insect populations, but be biologically renewable. Neem trees grown within an agricultural system could produce NSE thereby replacing the need for costly, industrially produced, toxic, petrochemical insecticides requiring large amounts of energy to produce, and distribute. Any excess NSE could be marketed for use in other agricultural crops. Another effect of Citrus-Neem tree interplantings being observed here are possible changes in insect populations found in citrus trees in close proximity to Neem trees. One could speculate that the presence of the neem trees growing in amongst the citrus trees could exert beneficial effects on citrus trees by serving as a natural repellant.

Several other growers are now using methods developed at the VBRS in their own groves. Also, the U.S. Fish and Wildlife Service have selected the VBRS to provide a low-input program for the citrus groves at Merritt Island National Wildlife Refuge that surrounds the Kennedy Space Center. Programs and projects over the last three years have included the following: a nontoxic spray program, a low-input fertility program, a compost demonstration project, a low-rate herbicide program, several seaweed studies, an evaluation of a nematode encapsulating fungus for the control of citrus nematodes, and root weevil control studies. Refinement of techniques is ongoing in the search for a sustainable agricultural system for citrus.

## STUDY AREAS AND MANAGEMENT

The VBRS is located in the heart of the noted Indian River citrus area on the east coast of central Florida. The climate is almost sub-tropical and has an annual rainfall of 49" per year and an average temperature of 72.5$^{o}$F. This affords a 365 day growing season except for intermittent freezes in the winter (three major freezes in the last decade). The VBRS includes 35 acres of citrus land divided into three groves or blocks designated the K-5, K-10, and K-20 blocks. We experienced a serious freeze in December of 1989 and many younger trees were killed and had to be replanted. Currently, the K-5 block contains 208 young and 85 mature Ruby Red Grapefruit trees along with 12 young and 110 mature Pineapple Orange trees. The young trees are grafted with Swingle citrumelo rootstock while the mature trees (75 trees/acre) are grafted with sour orange rootstock. As the older trees die or become unproductive, they are removed and resets are planted in their place. The K-10 block contains 1012 young Ruby Red Grapefruit trees on Swingle citrumelo rootstock (planted 140 trees/acre July 1987), and two acres of aged, nonproductive, Red Grapefruit trees that are projected for removal. The K-20 block contains 967 young Sunburst Tangerine trees on Swingle citrumelo (planted at 116 trees/acre in Dec. 1989) and 582 young Nova Tangelo trees on Cleopatra mandarin rootstock (planted at 140 trees/acre in May 1989) serve as pollinators. (For a more detailed site description see ref. 9)

Maintaining proper drainage is necessary in the flatwoods soils of Florida because of the high water table (36"-42" avg.). Citrus trees cannot tolerate wet roots and therefor are planted on beds with water furrows between. We installed PVC monitoring wells to measure the surficial groundwater level. Furrows are mowed and periodically reshaped to maintain good drainage.

We use a micro-irrigation system to provide water to the trees efficiently during dry periods. While Florida has abundant rainfall, it also has sandy soils that do not have high water holding capacities. The trees require regular irrigation for optimum yields. Irrigation is scheduled by using tensiometers and examining the feel and appearance of the soil. Currently, we irrigate the groves with water from an artesian well. However, the quality of the well water has been declining, and other possible sources are being investigated. One possibility is the reuse of treated wastewater from a nearby mobile home park.

Florida soils are characteristically sandy and low in fertility (11). This represents a challenge to any fertility program especially a sustainable one where nitrate levels must be low enough to avoid ground water contamination and still maintain economical production rates. Studies in California have shown practically no increase in groundwater contamination due to nitrates associated with foliar applications of nitrogen (4). Nitrate levels in groundwater were minimal with annual applications to the soil at less than 89 lbs. per acre of nitrogen. The balance of the nitrogen requirements were met with foliar applications without affecting fruit quality or yield (4, 5). Therefore to test these recommendations on Florida soils we reduced our soil applied nitrogen rates to 90 lbs. per acre applied by fertigation with the balance applied foliarly. Additional nutrients were applied by bioinjection and compost applications. Bioinjection is the injection of small amounts of biological materials such as bacteria, fish emulsion, humates, and seaweed into the irrigation system. Fertigation and bioinjection make use of the irrigation system to efficiently distribute nutrients precisely to the root system of each tree. Dry synthetic fertilizer is not used.

Pests are controlled as much as possible using natural and biological methods. Parasitic nematodes, *Steinernema carpocapsae*, (Biovector) are applied twice a year through the irrigation system for root weevil control (16,19). *Bacillus thuringiensis* (BT) is used to control orangedog (*Papilio cresphontes*) larvae. If insects reach economic thresholds as determined by scouting, non-toxic pest control sprays (generally spray oil) are applied with the air blast sprayer. The VBRS combines pest control applications with foliar fertility management into a collective program called the Nontoxic Spray Program. This is done for two reasons. Firstly, to achieve as many benefits as possible from a single spray application since the same sprayer is used for both foliar feeding as well as pest control sprays. And secondly, there is the reported benefit that by enhancing and maintaining optimum nutritional levels, the tree can resist insect and disease pressure.

