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Complied by

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List of Project Reports **Page No.**

Quarantine Screening and Selection of Imported Natural Enemies of the Olive Fruit Fly

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ABSTRACT

The widespread and rapid establishment of the olive fruit fly in California required immediate changes in olive IPM programs. After finding that resident natural enemies did not provide adequate control, researchers began a worldwide search for parasitoids. Foreign exploration took California researchers to the Republic of South Africa, Namibia, India, China, and other countries. Parasitoids were shipped to California and most were studied in Quarantine to determine the best species for release. Two parasitoid species – *Psyttalia lounsburyi* and *Psyttalia concolor* – are now being released throughout California's olive growing regions and researchers are studying their effectiveness. Here, we provide a description of the 2008 importation, quarantine, release, and recovery efforts conducted by members of the Berkeley campus laboratory. Results conducted by cooperators based at the Kearney Agricultural Center are presented separately. We also summarize the overall biological control program, which has yet been to be presented to the olive growers in a complete package. The summary details the natural enemies present in California, the foreign exploration efforts, quarantine studies, and the challenges presented by the biologies of the various natural enemies.

INTRODUCTION

The olive fruit fly (OLF), *Bactrocera oleae* (Rossi), was first found in southern California in 1998 (Rice et al. 2003). It dispersed rapidly throughout the state, facilitated by the adults' lengthy longevity and ability to fly long distances, and there was thus little opportunity to attempt a statewide eradication program. Current research efforts, therefore, emphasize long-term management practices – and biological control is a part of this program.

How might natural enemies contribute to OLF control? Commercial orchards now rely upon a broad-spectrum insecticide combined with a highly attractive bait (Johnson et al. 2006). The effectiveness of insecticide-based programs is, however, limited by abundant roadside and residential olive trees that act as reservoirs that contribute to the fly's reinvasion of treated orchards (Collier and Van Steenwyk 2003). Classical biological control, the importation and establishment of natural enemies from the pest's home range, offers the best opportunity to economically suppress OLF populations in these situations. Moreover, the fact that related fruit fly species (e.g., Oriental fruit fly, *Bactrocera dorsalis* (Hendel)) have been successfully suppressed using biological control (Wharton 1989) suggests that natural enemies may contribute to OLF management within California coastal regions with moderate temperatures.

Here, we described efforts to establish two parasitoid species – *Psyttalia lounsburyi* and *Psyttalia concolor*, in north coast olive orchards. We also review the four year biological control program, which included efforts to (a) document OLF natural enemies already present in California, (b) search for and import novel natural enemies from other countries, and (c) determine the effectiveness and limitations of these natural enemy species.

OBJECTIVES

1. Pre- and post-release monitoring of olive fruit fly and imported parasitoids;
2. Survey for extant parasitoids of olive fruit fly at release sites and surrounding areas; and
3. Review biological control efforts.

PROCEDURES

Objective 1. Pre- and post-release monitoring of olive fruit fly and imported parasitoids

Sources of insects and plants

A laboratory culture of *B. oleae* was maintained on olive fruit at the University of California Insectary and Quarantine Facility in Berkeley, California (Berkeley I&Q), using flies originally collected near Davis, California (Yolo County). A detailed description of rearing methods is provided in Sime et al. (2006b). Shipments of parasitoids to the UC Berkeley Quarantine were either reared on OLF, as described in Sime et al. (2006b), or released directly into the field after proper identification. All USDA-APHIS protocols were followed for the importation into and release out of the UC Berkeley Quarantine.

Field sites

OLF populations were surveyed at the potential release sites prior to parasitoid releases. Both the fly and the released exotic parasitoids were sampled following release at two north coast sites (Napa and Sonoma Counties). Additionally, team members have released and monitored OLF and parasitoids in non-commercial olives in Santa Barbara (coast, southern-California), San Luis Obispo (central coast), Fresno and Tulare Counties (interior, central California), and Amador, Yolo, and Butte Counties (interior, Northern California).

Trees used at the Napa and Sonoma sites were part of commercial olive orchards (for olive oil), not treated with any insecticides, free of commercial harvesting, and readily accessible for sampling. At both sites, the numbers of olives per tree were low in 2008, a result of the off-year production cycle in these blocks. The low number of available olives slightly altered sampling protocols as cages (see below) were used only in the Napa site. Also, adult flies were not monitored using ChamP traps, as described in the proposal, because the imported parasitoids were being released at both sites.

Quarantine processing

Six shipments of parasitoids were received and processed by the UC Berkeley Quarantine. After processing the material was sent to either Dr. Marshall Johnson (Kearney Agricultural Center), Dr. Charles Pickett (CDFA), or used in the experiments described below (UC Berkeley). Shipments are described in Table 1.

Release and monitoring of new parasitoids

Parasitoids were released openly into an olive tree that was central to others being monitored, as well as into caged fruit on selected trees. Open releases were used because parasitoids may need to fly some distance before settling down and ovipositing within suitable host larvae. The caged olives allow us to record a standard measure of oviposition and survivorship of resulting parasitoids, which can be used to compare fecundity among the different species released within and among different climatic regions. Most parasitoids will be released into the tree canopy, while only a fraction of those available will be released into small cages enclosing olives stung with flies. Open releases were made on 12 trees per site. Material released was as follows:

- *22 August 2008, Napa site*: 500 ♀♀ and 100 ♂♂ *Psyttalia* sp. nr. *concolor* (origin: Namibia, F3 EBCL laboratory and F2 wild).
- *22 August 2008, Napa site*: 100 ♀♀ and 20 ♂♂ *Psyttalia lounsburyi* (origin: Kenya, F43 laboratory).
- *26 August 2008, Napa site*: 500 ♀♀ and 100 ♂♂ *Psyttalia* sp. nr. *concolor* (origin: Namibia, F3 EBCL laboratory and F2 wild).
- *21 October 2008, Napa site*: 94 ♀♀ and 274 ♂♂ *Psyttalia* sp. nr. *concolor* (origin: Namibia, F4 UC Berkeley laboratory).
- *21 October 2008, Napa site*: 50 ♀♀ and 29 ♂♂ *Psyttalia lounsburyi* (origin: Kenya, F1 wild).
- *4 November 2008, Napa site*: 350 ♀♀ and 470 ♂♂ *Psyttalia* sp. nr. *concolor* (origin: Namibia, F4 and F5 EBCL laboratory).
- *4 November 2008, Sonoma site*: 350 ♀♀ and 465 ♂♂ *Psyttalia* sp. nr. *concolor* (origin: Namibia, F4 and F5 EBCL laboratory).

Table 1. Importation shipments processed in the UC Berkeley Quarantine in 2008 from suppliers in Kenya (through CDFA), the European Biological Control Laboratory (EBCL) of the USDA-APHIS facility in France, and ICIPE in Kenya.

Shipment date	Origin	Released to:	*Psyttalia concolor*		*Psyttalia lounsburyi* (Kenya)		*Psyttalia lounsburyi (*So. Afr.)		*Utetes africanus*	
			♀	♂	♀			♂	♀	♂
1 May	Kenya	Daane	-	-	-	-	-	-	27	31
21 Aug	EBCL	Johnson	800	-	200	-	-	-	-	-
		Pickett	700	-	161	-	254		-	-
		Daane	575	110	75	10	175	30	-	-
25 Sept	EBCL	Johnson	850	145	-	-	-	-	-	-
		Pickett	700	140	-	-	-	-	-	-
		Daane	650	120	-	-	-	-	-	-
		Daane	663	-	-	-	-	-	-	-
6 Oct	Kenya	Johnson	-	-	50	23	-	-	-	-
		Pickett	-	-	77	75	-	-	-	-
		Daane	-	-	50	29	-	-	-	-
31 Oct	EBCL	Johnson	2000	300	-	-	-	-	-	-
		Pickett	800	120	-	-	222		-	-
		Daane	700	735	-	-	-	-	-	-
14 Nov	ICIPE	Johnson	-	-	73	82	-	-	-	-

Additionally, an open release was made on 26 September 2008 utilizing cages to initially inoculate the olives. While we were relatively certain that there were OLF at each site, the cages were used to increase the density of the OLF on selected branches. For this, OLF females were added to each cage, followed two weeks later by the addition of parasitoids. Approximately two weeks after the parasitoids were added, the cages were opened to allow any emerging parasitoids the ability to disperse throughout the site. Ten cages were used, with ten female parasitoids released per cage.

26 September 2008, Napa site: 50 ♀♀ and 20 ♂♂ *Psyttalia* sp. nr. *concolor* (origin: Namibia, F4 EBCL laboratory and F3 wild) spread evenly in ten cages.

The numbers of immature OLF infesting olives were estimated monthly, beginning one month after parasitoid release and continuing into the winter period. Note that samples were taken the two previous years and no resident olive fruit fly parasitoids have yet been recovered. Summer and fall samples consisted of collecting 15 olive fruit, with signs of OLF infestation, from each release tree and 20-30 olives from trees adjacent to each release tree on each sample date. Evidence of infestation includes "stings" (egg placement scars), and "windows" or "exit holes" made by fly larvae. Note that in the original proposal we suggested "up to 200 per tree" would be collected and this was not done because of the low number of olives per tree. Samples were collected on 17 and 26 September, 21 October, and 4 November 2008.

The collected fruit were transported to the laboratory in insulated coolers. Data collected from each sample were the number of olives, the number of fruit with oviposition scars, and the number of OLF or parasitoids emerged for each sample date. Because most fruit collected were already darkening in color, the total number of oviposition scars per fruit were not recorded because the scars were becoming difficult to detect. Fruit were then placed in paper cans for emergence of flies and parasitoids, to estimate the number of larvae per fruit and parasitism. The emergence containers were held at 25ºC with a 14:10 (light:dark) photoperiod for up to 8 weeks, enough time for fly instars of any age inside fruit to develop to adults or exit the fruit. Containers were checked every other day, removing larvae, puparia, and adults. Larvae and puparia were placed in a separate paper can and held for parasitoid emergence, while adult flies were discarded.

Caged releases were conducted only at the Napa sites, as mentioned above, because there were not enough olives on the branches at the Sonoma site to isolate in cages. Separate cages were used for each species or origin location for imported parasitoid material, with five replicates each (including a no-release control cage). Each tree / cage combination represents a replicate.

Cages were placed in each release tree early in the season (July) when flies were at low numbers in the orchard and olives were still largely not susceptible to oviposition. Two weeks prior to releases of parasitoids, adult flies were added to cages, resulting in a cohort of fly maggots of roughly even age, and susceptible to parasitism. Flies were held in cages for 7 to 10 days, and fitted with a plastic vial for honey water. Ends of branches were protected from ants by placing a ring of Tanglefoot above the caged branch terminal. Each cage enclosed about 10 to 30 olive fruit. Numbers of flies and parasitoids released into cages were based on numbers of caged fruit, with a goal of 5 to 10 fly oviposition marks at the time parasitoids were added (we added ca. 1 adult female fly per 5 fruit).

Adult female parasitoids were added to reach a minimum ratio of 1 per 2 fruit, or 15 ♀♀ and 2 ♂♂ per cage. Approximately five weeks after addition of flies and three weeks after the addition of parasitoids, the cages were removed and all enclosed fruit were collected and taken to the laboratory for emergence of parasitoids and flies. The treatments (parasitoid material) were *P. lounsburyi* (South Africa), *P. concolor* (Namibia) and *P. concolor* (Kenya), as well as an untreated control.

Objective 2. Survey for extant parasitoids at release sites and surrounding areas.

Olives and OLF held for emergence for Objective 1 were used to determine the presence of extant parasitoids at release sites. All parasitoids emerging from collected OLF were identified to species and sexed.

Impact of released parasitoids were measured by comparing parasitism levels and infested fruit between the release tree and nearby, non-release control trees. Other non-release trees were located in the same geographical areas and greater than 1 km away. Assuming that parasitoids permanently establish, cage studies at release sites will also be used to compare olive fly larval densities in the presence and absence of established parasitoids.

Objective 3. Summary of biological control program

An article developed for *California Agriculture* is provided, in part, to summarize the past four years of research on OLF biological control, which has not yet been presented as a complete discussion to the California Olive Committee members.

RESULTS AND DISCUSSION

Objective 1. Pre- and post-release monitoring of olive fruit fly and parasitoids

Sampling from 2006 and 2007 suggested that no extant OLF parasitoids existed at either the Napa or the Sonoma site.

From the open tree release trial at the Napa site, there were no differences between release and adjacent trees, and these data are combined. More than 90% of the collected olives had signs of OLF infestation – either as an oviposition scar or an emergence hole (**Fig. 1**). On the first collection date (26 September), about 20% of the fruit had adult OLF emerge from them (**Fig. 1**) and this rose significantly on the later collection dates to about 0.6 OLF adults per fruit.

From the open tree release trial at the Sonoma site, there were differences between release and adjacent trees, and these data are provided separately. More than 90% of the collected olives had signs of OLF infestation – either as an oviposition scar or an emergence hole – in both the release and the adjacent trees (**Fig. 2**). On the first collection date (25 September), about 35 and 65% of the fruit had adult OLF emerge from them in the release and adjacent trees, respectively (**Fig. 2**). There was a significant difference in the number of OLF per fruit thereafter, with a steep decline of OLF (about 0.5 OLF per fruit) on fruit collected from the release trees while there was an increase (about 1.2 OLF per fruit) on the adjacent trees (**Fig. 2**). This difference may be a result of parasitoids stinging more OLF on the release trees – killing the fruit fly larvae, although no parasitoids were recovered (see discussion below).

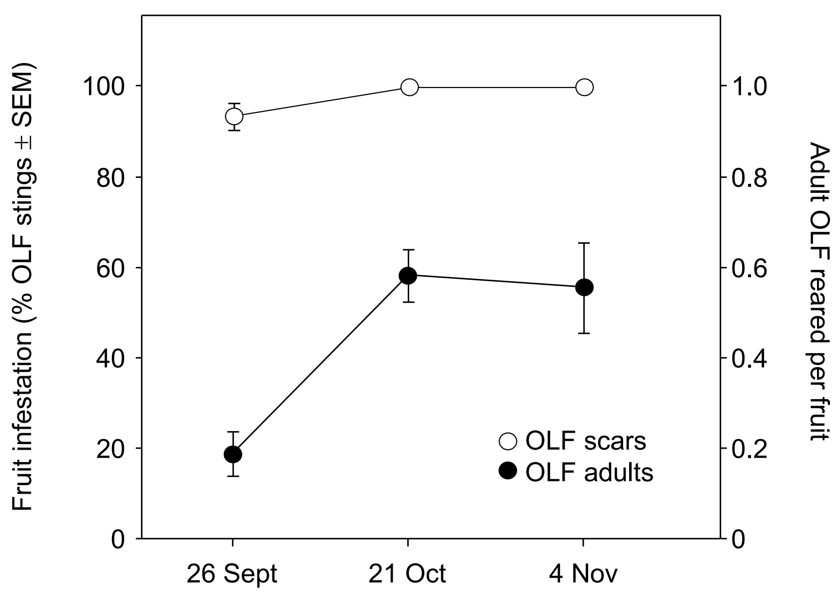

Fig. 1. The percentage fruit infestation (± SEM), as determined by oviposition scars and OLF emergence holes, and the average (± SEM) number of adult OLF reared per fruit for olive fruit collected on release and adjacent trees in a Napa county olive orchard.

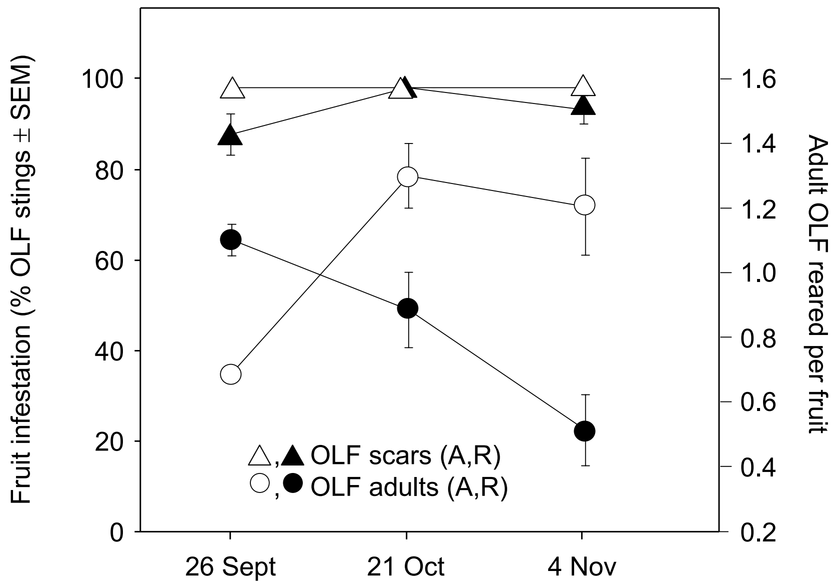

Fig. 2. The percentage fruit infestation (± SEM), as determined by oviposition scars and OLF emergence holes, and the average (± SEM) number of adult OLF reared per fruit for olive fruit collected on release trees (●, ▲) (R) and trees adjacent (○, △) (A) to the release trees in a Sonoma county olive orchard.

Objective 2. Survey for extant parasitoids at release sites and surrounding areas

There were 519 and 417 OLF adults reared from collected olives at the Napa and Sonoma County sites, respectively. There was only one parasitoid recovered, and this was from the cage study at the Napa site, where a male *P. concolor* was reared.

The most interesting result from the cage study was the difference in OLF adults reared from the cages compared with the open release trees. During the same time period, in late September, there was some difference in the level of infestation and parasitoids recovered from olives collected from the open release trees, which had about 90% of the collected fruit with some indication of OLF infestation, and caged trees, which had 55 to 75% infested fruit. There was no difference in fruit infestation levels between the treatments at the start of the experiment (**Fig. 3**, $F = 1.269$, $df = 3,16$, $P = 0.318$). However, from 508 collected olives in the caged parasitoid treatments, there were 266 olives with signs of OLF infestation, but no OLF were reared.

There was a single *P. concolor* (male) reared from these olives. Surprisingly, there was only 1 OLF reared from the five control cages (with 114 of 147 collected olives showing an indication of OLF infestation). This suggests that it was not a simple case of the release parasitoid "over-stinging" the OLF in the cages. More likely, the cages either created a condition that reduced OLF survivorship or fruit on the isolated branches were inoculated too early (August) in the season – before the fruit were soft enough for OLF survival.

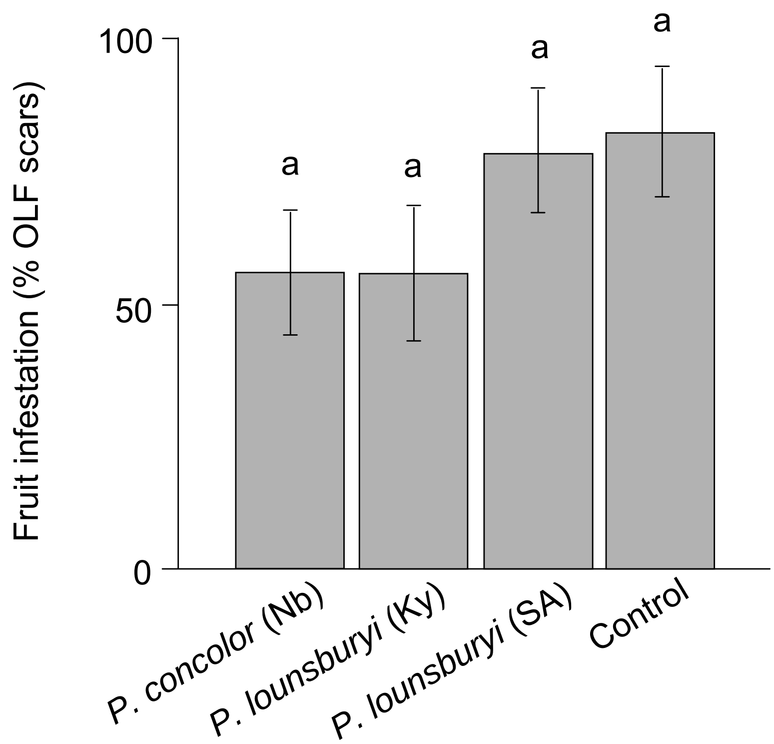

Fig. 3. The percentages fruit infestation (± SEM), as determined by oviposition scars and OLF emergence holes, for each treatment in the caged experiment in the Napa county olive orchard.

Objective 3. Review biological control efforts

Natural enemies in California

Although OLF is native to Africa and Asia, some North American predators and parasitoids may attack it. Insect predators such as lady beetles and lacewings are found in olive orchards. However, because the fly's eggs are embedded underneath the fruit's epidermis and the fly's larvae feed deep inside the fruit, the immature stages are protected from most generalist predators.

A window of exposure to predators is often created when the fly pupates. However, upon maturation some fly larvae leave the fruit, especially in the late summer and fall seasons, and drop to the ground to pupate in the soil beneath the tree. Orsini et al. (2007) placed fly puparia on the ground in olive orchards and used different barriers around each to distinguish mortality levels due to "abiotic" (e.g., climate) and "biotic" (e.g., predators) factors. In an August trial, pupae exposed to predators were reduced by ≈ 60% compared with other treatments (**Fig. 3**). Ants (*Formica areata*) were the most abundant predators on the ground and were observed carrying and killing OLF pupae. Predation rates vary among orchards, depending on factors such as the species and densities of predators present and the soil depth at which fly pupae are located. European studies similarly indicate that arthropods can inflict substantial mortality on OLF pupae (Bigler et al. 1986).

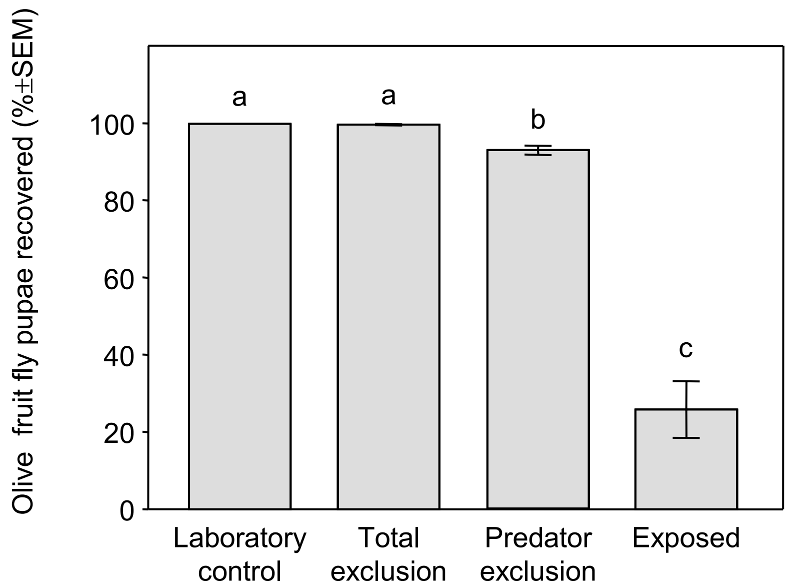

Fig. 3. Mean percentage (± SEM) of olive fruit fly pupae recovered after 4 d (August 2005) and held in a laboratory control and placed in an olive orchard where treatments were *total exclusion* of all natural enemies, *predator exclusion* that prevented walking predators from reaching the pupae, and *exposed* that allowed both flying and walking natural enemies access to the pupae. Different letters above each bar indicate significant differences (Tukey's HSD test, $P < 0.05$). (From Orsini et al. 2007)

Before the importation program began, a parasitic wasp was found attacking OLF in coastal Santa Barbara County. Specimens were identified as an undescribed species, similar to the European *Pteromalus myopitae* (Graham) (Hymenoptera: Pteromalidae) – hence the current "species near" description as "*Pteromalus* sp. nr. *myopitae*." It is a solitary (one parasitoid per fly larva) parasitoid that externally feeds on third-instar OLF. Infested olive fruit collected in San Luis Obispo County revealed an average parasitism level of 2.98% by *P.* sp. nr. *myopitae* (from data in Kapaun 2007). There was considerable variation in levels of parasitism, ranging from 0 to 33% (based on collections of 100 infested fruit per week) with activity highest in August and September (Kapaun 2007). Statewide surveys showed that *P.* sp. nr. *myopitae* is primarily found in coastal counties from San Luis Obispo to San Diego, although a few have also been recovered in Fresno, Alameda, and Yolo Counties. Because *P.* sp. nr. *myopitae* has never been reported elsewhere, it is likely a North American parasitoid of native fruit flies, which opportunistically parasitizes OLF.

Foreign exploration

Imported material. Resident natural enemies do not adequately suppress OLF populations below damaging levels. For this reason, California researchers began to seek natural enemies abroad in 2003. The search began in Africa, where OLF probably originated (Nardi et al. 2005), and where a rich diversity of fruit fly parasitoids is found. OLF parasitoids were reported in Africa as early as 1912 by the renowned Italian entomologist Filippo Silvestri, during surveys for parasitoids of Mediterranean fruit fly (Medfly), *Ceratitis capitata* (Wiedemann) (Wharton 1989).

Explorations were conducted by members of the USDA-ARS European Biological Control Laboratory (EBCL), the California Department of Food and Agriculture, the University of California, and cooperators in the Republic of South Africa, Namibia, Kenya, La Réunion, Canary Islands, Morocco, Pakistan, India, and China. Collections for "specialists" (i.e., natural enemies that primarily attack one species) were made primarily from wild olive fruit (*Olea europaea* spp. *cuspidata*) from south to northeast Africa, and from southwest Asia to central China. The parasitoids reared from OLF included *Psyttalia lounsburyi* (Silvestri), *Psyttalia concolor* (Szépligeti), *Psyttalia ponerophaga* (Silvestri), *Utetes africanus* (Silvestri), and *Bracon celer* Szépligeti (all Hymenoptera: Braconidae).

The greatest yield of parasitoids came from collections made in South Africa, Namibia, and Kenya (**Table 2**). The most common species were *P. lounsburyi* and *P. concolor* (**Table 2**). The highest levels of parasitism were found in Kenya collections where *P. lounsburyi* and *U. africanus* together parasitized > 57% of collected flies. This was followed by collections in Pakistan (37% parasitism by *P. ponerophaga*) and Republic of South Africa (28% parasitism by *P. lounsburyi*, *B. celer*, and *U. africanus*). Although *P. concolor* was the only OLF parasitoid found in Morocco and the Canary Islands, parasitism rates were limited to 14.6 and 2.3%, respectively. Similarly, in the Republic of South Africa, *P. concolor* accounted for less than 7% parasitism. However, in Namibia *P. concolor* was the dominant parasitoid and attained parasitism levels from 18 to 35%. In China, few OLF were collected, although one (unidentified) *Dichasmimorpha* species was obtained, and in India no fruit were found on wild olives during the 2006 and 2007 explorations.

Numerous fruit fly parasitoids are known to attack other flies in the genus "*Bactrocera.*" A few of these more "generalist" (i.e., natural enemies that attack numerous species) parasitoid species were also imported to California. These were *Fopius arisanus* (Sonan), *Diachasmimorpha kraussii* (Fullaway), and *D. longicaudata* (Ashmead). All were supplied by Russell Messing, University of Hawaii, where they had been reared on Medfly. Similarly, colonies of *P. concolor* maintained on Medfly in Guatemala were sent to California, supplied by Pedro Rendon, USDA APHIS-PPQ.

Quarantine non-target studies

Most of the imported parasitoids were either sent directly to the UC Berkeley Quarantine Facility or first to the collaborating laboratory in France and then to the Berkeley Quarantine. Before exotic natural enemies are released into California, quarantine studies should be conducted to determine their possible non-target impacts – will they attack insect species other than the intended target. Over 140 tephritids occur in California (Foote et al. 1993), including some endemic species and others that were brought into California for the biological control of weeds. Rather than test all of these species, researchers assessed the parasitoids' responses to fruit fly species representing the three common larval habitats – fruits, flower heads, and stem galls – thus taking advantage of the parasitoids' tendency to specialize on certain host habitats. Tested species were selected to maximize both practicality (ease of locating and/or rearing hosts) and potential for host acceptance (resemblance to olives in shape or size).

Through the Quarantine work, researchers found that *P. lounsburyi* was the only parasitoid tested that probed exclusively into infested olives and reproduced solely on OLF (Daane et al. 2008). It has been suggested that *P. ponerophaga* specializes on OLF because the parasitoid has only been reported from this species (Sime et al. 2007). Thus, quarantine screening studies of

Table 2. Fruit fly and parasitoids reared from field collected wild olives, 2003-2007, for importation into California.

Country	Year	Insects reared	Percentage species reared						
			Bactorcera spp.	*Psyttalia concolor*	*Psyttalia lounsburyi*	*Psyttalia ponerophaga*	*Utetes africanus*	*Bracon celer*	*Diachasmimorpha* spp.
Morocco	2004	318	85.4	14.6	0.0	0.0	0.0	0.0	0.0
Canaries	2004	965	97.7	2.3	0.0	0.0	0.0	0.0	0.0
Pakistan	2005	636	72.3	0.0	0.0	27.7	0.0	0.0	0.0
Reunion	2004	1786	40.0	0.0	0.0	0.0	0.0	0.0	100.0
Namibia	2004	597	69.2	18.1	0.0	0.0	3.7	9.0	0.0
Namibia	2007	874	58.0	31.3	9.0	0.0	1.6	0.0	0.0
Namibia	2008	3077	50.0	35.1	11.0	0.0	3.3	0.6	0.0
South Africa	2003	2218	49.4	6.3	29.4	0.0	45.0	18.9	0.0
South Africa	2004	794	32.2	3.2	21.2	0.0	68.0	7.7	0.0
South Africa	2005	377	72.2	0.0	15.1	0.0	12.7	0.0	0.0
Kenya	2005	3647	42.4	0.0	35.6	0.0	21.9	0.0	0.0
China	2007	438	97.5	0.0	0.0	0.0	0.0	0.0	2.5
India	2006	0	--	--	--	--	--	--	--
India	2007	0	--	--	--	--	--	--	--

non-target impacts were limited to the weed biological control agents (fruit flies that attack yellow star thistle and Cape ivy), and no fruit-infesting fly species were tested. Researchers observed *P. ponerophaga* adults probing into both yellow star thistle flower heads and galls on Cape ivy, but no parasitoid offspring were produced from either non-target host.

Psyttalia concolor should be viewed as a "species complex," as previously mentioned, and researchers found that *P. concolor* colonies from different locations did indeed have slightly different levels of host specificity (Sime et al. 2006b). However, all *P. concolor* populations tested (Italy, Kenya, and Namibia) were able to reproduce on non-target fruit flies. In other laboratory studies, *P. concolor* has similarly been reared from numerous fruit fly species (Wharton and Gilstrap 1983). However, small cage trials present very artificial conditions, and OLF and Medfly are primary hosts of *P. concolor* in its native range in Africa (Wharton et al. 2000).

Bracon celer also attacked and reproduced on Cape ivy fly, but surprisingly did not reproduce on the cherry fly, apple maggot or currant fly – the fruit-infesting flies tested with this species. However, *B. celer* did probe on host materials for all fruit flies presented. To date, *B. celer* has been reported only as a parasitoid of OLF and Medfly in field surveys (Sime et al. 2006a).

Utetes africanus, one of the more commonly recovered species in the South African collections, proved to be difficult to rear in quarantine. Researchers found that it reproduced on OLF, as expected, but they did not observe this parasitoid showing any interest in either the target or non-target hosts. Literature records indicate that *U. africanus* has been reared from OLF, Medfly, Oriental fruit fly, coffee fruit fly (*Trirhithrum coffeae* Bezzi), and the Natal fly (*Ceratitis rosa* Karsch) (Wharton and Gilstrap 1983).

Dichasmimorpha longicaudata and *D. krausii* were the most aggressive of the quarantine-screened parasitoids (Sime et al. 2006c), probing all host material presented and producing offspring from non-target fruit-infesting species as well as from the beneficial species. This result was not surprising because in total they have been reared from more than 20 fruit fly species (Wharton and Gilstrap 1983).

While *F. arisanus* is considered more of a generalist, it is not attracted to either *C. succinea* eggs on yellow star-thistle buds, or *P. regalis* eggs in Cape ivy stems or the associated galls (Sime et al. 2008). These results are consistent with studies in Hawaii that show *F. arisanus* only attacking fruit-feeding tephritids (Wang et al. 2004). Host range in *F. arisanus* is probably constrained by its host-searching behavior: females are generally stimulated to search for host eggs by fruit odors, smooth round fruit-surfaces, and oviposition punctures left by flies (Wang and Messing 2003). Introducing *F. arisanus* to California still requires evidence that native fruit-feeding Tephritidae are unlikely to be attacked. Sixteen tephritid species native to California feed in fruit (Foote et al. 1993). However, at least eight of these are found at higher elevations, where *F. arisanus*, a tropical species, is unlikely to flourish (Rousse et al. 2005).

Release and recovery

California researchers received USDA-APHIS approval to release *P. lounsburyi* and for limited release of *P. concolor*; approval is pending for *P. ponerophaga*; and permits for limited release of *Fopius arisanus* are being prepared. To date, *P. lounsburyi* and has been released and recovered in field-cage studies, but has not yet been shown to overwinter (Daane et al., unpublished data). More work has been done with *P. concolor*, which is easier to rear, and levels up to 60% parasitism have been reported from cage studies (Yokoyama et al. 2008, Wang et al. submitted). However, as with *P. lounsburyi*, there is no clear evidence to date that *P. concolor* can establish and thrive without repeated augmentation. There are, in fact, some potential problems with the biologies of OLF and its potential natural enemies that may limit the levels of biological control achieved. These are briefly summarized below.

Seasonal host availability. The fly's survival is limited in regions with high or low temperature extremes (Johnson et al. unpubl. data). The olives are susceptible to OLF infestation before consistent high temperature extremes are reached around mid-July, and for this reason there is a summer period when the fly population may survive primarily as adults. During these periods when OLF larvae are scarce, how will the parasitoids survive? Adult OLF can survive greater than six months from winter and into the summer, when ripe fruit are available (Nadel et al. unpubl. data), but the parasitoids do not live as long, as shown in Berkeley quarantine studies.

Wild vs. domestic olives. The domestic olive is a distinct subspecies of wild olive, with small fruit compared to most cultivated olives. For this reason, fly maggots tunnel deeper inside the larger domestic olive than the smaller wild olives. The ovipositors of specialized parasitoids (*P. lounsburyi* and *P. ponerophaga*) are too short to reach fly maggots feeding deep within the larger olives (Sime et al. 2007, Wang et al. 2008). The length of the ovipositor relative to the depth of the maggot within the fruit apparently limits the biocontrol agent's ability to successfully parasitize certain hosts, a problem that has been well documented for other fruit fly parasitoids (Sivinski et al. 2001). This is not a new idea, in fact, Latiere (1917) hypothesized that African parasitoids of OLF would fail to successfully establish on fruit flies in fleshier European cultivars because of their short ovipositors, which are an adaptation for foraging in small wild African olives.

Surveys in wild and cultivated olives in Africa provide support for this hypothesis. *Psyttalia lounsburyi*, *U. africanus*, and *B. celer* are most commonly reared from wild olives (Copeland et al. 2004), whereas in cultivated olives, *B. celer*, with its much longer ovipositor, predominates and the other species tend to be rare. In Berkeley quarantine studies, both *D. longicaudata* and *D. kraussii* did very well on cultivated olives, and these more generalists parasitoids have very long ovipositors (Sime et al. 2006b). Among the favorable characteristics of *F. arisanus*, as a potential biological control of *B. oleae*, are its relatively long ovipositor and the fact that it usually oviposits into eggs. Both features may help it circumvent the difficulties that some larval parasitoids encounter when attacking *B. oleae* in larger olive cultivars.

Natural enemy interactions. Natural enemies can interfere with each other. For example, the unexpected appearance of *P.* nr *myopitae* could potentially create a conflict with the classical biological control efforts. Parasitoids that immobilize the host, including *P.* nr *myopitae* and *B. celer*, may have a competitive advantage over larval parasitoids that allow the host to continue to develop and grow after parasitoid oviposition, such as the *Psyttalia* species (Godfray 1994). In quarantine experiments, researchers found that the egg-larval parasitoid *F. arisanus* prevails in competition against two species of larval-pupal parasitoids, *D. kraussii* and *P. concolor* (Sime et al. 2009). The intrinsic competitive superiority of *F. arisanus* over larval-pupal parasitoids must be taken into consideration for its use in California.

Insecticides and biological control. Insecticide use impacts biological control programs (Mills and Daane 2003). Repeated sprays of GF-120 Naturalyte F® (Dow AgroSciences LLC, Indianapolis, IN) are used to control OLF. Although this "spinosad" bait is classified as a reduced-risk material, its frequent use may disrupt biological controls. Nadel et al. (2007) investigated the impact of GF-120 on a green lacewing, *Chrysoperla carnea* Stephens, and showed that ingestion of GF-120 clearly poses some risk to lacewing populations due to adult mortality and reduced fecundity. The preference of *C. carnea* for sugary foods may, however, offset this risk to some degree because lacewing adults consumed less GF-120 when honey was available as an alternative food source. Laboratory studies indicated that several important braconid parasitoids of fruit flies, *F. arisanus*, *Diachasmimorpha tryoni* (Cameron), and *Psyttalia fletcheri* (Silvestri), would not feed on fresh GF-120 residues, but had low LC_{50} values (8.3 -17.5 ppm) in contact tests, indicating high contact susceptibility (Wang et al. 2005).

CONCLUSIONS

Biological control can be a practical, safe, and economically effective means of fruit fly control, and its importance continues to grow in regions where pesticide use is less desirable (e.g., sustainable agriculture) or more restricted (e.g., urban trees). The research programs described herein have provided background information on natural enemy biology, identified specific natural enemies for importation, and begun to release and evaluate novel parasitoids in California. Over the coming years, the researchers will better know the level of controls expected from imported natural enemies, and will improve IPM programs to integrate biological controls with the insecticides currently used in olive management.

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Developing Mechanical Harvesting for California Black Ripe Processed Table Olives: 2007-2010: Year 2 of 4 Progress Report

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ABSTRACT

This is the second year of a four year project. In 2006, the project focused on adapting the DSE canopy harvester for harvesting existing Manzanillo trees with sufficient efficiency and quality to produce commercially competitive California black ripe table olives. Simultaneous research focused on identifying an abscission agent that would enhance harvest efficiency and decrease fruit damage. However, results from 2006 through 2008 have demonstrated pruning existing trees, or training new orchards for, mechanical harvesting, and evaluating these orchards with all commercially available harvesters would generate faster progress. Screening for an abscission agent and postharvest treatments for maintaining fruit quality should be secondary objectives. The 2008 research objectives and results support this redirection.

Determine if mechanical topping and hedging to make fruit more accessible for mechanical harvesting will decrease yields. Mechanically topping and hedging mature 'Manzanillo' trees did not produce statistically lower yields in the same season. Mechanically pruned trees produced 19.3 pounds per tree of fruit valued at $1,131.40 per ton versus 22.1 pounds per tree

valued at $1,151.40 per ton for conventionally pruned controls trees. However, this annual mechanical pruning should be continued for four years to determine effects on long term yields.

Determine if training method hedgerow-configured orchards affects yield. An eight year-old 'Manzanillo' hedgerow training trial has consistently produced no significant differences in annual yields or fruit values from 2004 – 2008. By 2008 the conventionally pruned control trees, those pruned to a traditional rounded canopy, at the same spacing, produced 21.00 cumulative tons per acre versus 18.85 for free standing espalier, 21.12 for a woven trellised espalier, and 20.82 tons per acre for a trellised and tied espalier hedgerows. When yields plateau, expected within 2 years, this experiment will be completed.

Evaluate the harvest efficiency and effects on fruit quality and value of the DSE 008 harvester. The DSE 008 harvester produced a significantly lower, (88.0%***) cannable percentage, and adjusted value per ton, ($1013.80***), for mechanically harvested fruit, versus 96.2% and $1137.80 per ton for hand harvested olives. However, these canning percentages and values per ton are well within normal ranges. This indicates this canopy head can produce commercially acceptable fruit. The harvester averaged 57.8% final fruit removal efficiency. This poor harvest efficiency was partially due to the configuration and manipulation of the canopy heads resulting in a swath of unharvested canopy. Our evaluation indicates the current DSE 008 harvester is too large, slow, and expensive. The catch frame is incomplete and the total machine has poor potential for successful commercialization. More progress can be made evaluating the commercially available prune, pistachio, and pomegranate harvesters that use versions of this canopy head, or trunk shaking technology, combined with the double-sided catch frames now common. In summary, the canopy head is now producing fruit suitable for processing, but the total harvester efficiency, speed, and catch frame capacity must be improved.

Evaluate the harvest efficiency and effects on fruit quality and value of trunk shaking harvesters. Four different trunk shaking harvesters were evaluated on hedgerow and smaller trees. Three shakers produced unacceptable trunk damage and had final harvest efficiencies ranging from 55.1 to 71.8%. These three shakers produced cannable percentages no lower than 91.5%, and adjusted fruit values over $872.55 per ton.

Evaluate the harvest efficiency and effects on fruit quality of the MaqTec Colossus. Trials conducted in Argentina with 'Manzanillo' and Portugal with 'Hojiblanca' table olives demonstrated that this machine removed table olives with > 95% efficiency, but bruised, mutilated or cut virtually 100% of the fruit. Colossus will need considerable reworking if it is to have potential for harvesting table olives.

Screening for abscission and postharvest treatment agents. Screening trials for both agents continued, but the few potential candidates require further testing before incorporation into harvesting trials.

Conclusions

We now need to evaluate mechanically pruned and new hedgerow orchards with the currently available commercial potential harvesters. The DSE 008 harvester has demonstrated the picking head technology is viable for table olives. Other aspects of this harvester (e.g., size, cost, speed, catch frame technology and adaptability) need to be addressed by DSE. Additionally, commercially available trunk shaking and canopy harvesters mounted on double-sided catch frames should be evaluated in conventional and mechanically pruned and hedgerow trained orchards. Screening for abscission compounds and postharvest treatments should continue, but these compounds are so far from incorporation into mechanical harvesting trials, or registration, that mechanical harvesting of olives should be developed without these chemical aids.

INTRODUCTION

Why mechanical harvesting of California black ripe table olives is needed

The California table olive industry will need to develop mechanical harvesting for economic survival. The recent decreases in harvested acres support this contention; harvested acreage has decreased by 15% since 2005. Hand harvesting costs are remaining above $350.00/ton. Using current cost study figures (http://coststudies.ucdavis.edu/files/olives-tablesprinkler_sj-valley_2005_ol-sj-05.xls), it can be seen that picking costs will become a larger problem as future gross returns per ton drop from the 2008 peak $1210.00/ton.

Further, current economics and immigration enforcement efforts suggest manual labor pools will decrease. Even if they do not, the logistics of manual labor are difficult. Thus, developing mechanical harvesting is both an economic and logistical necessity for the California black ripe processed table olive industry.

Why mechanical harvesting is difficult to develop and how we are approaching it

The limiting factor in mechanically harvesting table olives is producing commercially acceptable black ripe table olives. This requires that the product delivered to the cannery be free of bruises and cuts that decrease processed table olive quality.

Olives destined for California black ripe table processing are harvested physiologically immature; the abscission zone between the fruit and stem is undeveloped. The fruit is borne on pendulous, flexible, vertical shoots at the outer periphery of the canopy. To remove an immature individual 5-10 gram olive fruit requires at much as half a kilogram of pull force. The two major methods of fruit removal, trunk shakers and canopy contact picking heads, both have specific limitations. Trunk shakers are inefficient and damage the trunks. Canopy contact heads damage the fruit. Both are currently marginally, economically efficient in terms of % fruit removal and tons or acres per hour harvested.

Thus, logically, one primary objective of a mechanical harvesting project should be developing an effective abscission agent to accelerate the development of the fruit abscission zone that will decrease the required pull force and therefore require less forceful trunk shaking or canopy head picking force. The result would be a higher harvest percentage of cannable fruit and less tree damage. Ethylene release compounds, (ERCs), primarily ethylene, have demonstrated the best potential thus far. However, decades of abscission research with ethylene, and our recent results, have demonstrated olive leaves are more sensitive to ERCs than olive fruits. The usual result is unacceptable leaf losses (over 25%). Further, ERCs perform erratically in trials. Finally, even if an effective abscission agent is developed it will require at least five years and considerable funding to generate the efficacy, residue, and environmental impact research (EIR) required for registration.

A logical, second primary objective should be development of effective, non-damaging harvesters. Our harvester evaluations thus far, strongly demonstrated altering the tree to make fruit more accessible to the harvester would greatly increase harvest efficiency Therefore, developing and adapting olive trees suitable for mechanical harvesting should become a major objective.

Finally, pre- and post-harvest antioxidants have shown some potential for decreasing fruit damage from the harvester. However, these chemicals face the same registration requirements as an abscission compound.

In summary, when initiated in 2007 the mechanical harvesting research program focused on simultaneously developing a specific mechanical harvester, the DSE 008, and identifying an abscission agent to increase harvester efficiency and decrease harvester fruit and tree damage. However, results thus far strongly indicate that the final two years of this project should focus on two equal priorities. First, research should focus adapting trees for mechanical harvesting through pruning of existing orchards and development of new hedgerow orchards. Second, all available commercial harvesters with potential for table olives should be adapted and evaluated on these reconfigured orchards. Trials with the DSE 008 have demonstrated the canopy contact picking head can successfully harvest commercially viable fruit. As research cooperators, we gratefully thank Dave and Karen Smith of DSE for their major role in helping the olive industry reinvigorate the mechanical harvesting research program.

Development of abscission compounds for decreasing fruit removal force, and anti-oxidant pre- and post-harvest treatments for decreasing fruit damage, should both be pursued as secondary objectives. However, neither chemical can be incorporated into mechanical harvest trials until potential compounds are identified in screening trials.

The following 2008 research report supports these conclusions.

OBJECTIVES

Outline

This project had four major objectives; outlined below. Each objective will be discussed in an individual section.

I. Evaluation of Pruning and Training Methods on Tree Yield and Fruit Quality

- Part A. Evaluation of Mechanical Topping and Hedging
- Part B. Evaluation of Olive Hedgerow Orchards

II. Evaluation of Mechanical Harvester(s) Efficiency and Effects on Fruit Quality and Value

- Part A. DSE 008
- Part B. Coe. Nielsen, OMC and Spanish Wrap Around Trunk Shakers
- Part C. MacTeq Colossus

III. Evaluation of Antioxidants and Preharvest Plant Growth Regulators to Reduce Physical Damage and Improve Firmness in ‘Manzanillo’ Olives in 2008

IV. Screening for Potential Abscission Compounds

I. Evaluation of Pruning and Training Methods for Mechanical Harvesting: 2008 Season

Part A. Evaluation of Mechanical Topping and Hedging: 2008 Season

Introduction

Preliminary work done in 2006 demonstrated that fruit on the canopy facing the row middle was mechanically harvested with the picking head type harvester significantly more efficiently than fruit on the canopy surface between the trees. This suggested that a typical orchard topped and side hedged to a hedgerow configuration could be harvested more efficiently with a picking head harvester. However, the effect of long term hedging and topping, (at least 4 years), on yield and fruit quality has not been demonstrated. Therefore this trial tests the hypothesis that a moderate, annual mechanical pruning program does not decrease yield or fruit quality over a four-year period.

The trial was also designed to test the efficiency of the DSE 008 harvester at four different ground speed (MPH) and picking head amplitude combinations (RPM). However, the DSE was delivered too late to accomplish this objective.

Procedures

Location: Block 17W: Rocky Hill Ranch, Exeter, CA

- Planted 1998
- 13 rows, 83 trees per row, 'Manzanillo' olives with 'Sevillano' pollinators
- Spaced @ 12 X 26 feet, 139 trees per acre

<u>June 16-17, 2008</u>
6 rows of 83 trees each were conventionally pruned
6 rows of 83 trees each were pruned for mechanical harvesting:

- All large, horizontal limbs extending into the row middle were pruned off
- Trees were skirted at 3 feet from the ground
- Trees were topped at 12 feet
- Trees were hedged on the west side 6 feet from the trunk

<u>September 23 – 24, 2008</u>
All of the 12 tree rows were divided into 5, 14 tree, replications with 1 buffer tree at each row end, and 2 buffer trees between each 14 tree replication:

- 1, 14 tree replication per row (12 total) was hand harvested into a separate bin
- Yield was weighed on a tared field bin scale
    - dropped fruit was collected from beneath trees and field weighed
    - fruit left in trees was hand harvested and field weighed
- Bin was reweighed at Musco receiving station
- COC sample grade pulled from each bin
- Yield per tree, % cannable, % of sizes and adjusted price/ton analyzed
- Samples were not sent for processing as this trial was to evaluate mechanical pruning effects on yield and fruit size

Results and Discussion

As can be seen in **Table 1** below, moderate mechanical topping and hedging in June, 2008 did not significantly affect yield, fruit quality, or value. In this test of six 14 tree replications the hand-pruned trees did yield 2.8 more pounds per tree than mechanically-pruned trees, but the difference was not statistically significant. There were no significant differences in % of cannable fruit, the % size distribution or the adjusted value per ton.

However, it requires at least four years of data, particularly in an alternate bearing species that produces on one year old wood, to draw conclusions about the effects of a long term pruning program on growth and annual yield. Therefore, while these results look promising this trial should be conducted for at least another three years.

The second part of this experiment was to evaluate the effect of mechanical-pruning, versus a hand-pruned control, on the harvester efficiency and effects on fruit quality, of the DSE 008 mechanical harvester. However, this trial was not able to be done because of harvester delivery delays. These trials were scheduled to begin 15 September 2008. Due to mechanical problems, the DSE 008 was not operational until 28 September. By then the fruit was seriously overripe.

Conclusion

Mechanical topping at 12 feet and hedging 6 feet from the trunk on one side of the tree in June did not affect tree yield or fruit quality and value within the same growing season. Fruit values were unaffected by the mechanical-pruning. This work will be continued for another four years to ensure there are no long term effects on tree growth or bearing.

Table 1. Yield per tree, percentage of olive sizes, culls, and trash in the sample, and adjusted price per ton. No significant differences in yield or fruit quality were found between the mechanically and hand-pruned trees.

Effect of Mechanical Topping and Hedging on Tree Yield and Value

Pruning treatment	Yield/tree (lb)	Percentage										Adjusted price/ton ($)
		Cannable	Extra large	Large	Medium	Small	Petite	Subpetite	Undersized	Culls	Trash	
Mechanical	19.3[x]	95.9	62.8	24.0	4.9	1.8	1.4	1.0	0.8	2.2	1.2	1131.50
Hand	22.1	97.4	67.9	22.2	3.1	1.6	1.4	1.0	0.8	1.1	0.8	1151.40

[x] Means separation within columns were performed with PROC TTEST procedure of SAS (SAS Institute Inc., Cary, NC); *, **, *** = 0.05, 0.01 and 0.001 level of significance. Where no symbol follows the mean values, no differences by pruning treatment were found to be significant.

I. Evaluation of Pruning and Training Methods on Tree Yield and Fruit Quality

Part B. Establishing and Training Manzanillo Table Olives for Mechanical Harvest: 2008 Season.
Section written by William H. Krueger

Introduction

Table olives in California are hand-harvested. The cost of hand-harvest can be as much as 50 percent of the gross. From 1997 to 2000, the California Olive Committee (COC), the table olive marketing order, sponsored the development of a mechanical harvester for table olives. Prototype canopy shake machines were developed. Although these machines looked promising, they had two major drawbacks: 1) Efficiency of harvest - when the picking head came into close proximity of the fruit, it was removed. However, leading and trailing canopy edges and inside fruit proved to be problematic because it was difficult to get the head close to fruit located in these positions. Fruit removal was often disappointing. 2) Fruit damage - The fruit can be damaged in the removal process. While this damage may appear similar to what may occur with hand-harvest, the bruises are generally deeper and more severe. One of the major table olive processors quit accepting mechanically-harvested fruit due to concerns related to fruit damage. This temporarily stopped progress toward mechanical-harvest with this machinery. A continued and increasing need for mechanical-harvest has rekindled interest. The COC resumed funding for mechanical-harvest research in 2006 and is continuing to support this research. The focus of the research has been on improvement of the previously developed machinery to increase removal and reduce damage, the development of loosening agents to facilitate mechanical-harvest and other types of mechanical-harvesters such as trunk shakers.

If a tree canopy could be developed in which all of the fruit was accessible to the picking head, a much improved harvest efficiency with reduced force and, therefore, reduced fruit damage should be attainable. The ideal tree and orchard configuration would appear to be a close-spaced hedgerow system, which would present a flat narrow fruiting wall to the harvester with no leading, trailing edge or inside fruit. A fruiting canopy approximately 6 feet in width and approximately 12 to 15 feet high would be appear to be ideal for maximum machine efficiency. With a narrow tree canopy and tree height such as this, narrower row spacing will be necessary to achieve maximum yields. This type of tree architecture should also be more adaptable to other types of mechanical-harvesters including existing trunk type shakers and other types of machinery which could be developed.

Objectives

1. Develop a narrow canopy hedgerow to facilitate mechanical-harvest;
2. Evaluate and demonstrate the feasibility of a high density hedgerow developed specifically for mechanical-harvest; and
3. Compare different training methods for developing a narrow canopy hedgerow.

Procedures

In the spring of 2000, Manzanillo variety table olives were planted on 2 acres at the Nickel's Estate in Arbuckle with a north-south row orientation and a tree spacing of 12 feet in the row and 18 feet between rows (202 trees per acre). The selected training treatments included "conventional" and three narrow canopy hedgerow treatments. The conventional training consists of thinning out fruit wood and opening up the center of the tree. The trees will eventually have 3 to 5 primary scaffolds. With the narrow canopy hedgerow treatments, permanent limbs are being trained parallel to the row in a narrow plane (approximately 1 foot wide) with flexible temporary fruiting wood extending approximately three feet out into the row on either side. Large stiff limbs extending into the tree row are positioned into the permanent limb plane or are removed. The narrow canopy hedgerow treatments are: Free Standing - where pruning alone is used to conform the trees to the system; trellised woven - where potentially permanent limbs are woven between three wires spaced at 4, 7, and 10 feet; and trellised tied - where potentially permanent limbs are tied to the wires. In 2007 the tied treatment was not pruned because cropping potential appeared light. In 2008 this treatment was pruned, but not tied. The pruning consisted of thinning the tree canopy. This treatment will gradually be brought back to the narrow canopy system through a combination of pruning and tying. The treatments are arranged in a randomized complete block design and consist of blocks of three rows of either seven or eight trees. There are four replications of each treatment. In 2008, harvest data was collected by hand and, in some cases, mechanically with trunk shakers. In the mechanically-harvested trees, total yield was determined by weighing mechanically-harvested fruit and adding it to the weight of the fruit gleaned by hand from the same trees. At harvest, 10 to 12 lb. samples were collected from each replication of each treatment and submitted to Musco Family Olives for commercial grading. The sample results were used to assign a value to the production.

Originally six trees of the Sevillano variety were strategically placed in the planting to provide for cross pollination for the partially self-incompatible Manzanillo. Due to disappointing growth of these trees, cross pollination was inadequate. Even though there was a good bloom, the fruit set for 2003 was disappointing and did not warrant harvest. During the summer of 2003, the center row of the planting was top worked to Sevillano to provide for adequate cross pollination. During bloom in the spring of 2004 and 2005, the block was artificially cross-pollinated using Sevillano pollen. The grafted pollinators developed well and artificial pollinization was discontinued in 2006. In the spring of 2007, about two weeks after full bloom, all of the plots were chemically thinned with Napthalene Acetic Acid (NAA). In 2008, bloom appeared lighter and less uniform than in 2007 so no chemical thinning was done.

Results and Discussion

Yields for 2008 were variable from plot to plot, but were generally good with an average for all treatments of 5.35 tons per acre. There were no statistically significant differences between any of the treatments for yield per acre, value per ton or value per acre (**Table 2**).

Cumulative yields for all treatments were very similar through the first eight years and would be considered good for this area. Cumulative yield for the freestanding narrow canopy hedgerow system has been slightly less than the conventional treatment. This would be expected due to the generally more severe pruning required to conform the trees to the system. To date, plot variability has kept this difference from being statistically significant. The tied narrow canopy treatment had the lowest yield per acre in 2008. Plot variability also kept this difference from being significant. However, it is believed that this difference, if real, is due to the higher yield that this treatment had last year and reflects the alternate bearing nature of olive.

Conclusions

To date, the results indicate that olives trees can be grown and maintained in a narrow canopy hedgerow configuration with no reduction in yield or fruit value.

Table 2. Nickel's Hedgerow Olive Harvest, 2004-08

Treatment	2004	2005	2006	2007	2008			Cum. Yield
	Tons/A	Tons/A	Tons/A	Tons/A	Tons/A	$/Ton	$/Acre	Tons/A
Conventional	4.09	1.75	2.81	6.39	5.96	$1,060	$6,137	21.00
Free Standing	3.66	1.51	2.26	6.40	5.04	$948	$4,594	18.85
Trellised, Woven	4.21	1.68	2.28	6.07	5.88	$1,004	$5,875	20.12
Trellised, Tied	3.58	3.45	1.76	7.51	4.52	$1,104	$4,983	20.82
	NS	NS	NS	NS	NS	NS	NS	

Numbers followed by different letters are significantly different at the 5% level using Fischer's test.

II. Evaluation of Mechanical Harvesters

Part A. DSE 008 Picking Head Harvester

Introduction

Earlier research demonstrated that the picking head of the DSE 008 harvester removed as much as 98% of the fruit if it was accessible. However, final efficiency (the percentage of fruit that is captured in the bin) averaged 72% due to fruit being inaccessible, or removed, but not captured by an incompetent catch frame.