Typical weed control measures include five applications per year of glyphosate (Roundup) under the trees. This is required to allow for an unobstructed irrigation emitter pattern and to control the rapid weed growth typical of a subtropical climate. Recently planted trees are treated with norflurazon (Solicam) a preemergant herbicide once a year for the first three years. We use a low rate herbicide program to cut down on herbicide costs. Bed middles are mowed periodically.

Mature trees are hedged and topped in alternate years and skirted every other year. We have found that skirting eliminates easy access to the canopy by root weevils, and allows for an unobstructed irrigation emitter pattern by removing the lower branches touching the ground. We hand prune and remove sprouts from young trees. Dead wood and broken branches are removed by hand to reduce the sites where melanose spores inhabit. Harvesting is done by local pickers that are hired by the buyer of the fruit. Currently most fruit is marketed as fresh, some of it being exported to other countries.

Additionally, the VBRS exports its proven sustainable management programs into cooperators' groves such as those at MINWR and Cook Citrus Groves. In return some of our cooperators allow us to use a portion of their groves to conduct testing. The site for the seaweed study located in St. Lucie County is a cooperator's grove. Briefly, this grove consists of Hamlin orange trees, an early season juice orange, grafted with a sour orange rootstock planted in 1975 on a double bed configuration (12.5 x 25'). The predominate soil type is mostly Winder loamy sand with a small proportion of the site being Winder sand, depressional. The grove was well maintained using conventional management for juice oranges and a micro-irrigation system provided water to the trees on a timely basis.

The Vero Beach Research Station has continued to develop and refine the demonstration programs that were reported in the 1986-1989 Project Summary (9). Much of the recent work has centered on improving spray application techniques and evaluating more effective foliar fertilizers and insect control materials. Techniques learned in foliar feeding have increased the efficiency of pest control sprays, as well. The combination of adding the right adjuvants with the right materials in conjunction with equipment designed to improve coverage has resulted in better insect and disease control, enhanced tree response to foliar feeding, and more efficient weed control. We are continually experimenting with cultural practices and looking for ways to improve them to develop more sustainable methods. Problems that arise in our grove, become new opportunities to seek out solutions that can be passed on to other growers.

## METHODS

### Nontoxic Spray Program

The Nontoxic Spray Program began development in 1988 in the K-5 block by eliminating the use of synthetic insecticides. Spray applications are made with a PTO powered airblast sprayer (Rear's Power Blast PB-500) on all the trees except the smaller tangerine and tangelo trees in the K-20 block where a spray hoop was used. The hoop encircles each tree with a dense spray that produces excellent coverage and by means of a switch avoids wasted spray between the smaller trees. Fertilizer sprays are applied to the leaves according to the tree's nutritional status as determined by leaf analysis. Oil sprays are applied to control insect pests common to citrus according to the level of insect pressure as determined by scouting. Two fungus diseases, greasy spot and sooty mold are also controlled by oil. Copper sprays are applied in a timely fashion to control melanose which is a fungus that blemishes the rind of the fruit and lowers the grade of the fruit. Each year it continues to be improved in the following areas: application methods and materials selection.

*Application methods:* Since better spray efficiency and coverage would increase the effectiveness of both foliar fertilizers and pest sprays, the following application methods were evaluated:

1. Nozzle selection- Three nozzle designs which produce hollow cone spray patterns were studied. Stainless steel and ceramic disc-core type nozzle and ceramic ConeJet nozzles (Spraying Systems Co.) were used for at least one spray season each. Each nozzle type was visually assessed as to the rate of wear, spray pattern uniformity, and droplet size.
2. Application rates- Spray volumes were compared from 500gpa to 25gpa by adjusting the ground speed, pressure, and nozzle orifice diameter. Various nozzle arrangements were tried.
3. Sprayer modification- two new nozzle manifolds were added to each side of the sprayer. This increased the number of nozzles on the sprayer by three times. By using more nozzles with smaller diameter orifices, we can increase the number of spray droplets and decrease the droplet diameter without increasing the spray volume per acre.

To help us select for the best spray patterns produced from these various combinations described, we used water sensitive paper (Spraying Systems Co.). Twenty two water sensitive papers, 52x76mm were stapled to leaves throughout the canopy of a mature Red Grapefruit tree. Water droplets which impacted the paper produced a color change that enabled us to visually evaluate the spray pattern in terms of droplet size and uniformity. By trial and error we evaluated different nozzle configurations, sizes, arrangements, and application rates to arrive at the best combination producing the best coverage.