Mechanically harvested fruit quality in 2007, as measured by receiving station grades, % cannable and adjusted price per ton, was lowered by fruit bruising and mutilation. The 2007 fruit post-processing sensory evaluations by Dr. JX Guinard demonstrated differences between processors were more detectable than the differences between hand and mechanically-harvested fruit. The trained sensory panel found larger differences in the fruit from the two different processors than they detected in mechanically-harvested versus hand- harvested fruit. However, mechanically-harvested fruit was also evaluated as having a softer, less desirable texture.

For evaluation of the improved DSE 008 in 2008 fruit, processed fruit evaluations in March 2009 will be done on both fresh and stored processed fruit to minimize the sensory evaluation differences between the processors. The results should be available by April 2009.

Procedures

Location: Block 17W Rocky Hill Ranch, Exeter CA

- Planted 1998
- 13 rows, 83 trees per row, 'Manzanillo' olives with 'Sevillano' pollinators
- Spaced @ 12 X 26 feet, 139 trees per acre
- On 16 and 17 July 2008 the western 6 of 12 rows were mechanically topped at 12 feet, hedged 6 feet from the trunk on the west side and skirted 3 feet from the ground on both sides.

September 29 – 20, 2008

The six mechanically pruned tree rows were divided into five 14 tree replications with 1 buffer tree at each row end, and 2 buffer trees between each 14 tree replication.

- One replication was hand harvested on 24 September to provide the data for Objective I.A
- One replication per row (6 row total) was hand-harvested as a control
- Three replications per row (6 row total) were harvested with the DSE 008
    - Dropped fruit were collected and weighed; but not combined with harvested fruit
    - Each tree was hand-gleaned, and fruit weighed; but not combined with harvested fruit
- The one hand-harvested replication and three machine-harvested replications were maintained in separate bins
- The separate bins were weighed at Musco receiving station
- A COC sample grade was done for each bin
    - A 40 pound sample of extra large/large fruit was collected from the running the fruit over the sizer
    - Separated into two, 20 pound samples for Bell Carter and Musco
        - One sample will be processed fresh
        - One sample will be processed stored
        - The samples were sent to the two processors that night

2 (harvest methods) X 6 (14 tree replications) X 2 (Processors) X 2 (processing methods) = 48 samples total

These 48 samples will be:

- USDA graded by the both processors in March 2009
- Evaluated by a sensory panel under the direction of Dr. Guinard in March through June 2009

Results and Discussion

The results, below in **Table 3**, demonstrate, as expected, that harvest method has no effect on yield per tree. Mechanically-harvested trees yielded 20.3 Lbs/tree versus 17.8 Lbs/tree for hand-harvested trees. However, the method of harvest significantly affected the cannable percentage and adjusted value per ton. Mechanically-harvested fruit was valued statistically significantly lower*** at $1013.80/ton with a significantly lower cannable percentage of 88.0*** versus $1137.80/ton and a cannable percentage of 96.80% for hand-harvested control fruit. However, while significantly lower than the values for hand-harvested fruit, these average values per ton and cannable percentages are well within acceptable ranges. It is important to understand what caused these decreases in value.

The decreases in olive quality and value were, in decreasing order, a result of a significantly higher % of trash and culls, and lower % of extra large fruit, in the mechanically-harvested fruit versus hand-harvested fruit. Based on these data, the greatest decreases in value were produced by the higher trash percentage at 6.5%, six times that of the hand harvested control. This was the result of a malfunctioning blower that could have been easily repaired, and should not be a problem in the future. The higher cull percentage also decreased the fruit value; 5.1% versus 2.2 % for hand-harvested fruit. The primary reason for cullage was overripe and wrinkled fruit. Again both factors could be decreased by an earlier harvest, and should not be a problem in the future. However, these easily avoidable factors significantly affected the 2008 harvest data. The 8.6% decrease in extra large fruit harvested, from 61.4% for hand-harvested versus 52.8% for mechanically-harvested trees is interesting. It conflicts with our 2002 research demonstrating that the canopy picking head type harvest preferentially removed, the larger more mature, more easily detached fruit first. And there are no significant differences in the balance of the other fruit sizes that would suggest compensation by the other fruit sizes; all the other fruit size percentages were insignificantly different from those of the hand-harvested controls. However, the respective percentages were consistently lower. Thus, while individually no individual value was statistically significant, the summed differences could provide compensation. However, fruit size distribution was the least significant of the factors that decreased the value of the mechanically-harvested versus the hand-harvested fruit.

This data given here can also be used to determine the removal and final fruit removal efficiency of the DSE 008. These values are calculated as follows:

$$\text{Fruit Removal Efficiency} = \frac{\text{Fruit in Harvest Bin + Fruit on Ground}}{\text{Total fruit on the tree}}$$

$$\text{Final Harvest Efficiency} = \frac{\text{Fruit in Harvest Bin}}{\text{Total Fruit on the Tree}}$$

This portion of the experiment was done entirely on mechanically topped and hedged trees; a pruning treatment that, hypothetically, should have enhanced mechanical harvesting efficiency. Even with this theoretical advantage, the efficiency of removal by DSE Harvester ranged from 44.1% to 77.6%, with a mean value of 57.8%. The efficiency calculation was based on fruit left and dropped on the ground. Fruit drop from the harvester was minimal; generally less than 0.25 lbs/tree (data not shown). This average decrease in efficiency from the average 72% removal in 2007 may be partially a result of a low crop. Low crops tend to be more scattered on the tree, resulting in less efficient removal.

Conclusions

In summary, the data given here demonstrate the canopy picking head can produce commercially acceptable quality fruit if receiving station grade is the final criterion. However, processed fruit grade USDA and sensory evaluations are the limiting factor in determining the viability of any mechanical harvester. The processed fruit USDA evaluations by the two processors and sensory evaluations by Dr. Gruinard's lab will be done March 2009 and available shortly thereafter.

The two major factors that decreased fruit grade and quality in this experiment can be easily overcome. Harvesting at the right time and proper blower function would have greatly increased the cannable percentage and value per. Most likely, if these two factors had not lowered the cannable percentage and adjusted value per ton, the mechanically-harvested fruit would have received a receiving station grade as high as that of hand-harvested fruit. Therefore, based on the data available at this time, the contact canopy picking head is a viable harvester option for California black ripe processed table olives. Particularly for appropriately pruned larger and older trees.

However, the efficiency of this specific harvester, the DSE 008, suggests that we have learned as much as we can from this prototype. This DSE 008 is too slow, large, and expensive. It lacks a complete catch frame. These factors make it unlikely that the DSE 008 can be successfully developed as a commercial olive harvester within the time frame of this grant. The major contribution of Dave and Karen Smith of DSE in restarting olive mechanical harvesting research is gratefully acknowledged. Canopy contact picking head research should now be adapted using the Agright and Coe pomegranate harvesters.

Table 3. Effect of harvest method on yield, percent cannable fruit, and fruit value per ton. Harvest method had no effect on yield, but mechanical-harvest significantly lowered the percentage and value per ton of cannable fruit. The major factors causing these decreases were significant increases in the percentages of trash and culls in mechanically harvested fruit. The high percentage of trash was the result of an inoperative blower. The higher percentage of culls was the result of overripe fruit.

Evaluation of Mechanical Harvesting on Yield and Receiving Station Value												
Harvest treatment	Yield/tree (lb)	Percentage										**Adjusted price/ton ($)**
		Cannable	Extra large	Large	Medium	Small	Petite	Subpetite	Undersized	**Culls**	**Trash**	
Mechanical	20.3	**88.0*** **	52.8*	25.1	5.0	2.2	1.4	1.1	0.8	**5.1** **	**6.5*** **	**1013.80*** **
Hand	17.8	**96.2**	61.4	26.7	4.1	1.6	1.2	0.8	0.8	**2.2**	**1.1**	**1137.80**

[x] Means separation within columns were performed with PROC TTEST procedure of SAS (SAS Institute Inc., Cary, NC); *, **, *** = 0.05, 0.01 and 0.001 level of significance. Where no symbol follows the mean values, no differences by harvest treatment were found to be significant.

Efficiency of removal by DSE Harvester ranged from 44.1% to 77.6%, with a mean value of 57.8%.

II. Evaluation of Mechanical Harvester(s) Efficiency and Effects on Fruit Quality and Value: 2008 Season

Part B. Coe, Nielsen and OMC Trunk Shakers

Introduction

Trunk-shaking oil olive trees is common in Europe. In the 1960s, University of California also developed pruning methods, and an 'inertia head" shaker for mature California table olive trees. However, the technology, never widely adapted, was designed exclusively for larger trees, not younger hedgerow orchards. Because a younger hedgerow orchard, developed by Krueger and Ferguson, discussed under Objective I.B of this report, now exists, there is an opportunity to re-examine trunk shaking of table olives.

Therefore, it was proposed to compare the harvest efficiency, effects on fruit quality and long term tree health of three commercially available trunk shakers on the four different training methods on 8 year old hedgerow olives. The companies and machines selected were the ENE Inc. pistachio harvester, the Coe pistachio harvester and the Mayo Shakermaker pistachio harvester. The objective was to test the efficiency, and effects on fruit quality of these three machines on one conventional and three hedgerow training treatments.

As the data given below will demonstrate, trunk shaking of young hedgerow orchards has potential, but currently has a limiting factor that must be addressed. The trunk-shaking produced receiving station cannable grades and value equal to that of hand-harvested trees. And, as the data below show, the final harvest efficiency needs to be significantly improved. But the most severe problem is that trunk-shaking produces unacceptable trunk damage.

Procedures

Locations: Nickels Estate: Greenway Ave, Arbuckle CA; Planted 7-8-01. Tree spacing = 12'x18' or 202 trees/ac; 'Manzanillo' cultivar with Sevillano (S) pollinators; center row budded to Sevillano 07-03

Experimental Design: 4 X 4 Factorial of Tree Training and Harvest Method.

Tree Training Method

Harvester (Tx #)	Conventional (1)	Free Espalier (2)	Woven Espalier (3)	Tied Espalier (4)
Coe	20	20	13	13
ENE	19	18	11	11
OMC	18	20	11	11
Hand Harvested Control	12	9	32	35

May, 2008: Four training treatments were trained or pruned as per treatment, and thinned if necessary.

October 7- 9, 2008: Harvester companies and operators were evaluated on:

Oct. 7: ENE Inc.: Erick Nielsen
Oct. 8: Coe Harvesters: Matt Coe
Oct. 9: OMC Shakermaker: Don Mayo

Harvest Procedure:
Each harvester shook the pruning treatment replications (4) designated above.

- Catch frame was cleaned
- Fruit in bin was weighed in field using a bin scale
- Fruit on ground under tree was collected and weighed in the field using baby scale
  - Held in extra bin for the entire row
- Fruit remaining on tree was hand-harvested and weighed in the field with baby scale
  - Held in extra bin for the entire row
- Mechanically-harvested fruit in the bin were sent to Orland Musco grading station for weight and COC grade and value
- Trees were evaluated on a four point scale for trunk damage, branch damage and leaf loss:
  - 0 = no damage or loss
  - 1 = mild
  - 2 = moderate
  - 3 = severe

Results and Discussion

Preliminary trunk shaking quickly demonstrated that severe trunk barking was a limiting factor in shaking olives. This also may have been exacerbated by late rains after normal irrigation had been discontinued. As a result, a complete data set was obtained with only one, of three potential, trunk shaking harvesters. The results from the Coe pistachio harvester are given below (**Table 4**). Limited data from the ENE Inc. and OMC Shakermaker harvesters, (data not given here), produced similar results.

The Nickels hedgerow orchard 2008 experimental data was probably severely compromised by a very light and variable crop per tree that produced widely differing size distributions within the treatments. As a result no significant differences were detected among the treatments, or relative to a hand-harvested control, in fruit quality factors; percent cannable fruit and adjusted value per ton. The analyzed data for this experiment is given in **Table 4**.

The data in **Table 4** demonstrate no significant differences in harvest efficiency among the four pruning treatments. The harvest efficiency values range from 63.6 to 71.8% of the fruit removed from the tree relative to the total crop on the tree. Therefore, trunk shaking is equally efficient, or inefficient, among the four pruning treatments. However, relative to hand-harvest, at a low estimate of 95% harvest efficiency, this means an average of 30% of the fruit remained on the mechanically-harvested trees versus hand-harvested trees. Therefore, harvest efficiency of trunk-shaking does need to be improved, even with young hedgerow orchards.

Table 4. Averaged final harvest efficiency (fruit in the bin/total fruit on the tree) of the Coe pistachio harvester for the control and three training treatments. There were no significant differences in % harvester efficiency among the three training and control treatments. The % cannable fruit and adjusted price per ton were only available as averaged percentages and therefore are not statistically analyzed.

Evaluation of Coe Trunk Shaker Harvester with Four Different Hedgerow Tree Training Methods

Tree Training Method	# of Trees	Harvest efficiency (%)*NSD	Yield /tree	% Cannable	Adj. $/ton	
Control						
				95.0	*974.45*	*Machine*
Total	20	71.8	67.4	*97.1*	*1,035.35*	*Hand*
				(-2.1)	(- 60.90)	(Difference)
Treatment 2 = Espalier - no trellis						
				96.4	*872.22*	*Machine*
Total	14	63.6	51.1	*96.3*	*1,041.66*	*Hand*
				(+0.1)	*(-169.44)*	(Difference)
Treatment 3 = Espalier - trellis, no tying						
				95.3	*963.27*	*Machine*
Total	13	65.3	51.0	*94.4*	*1,030.81*	*Hand*
				(+0.9)	*(-67.54)*	(Difference)
Treatment 4 = Espalier - trellis and tying						
				96.1	*1,130.90*	*Machine*
Total	13	69.4	46.8	*92.8*	*1,100.64*	*Hand*
				(+3.3)	*(+30.26)*	(Difference)

* NSD; no significant differences among training treatments.

The effects on fruit quality, the percentage of cannable fruit, and the adjusted price per ton were similarly insignificant among the four pruning treatments. The canning percentages among treatments ranged from 95% to 96.4%. Adjustable prices per ton ranged from $872.22 to $1,130.90 per ton. Both ranges are well within good receiving station grades.

Canning percentage differences between the hand-harvested controls and different machine harvested pruning treatments ranged from, -2.1% to +3.3%. Adjusted values per ton relative to the hand-harvested controls ranged from - $169.44 to + $30.36 per ton. Statistics were not done on these average value differences as the replications were too limited and uneven. However, values suggest there would be no significant differences in cannable percentages or adjusted values per ton between hand-harvested and trunk-shaker harvested fruit.

The data below (**Table 5**) are from a smaller trial comparing the performance of the ENE Inc. pistachio harvester and an imported Spanish wraparound harvester. Generally, the percentage removal efficiency, percentage of cannable olives, and adjusted prices per ton are comparable to the values in the Nickels trial. Trunk damage was also sustained in this trial. Generally, this second trial reinforces the need to decrease trunk damage and increase final harvest efficiency if trunk shakers are to be successfully used for table olive mechanical harvesting.

Table 5. Comparison of the ENE Inc. pistachio harvester and the Spanish wraparound olive harvester removal efficiency and effects on receiving station values. Values in a row followed by different letters are significantly different. The Spanish wraparound harvester had significantly higher % harvest efficiency than the ENE Inc. harvester. There were no significant differences among the harvesters and control treatment in % cannable fruit. Similarly there were no significant differences between the harvesters in adjusted price per ton. However the ENE Inc. harvester did have a significantly lower adjusted price per ton than the Spanish wraparound harvester. This was a very limited experiment with uneven numbers of replications and, while statistically analyzable, this data should be treated as preliminary to larger, more completely randomized and replicated trials.

Comparison of ENE Inc and Wraparound Trunk Shaker on Young Trees*.

	ENE Inc.	**Wrap Around**	**Hand Harvest Control**
Removal efficiency (%)	55.1a	61.5b	
Cannable %	91.5a	92.3a	95.3a
Adjusted Price per Ton	879.33a	998.40ab	1072.66b
Average Yield (lb/tree)	56.9	49.83	66.0

*Numbers in row followed by different letters are significantly different at the 5% level using Fischer's test.

Conclusions

In summary, the limited data in these two trials with trunk shaking harvesters demonstrates trunk-shaking young trees, (< 10 years), produces olive canning percentages and adjusted values per ton equal to that of hand-harvested fruit. Theses data demonstrate the strong potential trunk-shakers have for mechanically-harvesting young table olive trees. However, harvester efficiency will need to be improved for commercial adoption of trunk-shaker harvesters.

The data given here also demonstrate the major impediments to successful trunk-shaking will be eliminating trunk damage and increasing the final fruit removal efficiency. These two factors, as well as the more technical aspects of trunk-shaker performance evaluation are addressed in Drs. Uriel Rosa's and Sergio Castro's final reports.

III. Part 1. Evaluation of MacTeq Colossus

Section written by Sergio Castro

Procedures:
Date: 12 September 2008
Location: Ranch 'Rabadoa', Baleizao, Portugal
Harvester: MacTeq Colossus with rod drum modification and padded frame
Olive: 'Hojiblanca' cultivar, 5 years old, 7 x 4.8 m tree spacing

Harvesting tests in the AM:
At 12:20 pm. Five trees. Harvester used the highest drum speed, hardest conditions. Harvesting efficiency estimation (visual) = 90%.

Harvesting tests in the PM:
At 3.55 pm: Five trees. Harvester used the regular working conditions. Harvesting efficiency estimation (visual) = 60%.

Fruit removal force (FRF) was measured (cN) before and after harvesting, both in the AM and PM tests.

Collected Sample Classifications:

A = Belt.
Olives from the bottom belt; collected before fruit transport system. These olives show the damage from detachment system by canopy shaking and catch frame.

B = Belt.
Olives from the shortest conveyor belt after the transport system; collected from rear of the harvester. They came from the left bottom belt. These olives include a part of the fruit damage from the transport system.

C = Bin.
Olives from the longest conveyor belt after the transport system; collected from the rear of the harvester. They came from the right bottom belt. These olives include all fruit damage caused by the transport system.

D = Hand Control.
Hand-harvested olives.

Visual Damage Classification after 24 h.

- Sound: Fruit without damage. Fruit looks similar to those in the tree canopy.
- Bruised: Fruit with > one bruise, compression or abrasion without skin being cut. Olives from this classification could be processed. These olives have visual damage after 24 h of postharvest storage.
- Cut: Fruit with skin damage, primarily deep cuts.
- Mutilation: Fruit deformed and unsuitable for processing.

Fruit Detachment Force Evaluation:

Description of data collected. FRF is measured in centiNewton (cN)

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
FRF Control Morning Before Harvest	110	380,00	1040,00	627,5455	131,97294
FRF Morning After Harvest	47	200,00	880,00	565,1064	171,31045
FRF Control Evening Before Harvest	49	160,00	860,00	485,7143	135,09256
FRF Evening After Harvest	52	180,00	860,00	499,6154	146,94219
Valid N (listwise)	47				

T-tests with paired samples.

Differences between control measurements in AM and PM.: There were significant differences between mean values; FRF decreased from early AM through late PM.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	FRF Control Morning Before Harvest	656,1224	49	143,49530	20,49933
	FRF Control Evening Before Harvest	485,7143	49	135,09256	19,29894

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	FRF Control Morning Before Harvest - FRF Control Evening Before Harvest	170,40816	158,33718	22,61960	124,92841	215,88791	7,534	48	,000

Differences between FRF before and after harvesting: There are differences between the AM test when olives had a higher FRF and the harvesting process was more aggressive. However, this difference is not a good representation because the harvester removal efficiency was very high (90%) and the olives were located only on the lower branches, close to the ground. Also, FRF is less than earlier FRFs. Fruit removal doesn't depend totally on FRF; fruit location appears to be more important.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	FRF Control Morning Before Harvest	654,6809	47	143,87270	20,98599
	FRF Morning After Harvest	565,1064	47	171,31045	24,98820
Pair 2	FRF Control Evening Before Harvest	485,7143	49	135,09256	19,29894
	FRF Evening After Harvest	504,0816	49	149,72083	21,38869

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	FRF Control Morning Before Harvest - FRF Morning After Harvest	89,57447	213,25589	31,10657	26,96019	152,18874	2,880	46	,006
Pair 2	FRF Control Evening Before Harvest - FRF Evening After Harvest	-18,36735	181,51385	25,93055	-70,50421	33,76952	-,708	48	,482

DAMAGE EVALUATION

AM (Hardest conditions)

Numbers (#) of fruit classified by type of damage

	SOUND	BRUISE	CUT	MUTILATION	ALL
A	75	344	26	2	447
B	66	675	52	13	806
C	53	581	119	3	756
D	830	12	9	0	851

Weights (g) of fruit classified by type of damage

	SOUND	BRUISE	CUT	MUTILATION	ALL
A	213.1	912.9	75.9	3.3	1205.2
B	183.9	1774	149.5	32.1	2139.5
C	134.9	1573.9	324.7	4.3	2037.8
D	2102.4	28.3	19.4	0	2150.1

Percentages (%) of fruit classified according with type of damage

	SOUND	BRUISE	CUT	MUTILATION
A	16.8	77.0	5.8	0.4
B	8.2	83.7	6.5	1.6
C	7.0	76.9	15.7	0.4
D	97.5	1.4	1.1	0.0

PM (Regular conditions)

Numbers (#) of fruit classified by type of damage

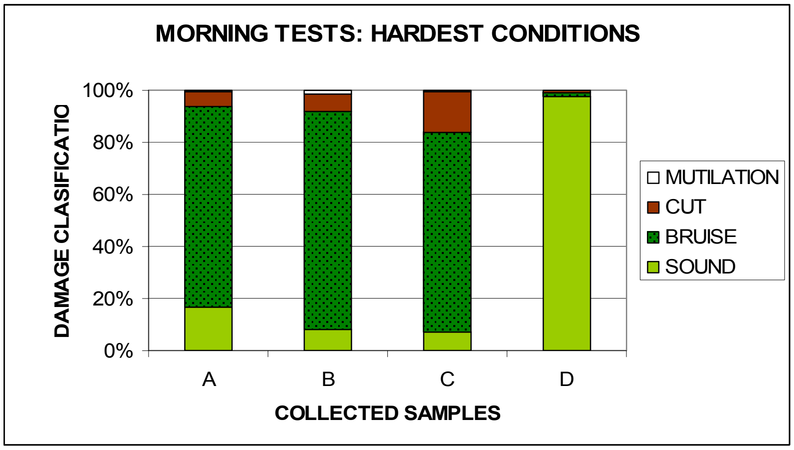
	SOUND	BRUISE	CUT	MUTILATION	ALL
A	101	494	28	1	624
B	33	680	36	4	753
C	33	797	51	3	884

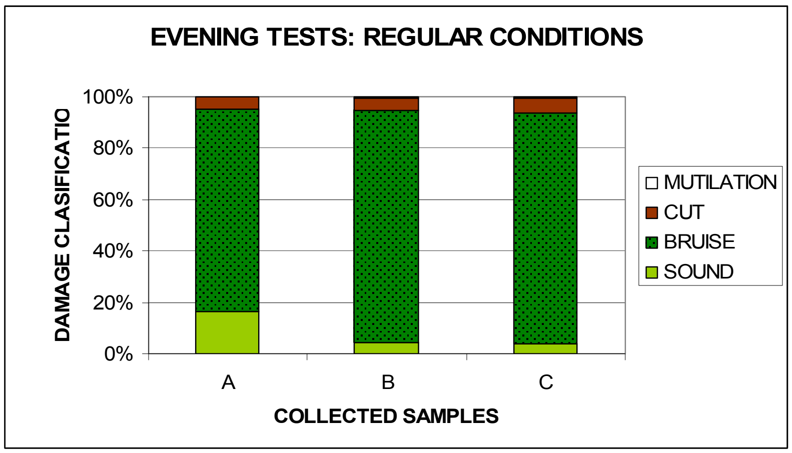
Weights (g) of fruit classified by type of damage

	SOUND	BRUISE	CUT	MUTILATION	ALL
A	265.6	1265.2	71.5	1.9	1602.3
B	91.3	1788.3	96.8	6.4	1982.8
C	83.8	2013	143.6	5	2245.4

Percentages (%) of fruit classified according with type of damage

	SOUND	BRUISE	CUT	MUTILATION
A	16.2	79.2	4.5	0.2
B	4.4	90.3	4.8	0.5
C	3.7	90.2	5.8	0.3





Conclusions

Very similar results were obtained in Argentina with 'Manzanillo' olives in February 2008. The MacTeq Colossus harvester can harvest table olives with efficiencies over 90%, but produces totally unacceptable fruit damage. The harvester will need major adaptations to its picking head, catch frame, and conveying system to be viable for table olive harvest.

III. Part 2. Evaluation of antioxidants and preharvest plant growth regulators to reduce physical damage and improve firmness in 'Manzanillo' olives in 2008

Section written by Kitren Glozer

Summary

2008 trials included testing of firmness and color instrumentation used in other fruit industries (Mitcham et al. 1996; Slaughter et al. 2005; Valero et al. 2003). These technologies are being applied to judge results from the pre- and post-harvest trials for improved quality. Tests of agents to reduce browning in 2008 included ascorbic acid, salicylic acid, sodium ascorbate, and sodium hydroxide (lye), reported to have benefit in reducing bruising in table olive (Ben-Shalom et al. 1978). Firmness in treated fruit was improved in most cases, however,

the greatest reduction in browning of bruises was found with sodium hydroxide. In 2008, we used visual versus colorimetric assessment of bruising using a colorimeter and determined that the colorimetric method will require significant modification of technique if adopted. We also implemented on a larger scale than in 2007 our use of firmness testing (FirmTech II) that has been adopted worldwide in many small fruit industries as well as research facilities.

Introduction

Enzymatic browning of fruit tissue damaged by rough handling, high pressure or machine harvest is caused by conversion of natural phenolics to quinones that are then oxidized to brown, red or black pigments (bruises). Thus, bruising results from cellular breakdown, which also often results in fruit softening. Exclusion of oxygen can reduce polymerization to colored pigments by immersion in brine or water alone. However, once fruit is removed to the air, oxidation continues.

Chemical additives can be used to reduce or prevent enzymatic browning if applied quickly enough and are appropriate to the particular type of enzymatic browning. Additives can include ascorbic acid and its analogs, sulfites (metabisulfites and bisulfites) that interact with quinones to form colorless products, and cysteine, a reducing agent. Further tests for optimum concentration, length of time prior to immersion after induced damage, temperature of lye solution, and length of immersion indicate some guidelines that may be implemented on a larger scale in future. Other treatments remain to be tested, including combinations of calcium products with bruise-inhibiting agents for improved firmness post-harvest. While Ben-Shalom et al. (1978) indicated that inhibition of enzymatic bruising in olive by polyphenol oxidase inhibitors or reducing agents is not possible due to impermeability of the whole fruit and that only dipping fruit in 0.4% NaOH (sodium hydroxide or lye) prevented bruising after mechanical injury, other procedures tested more recently on other crops show potential for reducing bruising, including calcium citrate, citric acid (Terdbaramee et al., 2003), and others. Recent research in olive characterizing the nature of the polyphenol oxidase enzyme from olive, its activity, and response to enzyme inhibitors (Segovia-Bravo et al. 2007) provides specific information that aids understanding of our own trial results and future possibilities. These authors found that the browning reaction in olive has maximum activity at pH 6, is completely inhibited below pH 3, regardless of temperature, and that pH inhibition at pH 9 is dependent on a temperature of 8EC, and at pH 11 at 25EC.

Development of instrumental techniques to assess olive fruit quality before and after processing, particularly with respect to bruising development and fruit firmness, would be beneficial to determine the effects of treatments and the comparative level of damage from different mechanical harvest techniques. In 2008, we moved from visual assessment alone of bruising to colorimetric assessment. We also implemented on a larger scale than in 2007 our use of firmness testing (FirmTech II) that has been adopted worldwide in many small fruit industries as well as research facilities. These instruments have allowed progress toward a better system of evaluation, but they are not yet optimal for use in immature olive, nor has the FirmTech been tested on processed fruit (hand- and machine-harvested) post-processing.

Objectives

1. Optimize quality measures that identify key maturity and quality parameters for table olive, using nondestructive and destructive measures, working in concert with quality researchers in

the industry processors and the USDA standards investigators, on fruit before and after processing.
2. Investigate anti-browning and plant growth regulator (PGR) potential for reduction of damage due to simulated mechanical harvest in both pre- and post-harvest applications.
3. Test treatments varying application method (preharvest spray, postharvest drench), exposure time, and concentration to maximize benefit and obtain baseline information about maximum damage reduction that might be expected of an ideal treatment.
4. Develop a strategy that would be consistent with mechanized harvest, postharvest transportation, and short-term storage, and the goals of fruit quality necessary for a high-quality processed product.

Procedures

Objective 1

Firmness, bruising and color baseline data development (Rocky Hill). Hand-harvested 'Manzanillo' fruit were obtained from the Rocky Hill commercial orchard (Exeter, CA) for testing for firmness and defect rating, to develop information on these quality measures and the instrumentation best suited to test the measures. Six replicate samples were evaluated, each a 2 lb sample from bins harvested from a 14-tree block within a tree row (each replicate was 14 consecutive trees, randomized among rows). A 50-fruit subsample was first graded by color (green-straw vs colored, showing any blush color development), then scored (yes/no) for cuts or punctures, compression (soft, flattened spots), light bruising or heavy bruising. Cuts were scored only if larger than 1 mm in length and/or 0.5 mm in width. All compressions were scored regardless of size. Bruising and overall darkening of the flesh due to oxidation were evaluated on a longitudinally cut surface, external to the pit axis. Light bruising consisted of less than 25% of the cut surface showing discoloration due to bruising, heavy bruising was 25% or more of the cut surface bruised. A second 50-fruit subsample of green-straw fruit only was tested for firmness using a FirmTech II firmness testing device (BioWorks, Inc.; http://www.bio-works.us/); this device is the standard for non-destructive firmness testing for the sweet cherry industry in California and Chile, and other fruit industries and researchers in various locations. Student's T tests were performed using SAS (SAS Institute Inc., Cary, NC) for differences in damage by color grade and means for firmness of green-straw fruit obtained for each replicate.

Color measurement methodology (used for bruise analysis). Bruising and oxidation response after mechanical damage and chemical treatment were measured on a longitudinally cut surface external to the pit with a Minolta colorimeter (Minolta, CR-200, Japan) and expressed in *LCH* color space, in which L^* = lightness, C is chroma (saturation) and H is hue angle. $L^* = 0$ is equivalent to black, $L^* = 100$ is equivalent to white. Of these measures, L and H appeared to correspond best to visual evaluation of darkening overall of the flesh with oxidation (measured as L) and darkening (browning) of bruises best measured by H. Hue angle decreases with browning (Samim and Banks, 1993); measurement of browning by reflectance is not uncommon in food quality studies (Bates, 1968; Jamieson et al., 2002). The aperture size of the colorimeter should be reduced in future tests by masking in order to reduce 'read' of tissue outside of bruised areas so as to obtain greater accuracy in measuring the bruises without measuring unbruised flesh.

Objectives 2 & 3

Antioxidant treatments. Fruit subjected to testing were bulk samples without replication, collected randomly at a uniform green-straw maturity from various mature 'Manzanillo' olive trees in the University of California, Davis, Pomology orchard (Davis, California). Fruit were treated to simulated mechanical harvest as in previous trial years by shaking a 20 to 50-fruit sample in a large closed plastic jar for 7 seconds, with external and internal damage induced in this manner similar to that of mechanically-harvested fruit under 'worse case' conditions. Fruit were evaluated after antioxidant treatment, in some cases after a several-hour delay period, simulating time delay between commercial harvest, grading at the receiving station and receipt at the processing plant. Those fruit held for an extended period were uncut and at ambient temperatures of ~75 ºF. In all trials, firmness was non-destructively measured prior to cutting fruit for bruise evaluation.

Analyses of Variance were performed with Proc GLM procedure of SAS (SAS Institute Inc., Cary, NC) and mean separations were tested by Duncan's Multiple Range Test; $P = 0.05$. PROC TTEST was used for comparison of firmness by harvest method (hand vs machine) within treatments for PGR applications in the preharvest trial.

a) *Antioxidants, survey group* -- Treatments (**Table 7**) included as controls: untreated and bruised only, as well as immersion in water with and without mechanical damage (bruising treatment). Although water immersion decreased browning initially, once fruit were allowed to air-dry, browning progressed as with bruised fruit that had not been immersed in water. Thus, water immersion gives a temporary benefit that ceases once exposure to oxygen occurs. Results from various water immersion results are omitted from the treatment lists and discussion as not being worthy of consideration.

   Antioxidants included: 0.3% ascorbic acid (AA, pH 3), 4 mM salicylic acid (SA, pH 7), 1% sodium ascorbate (SASC, pH 7), and 0.4% sodium hydroxide (lye, pH 13). Other antioxidants intended for testing included calcium citrate alone and in combination with AA or AA + SA, sodium erythorbate alone and in combination with AA. These antioxidants were not tested on fruit because of solubility problems. All immersions were in room temperature solutions, for 1.25 hr after bruising treatment, after which fruit were stored in air and ambient temperature before firmness testing and evaluation of bruise development.

b) *Sodium hydroxide series* -- This series used the results generated in the 'Antioxidant, Survey Group' test to further develop best conditions for lye reduction of bruise development, adjusting time between bruising and lye treatment (Immersion delay test), time of immersion (Immersion duration test) and Lye concentration test. There was no delay in testing for firmness and degree of bruising after treatment (no storage), other than as noted. All immersions were in room temperature solutions except as noted.

   i) Immersion delay test (**Table 8**) – Controls included: no treatment and bruised only. Lye treatments were all at 0.4% with immersion delays of 0, 1, 2, 3, 4, and 5 hours.

   ii) Immersion duration test (**Table 9**) – Controls consisted of no treatment, bruised only, bruised with immediate immersion for 15, 30 or 60 minutes. Lye treatments were all at 0.4% for the same immersion durations.

iii) Lye concentration test (**Table 10**) – Controls included untreated and bruised only. Lye treatments were all immersions for 30 minutes and varied as: 0.1% NaOH, 0.2% NaOH, 0.3% NaOH, 0.4% NaOH and 0.4% NaOH at 43EF (refrigerated).

Preharvest plant growth regulator and mechanical harvest trial. A single tree row of 'Manzanillo' olives spaced at 9' x 18' (269 trees per acre), running east-west, was pruned for mechanical harvest and utilized for this trial at the Erick Nielsen ranch, Orland, CA. Three treatments and an untreated control were randomized in a complete block design down the row in four replicate blocks. Treatments included ProGibb (30 g a.i. per acre of 4% GA_3; Valent BioSciences), Grow More LSE (4 pt/acre; seaweed foliar fertilizer; www.growmore.com), and Accel (30 g per acre of 1.8% 6-benzyladenine solution; Valent BioSciences). All treatments were applied on 29 August by handgun sprayer to runoff. No phytotoxicity was found with any treatment. Harvest occurred on 6 October; fruit were sampled from each treated tree prior to harvest (~100 fruit sample) and fruit were also sampled from the harvester bin immediately after fruit removal (~100 fruit sample). Mechanical harvest was with an ENE (Erick Nielsen Enterprises) trunk shaker. Fruit were then transported to UC Davis and a 25-fruit subsample of green-straw fruit evaluated for firmness, comparing hand-harvested and machine-harvested fruit, both treated and untreated (**Table 11**).

Results and Discussion

Objective 1

Firmness, bruising and color baseline data development (Rocky Hill). Firmness of green-straw colored fruit ranged from 622 to 1456 g/cm^2, however, mean firmness was 915-1030 (**Table 6**). When green-straw fruit were compared to colored fruit that were commercially hand-harvested into half-ton bins, green-straw fruit developed significantly more light bruising than did colored fruit (**Table 6**); heavy bruising wasn't different between treatments. Green-straw fruit were also more susceptible to cuts and punctures than colored fruit, with no significant difference in compression or soft spot development. The increased risk that green-straw fruit had toward light bruising and cuts might be due to higher tensile strength of the fruit skin than that of more mature fruit. We have not tested the firmness of colored fruit, however, it is likely that with maturity increase, fruit skin tensile strength may decrease and fruit be less prone to minor injury. Whether the same susceptibility is true under mechanical harvest conditions is not known, nor is it known what this level of damage, or the change in firmness with maturity change will affect fruit quality after processing.

Color measurement methodology (used for bruise analysis). While the colorimeter gave some indication of browning and darkening of flesh, the results were not as clear-cut as desired, possibly because the olive fruit is very hard at green-harvest stage, not allowing compression of the instrument against the flesh so as to exclude extraneous light, and because the aperture size is much larger than the typical diameter of bruises due to mechanical damage. While the second problem might be readily addressed, the first is inherent to the fruit. Other fruits that work well with the colorimeter have some 'give' to their flesh or skin, thus allowing complete contact with the instrument. Although results using the colorimeter are presented, the current system of judging visually the extent of the damage is sufficient for survey purposes, as is the case in these trials.

Objectives 2 & 3

Antioxidant treatments

A. *Antioxidants, survey group* (**Table 7**) – Firmness was least in untreated control fruit and bruised fruit with no other treatment. All antioxidant treatments improved firmness with salicylic acid, sodium ascorbate, and sodium hydroxide (lye) increasing firmness most. Any of these treatments would be acceptable for the purposes of improving post harvest fruit firmness, but sodium ascorbate showed the greatest improvement.

Lightness, or measure of darkening of cut flesh due to oxidation after cutting, was not greatly different in any treatment, especially when comparing the untreated control and the bruised control. Darkening of bruises was least in the lye-treated fruit, compared to the bruised only control, as indicated by the lowest value for hue angle. Because results for bruising were best for the lye-treated fruit, particularly as it corresponded very well to the visual assessment, lye was chosen for all other treatment series, concentrating on concentration, delay before immersion and length of immersion.

The benefit of immersion in weak solutions of lye immediately after mechanical harvest has been reported in the literature (Ben-shalom et al. 1978; Kailis and Harris 2004). Bruising consists of a local degradation of tissue combined with intracellular water exit (free water) and browning (oxidation) of phenolic compounds from released intracellular water. Shomer et al. (1979) found that browning of bruised olives is due to the enzyme catechol oxidase, which is found in chlorophyll-rich green olives. As the fruit ripens and turns black, the enzyme is released once the chloroplasts degrade. Solutions of caustic materials such as lye inactivate the enzyme, inhibiting browning associated with bruised flesh. Exclusion of the oxygen required for oxidation changes in pigments is another method of decreasing bruising, as is cold storage as soon as possible after harvest (Kader et al. 1989).

In these preliminary tests, pH of antioxidant solutions was noted, but not adjusted to fit within the pH optima found by Segovia-Bravo et al. (2007). It is to be expected that lye (pH 13) would be effective, given the alkaline nature of the treatment, less expected where pH was 7 (salicylic acid and sodium ascorbate).

B. *Sodium hydroxide series*

Immersion delay test (**Table 8**). Firmness was improved by immersion in 0.4% NaOH compared to the 'bruised only' control numerically by all lye treatments, however, a statistically significant difference was found only when lye immersion occurred at 1 hour after bruising treatment. All fruit discolored (reduced L or lightness) when cut compared to the untreated control, although a single lye treatment showed statistical equality to the control. This data, as well as that for bruising generated by the colorimeter, was inconclusive, however, visual inspection suggested that immersion within a short period of time after bruising treatment was better than longer delays.

Immersion duration test (**Table 9**). Firmness was significantly improved by immersion of 15 and 60 minutes in lye solution, compared to the bruised control. Lightness was significantly improved by immersion for 30 to 60 minutes compared to the bruised control, and browning was significantly less in the same immersion treatments.

Concentration test (**Table 10**). Firmness of bruised fruit was significantly improved by immersion for 30 minutes in room temperature lye at 0.3 and 0.4%, as well as 0.4% lye at 43EF, which also improved firmness compared to the untreated control. This firmness increase was not due to colder fruit at the time of measuring firmness as the fruit was allowed to come to room temperature. Thus, cold storage may provide a benefit in addition to that of lye, consistent with previous reports for table olive (Kader et al., 1989, 1990). Fruit treated in lye at 0.2 and 0.4% developed less overall flesh darkening compared to the bruised control; fruit treated with 0.4% lye in refrigeration had significantly less browning due to bruising than the bruised only control.

Results of the antioxidant tests indicate that immersion in 0.4% lye as soon as possible after mechanical harvest, for a duration of at least 30 minutes, preferably in refrigeration, would ameliorate bruising damage significantly. Other treatments that have potential for this purpose that should be tested include sodium benzoate and sodium chloride.

Preharvest plant growth regulator and mechanical harvest trial. Harvest method effects on firmness: Firmness was significantly reduced in machine-harvested fruit compared to hand-harvested fruit when untreated fruit were compared; the change in firmness due to harvest method was highly significant (0.1% level), however, fruit were still very firm after machine-harvest (more than 1 kg/cm^2), and while a greater loss of firmness may occur in processing and storage with machine-harvested fruit that were initially this firm, that remains to be tested. Firmness was also significantly different by harvest method in fruit treated with ProGibb and Accel (0.1% and 1%, respectively), but no significant difference was found due to harvest method in the Goëmar-treated fruit. All PGR treatments significantly increased firmness compared to the untreated controls, regardless of harvest method. These results indicate that a more extensive trial of these PGRs should be made with and without machine-harvest.

Table 6. Fruit quality measures of hand-harvested fruit, Rocky Hill orchard (Exeter, CA) in 2008.

Color (fruit skin)	% Light bruise	% Heavy bruise	% Cuts/punctures	% Compression, soft spot
Green-straw	35.4 a	0.6 a	23.0 a	0.6 a
Colored (exhibiting any red-purple development)	7.6 b	3.3 a	3.9 b	4.0 a

Green-straw fruit, range of firmness (g/cm^2; FirmTech II, BioWorks Inc.) minimum 622, maximum 1456; average fruit firmness 915-1030

^{x} Means separation by Student's T test, P = 0.05.

Table 7. *Bruising reduction chemicals*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and antioxidant treatments in 2008. Immersion was for 1.25 hr; evaluation after 20 hr in air and ambient temperatures (high of ~75 ºF). Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated	967.3 c [x]	59.6 ab	92.3 ab
Bruised only	1002.0 c	60.4 a	92.7 a
0.3% ascorbic acid (pH 3)	1078.1 b	58.6 bc	91.5 ab
4 mM salicylic acid (pH 7)	1103.2 ab	56.9 b	91.4 ab
1% sodium ascorbate (pH 7)	1171.6 a	59.3 ab	92.8 a
0.4% sodium hydroxide (pH 11)	1108.5 ab	58.3 bc	90.4 b

Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.

[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 8. *Immersion delay test*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and immersion in 0.4% NaOH in 2008. Immersion in NaOH followed a time course of 0-5 hours post-bruising, at hourly intervals; evaluation after ~30 min in air and ambient temperatures. Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Interval (hr) between bruising and immersion treatment	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated		1175.1 ab[x]	70.2 a	104.7 ab
Bruised only		1125.8 b	66.0 d	104.3 ab
NaOH	0	1165.8 ab	68.2 bc	105.0 ab
	1	1201.7 a	67.0 cd	104.5 ab
	2	1158.3 ab	67.3 bcd	104.1 b
	3	1198.5 ab	68.2 bc	105.8 a
	4	1160.0 ab	68.9 ab	105.6 a
	5	1174.3 ab	66.4 d	105.6 a

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.
[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 9. *Immersion duration test*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and immersion in 0.4% NaOH in 2008. Immersion in NaOH or water (control) followed a time course of 0-1 hours ost-bruising, at 15 minute increments; evaluation after ~30 min in air and ambient temperatures. Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Duration of immersion	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated	0	1175.1 ab[x]	70.2 a	105.3 ab
Bruised	0	1125.8 b	66.0 d	104.7 b
NaOH	15 min	1220.5 a	67.1 cd	105.1 ab
	30 min	1151.2 ab	69.5 ab	106.4 a
	60 min	1223.4 a	68.4 bc	106.5 a

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.
[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 10. *Concentration test*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and immersion in varying concentrations of NaOH in 2008. Immersion in NaOH was for 30 min; evaluation after ~30 min in air and ambient temperatures. A single treatment was included a 'cold' (43EF) treatment. Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Concentration	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated		1175.1 bc[x]	70.2 a	105.3 ab
Bruised only		1125.8 c	66.0 d	104.7 b
NaOH	0.1%	1198.9 bc	67.3 cd	104.6 c
	0.2%	1206.4 bc	68.5 abc	105.5 bc
	0.3%	1216.3 b	67.7 bcd	104.7 c
	0.4%	1151.2 ab	69.5 ab	106.4 b
	0.4%, cold	1307.8 a	67.7 bcd	108.7 a

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.
[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 11. Fruit firmness after plant growth regulator treatment preharvest, comparing hand-harvested and machine-harvested fruit in 2008. Trial location was the Erick Nielsen Ranch, Orland, California. Preharvest treatments were applied August 29 and harvest was October 6. Firmness was tested nondestructively on a FirmTech II (g/cm^2; BioWorks, Inc.).

Treatment	Hand-harvested fruit firmness	Machine-harvested fruit firmness	Significance by harvest method within treatment[y]
Untreated control	1057.8 b	1014.8 b	***
ProGibb (30 g a.i. per acre of 4% GA_3)	1088.3 a	1126.8 a	***
Goëmar BM 86 (4 pt/acre; seaweed foliar fertilizer)	1104.6 a	1103.4 a	ns
Accel (30 g per acre of 1.8% 6-benzyladenine solution)	1113.7 a	1145.1 a	**

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's multiple range test.

[y]Significant differences by Student's ttest by harvest method (hand vs machine) for a given PGR treatment; ns, *, **, *** = non-significant, significantly different at 5%, 1% or 0.1% level, respectively.

IV. Screening Abscission Compounds for Black Ripe Table Olives: 2008 Season

Section written by Jacqueline K. Burns

Introduction

Olive abscission compound screening trials were conducted at two locations: Lindcove Research and Extension Center, Exeter, and Nichols Estate, Arbuckle, CA. Trials were conducted in September 2008. The objective of these trials was to continue olive screening with compounds from the Florida citrus fruit abscission agent library. The long-term goal of this project is to adapt table olives to mechanical harvesting. Identification of a suitable abscission agent is viewed as a key to industry adoption of mechanical harvesting, as mechanical harvesting could be performed less aggressively and fruit damage could be minimized.

Procedures

Lindcove Research and Extension Center Trial

A trial was initiated on 16 September 2008 in a block of olive trees located on the Lindcove Research and Extension Center, Exeter, CA. Four uniform 'Manzanillo' trees with good fruit load were selected, and one replicate branch on each tree was tagged for each treatment. Thus, treatments were replicated four times. Each branch contained at least eight fruit and 25 leaves. Fruit number was recorded. All treatments were randomly assigned to the branches on each tree. Abscission compounds were dissolved in water containing 0.05% Activator-90 and applied between 9:00 am and 2:30 pm with a hand-held 1.5 L pressurized sprayer until run-off. A water control containing adjuvant was included in all trials. Treatments were Ethrel (1000 and 2000 ppm); salicylic acid (SA; 1000 and 2000 ppm); 1000 ppm SA + 1000 ppm Ethrel; Embark (1000 and 2000 ppm); 1, 2 and 4 ppm LA-901; 1 and 2 mM QCR; three formulations of dikegulac at 2000 and 4000 ppm (DK-B1, BK-B2 and DK-B3); and water. Maximum, minimum, and average temperatures on the day of application were 39, 17, and 26 ºC, respectively. Fruit detachment force (FDF) in grams-force was measured 10 days after application using an Imada DPS-11 digital force gauge.

Nichols Estate, Arbuckle Trial

A trial was initiated on 20 September 2008 in a block of trees located at the Nichols Estate, Arbuckle, CA. Trees selected were trained, hedged, pruned and trellised. This trial was conducted as in Lindcove described above, and treatments were identical. Maximum, minimum, and average temperatures on the day of application were 26, 10, and 18 ºC, respectively. FDF was measured 21 days following application. Maximum, minimum and average temperatures for the duration of the trial were 28, 10, and 19 ºC, respectively.

Results

Lindcove Research and Extension Center Trial

Maximum, minimum, and average temperatures for the duration of the trial were 33, 14, and 23 ºC, respectively. No fruit or leaf drop occurred at the time of measurement (data not shown). Slight variation in FDF was measured between treatments, but no significant differences were detected (**Fig. 1**, *see page 50*, top panel). Ten days after application is not a sufficient period of time to allow loosening for olive, even at these favorable temperatures.

Nichols Estate, Arbuckle Trial

No differences in FDF (**Fig. 1**, middle panel) or leaf drop (data not shown) were measured. However, fruit drop was significantly higher in the 2000 ppm Ethephon and 4 ppm LA-901 treatments when compared to most others (**Fig. 1**, bottom panel). This behavior can be explained by the extended time period selected for loosening. Olive fruit capable of reacting to the abscission compounds dropped after 21 days, but the remaining fruit on branches either did not react or partially reacted and 'tightened' via the wound healing process.

Conclusions

1) Nine abscission compounds or combinations were screened; 2) The trial at Lindcove was inconclusive due to inadequate loosening time before measurements were made; 3) The trial at Arbuckle indicated that Ethephon and LA-901 significantly increased fruit drop when compared with most other treatments; and 4) Fruit loosening at Arbuckle was not significantly different for any treatment, due in large part to the extended loosening period.

OVERALL 2008 SEASON PROJECT CONCLUSIONS

Based on the combined results of the four objectives discussed above, further research should focus on simultaneously adapting current orchards with hand and mechanical-pruning, developing new hedgerow orchards, and evaluating these orchards with all the currently available commercial harvesters. Trials with the DSE 008 have demonstrated the canopy contact picking head can produce commercially acceptable black ripe processed table olives. The DSE 008 harvester has insurmountable problems of size, cost, head maneuverability, catch frame technology, and adaptability, and poor potential for commercial production. Research should now focus on the currently commercially available trunk shaking and picking head harvesters mounted on double sided catch frames. These should be evaluated in conventional, mechanically pruned and hedgerow trained orchards. Screening for abscission compounds and postharvest treatments should continue, but these compounds are so far from incorporation into mechanical harvesting trials, or registration, that mechanical harvesting of olives should be developed without these chemical aids.

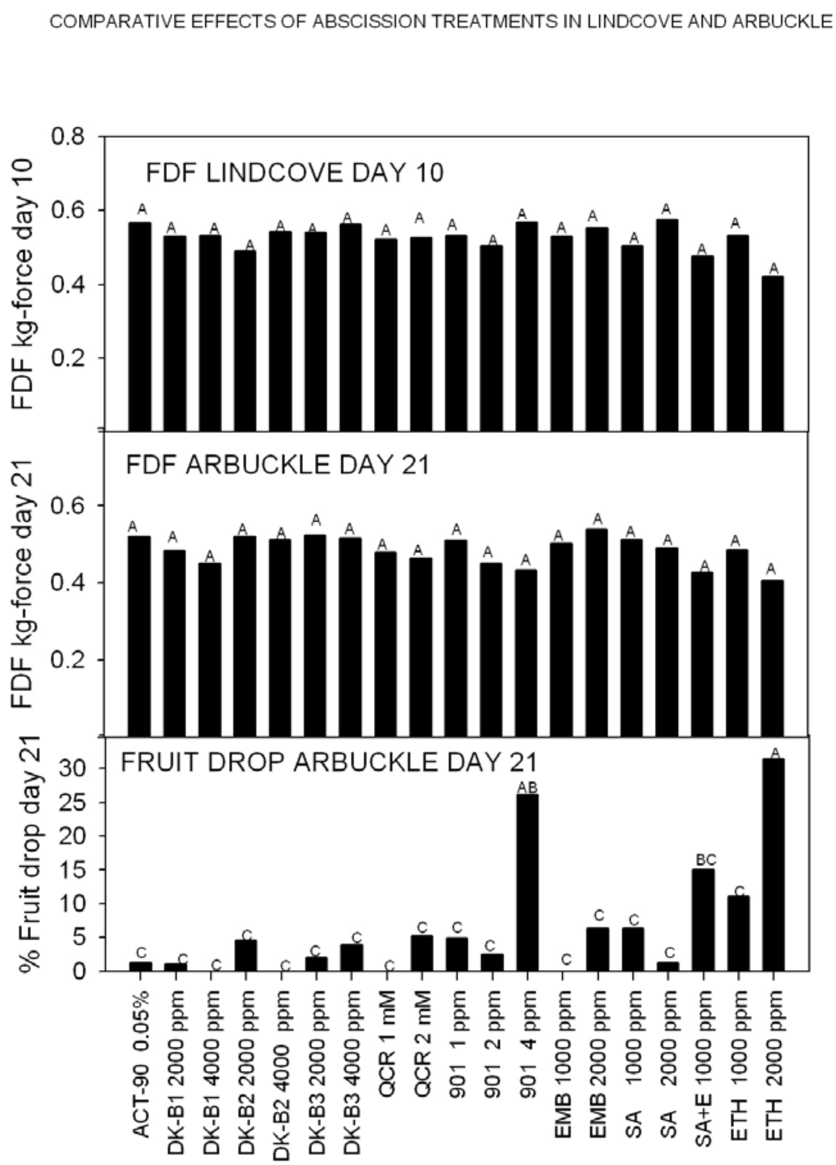


Fig. 1. Fruit detachment force and fruit drop after application of abscission compounds. See text for details.

FUNDING

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Implement Diagnosis, Epidemiology, and Control Methods for Fungal Pathogens Causing Stem Canker and Branch Dieback of Olive Trees in California

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SUMMARY

Canker and branch dieback of olive trees (*Olea europaea* L.) has long been a major concern to farmers throughout the main olive-producing areas in the Mediterranean regions of Greece (Rumbos 1988, Rumbos 1993), Spain (Romero et al. 2005), Portugal (Phillips et al. 2005), and Italy (Lazzizera et al. 2008). The disease is responsible for important yield reduction in addition to increased production costs as a result of cultural and chemical preventive measures as well as diseased wood removal from the infected trees. The California olive industry (table and oil) presently comprises over 40,000 acres and represents 99% of the total olive production in the United States (CDFA 2006). However, little is known in regards of "twig and branch dieback of olive trees" in the State. During the past few years, severe twig and branch dieback of olives trees from the main production areas in California has been reported to our laboratory from both farm advisers and growers. Therefore, the first goal of this project was to determine the incidence of "twig and branch dieback of olive trees" in California and identify the major fungal pathogens associated with canker and dieback disease in both mature orchards and young plantings of olive trees in the State.

To date, field surveys have been conducted throughout 10 California counties including Tehama, Glenn, Butte, Napa, Yolo, Sacramento, Merced, Madera, Fresno, and Tulare Counties. In addition, more field surveys are underway in order to fully characterize the importance and incidence of olive dieback throughout California. Symptoms on affected trees were characterized by an abundance of dead twigs, which often show attached wilted leaves. Death of the twigs was frequently associated with cankers that extend through the stems and continue through the main scaffold branches. In most cases, cankers were found to develop from pruning wounds on the main branches, causing dieback and eventual death of the productive tree parts. Cankers were also observed in branches and trunks with mechanical injuries as well as natural openings.

Cankers often were observed to colonize the main trunk causing the collapse of the whole tree. In all, over 450 samples of cankered twigs, branches, and trunks have been collected from 40 different olive orchards. Samples were brought to the laboratory in an attempt to isolate and identify the canker-causing agents. "Twig and branch dieback of olive trees" was observed in all orchards surveyed in California. However, incidence of the disease varied with location and age of the orchards.

To date, results from the isolations of cankered twigs and branches showed at least several fungi to be associated with olive dieback. Based on morphological characters (mycelium color and growth, spores morphology, and fruiting structures), these fungi were classified into three ascomycete families, one basidiomycete family, and one fungal group. In order of importance, these ascomycete families were Botryosphaeriaceae, Diatrypaceae, and Valsaceae. In addition, several fungi were classified into the mitosporic fungal group. Botryosphaeriaceae spp. were the most common fungi isolated from perennial olive cankers in California and were found in all counties surveyed. Analyses of fungal DNA along with phylogenetic analyses of the internal transcribed spacer region (ITS1-5.8S-ITS2) allowed us to identify the most predominant fungi isolated from cankers to species level. To date, we have identified at least seven different species within the Botryosphaeriaceae family, two species within the Diatrypaceae family, one species within the Valsaceae family, one Basidiomycete species, and five species within the mitosporic group. Species of Botryosphaeriaceae and Diatrypaceae constitute the primary cause of cankers and consequent grapevine dieback in California (Trouillas and Gubler 2004, Úrbez-Torres et al. 2006). Therefore, their common occurrence in olive trees may suggest that these fungi could also play an important role in olive twig and branch dieback. Consequently, and based on means of pathogenicity tests, work is underway to determine which fungal species isolated from cankers of olive trees are the main pathogens causing dieback of olive.

OBJECTIVES

1. Identification and characterization of the current population of fungal pathogens associated with stem perennial cankers and branch dieback of olive trees in California;
2. Understand the epidemiology of olive canker pathogens:dispersal patterns, as essential for IPM control strategy design; and
3. Development and implement chemical, biologicalcontrol methods for fungi involved in branch dieback of olive.