*Spray materials selection:* All spray materials were tested for phytotoxicity, effectiveness, application rates, and compatibility. Two basic categories of spray materials were evaluated: nontoxic pest control materials and foliar fertilizers. Pest control materials evaluated include four different petroleum spray oils (Table 1), Safer Insecticide Concentrate (now called M-pede, Mycogen Corp.), Bt products (DiPel 2X, Condor OF), and Agrimek, a bacterially produced miticide/insecticide. Spray oils were applied to bearing trees at rates ranging from 1 to 8 gals. per acre. The spray oil rates for resets and non-bearing trees were applied to run off and are reported as a percent of solution (v/v). This is due to large variation in canopy volume. Oil and Bt applications were made at spray volumes of 477 gpa for dilute sprays and 250, 125, 75, and 50 gpa for concentrate sprays. Safer Insecticide was applied at 1 and 2% rates (v/v). Agrimek was applied at the label rate of 10 oz. per acre with 8 gal. of Sun 9E spray oil at 477 gpa. As insect pest populations reached easily detectable levels throughout a particular block, they would be challenged by the appropriate pest control material. The effectiveness of the pest control spray was determined by scouting. Photographic slides were taken with the aid of a stereo microscope of the insect pests to document the effect of the sprays.

**Table 1. Petroleum spray oils**

| Product | 50% Distillation Point | Percent by wt. Emulsifier | Duration on Leaf (6, 23) |
|---|---|---|---|
| SunSpray Ultra-Fine™* | 414°F | Sun Oil, 1.2% | 3-4 days |
| SunSpray 6E[x] | 412°F | Sun Oil, 1.2% | 3-4 days |
| 435 Petroleum Oil[y] | 435°F | 1.0% | 10 days |
| SunSpray 9E[x] | 455°F | Sun Oil, 1.2% | 6 weeks |

*Mycogen Corporation, [x]Sun Oil Company, [y]Manufacturer not specified

Foliar fertilizers (Table 4) were evaluated for their effectiveness by performing leaf analyses before and after their application. Visual observations to indicate mineral deficiencies such as leaf color and leaf patterns were made between treated and untreated sites. Some materials were evaluated as to their ability to increase the brix content of the juice. All sprays were observed as to pH, presence of precipitates, and phytotoxicity. Fertilizer combinations producing precipitates were recorded.

**Low Input Fertility Program**

The low input fertility program is a demonstration of a combination of fertigation, broadcast spreading of broiler chicken manure, and foliar feeding. No synthetic or conventional, dry fertilizer is currently used. The goal of this program is to demonstrate alternative fertility methods that minimize the leaching of nutrients that occurs with the application of large quantities of ground applied fertilizers. Approximately 40% of nitrogen recommended by IFAS (11) is applied by fertigation with the remainder provided by the chicken manure. All the secondary and micronutrients are applied foliarly using an air blast sprayer on mature trees and a hoop sprayer on young trees. Use of manure by growers helps solve the current poultry manure disposal problem while increasing the fertility of the soil in the groves. On mature trees in the K-5 block we applied 2 tons/acre in 1990, 3 tons/acre in 1991, and 4 tons/acre in 1992. Production and fruit quality records were maintained during the evolution of this program including the early years when conventional dry fertilizers were used.

**Compost Demonstration Project**

The compost demonstration project uses horse manure and bedding from nearby stables that was formerly being sent to a landfill. This material is windrowed on an unused bed. It is turned periodically with a tractor mounted tiller. After composting, we spread the material around young trees (1-4 yrs.) at the rate of 42 lbs/tree (2.5-3 tons/acre). Samples are also given to other growers who want to see firsthand the benefits of compost. Also as part of this project, a local organic grower in cooperation with the VBRS tested the effectiveness of a commercial inoculant to improve the composting of wood chips, lawn clippings and other yard waste materials.

**Low-rate Herbicide Program**

The low rate herbicide program has continued to be refined. We continually evaluate new adjuvants as they become available. Organo-silicone surfactants have recently been tested as an alternative to the current penetrants and surfactants. The current mix is detailed in Table 2. Herbicide applications are required five times each year. This results in a pH of 5.0 for the herbicide solution.

**Table 2. A recommended tank mix (100 gal) for Roundup herbicide using low-rate technology.**

| Product | Amount | Rate/Acre |
|---|---|---|
| EDTA | 1.0 oz | |
| Ammonium Sulfate | 17.0 lbs | |
| Roundup (1.5 qt/ac)* | 2.5 gal | 1.5 qt |
| Organo-silicone surfactant[x] | 12.0 oz | |
| Add water to equal | 100 gal | |

*The final herbicide solution is applied at 15 gpa which results in 1.5 qt of Roundup applied per acre.

[x]Examples of Organo-silicone surfactants include Silwet L-77, Kinetic, and Herbex.

**Seaweed Studies**

This study focused on the potential economic benefits of using Soluble Seaweed Extract on juice oranges. In this study eight 7-acre blocks of Hamlin orange trees on sour orange rootstock were divided into two groups of four blocks each. The blocks were grouped according to previous production records so that each group produced the same average fruit crop in boxes per acre. The control group received the standard foliar fertilizer treatment, while the seaweed group received the same treatment plus seaweed extract at the rate of 1.25 lb per acre. Five applications at 20 gpa over a period of a year were applied. Leaf samples were taken before any fertilizers were applied and again after the last application. These samples were then tested for mineral content. Yield and juice quality data were obtained from grower furnished harvesting records and state juice inspection certificates respectively.