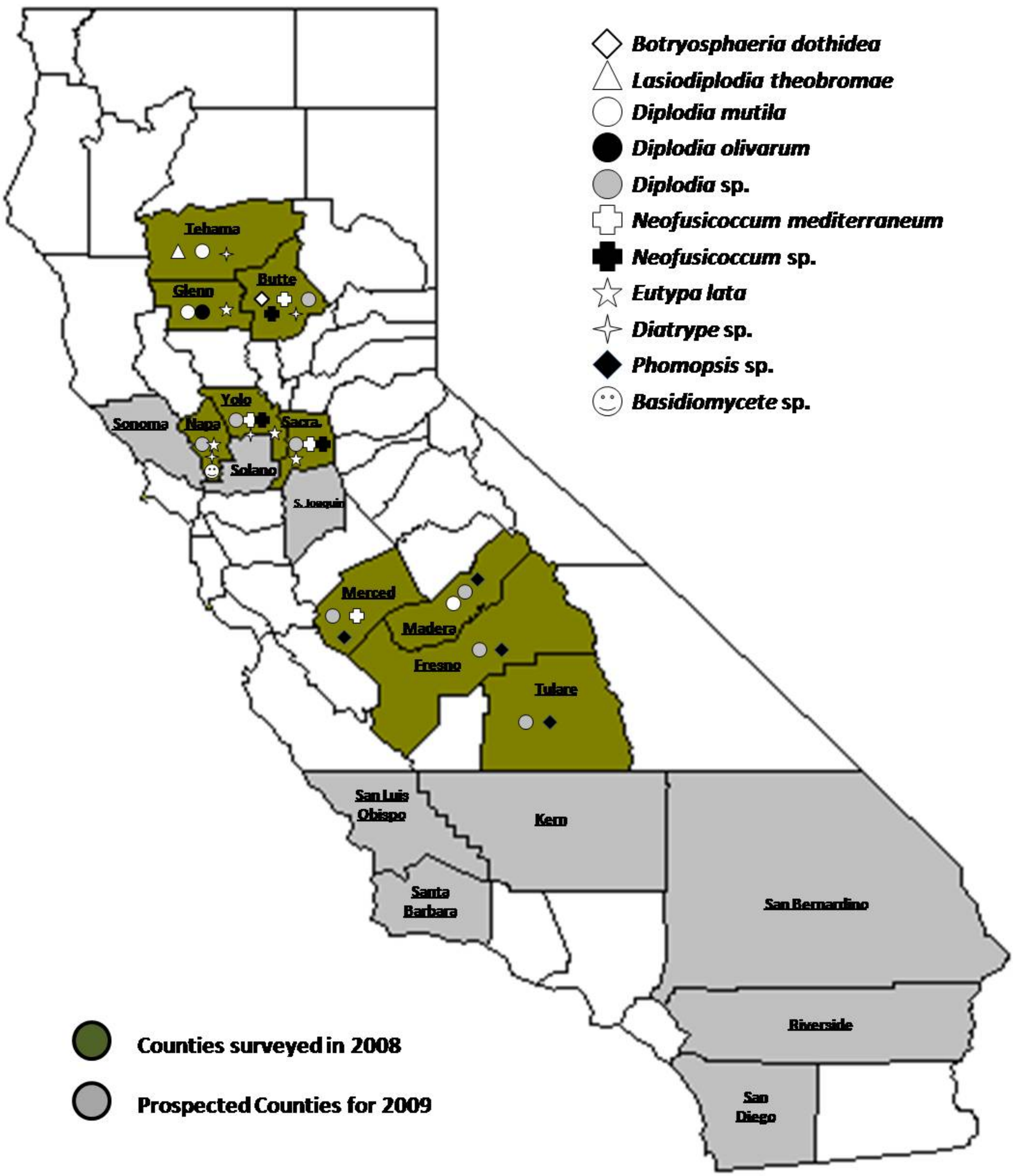
MAJOR RESEARCH ACCOMPLISHMENT AND RESULTS

Objective 1. Identification and characterization of the current population of fungal pathogens associated with stem perennial cankers and branch dieback of olive trees in California

Field surveys

To date, field surveys have been conducted in 10 different counties including Tehama, Glenn, Butte, Napa, Yolo, Sacramento, Merced, Madera, Fresno, and Tulare Counties (**Fig. 1**). Moreover, field surveys are still underway in Sonoma, Solano, San Joaquin, San Luis Obispo,

Figure 1. Olive field surveys conducted in 2008 and geographical distribution of the dominant fungal species isolated from cankers.



and Kern Counties, as well as other olive production areas of southern California in order to obtain a complete map of the current situation of the pathogenic fungi associated with stem cankers in olive trees in the State (**Fig. 1**). Field surveys conducted to date have shown the significance of “twig and branch dieback of olive tree” in California. Olive dieback was observed in all counties surveyed and was more prominent in orchards older than 20 years-old no matter the cultivar surveyed (**Table 1**). Although tree dieback was observed in 39 out of 40 olive orchards surveyed, the incidence of affected trees varied with location. Depending on the orchard surveyed, olive dieback could be categorized from 75-100% (almost all trees in the orchard were affected) to 0-25% (only some trees in the orchard showed some dieback). To date, over 450 samples of cankered twigs, branches, and trunks have been collected from 40 different olive orchards (**Table 1**).

Symptoms observed

Affected trees were characterized by abundant death of the twigs (**Fig. 2a**) and dieback of stems and main branches (**Fig. 2b**). These cankers often extended through the main branches (**Fig. 2d**) until reaching the trunk, causing dieback and eventual death of the tree (**Fig. 2c**). Wedge-shape cankers were the most common vascular symptom observed when affected branches were sectioned (**Fig. 2e**). However, other vascular symptoms, such as dark wood streaking and/or dark brown tissue, were observed in contrast to the yellowish green of healthy tissue. Cankers were also observed in young trees affecting the crown of the tree (**Fig. 2f**). Although cankers were found to develop mostly from pruning wounds inflicted in the main branches they were also observed to develop from galls caused by *Pseudomonas syringae* subsp. *savastanoi*, the causal agent of “olive knot” (**Fig. 2h**). Olive trees have to be pruned back when severe dieback affects main branches and trunks causing severe economic losses to farmers (**Fig. 2g**).

Fungal isolation and identification

Cankers in twig and branch samples were surface disinfested in 10% sodium hypochlorite for 10 minutes. After air drying, the surface tissue was cut away to expose canker margins and small pieces of tissue from margins of the cankers were placed on Petri dishes containing 4% potato dextrose agar (PDA) amended with 100 ppm of tetracycline (PDA-tet). To date, results from the isolations showed several fungi to be associated with olive dieback. Based on morphological characters, three different ascomycete families were identified including Botryosphaeriaceae, Diatrypaceae, and Valsaceae. Species of Botryosphaeriaceae were the most common fungi isolated from perennial olive cankers in California followed by Diatrypaceae and Valsaceae species (**Table 1**). Botryosphaeriaceae spp. were found associated with olive dieback in all counties surveyed (**Fig. 1**). On the other hand, the incidence of Diatrypaceae and Valsaceae species varied with location (**Fig. 1**). Morphological features to characterized Botryosphaeriaceae spp. were the dark color mycelium (olivaceous-green to dark-green), the fast growth of the mycelium on PDA-tet medium (reach 85 mm diameter in less than 72 hours), and the characteristic color (dark or hyaline), shape (ellipsoidal to ovoid), and size (> 15 um) of the spores (conidia) (**Fig. 3a,b,c,d**). On the other hand, morphological features of species within the Diatrypaceae and Valsaceae were a much slower growth of the mycelium, a white and/or light

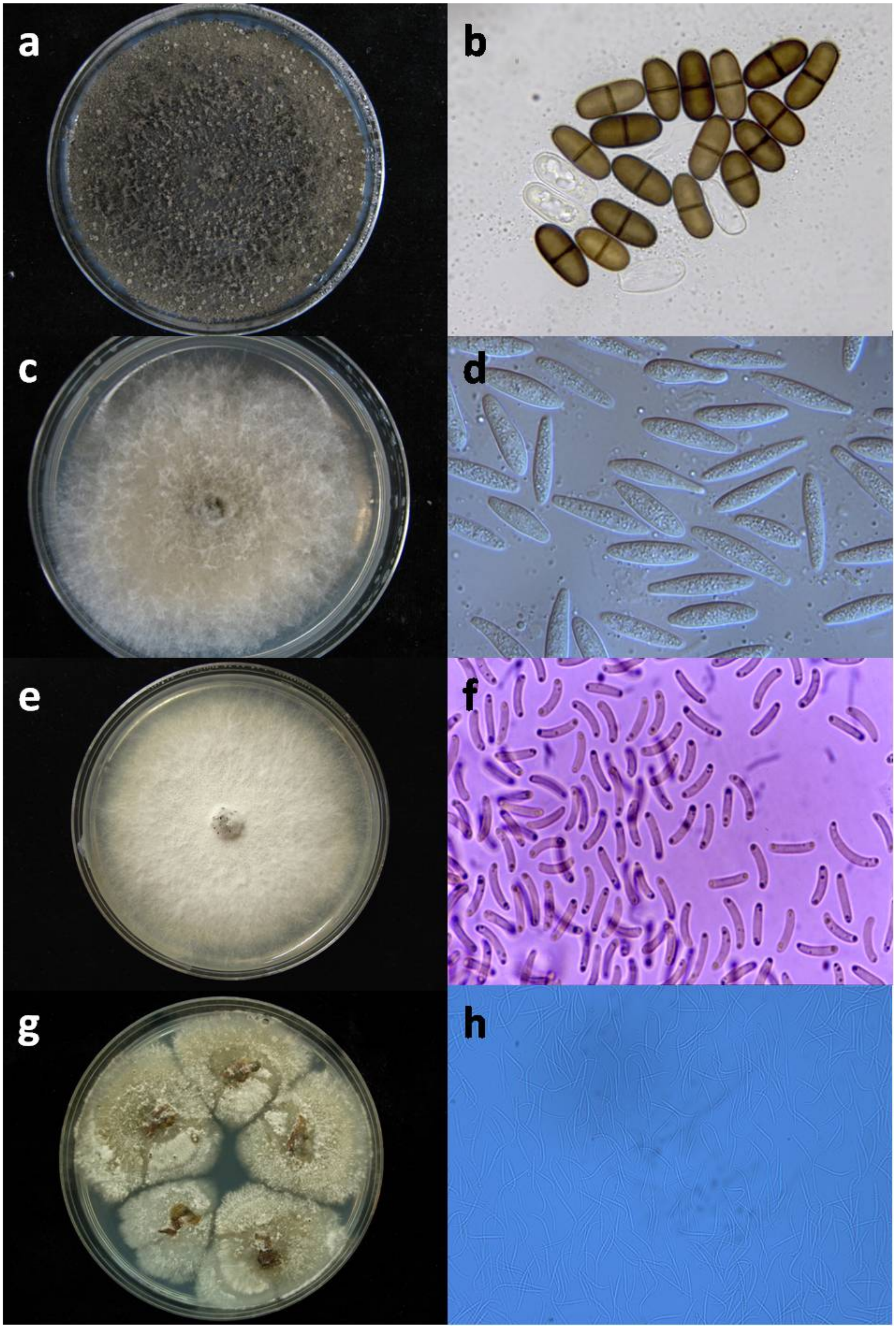
<u>Table 1.</u> Olive twig and branch dieback in California and incidence of the dominant fungal species isolated from dead twigs and branch and trunk cankers.

				Number (%) of samples yielding				
Olive region	**Orchards surveyed**	**Orchards showing dieback**	**Total samples collected**	**Botryosphaeriaceae**	**Diatrypaceae**	**Valsaceae**	**Mixed fungi [a]**	**Others [b]**
Tehama Co.	3	3	35	7 (20%)	1 (3%)	-	7 (20%)	20 (57%)
Glenn Co.	5	5	48	7 (15%)	3 (6%)	-	3 (6%)	35 (73%)
Butte Co.	6	6	73	22 (30%)	7 (9.5%)	-	5 (7%)	39 (53%)
Napa Co.	5	5	59	6 (10%)	14 (24%)	10 (17%)	9 (15%)	20 (34%)
Yolo Co.	2	2	28	20 (70%)	1 (3.5%)	-	3 (10%)	4 (14%)
Sacramento Co.	3	3	43	14 (33%)	1 (2%)	-	1 (2%)	27 (63%)
Merced Co.	5	5	65	24 (37%)	-	6 (9%)	2 (3%)	33 (51%)
Madera Co.	6	6	60	32 (53%)	-	4 (6.5%)	4 (6.5%)	20 (33%)
Fresno Co.	1	1	10	2 (20%)	-	3 (30%)	2 (20%)	3 (30%)
Tulare Co.	4	3	40	22 (55%)	-	1 (2.5%)	5 (12.5%)	12 (30%)
TOTAL	**40**	**39**	**461**	**156 (34%)**	**27 (6%)**	**24 (5%)**	**41 (9%)**	**213 (46%)**

[a] Number of samples from which Botryosphaeriaceae, Diatrypaceae, and/or Valsaceae were isolated together.
[b] In this category are included all mitosporic fungi such as species of *Aspergillus*, *Alternaria*, *Epicoccum*, *Nigrospora*, *Penicillum*, etc.

Figure 2. "Twig and branch dieback of olive trees" symptoms.

Figure 3. Characteristic colony and spore morphological features of the most common fungi isolated from olive perennial cankers from twig and branch dieback.



cream color of the colonies, and a much smaller size as well as different shape of the spores (conidia) (**Fig. 3e,f,g,h**).

Phylogenetic studies

Identification using morphology was not always possible because isolates collected in their anamorph stage did not show enough morphological characters to be compared with previously described species. Therefore, several olive isolates characteristic of Botryosphaeriaceae, Diatrypaceae, and Valsaceae from California were placed in phylogenetic analyses to be identified to species level. Phylogenetic analyses of the internal transcribe spacer region (ITS1-5.8S-ITS2) showed the different Botryosphaeriaceae isolates to group with various GeneBank isolates selected (**Fig. 4**). Based on phylogeny, we have identified at least seven different species within the Botryosphaeriaceae family including *Lasiodiplodia theobromae*, *Diplodia mutila*/*Diplodia olivarum*, *Botryosphaeria dothidea*, *Neofusicoccum mediterraneum*, and two unidentified species named *Diplodia* sp. 1 (characterized by having dark conidia) and *Neofusicoccum* sp. 1 (characterized by having hyaline conidia) (**Fig. 4**). Phylogenetic analyses allowed us to separate three species within the Diatrypaceae family including *Eutypa lata*, *Diatrype* sp. 1, and *Diatrypella* sp. 1 (**Fig. 5**). Within the Valsaceae family an unknown *Phomopsis* sp. was identified based on phylogeny and comparing with previous *Phomopsis* sp. isolates deposited into GenBank (**Fig. 6**). Future molecular work and a multigen phylogenetic analyses of part of the beta-tubulin gene (β-tubulin 2B), and part of the translation elongation factor 1-α gene (EF1-α) will be necessary to allow us to characterize the unidentified species. Furthermore, five different mitosporic fungi were identified including *Aspergillus* sp., *Alternaria citri*, *Alternaria alternata*, *Epicoccum nigrum*, and *Nigrospora oryzae*. Identification of several Basidiomycete species is currently underway. Occurrence and geographical distribution of the different fungal species varied with location and are shown (**Fig. 1**).

Pathogenicity tests

In order to determine which fungal species are important pathogens and to differentiate those from saprophytes, secondary colonizers or weak parasites, pathogenicity tests are underway. *In vivo* and *In vitro* pathogenicity tests are being conducted in our laboratory and in the University of California Field Station at Davis. Because inoculated olive branches with the different fungal species need an incubation period, no data were available at the time this report was prepared. Pathogenicity test results and pathogenic characterization of each fungal species will be provided in the next report.

Objective 2: Understand the epidemiology of olive canker pathogens:dispersal patterns, as essential for IPM control strategy design

No results to report at this time. Continuing funding of the project will allow us to accomplish this objective.

<u>Figure 4.</u> One of the most parsimonious trees with bootstrap value using 1000 replicates generated in PAUP 4.0b10 from the ITS region. Tree show the occurrence of 7 phylogenetic species of Botryosphaeriaceae from olive. Bold isolates represent isolates from olive trees from California.

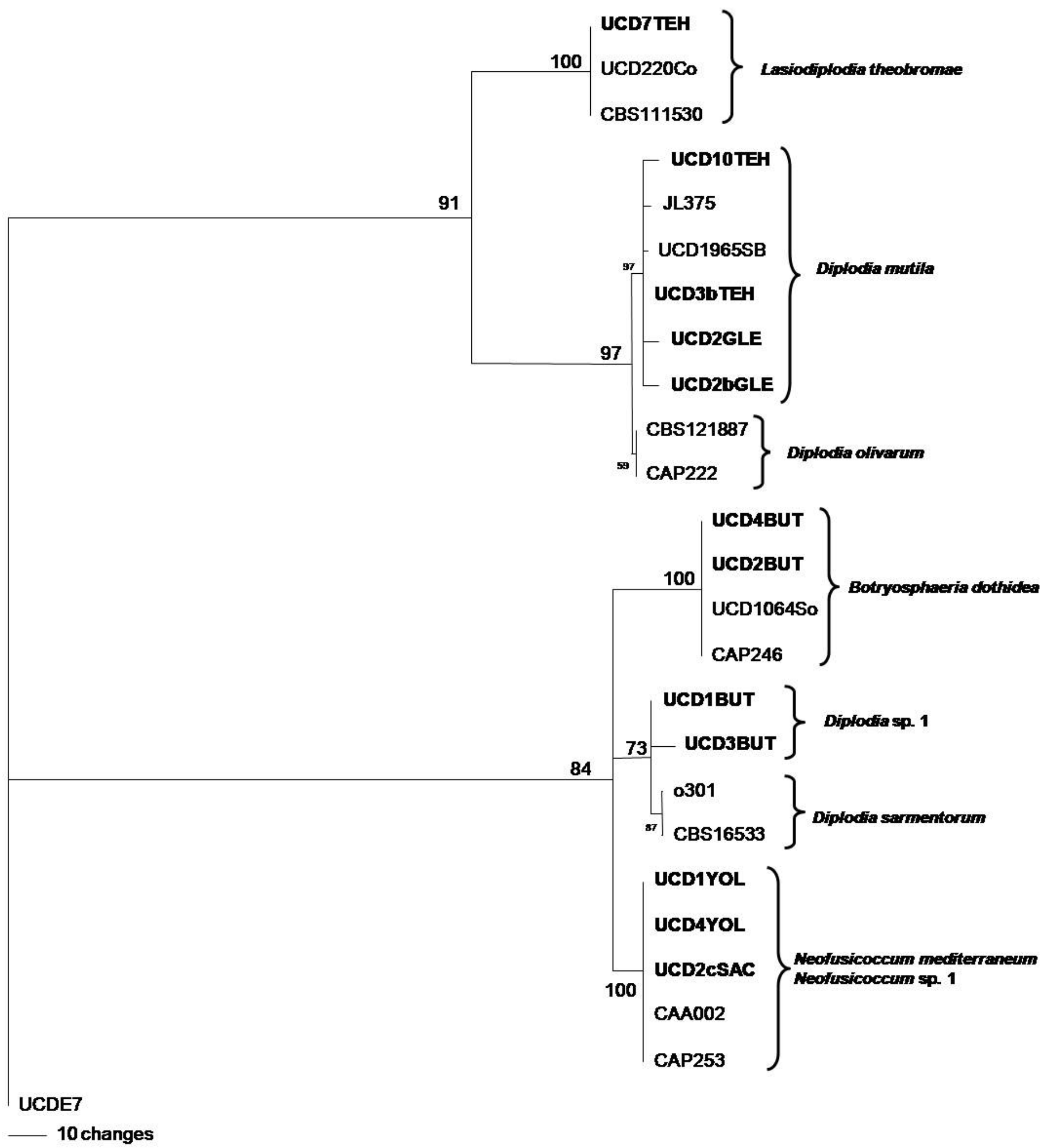


Figure 5. One of the most parsimonious trees with bootstrap value using 1000 replicates generated in PAUP 4.0b10 from the ITS region. Tree show the occurrence of 3 phylogenetic species of Diatrypaceae from olive. Bold isolates represent isolates from olive trees from California.

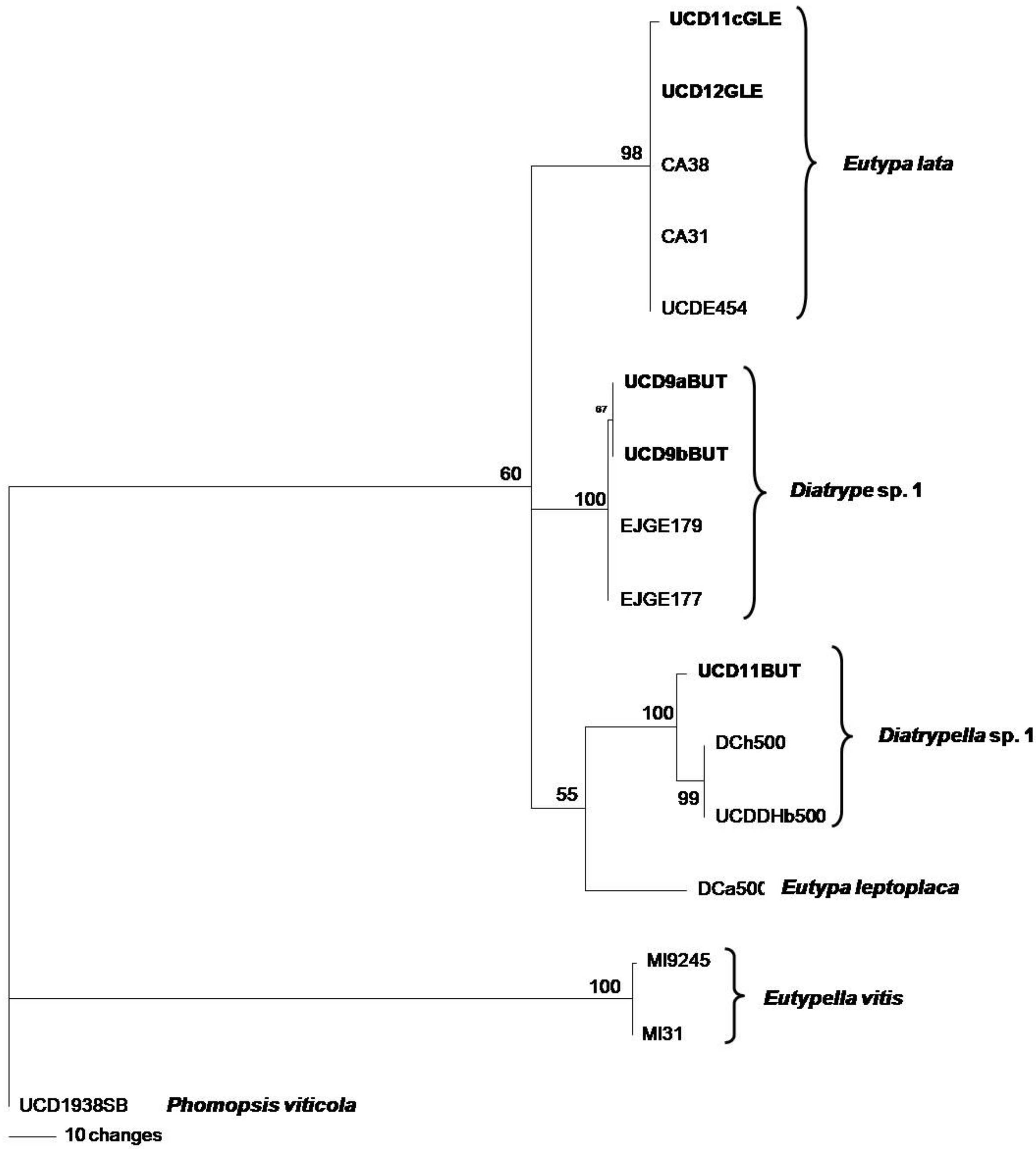
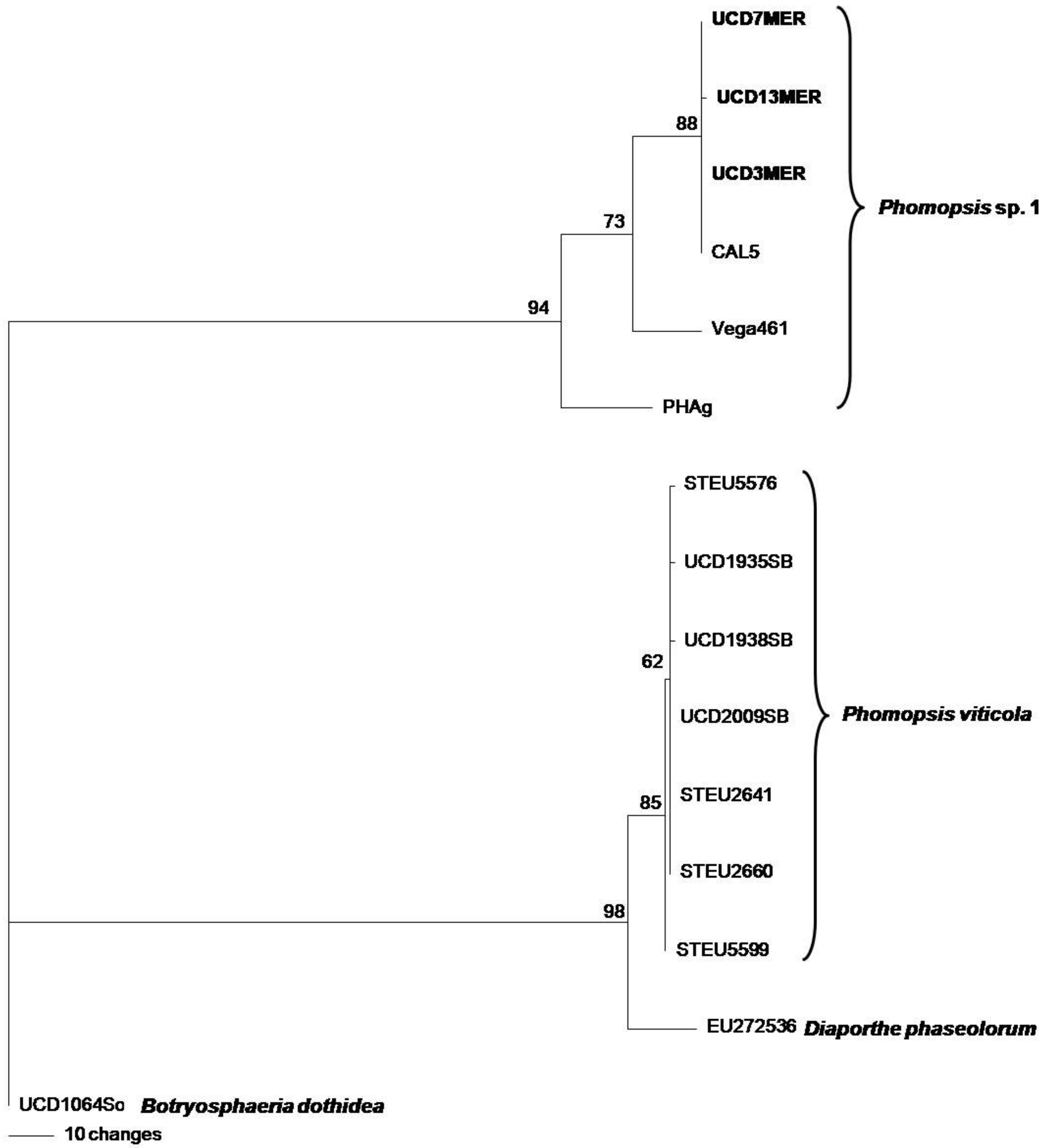


Figure 6. One of the most parsimonious trees with bootstrap value using 1000 replicates generated in PAUP 4.0b10 from the ITS region. Tree show the occurrence of 1 phylogenetic species of *Phomopsis* from olive. Bold isolates represent isolates from olive trees from California.



Objective 3: Development and implement chemical, biologicalcontrol methods for fungi involved in branch dieback of olive.

No results to report at this time. Continuing funding of the project will allow us to accomplish this objective.

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In preparation:

Úrbez-Torres, J. R. and Gubler W. D. Identification, distribution, and pathogenicity of the fungal species causing twig and branch dieback of olive trees (*Olea europaea* L.) in California.

Olive Fly Trapping Results for Glenn and Tehama Counties for 2008

Project Leader

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Cooperators

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Reporting period: April 2008 to November 2008.

ABSTRACT

Olive fruit fly populations were monitored weekly at five sites in Glenn County (Orland area) and five sites in Tehama County (Corning area) using plastic McPhail traps. Monitoring started on 4 April 2008 and ended 14 November 2008. In addition to the three sites in Glenn County and three in Tehama County that have been monitored since 2006, two more unsprayed sites were added in each county, bringing the total number of sites to 10. Trap results and observations were posted weekly on the Glenn County UC website (http://ceglenn.ucdavis.edu) and made available to the California Olive Committee for further distribution. Trap catches began in early April, peaked between 13 – 20 June, and declined to near zero flies with the onset of heat by 11 July. The resumption of trap catches with the onset of cooler weather in October was less pronounced than in previous years. Only three of the 10 sites caught any flies after 11 July. All, but 2 flies caught after this time, were in an unsprayed site that was added in 2008. This one site accounted for over 50% of all flies caught at all locations all season. Fly catches at the six sites that have been monitored since 2006 have declined every year going from 1583 in 2006 to 801 in 2007 to 110 in 2008. Total trap catches in all 10 sites monitored in 2008 were 444.

INTRODUCTION

Since the detection of olive fruit fly in California in 1998, it has been a concern to olive growers. In commercial orchards, preventative sprays are necessary. Trapping to monitor olive fruit fly populations in individual orchards is recommended. This will allow growers and PCAs to follow trends in their orchards and help evaluate spray program efficacy. Knowledge of area-wide population trends will help growers and PCAs interpret results from their orchards.

OBJECTIVES

1. Provide timely information to area growers regarding area wide olive fruit fly population trends.
2. Begin to develop a historical perspective of olive fruit fly populations for the area.

PROCEDURES

Starting on 4 April 2008, plastic McPhail traps, using Torula yeast dissolved in water as bait, were hung in olive trees. Earlier work in Glenn and Butte Counties showed that these traps catch more flies than the commonly used yellow panel trap. Traps were placed in the same six locations as in 2005 and 2006, three sites in Glenn County (Orland area) and three sites in Tehama County (Corning area). In response to a concern about the limited number of sites and to check more unsprayed sites, additional traps were placed in four unsprayed sites (two in Glenn County and two in Tehama County). With the exception of an original site at the Glenn County Fairgrounds and a new site in Glenn County, where there was a limited number of trees, two traps were placed at each site. Flies were counted and the traps were serviced weekly. The results and field observations were posted weekly on the Glenn County UC website (http://ceglenn.ucdavis.edu) and reported to the COC for further distribution. Trapping results were reported as male and female flies for individual traps and combined and averaged by site for a graphic presentation of the data (**Fig. 1**). Trapping and reporting continued through 14 November 2008.

RESULTS AND DISCUSSION

We began catching flies on 4 April 2008 (**Fig. 1**). Trap catches peaked between 6 – 13 June. With the onset of high temperatures towards the middle of July, trap catches declined to zero flies in all locations. Trap catches in all sites were zero from 1 August until 3 October. Seven of the ten sites caught no flies after 11 July. Trap catches in the six sites monitored since 2006 have continued to decline going from 1583 in 2006 to 801 in 2007 to 110 in 2008. In fact, only 444 flies were caught in 2008 at all ten sites and more than half of the total catches came from an unsprayed site, that was added in 2008 and was suspected to be in an area of high fly concentration.

Lower trap catches in 2008 corresponded with lower levels of reported damage compared to 2007. It is interesting to note the steady decline in trap catches, but it is not completely understood. Generally, trap catches did not rebound with the onset of cooler weather as they had in the previous two years. With the exception of a site in Orland, which was responsible for more than half the total fly catches, only 2 flies were caught from 11 July onwards.

CONCLUSIONS

This information is valuable to growers and PCAs to visualize what is happening on an area-wide basis and to help interpret what is going on in their particular situation, but it should not be used to make treatment decisions in specific locations. It is easily available through the internet.

We would like to continue the monitoring program in 2009. We are planning to use the same sites as 2008 to continue developing a historical perspective. As more information becomes available on the effect of environment (temperature and food and water availability) on olive fly populations, it may better explain what is observed in the traps and allow us to use trapping information as part of the information used to determine when and if sprays are necessary.

Funding Sources: California Olive Committee.

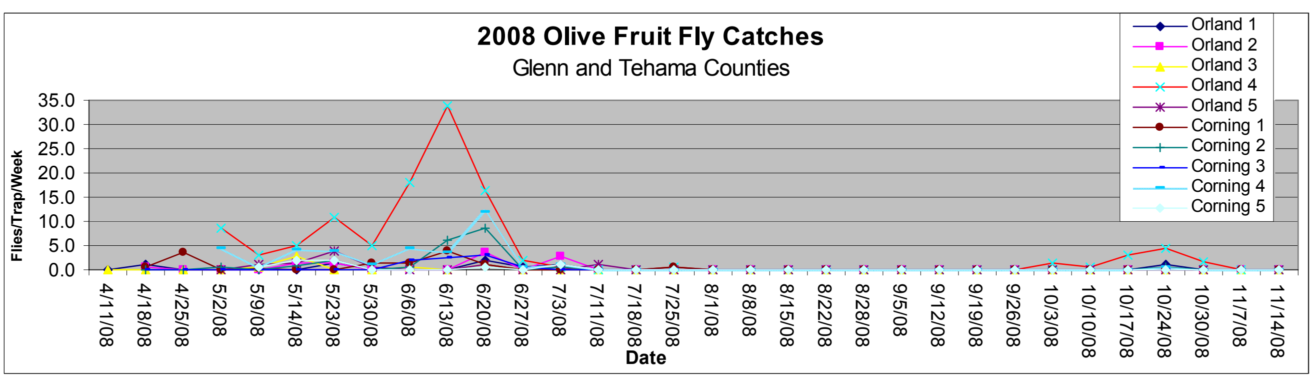

Fig. 1. Olive fruit fly trap catches for 2008 in selected orchards in Glenn and Tehama Counties.

Performance Evaluation of a Canopy Shaker Harvester Monitored by the Olive Yield Monitor (OYM) Developed at UCD. Part III of "Damage Mitigation of California Table Olives Mechanically Harvested"

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Reporting period: 15 April to 31 December 2008

ABSTRACT

Manual harvest costs for olives in California account for more than 50% of grower's gross return. Decreasing harvest cost by implementing mechanical harvesting with increased fruit removal efficiency, without bruising fruit, is a promising way to increase the profit margin in olive production. Two mechanical harvesting concepts were analyzed in 2008 to harvest table olives: canopy shaker and trunk shaker.

Field tests with the DSE canopy shaker harvester have produced quality fruit acceptable to the processors, indicating the shaker head has achieved our goal of picking the fruit without producing excessive fruit injury. We do not consider the penalties imposed by the processors for excessive trash and late and shriveled fruit as fundamental problems because these could be solved by fans and harvesting at the proper time. On the down side, however, the in-field tests and field performance of the DSE harvester, as monitored by the on-board Olive Yield Monitor (OYM)(from UC Davis), indicated that the harvester field capacity could not be increased to levels already obtained in 2007. It was a consensus, but not a surprise, because it has been pointed out by DSE that the ideal ground harvesting speed for their harvester was around 0.25 mph. Perhaps, with operator training a speed of 0.5 mph could be attainable. However, 1.0 mph speeds are far beyond reasonable for the tested equipment. Results from our collected GPS and hand-written time losses data also indicated machine reliability needs to be increased. Time lost during the trials, because of conveyor belt overload or machine component reliability, excessively reduced the effective field capacity of the harvester.

Field tests performed with trunk shakers (please see Louise Ferguson's 2008 report for machine evaluation results) have shown that the current California trunk shaker equipment have been developed and work very well for nuts. The adaptation to olives, however, has progressed fast, especially in this year. Olive trees present unique aspects that require some resizing and reengineering of the fundamental aspects of vibrating young olive trees. The fruit harvested by this type of equipment show excellent quality, comparable to hand harvested fruit (please refer to Louise Ferguson's 2008 report). However, it is common sense that if this principle will be extensively adopted in California, trunk shaker bark injury has to be understood and controlled, if not completely eliminated. The progress achieved by one shaker manufacturer at the end of the season was encouraging. We are looking forward to working along with ENE in 2009 to implement a few principles on a new shaker head that intends to mitigate bark damage, increase fruit removal efficiency, and at same time enhance shaker controllability. We have worked closely with ENE and COE to instrument and evaluate the vibration characteristics of their shaker heads and have submitted exclusive technical reports directly to them. Dr. Sergio Castro-Garcia has been instrumental in this analysis. He brought along great experience acquired from testing and using olive shakers adapted for olive oil harvesting that has been employed in Europe for many years.

INTRODUCTION

Manual harvest costs for olives in California account for more than 50% of grower's gross return. Decreasing harvest cost by implementing mechanical harvest with increased fruit removal efficiency, without bruising fruit, is a promising way to increase the profit margin in olive production. Two mechanical harvesting concepts were analyzed in 2008 to harvest table olives: canopy shaker harvesting and trunk shakers.

OBJECTIVES

The objective of this proposal was to collect extensive field performance data with the DSE canopy shaker harvester improved by DSE to operate during the 2008 season. Specific objectives were to:

1. Vary machine parameters such as ground (mph) speed and head speed (rpm) to try enhancing machine productivity; and
2. Evaluate the picking head harvester efficiency on a hedgerow orchard prepared for mechanical harvesting versus an unprepared orchard, and evaluate the effects on fresh and processed fruit quality.

PROCEDURES

Location: Block 17W:Rocky Hill Ranch, Exeter, Ca.
Planted 1998, 13 rows, 83 trees per row, 'Manzanillo' olives with 'Sevillano' pollinators, spaced 11 x 26 ft, 160 trees per acre were available for our evaluation trials originally scheduled for 13 – 24 September 2008 and executed on 29 – 30 September 2008. The testing procedure is completely described in the 2008 Louise Ferguson's proposal to the COC and thus will be omitted here.

RESULTS AND DISCUSSION

Items reported here are: 1) DSE 2008 canopy shaker test results; 2) trunk shaker test results; 3) MaqTec oil olive canopy harvest evaluation for table olives; and 4) demonstrations of emerging pomegranate (and oil olive) harvesters with potential for tests next year.

Section 1. DSE 2008 Canopy shaker Test Results

1.1. Data collected during the 2008 season with the DSE 0007 have been analyzed and are available, partly here within and partly in Louise Ferguson's 2008 final report to the COC. Some points can be drawn from this analysis. It is clear that due to operator response in guiding the picking heads into the canopy that a maximum feasible ground speed can not exceed about 0.5 mph. The ground speed is also limited by tree size and unprepared canopy structure. The fruit quality obtained during the 2008 season seems to be adequate to the processors, although we still need to wait for this year's results from the canned fruit analysis. The problem of excessive amounts of trash produced by the harvester, which were sent within the loads/samples to the grading stations, can be easily solved by installing a proper cleaning fan. However, although the picking principle (i.e., properly padded fingers and catching frame) seems to perform reasonably well, the effective harvester ground speed did not achieve full potential (0.5 mph) as we show in speed maps produced by the on-board Olive Yield Monitor (OYM)(from UC Davis) (**Figs. 1 – 6**). The machine operating reliability limitation was due to the machine difficulties with the steering mechanism and with the conveyor belts to transport loosened broken branches and trash. Constant ground speed also requires constant flow of trash through the conveyors to avoid frequent cleaning stops. The occurrence of maintenance stops lowered the effective picking speed of the machine.

It seems to us, in general, that to be economically viable the canopy shaker needs to harvest faster while maintaining good quality of picked fruit. We think this can be accomplished by properly preparing the canopy structure for the harvester, limiting the tree height, and possibly eliminating one of the operators by using an available automatic canopy following mechanism that guides the picking drum into the canopy. Our 2009 project proposals submitted by Louise Ferguson and Uriel Rosa address these issues.

1.2. This section presents the results and analysis of data collected with our OYM during the evaluation of the six, pruned Rocky Hill rows in which the DSE 2008 performed. It can be seen that the overall field performance of the DSE 2008 is influenced by the mechanical interruptions in the work.

1.2.1. *Olive Data Analysis – (Navdeep S. Boparai)*. The olive harvest for summer 2008 was performed on Rocky Hill Ranch: Block 17-W. The harvester was equipped with the insight yield monitor and a custom-made rabbit yield monitor to collect yield, speed, and machine performance data. In addition, hand written notes were also taken. There were a total of six rows harvested, and each row consisted of six trials, three on each side, for three theoretical speeds of 0.25, 0.5, and 0.75 mph. Each trial consisted of a harvest operation on 14 trees.

Data recorded for each trial were combined with data taken from the yield monitor, and this information was used to analyze the machine performance at each of the theoretical speeds. The data for the speed of the machine, collected by the yield monitor, allowed us to compare how much the actual speed varied from the theoretical speed.

Theoretical Field Capacity *is the rate of field coverage that would be obtained if the machine were performing its function 100% of time.* Thus, the theoretical field capacity was calculated for each row by using the theoretical speeds. **Theoretical time per acre** *is the time that would be required at the theoretical field capacity, and this was calculated accordingly*.

The analysis of machine performance was based on the comparison between theoretical field time and effective field time. The effective field time for each row was obtained by using the data from the yield monitors, and the hand written data for each trial. Microsoft Excel® was used to make graphs that showed comparisons between effective and theoretical field time for each theoretical speed and each row. SMS spatial software was also used to make a map of the actual machine speed during the harvest.

It is important to note that effective field time includes the period of time that the machine is not operating due to stops because of maintenance and repairs. The frequency and span of these stops contribute to the decrease in operation efficiency. <u>Field efficiency</u>: Therefore, field efficiency was obtained by taking the ratio of theoretical field time to effective field time. Our notes show that the machine was stopped during at least six of the 36 trials due to maintenance or breakdowns. When the machine was not stopped, the effective time may not approximate the theoretical in some cases. This is due to the fact that the actual speed of the machine may have varied from the theoretical at some instances of the trial.

1.2.2. *Definitions and Calculations* **—** (*Navdeep S Boparai)*

Theoretical field capacity: *is the rate of field coverage that would be obtained if the machine were performing its function 100% of time.* There were 139 trees/acre, and 14 * 3 = 42 trees were harvested each row. Thus, 42/139 = 0.3022 acres of area that were covered in each row. Given six trials in a row, two were at 0.25 mph, two were at 0.5 mph, and two were at 0.75 mph. Given 1 mph = 1.4667 ft/sec. Thus, two were at (0.25)(1.4667 ft/sec**) = 0.367 ft/sec**, two were at (0.5)(1.4667 ft/sec**) = 0.733 ft/sec**, and two were at (0.75)(1.4667 ft/sec) = **1.10 ft/sec.** Fourteen trees were spaced in a distance equal to (14 – 1)*12 ft = **156 ft.** Total time for 42 trees equals 2(156/.367) + 2(156/.733) + 2(156/1.10) = 26 minutes. Thus, 6(26) = 156 minutes; and 6(42) = 252 trees.

Theoretical field capacity **=** 156 minutes/252 trees. There were 139 trees/acre. Thus, (139/252)(156mins) = 86 minutes/acre **=** 1 hour 26 minutes/acre **= *0.6977 acres/hour***

Theoretical time per acre: *is the time that would be required at the theoretical field capacity* = ***1/.6977 = 1.43 hours = 1 hour and 26 minutes***

Effective operating time per acre: *is the time during which the machine is actually performing its intended function. The effective operating time per acre is greater than the theoretical time per acre if less than the full rated width is utilized.* We have data for 252 trees for which the total time is 185 minutes, and there were 139 trees/acre. Thus, ***Effective operating time per acre = (139/252)*(185 minutes) = 102 minutes= 1 hour and 42 minutes***

Effective Field Capacity: *is the actual time it took for the machine to cover the field.*

Total time = (effective operating time) + (time lost in service, repairs)

Total time = (sum of times of all trials from data w/ repairs time included)

Total time = 243.427(minutes)/252(trees). There were 139 trees per acre. Thus, (139/252)(243.427) = **134.27 minutes/acre** = **2 hours and 14 minutes/acre = 0.4478 acres/hour**

Field Efficiency: is the ratio of effective field capacity to theoretical field capacity, expressed as percent. **Field Efficiency = 0.4478/.6977 = 0.6418 = 64%**

1.2.3. **Table 1** provides information on yield, speed, and time recorded with the DSE 2008 for each trial.

1.2.4. DSE performance for Rows 2 to 7.

The reader should note the “stopped” tests indicated in the figures. Due to interruptions and limited trials statistical analysis was not performed.

Visual observation of figures showing the effective field time for trials 2 to 7 indicated when there were no “stops” for repair/ maintenance involved in the trials (14 trees per trial – both sides of tree), and the recorded time to harvest the trial trees corresponded to the expected times indicated. Also, the ground speed was relatively constant and close to the target speed for each set: 0.25, 0.5, and 0.75 mph. However when stops occurred, the time increased and the harvester productivity was reduced in rows 2 – 4 and 6 – 7 (see **Figs. 1 – 6**).

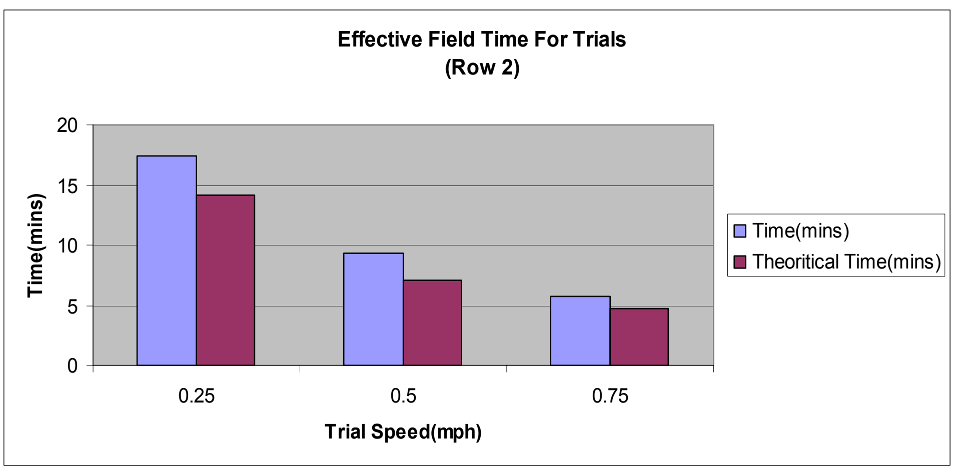


Fig. 1. Effective field time for trials — Row 2.

Accompanying data for **Fig. 1.**

Speed (mph)	Time (mins)	Theoretical Time (mins)
0.25	17.38	14.17
0.50	9.31	7.09
0.75	5.68	4.73

Table 1. Yield, speed, and time recorded with the DSE 2008 for each trial.

Row	Yield (lb)	Speed (mph)	Time (min)
1	143	0.25	9.51
1	60	0.5	4.61
1	113	0.75	2.83
1	232	0.75	2.85
1	109	0.50	4.50
1	177	0.25	7.86
2	56	0.25	10.06
2	43	0.75	3.05
2	68	0.25	8.33
2	154	0.25	5.25
2	40	0.75	3.11
2	139	0.25	7.38
3	114	0.25	9.23
3	63	0.75	2.75
3	121	0.50	3.91
3	247	0.50	3.93
3	139	0.75	2.50
3	232	0.25	8.46
4	46	0.50	3.70
4	116	0.75	2.35
4	86	0.25	8.52
4	274	0.25	9.65
4	192	0.75	2.81
4	111	0.50	4.06
5	54	0.25	6.91
5	48	0.50	3.75
5	59	0.75	2.50
5	135	0.75	2.85
5	107	0.50	3.83
5	113	0.25	8.08
6	56	0.25	7.06
6	51	0.50	3.91
6	74	0.75	2.96
6	193	0.75	2.033
6	120	0.50	3.30
6	114	0.25	7.06

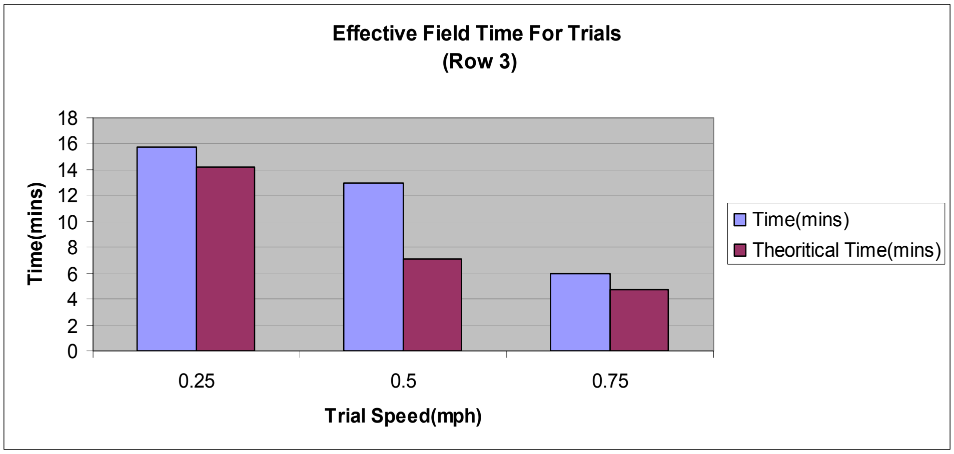


Fig. 2. Effective field time for trials — Row 3.

Accompanying data for **Fig. 2.**

Speed (mph)	Time (mins)	Theoretical Time (mins)	
0.25	15.71	14.17	*stopped for repair/maintenance
0.50	12.93	7.09	*stopped for repair/maintenance
0.75	5.93	4.73	

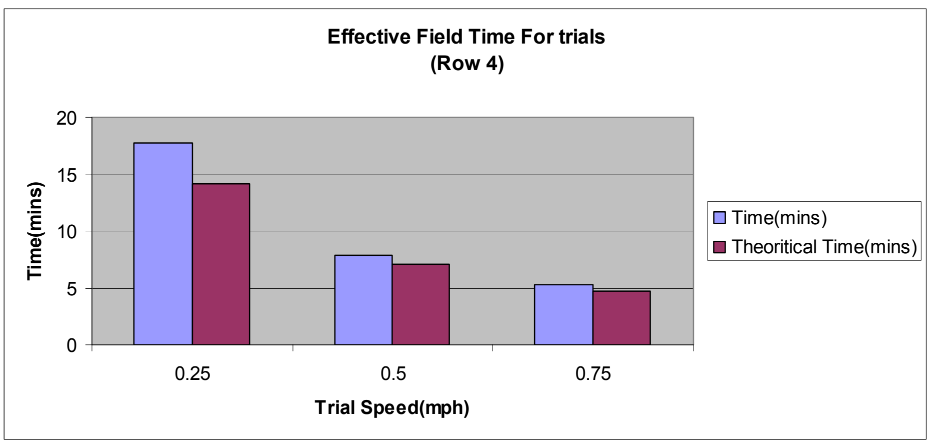


Fig. 3. Effective field time for trials — Row 4.

Accompanying data for **Fig. 3.**

Speed (mph)	Time (mins)	Theoretical Time (mins)
0.25	17.70	14.17
0.50	7.85	7.09
0.75	5.25	4.73

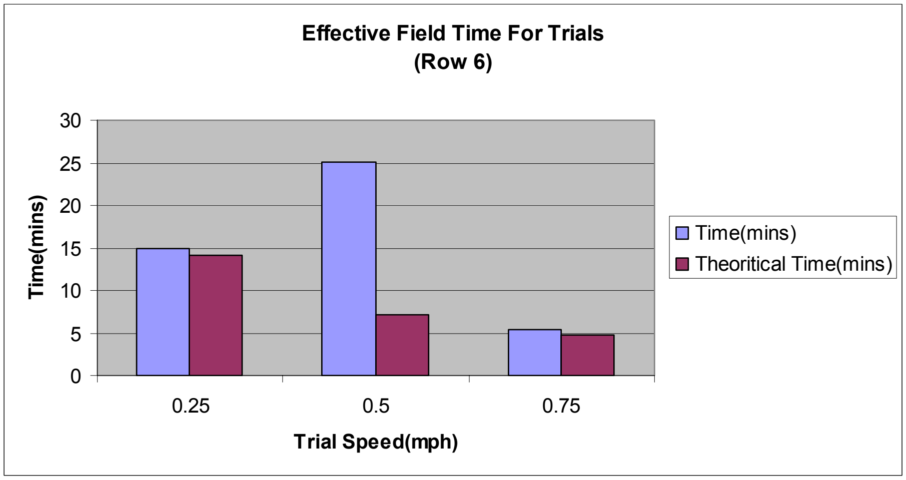


Fig. 5. Effective field time for trials — Row 6.

Accompanying data for **Fig. 5.**

Speed (mph)	Time (mins)	Theoretical Time (mins)	
0.25	38.91	14.17	*stopped for repair/maintenance
0.50	7.76	7.09	
0.75	24.81	4.73	*stopped for repair/maintenance

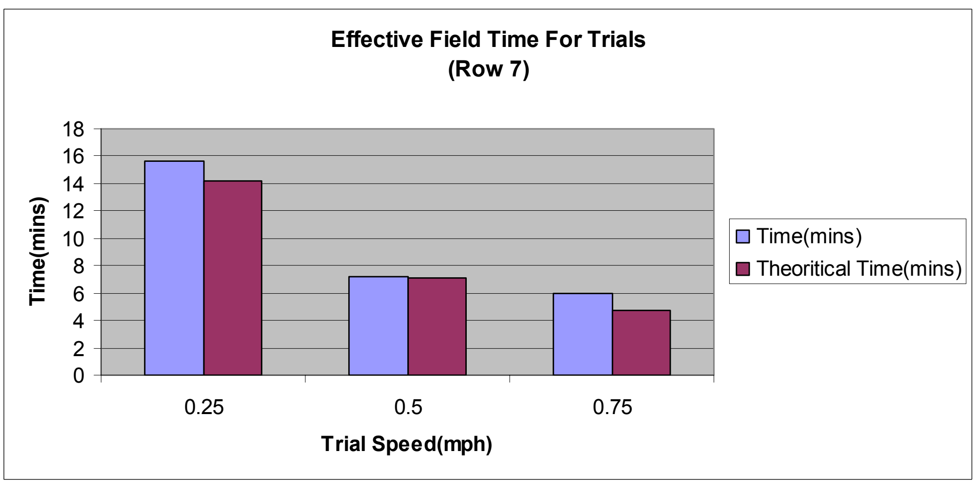


Fig. 6. Effective field time for trials — Row 7.

Accompanying data for **Fig. 6.**

Speed (mph)	Time (mins)	Theoretical Time (mins)	
0.25	15.63	14.17	*stopped for repair/maintenance
0.50	7.21	7.09	
0.75	6.00	4.73	

Figures 7 – 13, theoretical speeds versus harvested yield (lbs), show great data variability. Although it was initially suggested during field tests and the preliminary trials on Row 1 that tree yield would be reduced with increased in ground speed, the variability of the data does not show obvious conclusions on this point.

Fig. 7. Theoretical speeds versus harvested yield (lbs) for Row 2.

Speed(mph)	Yield(lbs)
0.25	320
0.5	169
0.75	345

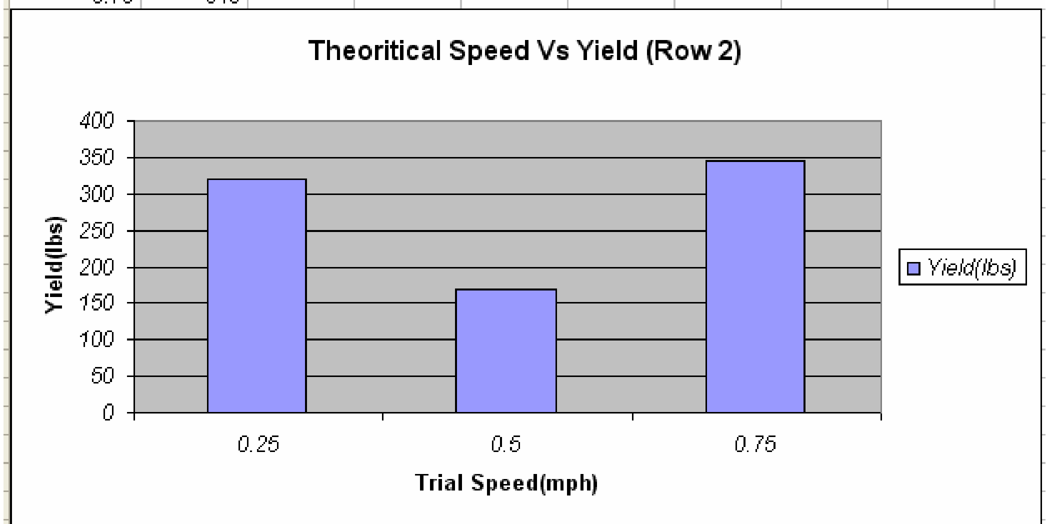


Fig. 8. Theoretical speeds versus harvested yield (lbs) for Row 3.

Speed(mph)	Yield(lbs)
0.25	195
0.5	222
0.75	83

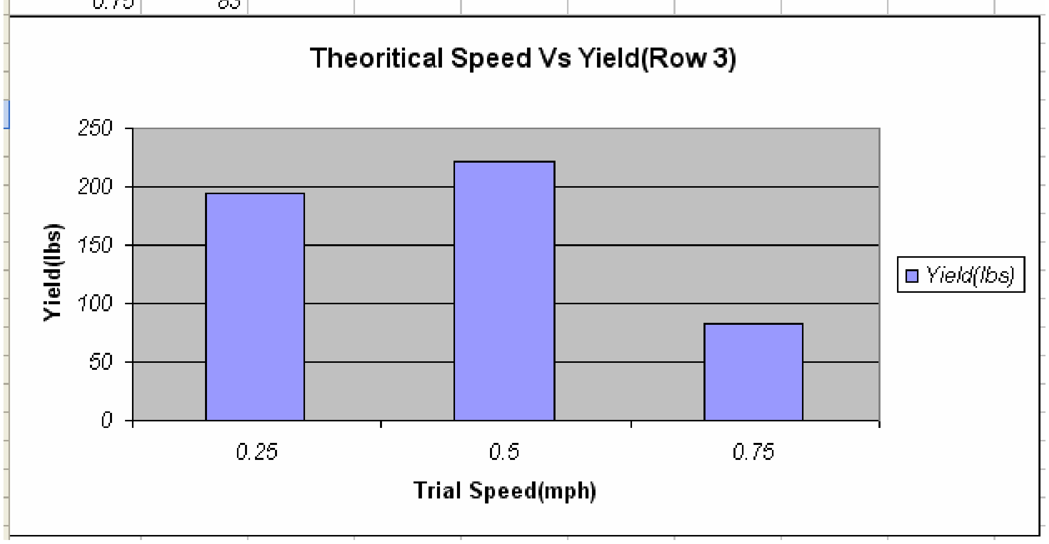


Fig. 9. Theoretical speeds versus harvested yield (lbs) for Row 4.