**Nematode Encapsulating Fungi Study**

We evaluated a commercial product (Nemout) containing a parasitic fungus that has been shown to control nematode pests (16). We selected as a test site a two-acre section of grove containing 120 mature Red Grapefruit trees infested with citrus nematodes (*Tylenchulus semipenetrans*). Ninety trees received the beneficial fungus treatment by injecting it into the micro-irrigation system. Each tree had one irrigation emitter capable of wetting a 22-foot diameter pattern. Thirty trees were blocked off from the rest of the irrigation system to serve as a control. We dissolved 0.5 lb of the product into 30 gallons of water. The entire amount was injected into the irrigation system at a rate of 1.5 gallons per minute and thereby applied to the ninety trees. After injection the system was allowed to run for one hour to flush the lines and water the material into the ground. After 30 days, we applied another identical treatment. The application rate was 0.64 lb. per treated (wetted area times 90 trees) acre for each application. Root samples were taken one week before and two weeks after the second treatment. Pioneer Laboratory in Ft. Pierce weighed and microscopically examined the roots and counted the nematodes in each sample.

**Root Weevil Control Study**

After the discovery of the Apopka Root Weevil, several methods were used in an attempt to control this pest. One popular method uses a biological control product (Biovector) containing a beneficial nematode (*Steinernema carpocapsae*) (19). Treatment consists of injecting live nematodes into the irrigation system. Another possible means of biological control makes use of a parasitic fungus (*Beauveria bassiana*) (13). This method is still in the developmental stage and is not yet available for large scale research use. The use of NSE as an insect growth regulator is also being challenged as a possible method of control. Root weevils are collected and sent to the University of Florida Citrus Research and Education Center in Ft. Pierce. The USDA in Orlando is also participating in the effort to combat this serious pest.

## RESULTS

**Non-toxic spray program**

Various investigators (3, 14, 20) have indicated that good coverage improves the effectiveness of both foliar feeding and pest control. Furthermore, it has been documented that as spray volume per acre is reduced, so are energy costs in terms of application and pesticides reduced (8). To improve coverage at lower spray volumes i.e. concentrate sprays, it is necessary to decrease the droplet size. We have observed that concentrate sprays improve the efficiency of leaf uptake of foliarly applied fertilizers. Apparently a high concentration of nutrients on the outside of the leaf drives a greater amount into the leaf by diffusion. This is the same mechanism for the response we see in the Low-Rate Herbicide Program where lower gallons of water applied per acre at equal rates of herbicide produces a better response. Possibly some of the poor responses some investigators have observed with foliar feeding have been due to applications at too high a spray volume (i.e. too dilute). Therefore our goal was to achieve the best possible foliar coverage at the lowest spray volumes per acre. To do this we had to decrease the droplet size, decrease the nozzle orifice diameter, and increase the number of droplets.

Initially we used stainless steel discs and brass cores as spray tips. When we decreased the nozzle diameter and increased the pressure, there was a dramatic increase in wear on the brass core. Trials using hardened stainless steel cores and discs resulted in rapid wear also. This made accurate calibration difficult. Replacement with ceramic discs and cores virtually eliminated wear and also produced a more uniform pattern. The only drawbacks were their susceptibility to breakage and difficulty in seeing the size number on the disk or core. The use of the ceramic conejet nozzles eliminated both these problems since they came with a color coded plastic body. Besides being easy to use, they produced excellent patterns and had smaller average droplet sizes.

To achieve maximum spray distribution throughout the tree, nozzle arrangements were made so that two-thirds of the spray volume was directed to the top half of the tree and one-third was directed to the bottom half (10). To do this, nozzle sizes were increased as they were placed from the bottom of the manifold to the top of the manifold. This directed larger droplets with more momentum towards the top of the tree since they have to travel greater distances and large droplets are less subject to evaporation.

We made significant improvements in our concentrate spray coverage by adding two new nozzle manifolds to each side of the sprayer. This tripled the number of nozzles and allowed us to dramatically decrease our nozzle size with the resultant decrease in droplet size while still applying the same amount of spray volume per acre. By comparing the spray patterns produced on water sensitive papers with one manifold against our modified triple manifold, a dramatic improvement in coverage was observed.

The last parameter in the improvement of application methods was to select a suitable concentrate spray volume per acre using our new manifold assembly fitted with the conejet nozzles. Ultra-low application rates can be troublesome in hot or dry conditions due to evaporation of fine spray droplets and clogged nozzles becomes a problem as sizes are reduced. Also the volume of water necessary to dissolve the spray materials ultimately limits the spray volume applied. Conversely at high spray volumes, efficiency decreases as excess water runs off the leaves, droplet size increases, and fewer acres can be sprayed per tank. We found that to spray mature citrus trees (16-18 ft. Ht.) that our best concentrate coverage was achieved at seventy-five gallons to the acre at 2.0 mph. This spray volume was ideal for applying foliar fertilizers. Using these modifications, spray applications produced clouds of small droplets that resulted in better contact with the underside of the leaves. This is the primary area of leaf uptake (7, 14). Also concentrate applications of copper sprays for fungus control and other pesticides were very effective at this rate. However, concentrate applications of spray oils were only marginally effective and never gave the excellent results that the dilute (477 gpa) sprays did.