Speed(mph)	Yield(lbs)
0.25	346
0.5	368
0.75	202

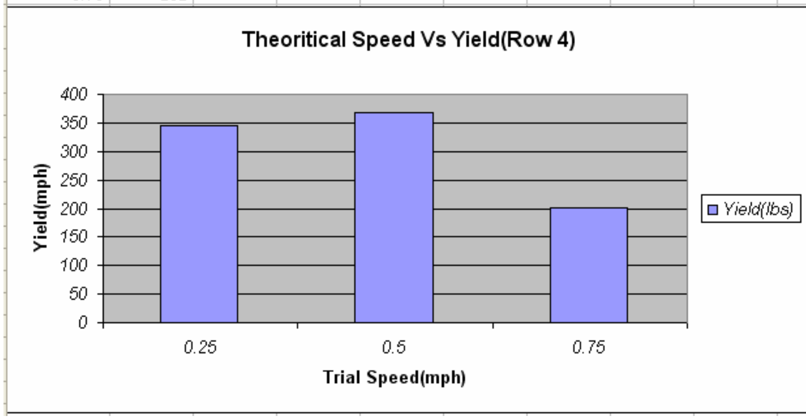


Fig. 10. Theoretical speeds versus harvested yield (lbs) for Row 5.

Speed(mph)	Yield(lbs)
0.25	360
0.5	157
0.75	308

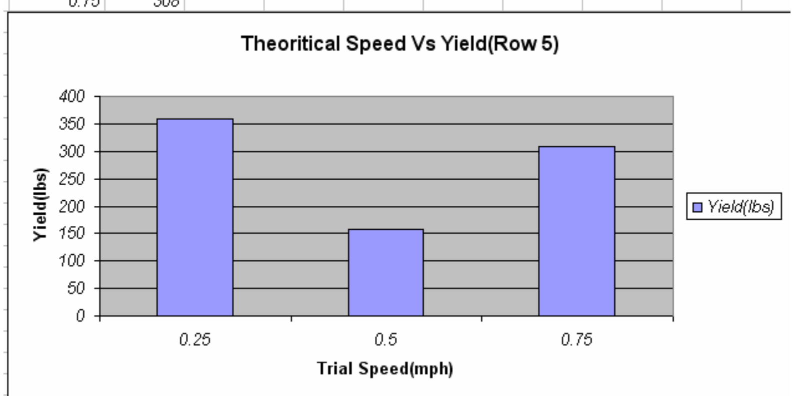


Fig. 11. Theoretical speeds versus harvested yield (lbs) for Row 6.

Speed(mph)	Yield(lbs)
0.25	167
0.5	155
0.75	194

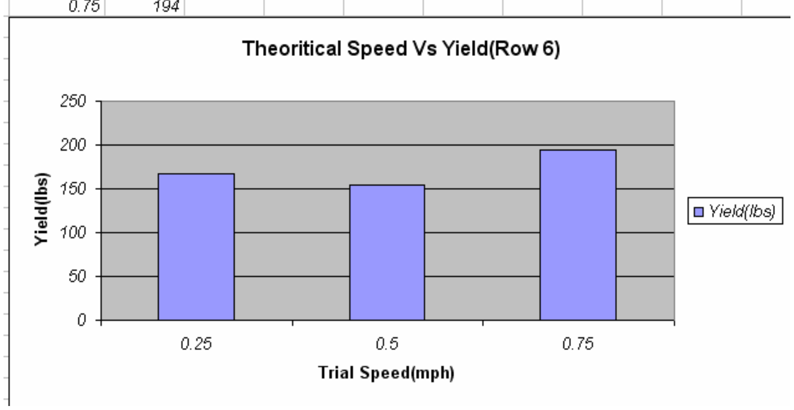
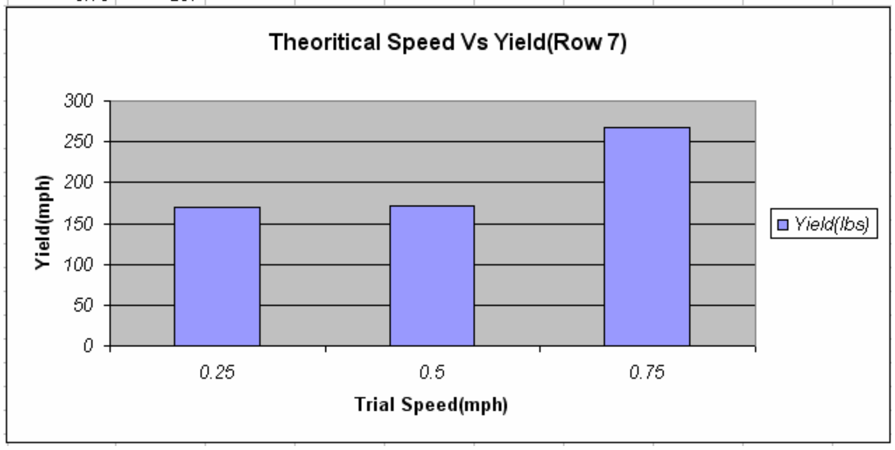


Fig. 12. Theoretical speeds versus harvested yield (lbs) for Row 7.

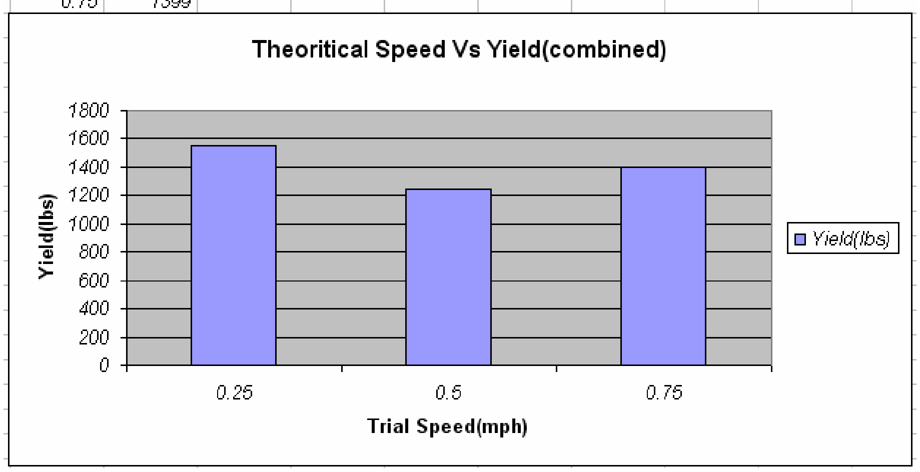
Speed(mph)	Yield(lbs)
0.25	170
0.5	171
0.75	267



The combined average of the data presented in **Figs. 7 – 12** suggests that removal efficiency reduces with increase in speed (**Fig. 13**). Extended tests and data analysis may be required to confirm this assumption.

Fig. 13. Theoretical speeds versus harvested yield (lbs) for Row 7.

Speed(mp	Yield(lbs)
0.25	1558
0.5	1242
0.75	1399



1.2.5. See APPENDIX A for extended maps and row trial explanations.

Section 2. **2008 Trunk Test Results performed by Trunk Shaker Manufactures**

2.1. Field evaluation tests were carried out in a table olive orchard at Nickels Soils Laboratory, Colusa County, to access the ability of commercial trunk shakers to harvest table olives in California. All trees in this orchard were 'Manzanillo' variety, planted in 7/8/01 with a tree spacing of 12' x 18' (202 trees/ac). Eight trees were randomly selected and shaken by the ENE trunk shaker. Tests were conducted on 7 October 2008 and continued in Erick Nielsen's orchard (ENE) during the following week after shaker adjustments were performed to reduce bark damage. Data were recorded with two accelerometers placed on the shaker head and on the tree trunk close to the shaker arms. Because some shaker manufactures gave us permission to instrument their equipment by placing sensors (two tri-axial accelerometers, one on the shaker head and another on the tree being shaken) on their equipment, we agreed to analyze the data and submit complete reports exclusively to them. It is clear these California nut shakers have been optimized for nut and stone fruit harvesting over the years and work very well on these crops. However, in olives some learning and some adaptations were required and have been studied and started to be implemented. Some general results from this analysis are presented as follows.

The measured trunk shaker mean frequency was low compared with the olive trunk shakers commonly used in Spain, where this technology is largely used to harvest olives (Dr. Sergio Castro, personal communication). Shaking the tree with higher frequency excitation allowed us to remove more fruit. However, we suggest increasing the shaker operating frequency values up to 28-30 Hz (1680-1800 rpm). This frequency range recommendation is based on observations and research done on olive tree vibration behavior under forced vibration and on the extensive experience of some of our team members in performing similar tests.

Acceleration values, as measured on the shaker head in the main direction of vibration, produced around 4 g (starting period) to 8 g (end period). However, in the perpendicular direction, acceleration values ranged from around 2 to 3 g. The acceleration in this direction produced a mean vibration value close to 40% of the value in the main direction. We suggest that an increase in the acceleration value, to about 20 g, in the main vibrating direction will ensure proper fruit detachment.

Displacement. The relative displacement between the shaker and tree trunk is one source of bark damage. Also, frequency and displacement show an inverse correlation (i.e., high frequency, low displacement). Limitation of displacement to reasonable values, as a result of increased operational frequency (also due to power limitation), is expected to reduce bark damage, mainly in the starting and end period of the vibration. During theses periods, relative displacement can increase due to natural frequencies of tree or shaker. Our recommendation of shaking the tree with high frequencies leads to a reduction in bark displacement reduction, which can help reduce damage. Our tests indicate that the mean displacement measured in the main direction of vibration produced values around 0.826 and 0.905 inches on the shaker head and trunk, respectively.

Vibration transmission. Vibration transmission between machine and tree trunk depend on the clamping pressure, padding material, and frequency. These are important parameters that can be adjusted to help to reduce bark damage. The main function of the machine is to completely transmit the input acceleration to the tree. However, some loss can be expected. In general, vibration transmission increases with the frequency increase. For the main vibration direction (Y axis), the mean vibration transmission ratio was 1.1. This shows a low amplification of this transmission. However, in a perpendicular direction (X axis), mean vibration transmission was 0.7, producing acceleration reduction on the trunk. The vibration transmission analysis is important in designing a proper shaker head for olive trees.

Removal efficiency. Removal efficiency values were typically low, with mean values ranging from 50 % to 60%. This is due to the fact the harvester shaker head has been designed and developed for other types of tree crops and has been adapted for olives. Besides that, removal efficiency depends on parameters such as fruit detachment force, frequency, acceleration, displacement, and vibration repetitions. Our experience shows that improved removal can be achieved with specific patterns and other unique ways to shake the trees.

To increase removal efficiency, the shaker needs to be operated with increased motor revolutions to produce a broader frequency range. However, this increase in frequency is limited. One alternative, if bark damage can be limited and reduced, is to make two short vibrations, to break the period movement of the fruit and tree and, thus, it will produce better removal.

Bark damage. Bark damage was evaluated as 1.4 in our scale from 1 to 3, meaning medium bark damage. This is not a good result if the machine needs to be applied to olive trees. More work has to be done in this case to reduce bark damage before trying to increase removal efficiency. All trees were damaged with various levels of damage severity.

After these results were obtained during the initial tests with our collaborative work with the shaker, the manufacturer produced an improved shaker head with encouraging results. Thus, we propose to continue this effort and properly design, fabricate, and test a new high frequency shaker head to better suit the requirements of olive trees.

Due to the willowy nature of olive trees, we propose to design a new shaker head by using known principles and test this machine on tree structures pruned for trunk shakers in orchards properly prepared by Dr. Louise Ferguson.

2.2. Trunk shaker evaluation in conventional training olive orchard: The following report, copied in part here, was sent with a complete analyzed data set as part of our collaborative effort to work with the trunk shaker manufacturers to improve their shakers' heads for working on young table olive trees.

TRUNK SHAKER EVALUATION IN CONVENTIONAL TRAINING OLIVE ORCHARD

Machine tested: (COE or ENE) Trunk Shakers – *individual reports prepared for each manufacturer*

Bio-Automation Lab

Authors: Sergio Castro-Garcia and Uriel A. Rosa

Date: 28 October 2008

Field evaluation tests were carried out in a table olive orchard at Nickels Soils Laboratory, Colusa County, to assess the ability of commercial trunk shakers to harvest table olives in California. All trees of this orchard were of the 'Manzanillo' variety, planted in 7/8/01 with a tree spacing of 12' x 18' (202 trees/ac). Eight trees were randomly selected and shaken by the ENE trunk shaker. Tests were conducted on 7 October 2008.

The shaker head and the tree were instrumented with two triaxial accelerometers (PCB, 356A22) to evaluate the dynamic behavior of the tree-shaker system. The instrumentation utilized to record the accelerometer signals consisted of PCB charge amplifiers for the accelerometers, a 5 kHz anti-aliasing low pass analog filter, and a Tektronics 3014B storage oscilloscope. The scope was setup to record four simultaneous channels at a scanning rate of 1 kHz. The maximum stored time for a single shaking event was limited to 10 seconds. The single accelerometers signals were AC coupled to the scope. One accelerometer was mounted at the shaker top right arm, close to the eccentric mass, and worked as a reference to measure the vibration produced by the machine. From the three available signals generated by this accelerometer only two were recorded. These two signals corresponded to two orthogonal directions horizontal to the ground. The second sensor was placed on the olive trunk, close to the shaker clamping point, but on the opposite side of the shaker head. In all, four signals were recorded in the horizontal plane (x and y). Vertical accelerations were not measured. The X axis corresponded to the longitudinal direction of the shaker, i.e., perpendicular to the direction of the harvested tree line, and the Y axis corresponded to the direction parallel to the shaker, i.e., parallel to the tree line. The accelerometers were mounted at the height where the clamping system was attached to the trunk, typically 30 inches from the ground (**Fig. 14**).

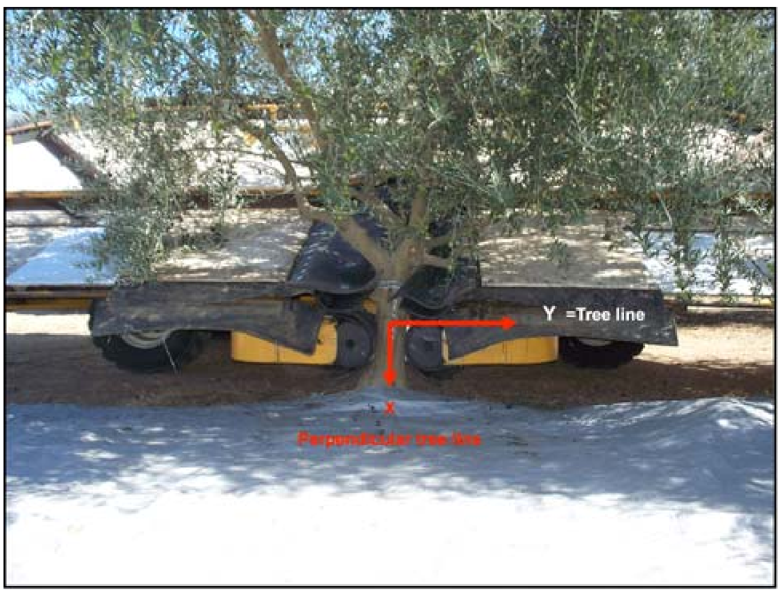


Fig. 14. Reference system used in the shaking field tests

Channels of measurement:

CH 1 = Acceleration measured on the shaker head in the direction parallel to the shaker head,
CH 2 = Acceleration measured on the shaker head in the direction perpendicular to the shaker head,
CH 3 = Acceleration measured on the tree trunk, in the direction parallel to the harvested tree line, and
CH 4 = Acceleration measured on the tree trunk, in the direction perpendicular to the harvested tree line.

A four-channel scope (Tektronic, TDS 3014B) was used to display and record the accelerometer signals. A fifth channel was used to perform real time FFT on CH2. The FFT data were also recorded for each run (again, each signal contained 10 seconds in duration with a total of 1000 data points per second). All recorded acceleration signals were analyzed by using specialized software, The OROS NVGate, v.5.1. The resulted parameters obtained from this analysis were:

Frequency (Hz): rotational speed of the unbalance mass. Also, it is expressed as revolutions per minute (rpm). In these tests, this value usually increases during the tree vibration due to increase motor revolution.

Acceleration (g): expresses the RMS acceleration value for each shaker frequency. It is measured in g (gravity acceleration = $9.81 m/s^2$).

Displacement (millimeters): expresses the movement maximum (peak to peak) of the measurement point for each shaker frequency.

Vibration Transmission: this is the relationship between the acceleration in the trunk to the shaker. When this value is 1, it means that the acceleration generated in the shaker is completely transmitted to the trunk in one studied direction. Values under 1 showed a low vibration transmission, with a of loss acceleration value. Values up to 1 showed vibration amplification during the shaking process. Desirable values are closed to 1.

These parameters were complemented with the Removal efficiency data associated with the induced vibration on the tree trunk, and a four point scale damage evaluation of the tree trunk:

Removal efficiency (%): After shaking, the olives removed were harvested and weighed. Then, the olives remaining on the tree were manually harvested and weighed.

Trunk Damage: visual estimation of bark trunk damage.

0 = No damage
1 = Low-medium damage
2 = Medium-high damage
3 = High and severe trunk and branch damage.

RESULTS

DATA OMMITTED HERE: Directly Reported To Participating Manufacturers
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Section 3

The Maqtec harvester evaluated by our research group in Portugal performed below our expectations for table olives. Extensive modifications will be required if this machine is to be used on table olives. The harvested fruit were virtually one hundred percent bruised, cut, or mutilated. No attempt had been made to test our padding recommendations by the time of our visit to the Portuguese olive site.

Section 4

In late 2008, we visited two field demonstrations of emerging technology that while maintaining the promising canopy shaker picking principle, also had the potential to offer high equipment reliability, increase field capacity, and perhaps attainable equipment costs. The over the row Ag-Right harvester and the COE canopy shaker and catch frame pair have targeted harvesting of pomegranates with apparent success. We were encouraged by attending a demostration of these two pieces of equipment later in olive oil harvest season in Sanger and Winters, CA. We are looking forward to collaborating with these two companies in 2009 as well.

CONCLUSIONS

The DSE 008 harvester has demonstrated that the picking head technology is viable for table olives. The DSE effective field capacity, however, needs to be improved. The observed ground speeds did not reach the expected 1.0 mph to be economically viable. Typical speed is 0.25 mph and perhaps 0.5 mph, if the operator is trained to quickly react on the controls. Frequent maintenance and reliability stops, however, limit the machine's ability to achieve expected harvest field capacity.

Research should now focus on the currently commercially available trunk shaking and picking head harvesters mounted on double-sided catch frames. These should be evaluated in conventional, mechanically pruned, and hedgerow trained orchards.

FUNDING SOURCES

The 2008 research proposal was funded by the COC at a total of $61,675.

ACKNOWLEDGEMENTS

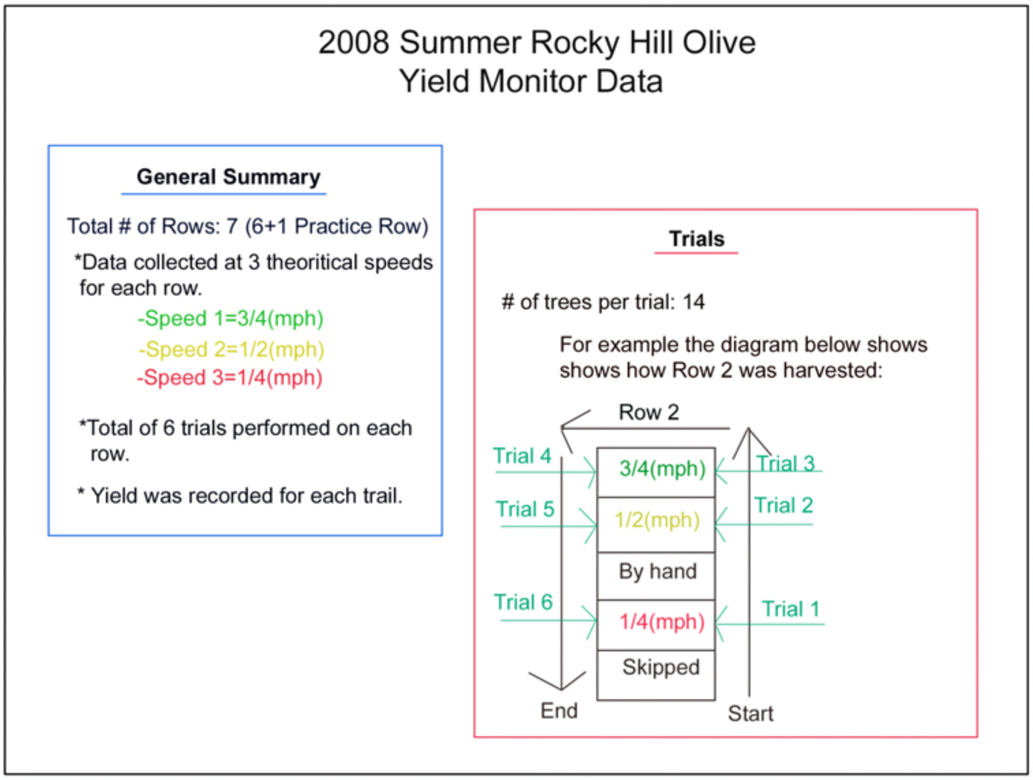
We gratefully acknowledge the funding support of the California Olive Committee. We gratefully acknowledge the cooperation of Musco Family Olive Company, particularly Edward Melanesio, Jesus Lopez, Dennis Burreson, Matthew Koball, and Abdul Sigal and Bell Carter Olives, particularly Jane Yegge and Cody McCoy. These California experiments would not have been possible without the cooperation of Rocky Hill Ranch and Marc Pascoe and Jesse Luna, Nielsen Ranch and Erick Nielsen, and Dennis and Heath Burreson of Burreson Ranches. We wish to thank Erick Nielsen of ENE Inc., Matt Coe of Coe Harvesters, and Don Mayo of OMC Shakermaker Harvesters for their patient and flexible cooperation in trunk shaking experiments.

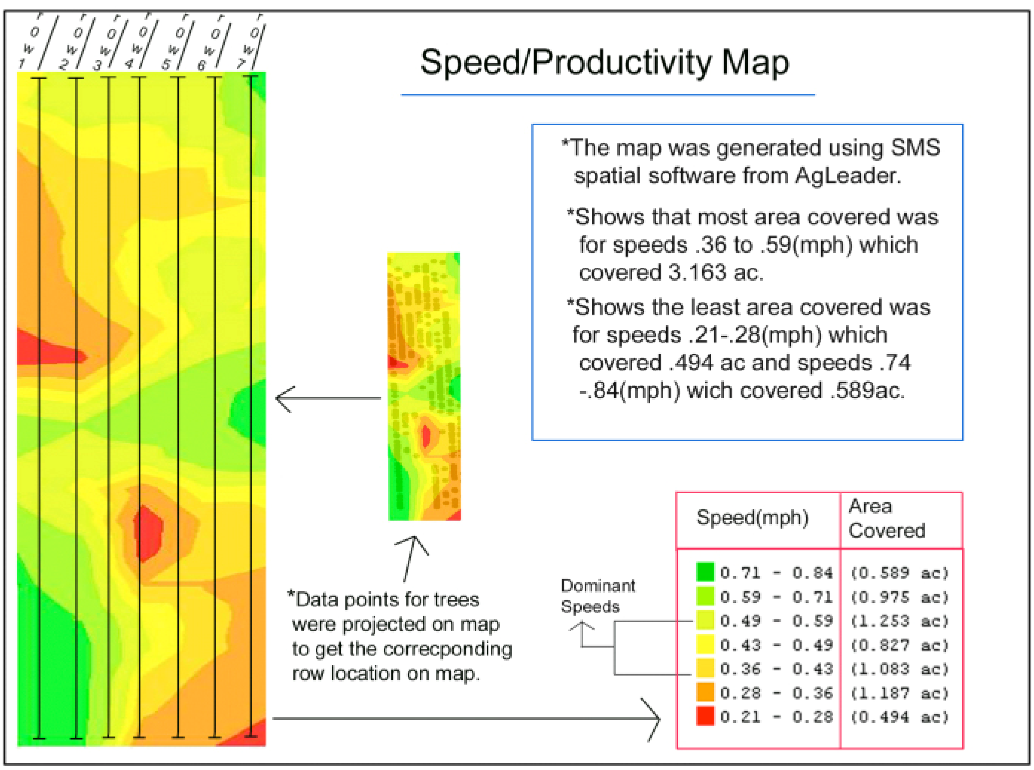
The Argentina experiments would not have been possible without the cooperation and hospitality of Nicholas and Carolina Shawnee of Finca La Bella and their ever helpful management team. The Portugal experiments would not have been possible without the cooperation and hospitality of Rabadoa Ranch, Portugal.

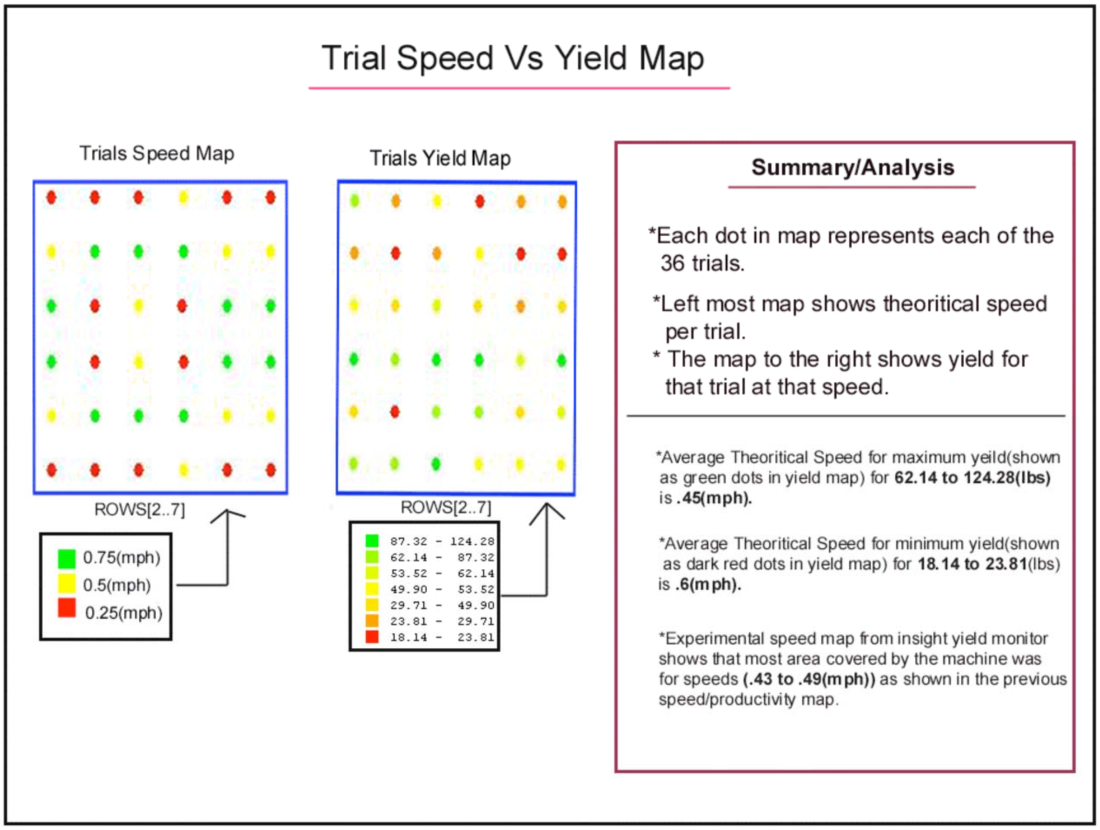
We also wish to thank Martin Bonadeo and Jose Mourelle of MacTeq for the generous use of the MacTeq Colossus Olive Harvester.