The nontoxic spray program addresses two distinct fields of agriculture in one spray program, pest control and fertility. The first is by the timely use of pest control sprays to directly reduce pest levels and the second is to provide the tree with proper nutrients at the right time via foliar feeding to decrease our use of ground applied fertilizers. The materials selected for use in our nontoxic spray program are divided into two categories for discussion and they are pest control materials and foliar fertilizers.

**Table 3. Citrus pests controlled by 455 Spray Oil**

| Type of Insect |
|---|
| Armored Scales (Glover, purple, chaff, yellow, red, and *dictyospermum* scales) |
| Whiteflies |
| Spider Mites |
| Rust Mite |
| Mealy Bugs |
| Aphids |
| Sooty Mold |
| Greasy Spot |

*Source*: Davidson et al., Univ. Calif., Agric. Nat. Res., Publ. 3347 (1991); Fisher, Citrus Industry 68(7):27-30, (1987); and Trammel and Simanton, Proc. Fla. State Hort. Soc. 79:12-18 (1966).

*Pest control materials*

The VBRS has been using petroleum spray oils to control citrus pests since 1988 (9). We have found spray oils to be effective insecticides (Table 4), good fungicides (sooty mold and greasy spot), easy on beneficial insects, safe to handle, and unlikely for insects to develop a resistance to it. Spray oils kill insects by blocking the exchange of respiratory gases at the spiracles or more simply, by suffocation (17). Therefore the oil must make good contact with the insect. We have found that dilute applications of oil consistently produces the best results as an insecticide. While our concentrate sprays described above performed well for all our other spray materials, oil sprays were the single exception. To explain this observation, we need to understand how spray oils are mixed and what happens when they are applied. Spray oils contain emulsifiers that allow them to be mixed with water to produce a milky white solution called an emulsion. This emulsion is designed to "break" or separate into oil and water after first coating the fruit or leaf. As the water runs off the leaf, the oil coating remains. Good coverage is assured only when trees are wetted to runoff and a large volume of spray solution is necessary to thoroughly wet the entire tree to runoff. This volume is dependant on the size of the trees being sprayed. This required spray volumes of 477 gpa for 16-18 ft. tall grapefruit trees at the VBRS.

We compared three different spray oils with the industry standard 435 Petroleum Oil (Table 1). The following reported characteristics were generally confirmed by use in our groves. The heavier (higher distillation point) oils possess greater insecticidal qualities and are better at controlling greasy spot (6, 23). The heavier oils also remain on the leaves longer (6). These qualities make the 455 oil a good choice for use in the summer oil spray where rust mites and greasy spot are the principle pests. The lighter oils are less phytotoxic and are safer to use particularly in the spring and fall. We have applied SunSpray Ultra-Fine Oil™ in the spring at 2.5% v/v to resets with tender young leaf flushes to control aphids with acceptable results. The 414 oil is a highly refined oil and produced excellent results for aphid control at even higher oil volumes but it costs three and a half times more than the 412 oil. The use of 435 oil was replaced by the more effective 455 oil in our program. The application rates we used in our summer oil spray was eight gallons of 455 oil in 500 gal. This spray mix (1.6% oil v/v) was applied to all tree sizes. The spray volume applied per acre was proportional to the size of the tree. All trees were sprayed to runoff. The duration of mite control varied according to weather conditions and to rust mite population levels before application. In general it was not unusual to receive mite control for 45 days. Duration of control was significantly reduced when applied to high populations.

Precautions to take when applying spray oils include:

1) Be sure a good emulsifier is present at 1% wt./wt. or higher
2) Do not apply to temperature stressed trees (avoid sprays above 90$^{o}$F)
3) Do not apply to drought stressed or stressed trees in general
4) Do not apply with or near sulfur applications (or other materials incompatible with oil)

Other insecticides used were various Bt products which all gave excellent control of orangedog larvae but the duration of control only lasted a few days or until rainfall. Insecticidal soaps were tried on aphids with marginal success. Due to our hard water (1,550 TDS), expensive compatibility agents were required. Oil proved to be a much better choice.

Oil sprays are effective at controlling citrus pests (Table 3) although multiple applications are required. By using the 455 oil, rust mite control can be extended to 45 days. For growers requiring a minimal number of trips through the grove, we recommend the addition of Agrimek to their summer spray oil application. The material works together with spray oil, and protects the fruit up to four times as long as spray oil alone. While this material might not be called nontoxic, it is less toxic than conventional methods. In any event, it is effective as a miticide and insecticide and is compatible with IPM as it does not harm beneficials.

*Foliar Fertilizers*

Countless foliar fertilizers and nutritionals confront farmers claiming to increase growth, yields, and fruit quality. The VBRS' primarily interest in foliar fertilizers is as a means to decrease the amount of ground applied fertilizers to minimize their leaching and presence in surface runoff (4, 5). Due to the large variety of fertilizer choices available for foliar application, we selected materials successfully used on citrus and other crops (7, 12, 14, 20). As indicated in the methods section, evaluations were made and recorded. Materials producing a positive response are summarized in Table 4.

Fertilizers that displayed particularly good responses as determined by leaf analysis were urea, N-Sure (Trizone nitrogen), potassium phosphate (hot mixes), potassium nitrate, magnesium nitrate, and solubor. Some comparisons were made between different chelated micronutrients and are presented in Table 5. The data here indicates all three iron chelates increased leaf iron levels. The effectiveness of foliar uptake can be enhanced by the addition of urea, lowering the pH of the spray solution, the use of silicone surfactants, and the already described use of concentrate spray applications (7, 14, 15, 20). These modifications were used by us except that we routinely applied seaweed with the fertilizers and in particular, the potassium phosphate fertilizers. This was done since seaweed is a natural source of nutrients and contains plant growth regulators (PGR) (18). PGR's have been reported to increase the uptake of nutrients by leaves but the evidence is limited (7).

**Table 4. Materials demonstrating agronomic potential as foliar fertilizers**

| Fertilizers | Chelated Nutrients | Organic Nutrients |
|---|---|---|
| Ammonia | Calcium Glucoheptanate | Fish Emulsion |
| Urea | Calcium Trihydroxyglutarate[y] | Seaweed Ext.[+] |
| N-Sure* | Zinc Citrate | Humates |
| Monoammonium phosphate | Zinc Glucoheptanate | Sucrose |
| Potassium phosphate[x] (Hot Mix) | Zinc Metalosate[z] | Dextrose |
| Potassium nitrate | NZN* | Molasses |
| Calcium nitrate | Iron Citrate | Corn |
| Steepwater | | |
| Magnesium nitrate | Iron Glucoheptanate | |
| Ammonium Thiosulfate | Iron Metalosate[z] | |
| Zinc sulfate and nitrate | IronPlex | |
| Manganese sulfate and nitrate | Manganese Citrate | |
| Solubor | Manganese Glucoheptanate | |
| Boric Acid | Manganese Metalosate[z] | |

*Arcadian Corporation, [x]Na-Churs Plant Food Co., [y]Nutri-Cal, [z]Albion Laboratories, Inc., [+]Acadian Seaplants, Ltd.

**Table 5. Effect of foliar applications of iron chelates on iron content of spring flush grapefruit leaves.**

| Treatment* | Application Rate/Acre | Increase in Iron Content of Leaf ($\mu$gFe/gm dry wt.) | % Increase of Control |
|---|---|---|---|
| Control | - | 18 | 0 |
| 5% Iron Glucoheptanate | 3 qts | 65 | 261 |
| 5% Iron Metalosate | 2 qts | 62 | 244 |
| 6.25% IronPlex | 3 qts | 54 | 200 |

*All sprays contained 2.5 lbs. Urea/50 gal. and were adjusted to pH 6.6 with Citric Acid. Spray Volume = 30 gpa

The presence of carbohydrates (sugars) may seem puzzling at first but it should be noted that carbon is required by plants in far greater quantities than nitrogen. The carbon in sugars represents another form available to plants besides carbon dioxide. When these materials were applied with other fertilizers, a 10-15% increase in brix was observed in ripening grapefruit. However the greatest response for these materials most likely will be their use in bioinjection and is discussed below.

Further work developing fertility programs where higher amounts of nitrogen are applied foliarly with proportionally decreasing quantities of ground applied nitrogen are warranted. Also studies comparing the effectiveness of different fertilizers applied foliarly. For example which nitrogen source is most readily taken up by the leaves and which is the most economical.

**Low input fertility program**

The rate of nitrogen applied by fertigation has been cut 50% since 1989 to 90 lbs. per acre. We feel that with an irrigation system that provides a good wetted pattern to the root zone, growers can get by with less fertilizer with fertigation due to more efficient nutrient utilization. This efficiency is due to the fact that the fertilizer is applied directly to the roots, it is already dissolved in water so it is rapidly absorbed by the roots, it is not likely to be washed away by heavy rains, and it can be applied in several applications according to the nutrient needs of the trees. Bioinjection which has been described earlier (9) continues to provide valuable nutritional benefits to our groves. A new material, corn steepwater, which is a waste product from the production of corn syrup and corn sugar, has produced excellent microbial responses when injected. By providing soil bacteria with a large source of carbohydrates, their population levels increase exponentially. As they out strip their food supply, they die and decompose providing the tree roots with a readily available supply of naturally produced nutrients. This same response can be produced with the other organic nutrients listed in Table 4.

The use of conventional dry fertilizer has been replaced by two applications of chicken manure at two tons per acre. Good growth responses have been observed after these applications. The greatest responses have been observed in young trees (1-5yr.) which received 40 lbs. of manure per tree. At 100 trees per acre, this also would be two tons per acre. The difference was that the manure was shoveled directly onto the rootzone by hand. Broadcast application to the mature trees at the same rate resulted in a much thinner application and consequently a more subtle response. The main drawbacks were the potent odor which without rain lasted a week and it is subject to loss by heavy rainfall. It has some of the same environmental vulnerabilities as dry fertilizer, namely nitrate leaching in ground water and nutrients in surface water. However with moderate rainfall the odor quickly dissipates and the valuable nutrients (Table 6) are slowly moved through the soil to the tree roots.

**Table 6. A typical analysis of chicken manure as applied (34.4% moisture)**

| Primary & Secondary Nutrients | (lbs/ton) | Micronutrients | (lbs/ton) |
|---|---|---|---|
| Nitrogen (N) | 46.2 | Iron | 1.62 |
| Phosphorus ($P_2O_5$) | 51.3 | Manganese | 0.35 |
| Potassium ($K_20$) | 37.8 | Copper | 0.43 |
| Sulfur | 6.8 | Zinc | 0.35 |
| Magnesium | 6.0 | Sodium | 7.1 |
| Calcium | 31.6 | Aluminum | 1.0 |

As a result of the techniques that have been developed, as described earlier, foliar feeding is now an integral part of the fertility program. Primary, secondary, and micro-nutrients are all applied foliarly. Foliar applications of 3-18-18 hot mix liquid fertilizer, increased leaf concentrations of phosphorus and potassium. N-Sure increased leaf N higher than urea when applied at equal amounts of nitrogen. N-Sure applied with seaweed in the summer oil application produced strikingly deeper green foliage. Iron chelates when applied to an expanding flush have dramatically increased leaf iron levels (Table 5).

This fertility program plus the use of these foliar materials new to citrus have increased our yields while decreasing the amount of applied fertilizers (Table 7). Our grapefruit yields have increased 38% since 1989 and the pounds solids per tree (lbs. solids times the number of boxes per tree) for oranges have increased 29%. We feel that our ground applications of fertilizer chicken can be dramatically cut back by increasing the amount of foliarly applied N without significantly affecting our yield. This would further reduce any adverse environmental effects due to nitrates leaching or their runoff in surface water. Further testing is required to substantiate this.

**Compost Demonstration Project**

The compost demonstration project has continued to provide a cheap source of nutrients for our young trees. Application of the compost, unfortunately, is labor intensive. The initial test using an inoculant was inconclusive. The grower who tested the inoculant could see no difference in decay rate or quality between inoculated compost and compost made without inoculant. It may be that Florida's hot, humid climate may make inoculants unnecessary in some cases. Soils here are typically very low in organic matter, due to the rapid natural decay rate making compost applications a continual process.

**Low-Rate Herbicide Program**

This program is currently being followed by growers. A fact sheet providing a step by step guide describing how to implement this program has been completed and is being distributed. New developments have been made in surfactant technologies with the availability of the new organo-silicone surfactants. We have found that just 12 oz. per 100 gal. of spray solution of these powerful surfactants produces the same excellent results as our earlier reported choice of surfactants (9) and costs less. Table 2 gives our current recommended spray mix.

**Seaweed study**

In the seaweed study there were significant increases in individual fruit weight 8.1%, % juice 0.5%, % soluble solids 0.8%, acid 1.5%, and soluble solids per box (1.3%). The soluble solids/acid ratio decreased (0.7%). There was no significant increase in the number of boxes harvested per acre. Leaf samples were taken in September, before and after the four spray program, and were analyzed for mineral content. There were no significant differences in leaf mineral content from the seaweed treated blocks vs. the check blocks although elevated iron levels were observed in the seaweed treated blocks.

**Nematode Encapsulating Fungi Study**

The results of the study showed a dramatic decrease in the number of citrus nematodes in samples from the treated area when compared to the number found in samples from the control block. Details of the results will be made in a separate report. This product could provide a safe alternative to using conventional toxic chemicals for nematode control.

**Root Weevil Control Study**

The Apopka Root Weevil has proven to be an extremely difficult insect to control. This is due to the prolonged time (8-24 mo.) the larva spends underground feeding on roots. A second complicating factor is that adult emergence occurs throughout the year, making the use of adulticides impractical. The devastating effects of this insect pest are evidenced by the fact that three larvae per tree can kill a young citrus tree. To put this in better perspective, an adult female can lay up to 5,000 eggs in a lifetime. With a 1% survival rate, that would be 50 larvae. At the VBRS we have counted 27 larvae in 10 sq. ft. under one side of a three yr. old tree. This problem is at the forefront of our research efforts. Unfortunately the results of the parasitic nematodes applications have been inconclusive.

**Table 7. VBRS demonstration grove production records (K-5 Block)**

Pineapple Oranges (50-year old on Sour Orange Rootstock)

| Crop Year | Number of Trees | Total Boxes | Boxes per Tree | % Change | Pounds Solids/Bx |
|---|---|---|---|---|---|
| 85-86 | 124 | 243 | 2.0 | - | N/A |
| 86-87 | 124 | 140 | 1.1 | -57.6 | 5.68 |
| 87-88 | 118 | 420 | 3.6 | 315.3 | 6.95 |
| 88-89 | 118 | 405 | 3.4 | -3.4 | 6.49 |
| 89-90* | 118 | 470 | 4.0 | 16.0 | 6.24 |
| 90-91* | 116 | 506 | 4.4 | 6.5 | 6.16 |
| 91-92* | 112 | 433 | 3.9 | -11.3 | 7.24 |
| 92-93 | 110 | 461 | 4.2 | 8.4 | 7.67 |

**Red Grapefruit** (50 year old on Sour Orange Rootstock)

| Crop Year | Number of Trees | Total Boxes | Boxes per Tree | % Change | % Pack Out |
|---|---|---|---|---|---|
| 85-86 | 217 | 578 | 2.7 | - | Juiced |
| 86-87 | 217 | 620 | 2.9 | 7.5 | Juiced |
| 87-88 | 135 | 840 | 6.2 | 217.5 | Juiced |
| 88-89 | 135 | 880 | 6.5 | 4.8 | 86.2+ |
| 89-90* | 135 | 890 | 6.6 | 1.1 | 78.5+ |
| 90-91* | 118 | 910 | 7.7 | 16.7 | 75.0 |
| 91-92* | 107 | 876 | 8.2 | 6.2 | 89.5 |
| 92-93 | 85 | 770 | 9.1 | 10.7 | Juiced |

*Note: The crop years indicated by an asterisk represents crops produced under a non-toxic spray program.

**Outreach programs**

Outreach is accomplished through a variety of means. One successful method has been the cooperator program. Several growers have contacted us for advice on how they can adopt the methods used at the VBRS. Some of these growers have agreed to allow demonstrations to be done in their own groves. Another form of outreach is through our demonstration grove which gives growers a chance to see the results of our programs described above. It is on these tours where growers can see first hand, beneficial insects and biological pest control in action.

Another exciting program is the work we are doing at Merritt Island National Wildlife Refuge, which surrounds the Kennedy Space Center. When the space program was started, all of the land around the Center was purchased and turned into a wildlife refuge. There are 1566 acres of citrus groves on the property. The U.S. Fish and Wildlife Service now lease these groves to growers. We were selected to help the growers to develop an IPM program and implement agronomic methods that minimize the use of pesticides.

Occasionally, seminars are given at grower meetings such as the Indian River Citrus Seminar and Equipment Show in Ft. Pierce. Several slide presentations have been developed that have been shown at these seminars, including the following topics: "Sustainable Citrus Practices at the VBRS", "Foliar Feeding", "Low Rate Herbicide Use", "Spray Oil & Nontoxic Pest Control", and "Apopka Root Weevils & the Use of Parasitic Nematodes in their Control." We also work with the Soil Conservation Service and County Extension offices. The VBRS was featured in two articles published in **Citrus Industry**, the leading trade publication for citrus growers in Florida. The first article, "Sustainable Agriculture: Applications for Citrus," appeared in October 1991 (1). The second article, "Citrus Research at the Kerr Center," appeared in November 1991 (2). We have received visitors from as far away as Australia, Canada, Israel, and South Africa who are interested in our work.

## WHAT WE LEARNED

Concentrate sprays can save energy and increase the effectiveness of foliar applications of fertilizers and pesticides. Increasing the number of nozzles and nozzle selection can produce visibly better spray coverage. Oil sprays are best applied dilute (500 gpa) and if applied properly can control most citrus insect problems. 455 spray oil produced the best results in our summer oil program by providing 45 days of mite control. A drawback to using spray oil for pest control is that multiple oil applications are required. Foliar fertilization does provide nutrients to trees and appears to provide a solution to the environmental problems associated with ground applied fertilizers. Some materials are taken up by the leaves better than others. Leaf uptake can be increased by adding surfactants, urea, adjusting the pH, and applications made to young expanding leaves. Further work developing fertility programs where higher amounts of nitrogen are applied foliarly with proportionally decreasing quantities of ground applied nitrogen are warranted.

Compost applications to citrus are beneficial but continual applications are required and are labor intensive. The best response is on young trees. Seaweed applications were shown to increase the soluble solids per box in juice oranges 1.3%. Our experiments with biological control have had mixed results. We observed a dramatic drop in harmful citrus nematodes levels where a parasitic fungus was applied to a small block of old trees. When we applied beneficial nematodes to control Apopka Root Weevil larvae in the soil, only very meager control was observed. This is a tremendous problem for our grove and surrounding groves and will require our best efforts.

Some of the outreach efforts have been very effective. Several growers are now applying techniques in their groves that were developed at the VBRS. The articles in **Citrus Industry** (1, 2) have been well received. Seminars have resulted in grower visits to the VBRS. Possibly the best evidence of the success of the outreach program is the cooperative effort at Merritt Island National Wildlife Refuge. Perhaps the biggest reason for this success, besides environmental reasons, has been the continuing pressure on growers to cut costs. Grower worries about the impact of the North American Free Trade Agreement (NAFTA), along with concerns about increasing citrus acreage and lower prices, have made growers anxious to save money wherever possible.

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**Acknowledgments and Disclaimers**

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