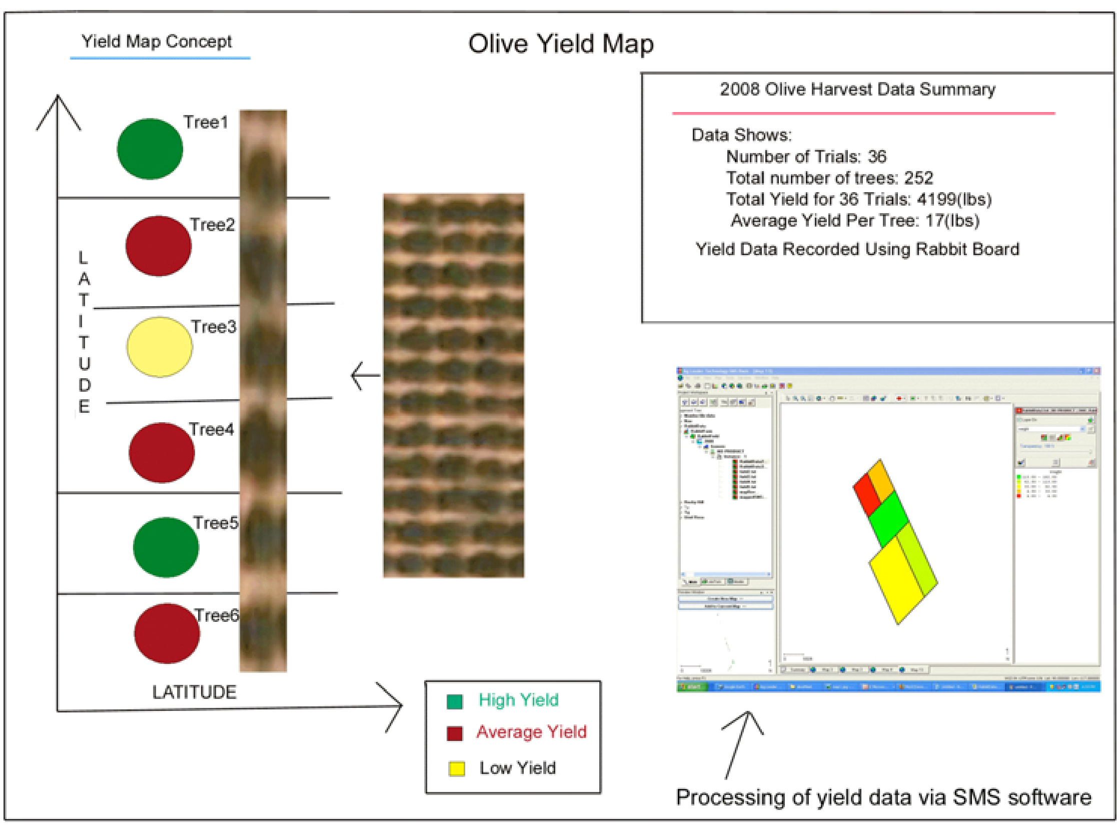
Finally, we thank volunteers John Henry Ferguson BS, MBA, and Peter Kulakow, PhD, for their much appreciated and reliable experimental field and assistance.

Appendix A


2008 Summer Rocky Hill Olive
Yield Monitor Data
General Summary
Total # of Rows: 7 (6+1 Practice Row)
*Data collected at 3 theoritical speeds for each row.
-Speed 1=3/4(mph)
-Speed 2=1/2(mph)
-Speed 3=1/4(mph)
*Total of 6 trials performed on each row.
* Yield was recorded for each trail.
Trials
# of trees per trial: 14
For example the diagram below shows shows how Row 2 was harvested:
Row 2
Trial 4
Trial 3
3/4(mph)
Trial 5
Trial 2
1/2(mph)
By hand
Trial 6
Trial 1
1/4(mph)
Skipped
End
Start


row 1
row 2
row 3
row 4
row 5
row 6
row 7
Speed/Productivity Map
*The map was generated using SMS spatial software from AgLeader.
*Shows that most area covered was for speeds .36 to .59(mph) which covered 3.163 ac.
*Shows the least area covered was for speeds .21-.28(mph) which covered .494 ac and speeds .74 -.84(mph) wich covered .589ac.
*Data points for trees were projected on map to get the correcponding row location on map.
Dominant Speeds
Speed(mph)
Area Covered
0.71 - 0.84 (0.589 ac)
0.59 - 0.71 (0.975 ac)
0.49 - 0.59 (1.253 ac)
0.43 - 0.49 (0.827 ac)
0.36 - 0.43 (1.083 ac)
0.28 - 0.36 (1.187 ac)
0.21 - 0.28 (0.494 ac)


Trial Speed Vs Yield Map
Trials Speed Map
Trials Yield Map
ROWS[2..7]
ROWS[2..7]
0.75(mph)
0.5(mph)
0.25(mph)
87.32 - 124.28
62.14 - 87.32
53.52 - 62.14
49.90 - 53.52
29.71 - 49.90
23.81 - 29.71
18.14 - 23.81
Summary/Analysis
*Each dot in map represents each of the 36 trials.
*Left most map shows theoritical speed per trial.
* The map to the right shows yield for that trial at that speed.
*Average Theoritical Speed for maximum yeild(shown as green dots in yield map) for 62.14 to 124.28(lbs) is .45(mph).
*Average Theoritical Speed for minimum yield(shown as dark red dots in yield map) for 18.14 to 23.81(lbs) is .6(mph).
*Experimental speed map from insight yield monitor shows that most area covered by the machine was for speeds (.43 to .49(mph)) as shown in the previous speed/productivity map.


Yield Map Concept
Olive Yield Map
Tree1
Tree2
Tree3
Tree4
Tree5
Tree6
LATITUDE
LATITUDE
High Yield
Average Yield
Low Yield
2008 Olive Harvest Data Summary
Data Shows:
Number of Trials: 36
Total number of trees: 252
Total Yield for 36 Trials: 4199(lbs)
Average Yield Per Tree: 17(lbs)
Yield Data Recorded Using Rabbit Board
Processing of yield data via SMS software

Development and Performance Evaluation of the DSE Mechanical Olive Harvester

Project Leader

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Project Year: Harvest 2008

INTRODUCTION

Confronting the problem of mechanical olive harvesting is a unique endeavor because there are many aspects to be considered. The olive harvested for table quality must meet specific criteria — limited bruising, no cuts, holes, or abrasions with an overall pristine appearance. Unfortunately, the olive fruit does bruise and damage easily. Therefore, with these characteristics in mind every care must be taken to lessen that possibility. Another consideration is harvester efficiency with overall fruit removal. It remains imperative that percentage of fruit removal be optimized with regard to optimum ground speed of machine.

The mechanical olive harvester must become a viable option to hand-harvested fruit if the industry is to survive. No longer can olive farmers afford to maintain their orchards properly with the ever accelerating cost of chemicals, fuel, maintenance, and the most costly of all the expenditures for harvest. Because harvest is the most costly with it being approximately 50% of a grower's total annual cultural outlay, mechanical harvesting becomes a viable option. The perfection of the harvester therefore becomes imperative.

OBJECTIVES

Improve performance of the DSE 007 olive harvester by incorporating required design changes resulting form 2007 field testing by:

1. Developing a fruit collection (catching efficiency) system that collects > 95% of harvested fruit;
2. Lowering fruit damage to "processor acceptable" levels; and
3. Maintaining > 95% fruit removal from well-trained trees.

PROCEDURES

Objective 1. Develop a fruit collection system that collects >95% of harvested fruit

* Design and fabricate independent, tractor-towed, opposing side-catcher, and fruit-transfer system with bin at rear.
* Fabricate and install low profile, belt-driven catcher system.

* Engineer and install new style collector belts.
* Redesign trash and brush removal system.
* Test system in well pruned orchards established and provided in Louise Ferguson's project" Developing of Mechanical Harvesting for California Olives" 2007-2010.

Objective 2. Lower fruit damage to "processor acceptable" level

* Retrofit rear delivery belt to blower with soft-cleated belt to reduce fruit damage.
* Fabricate picking head enclosures to reduce fruit travel and bounce.
* Test system in well pruned orchards established and provided in Louise Ferguson's project.

Objective 3. Maintain >95% fruit removal from well trained trees.

* Re-design picking heads: Engineer and fabricate to allow greater penetration into tree. More efficient harvesting with less amplitude. Modify heads to reduce rod-gap between heads with new style rod holders and additional rod angle pitch to better access fruit on well-pruned trees.
* Test system in well pruned orchards established and provided in Louise Ferguson's project.

RESULTS AND DISCUSSION

The new collector system that was developed and installed on the mechanical harvester and opposite side tractor-towed secondary catcher proved to be very efficient. Movement of the harvested fruit to the rear bin was much improved with the low profile belt collector system. Given the nature of the belt material and the low profile concept, fruit bruising was minimal.

Brush removal at the rear of harvester was greatly improved with the use of cleated rough top belting, but complete trash removal from harvested olives still remains a problem and will be addressed in the 2009 harvest season. With our ongoing research into the perfect trash removal system, it appears that the concept used in pistachio harvesters may prove more efficient.

The pyramid-designed padding and brush concept on belt edges between the conveyors stopped fruit bruising in these areas. This feature made the harvester self-cleaning because fruit were directed to the end location with gentle ease. Fruit were not retained on the belting system as result of these measures.

CONCLUSIONS

We have exhausted the three headed shaker design with numerous changes and come to the conclusion that no matter what the configuration, there still remains a rod gap problem that cannot be changed due to physical limitations. This problem may only be remedied by adapting two Studer style shaker heads. There would be no rod gap between heads if installed utilizing a concave design. These heads also allow for better operator control because only two joy sticks are necessary to function properly.

The 2008 harvest season produced excellent results. With the implementation of important changes, fruit bruising was held to a minimum while harvested fruit were guided to collection bins as designed. It was determined that optimum ground speeds were essential and should not exceed 0.25 mph. Maintaining the proper speed produced maximum fruit removal. Above the optimum speed, fruit was bypassed and left on the tree. Overall harvested fruit quality was excellent with minimal fruit damage and superior pack out reports.

FUNDING SOURCES

The 2008 Mechanical Harvester Project was funded by the California Olive Committee.

2008 Southern San Joaquin Valley Olive Fruit Fly Monitoring Project - Final Report

Project Leader

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Cooperating Personnel

Bert Quezada, Gary Austin, Rod Burkett, Bob Felts, and Judy Stewart-Leslie

Reporting Period: 1 April – 26 November 2008

INTRODUCTION

The monitoring of olive fruit fly (OLFF) in commercial olive groves in the Southern San Joaquin Valley started in 2001. Initially the project started with 10 groves located in Madera, Fresno, Tulare, and Kern Counties. Monitoring was done by using five yellow panel traps with ammonium carbonate bait plus pheromone and five yellow panel traps with bait only per location. In order to save time and expense while maintaining a meaningful program, the locations were reduced to eight locations in Tulare County and one location in Kern County in 2006. In addition, yellow panel traps were reduced to two per location and both contained the bait plus the pheromone lure. In 2007, the locations were increased to nine and all were in Tulare County. Traps were monitored weekly and results were sent via the Internet or faxed to the California Olive Committee and others that requested the information. Traps were deployed during the first week of April and ended the last week of November 2008. OLFF is currently the most significant insect pest in commercial olives. Black scale is a pest that can be a problem in only certain years (especially years with cooler than normal late spring and early summer temperatures). Ivy and Greedy Scales rarely require treatment in this area.

OBJECTIVES

The objective of this project was to continue the monitoring program of adult OLFF in commercial olive groves in the Southern San Joaquin Valley. Detection and seasonal monitoring of OLFF and the accurate timing of control measures, primarily bait sprays, were the goals of this project. In addition, monitoring continued to give growers information on the general OLFF population. This information was specific for only the groves being monitored and was available to growers to aid in making OLFF management decisions in their respective production areas.

PROCEEDURES

A minimum of nine sites in commercial olive groves was set up with traps. The locations were Ivanhoe, Woodlake, Exeter, South Exeter, Tonyville, West Lindsay, Strathmore, Porterville, and Terra Bella. All of these sites were in Tulare County where a high percentage of the commercial olives were located in the Southern San Joaquin

Valley. All traps were in place by the first week of April, and the program ended the last week of November. Traps were serviced and OLFF counted weekly. Reports detailing the number of OLFF found at each location were submitted on a weekly basis. Two yellow panel traps with ammonium carbonate bait and male pheromone were used per block.

RESULTS AND DISCUSSION

The trap results indicated that the general population of olive fruit fly was above last year's level and also the 7-year average (**Fig.1**). From 2001 though 2006, the Bakersfield location caught the most OLFF while the Terra Bella location caught the second most OLFF (**Fig.2**). During 2007, the Bakersfield location was not trapped due to the grove being removed; the Terra Bella location caught the most flies. In 2008, the Tonyville location caught the most flies with the Terra Bella location catching the second most numbers. The lowest numbers of flies were caught at West Lindsay and South Exeter.

FUNDING SOURCES

California Olive Committee	(1/3) $5,200.00
Leffingwell Ag Sales Co., Inc.	(1/3) $5,200.00
Ag IPM Consultants, Inc.	(1/3) $5,200.00
Total	**$15,600.00**

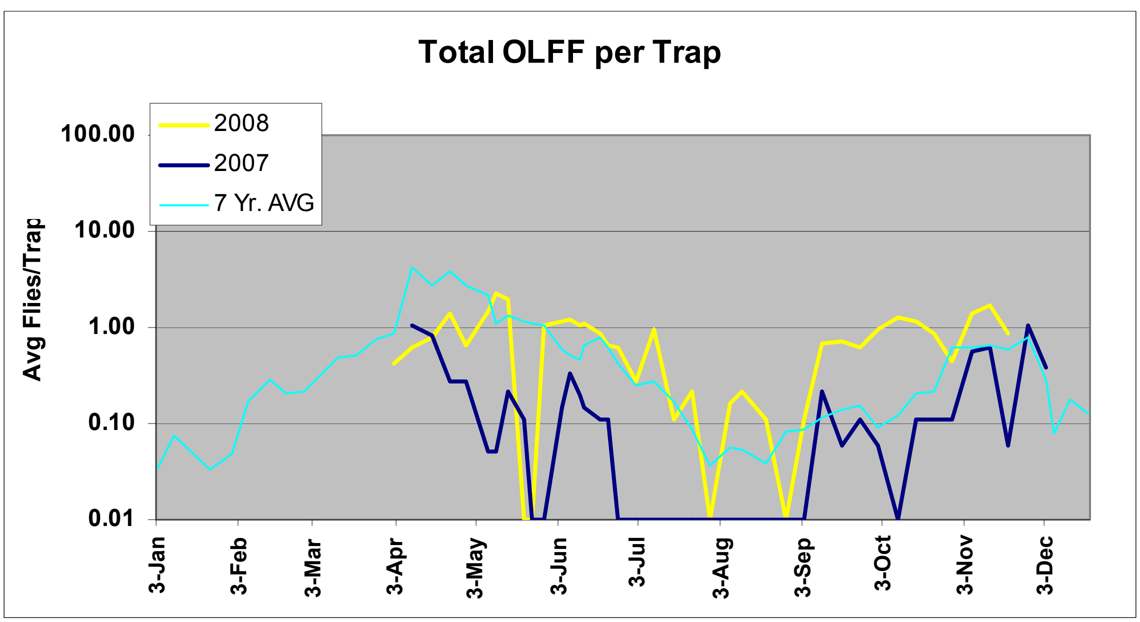

Fig. 1

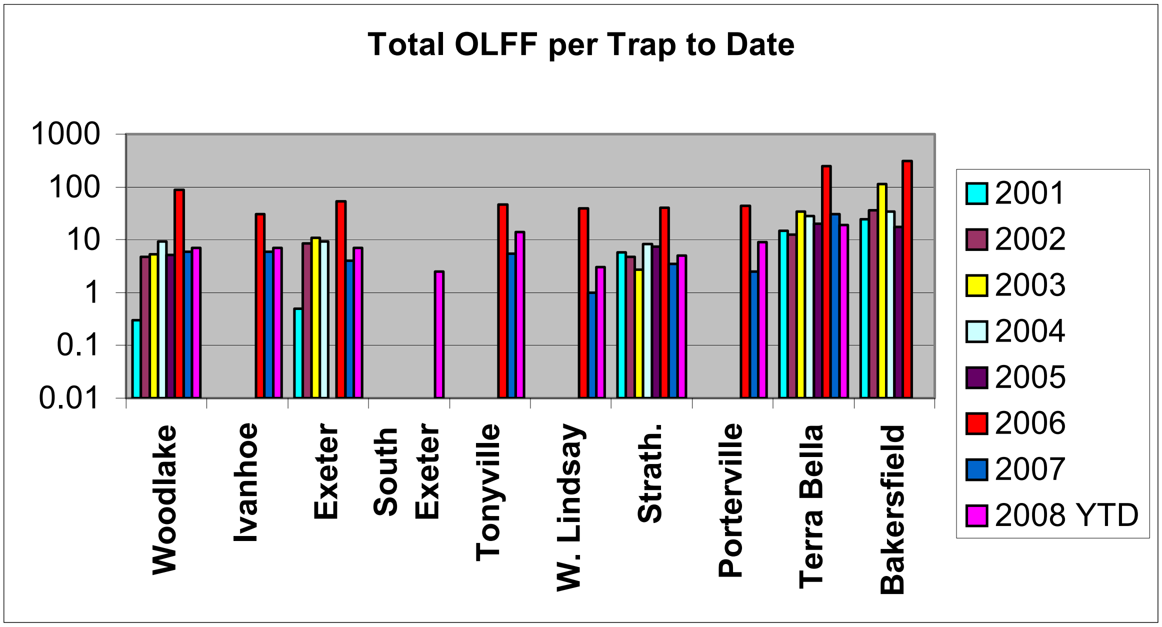
Total OLFF per Trap to Date
1000
100
10
1
0.1
0.01
Woodlake
Ivanhoe
Exeter
South Exeter
Tonyville
W. Lindsay
Strath.
Porterville
Terra Bella
Bakersfield
2001
2002
2003
2004
2005
2006
2007
2008 YTD

Fig. 2

Biological and Cultural Control of Olive Fruit Fly in California — Utilization of Parasitoids from USDA-AHIS-PPQ, Guatemala

Project Leader

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Cooperator

Pedro Rendón, USDA-APHIS-PPQ-CPHST, American Embassy, Guatemala City, Guatemala

Reporting period: 1 July 2008 — 30 June 2009

ABSTRACT

The parasitoid *Psytallia* cf. *concolor* (Szépligeti) was reared on sterile Mediterranean fruit fly larvae at the USDA-APHIS-PPQ, Petapa Quarantine Laboratory in Guatemala and shipped to the USDA-ARS, Parlier, for wide-spread release and biological control of olive fruit fly in California. As many as 37,000 parasitoids were received per shipment and released in olives infested with olive fruit fly in San Diego, San Luis Obispo, Tulare, Santa Clara, San Joaquin, Santa Barbara, Napa, Glenn and Butte Counties. The first or second generation of parasitoids from released adults was recovered from olive fruit fly pupae in most locations. Olive fruit fly populations were very low in interior valleys based on trap captures and fruit collections, but an unusually high population was found in Lodi. The number of olive fruit fly larvae in fruit exposed to the parasitoid was about 59% lower than in non-exposed fruit in the Solvang location. More parasitoids were recovered from olive fruit fly in fruit collected in the upper tree canopy than in the lower canopy. A proposal was submitted to the Guatemala Ministry of Agriculture for entry of US fruit fly species into the Petapa Quarantine Laboratory for parasitoid host tests.

INTRODUCTION

Research to determine the effectiveness of the parasitoid *Psytallia* cf. *concolor* (Szépligeti) from Kenya, Africa, to control olive fruit fly was begun in 2002 in collaboration with Dr. Pedro Rendón, USDA-APHIS-PPQ, Moscamed, Guatemala, and Dr. John Sivinski, USDA-ARS, Gainesville, FL. The results showed that the parasitoid could establish multiple generations on olive fruit fly in cage tests and could be recovered in subsequent generations after field releases. The previous investigations included different areas in California including San Diego, Los Angeles, Santa Barbara, Grapevine, Arroyo Grande, San Jose, Orland, San Juan Bautista, Cayucos, and Sylmar. Over the past years, *P*. cf. *concolor* has shown promise for biological control of olive fruit fly by augmentative field releases with resultant 96% parasitism of olive fruit fly in some areas.

Establishment of the parasitoid on olive fruit fly in California has not yet been achieved, but may be possible by releasing high numbers of adult parasitoids in olive growing areas that are abundant with olive fruit fly. Providing sufficient numbers of the parasitoid may enhance multiple generations in the host. In this investigation, we conducted large-scale production of *P*.

cf. *concolor* for wide-spread release and distribution in California to support establishment of the parasitoid for sustained biological control of olive fruit fly.

The USDA-APHIS-PPQ, Moscamed, laboratory in San Miguel Petapa, Guatemala, currently mass produces parasitoids for control of Mediterranean and Mexican fruit fly, including *Psyttalia humulis* = *P.* cf. *concolor* from Kenya 1997, which is the species that we have released; *P. concolor* from Kenya 2001; *P. cosyrae* from Kenya 2002; and *Fopius ceratitivorus* from Kenya 2001. These species are available and have been selected as good candidates for testing on olive fruit fly, but additional studies on non-target hosts is necessary to obtain USDA-APHIS-PPQ permits for importing the parasitoids from Guatemala to California. We proposed that these studies be conducted in the Petapa quarantine laboratory in Guatemala and began the permit process with USDA-APHIS-PPQ and the Guatemala government to ship non-target fruit fly species from the USA.

OBJECTIVES

1. Continue releases of the parasitoid *P.* cf. *concolor* in regions in California where olive fruit fly occurs as a pest; and
2. Evaluate other parasitoids that are mass-reared in Guatemala for biological control of olive fruit fly, and determine the response of these parasitoids to non-target hosts to acquire importation permits.

PROCEDURES

Objective 1. Continue releases of the parasitoid P. cf. concolor in regions in California where olive fruit fly occurs as a pest

The *P.* cf. *concolor* adults used in this investigation were reared on Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), and on Mexican fruit fly, *Anastrepha ludens* (Loew), in the Moscamed facility in San Miguel Petapa, Guatemala, under the direction of Dr. Carlos Cáceres and Dr. Pedro Rendón, USDA-APHIS-PPQ. California Olive Committee funding was used to support personnel to rear, collect, and package the parasitoids for shipment to California.

The parasitoids were shipped weekly by DHL air courier contract from Guatemala City and entered the USA through Miami, FL. The shipments arrived in Parlier, CA, within two days. Shipment of *P.* cf. *concolor* resulted in 1-3% mortality in transit. The parasitoids were unpackaged in an isolated screened room and released into cages, fed honey, and provided with water. The insects were held for 1-2 days for observation and mating, and transported by automobile to release sites.

Release sites were made available by individuals and industry cooperators in San Diego, Los Angeles, Santa Barbara, San Luis Obispo, Santa Clara, Tulare, San Joaquin, Napa, Butte, and Glenn Counties. Olive fruit fly adult populations were monitored in infested olive trees with yellow sticky traps with spiroketal lures and ammonium carbonate baits. Pre-release fruit samples were collected at each location and held in the laboratory to determine the number of mature olive fruit fly larvae (3rd instar larvae emerge in four days) available to the parasitoids at the time of release, and the total number of olive fruit fly larvae in the fruit. The parasitoids were released from opened cages into trees with potential olive fruit fly infestations. Parasitoid releases were made once or multiple times in the designated areas. Temperature and humidity data were recorded with data loggers.

Post-release samples of fruit infested with olive fruit fly and exposed to the parasitoid were collected about one to three weeks after release, and maintained in the laboratory to determine emergence of the host and parasitoid. Rates of parasitism were calculated from numbers of mature 3rd instar larvae collected from pre-release fruit samples, and the number of parasitoids emerging from post-release fruit using previously published formulas.

The effect of parasitoids on olive fruit fly infestations was determined by comparing the total number of larvae that emerged in fruit exposed to parasitoids versus non-exposed, control fruit. Control fruit samples were collected from trees in the vicinity of parasitoid release sites and held in the laboratory until all olive fruit fly larvae had emerged.

RESULTS AND DISCUSSION

Objective 1. Continue releases of the parasitoid P. cf. concolor in regions in California where olive fruit fly occurs as a pest

Work accomplished with 2008 California Olive Committee Funding is still in progress. The final findings will be reported in a scientific journal and submitted to the California Olive Committee. We are still receiving shipments of parasitoids from Guatemala. Fall through January 2008 has been relatively mild and irrigated trees have retained fruit that are infested with olive fruit fly. Work will be continued until olive fruit are no longer available. Preliminary results show that the parasitoid can remain in olive fruit fly pupae without emerging for a long period of time. This observation supports the possibility of parasitoid viability in the immature stages of the host from one season to the next. Late releases and slow development may support parasitoid longevity until 2009 fruit becomes infested by olive fruit fly in early June.

The Petapa Quarantine Laboratory in Guatemala was successful in greatly increasing production of *Psyttalia* cf. *concolor*. The parasitoid was reared from Mediterranean fruit fly (Medfly) and Mexican fruit fly. However the parasitoids reared from Medfly were more vigorous. A new collection method to harvest parasitoids from Medfly pupae was developed and numbers of parasitoids increased from 3,000 to > 30,000 in each shipment.

Medfly larvae were sterilized by irradiation prior to parasitism to increase the security of the rearing procedure. The larvae were exposed to oviposition by parasitoids and allowed to pupate. Adult parasitoids that emerged from Medfly pupae were collected, placed in waxed cups, and provided water on a sponge and honey on the cloth lid of the cup. An informal inquiry was made to the Fresno County Department of Agriculture about potential importation of parasitized, sterile Medfly pupae to greatly increase the number of imported parasitoids, but was not accepted due to security issues.

Parasitoid adult mortality in each shipment after two days by air and ground transport was minimized by modifying techniques to supply food and water. Methods were investigated to reduce shipping expenses without the loss of insect quality. The cost of each shipment ranged from $500 to $900 and was paid by the USDA-ARS-SJVASC.

Regional parasitoid releases in California (**Table 1**) were begun in August and are on-going in olive fruit fly infested olive trees in different areas. Releases have been conducted in San Diego, Cayucos, San Jose, Lemon Cove, Strathmore, Cayucos, Lodi, Paso Robles, Solvang, Napa, Orland, Oroville, and other locations with persistent fruit in trees.

The progeny from released parasitoids have been recovered from all release locations except for those in which olive fruit fly larvae were not collected from the pre-release fruit samples. The olive fruit fly infestations in the interior valley locations such as Strathmore and Lemon

Table 1. Import dates, number and percentage female *Psyttalia* cf. *concolor* received from Guatemala; parasitoid release dates, alocations, total number of olive fruit fly larvae per olive fruit, and number of mature 3rd instar larvae susceptible to parasitism in California sites; post-release period and recovery of first or second generation of parasitoids from released parents (work still in progress)

2008-2009 Import date	Parasitoids		Releases			OLF Larvae		Post-release period, wks	F_1 or F_2 Parasitoids
	No.	% ♀	Date	Site	County	Total no./ fruit	No. 3rd instar/ fruit		
Sept 18	9,600	50	Sept 20	Rancho Bernardo	San Diego	0.80	0.09	>2	Yes
Sept 22	18,244	53	Sept 25	Cayucos	San Luis Obispo	0.70	0.06	>2	Yes
Sept 30	4,962	54	Oct 3	Strathmore	Tulare	0.0	0.0		No
Oct 8	11,111	40	Oct 9	San Jose	Santa Clara	1.83	0.25	1	Yes
Oct 15	19,590	56	Oct 16	San Jose	Santa Clara	1.95	0.58	1	Yes
Oct 29	4,740	34	Oct 30	Lemon Cove	Tulare	0.04	0.0		No

Nov 12	16,600	36	Nov 14	Lodi	San Joaquin	3.82	0.97	<1	Yes
Nov 20	11,571	52	Nov 21	Paso Robles	San Luis Obispo	1.12	0.29	<1	Yes
Nov 26	12,390	34	Nov 28	Lodi	San Joaquin	1.21	0.74	>2	Yes
Dec 3	13,596	35	Dec 4	Solvang	Santa Barbara	2.64	0.34	1	Yes
Dec 10	17,084	54	Dec 11	Solvang	Santa Barbara	2.39	0.15	1	Yes
Dec 10	13,830	54	Dec 13	Napa	Napa	0.20	0.08	<1	
Dec 17	16,882	38	Dec 18	Solvang	Santa Barbara	1.47	0.50		
Dec 17	20,552	38	Dec 18	San Jose	Santa Clara	0.45	0.22		
Jan 8	14,364		Jan 9	Orland	Glenn				
Jan 8	11,172		Jan 10	Oroville	Butte				

Cove were very low in 2008 based on collection of adults in yellow sticky traps and larvae that developed to the adult and pupal stages from pre-release fruit samples. Unusually high numbers of olive fruit fly were collected from Lodi, which seems to be an anomaly with the hot, dry conditions of the location. Evaluation and statistical analysis of rates of parasitism in relation to olive fruit fly populations, and weather data from each location is still in progress.

The total number of olive fruit fly larvae per fruit from trees in which parasitoids were released versus non-exposed control trees was 1.47 and 2.50, respectively, in the Solvang location on 18 December 2008. This significant difference suggests the parasitoid reduced the olive fruit larval infestation by 58.8%.

Studies of the dispersal capacity of parasitoids showed that more progeny of released adults were recovered from fruit infested with olive fruit fly that were collected higher in the canopy of olive trees than lower. The parasitoid has been tethered to determine the distance that the parasitoid can fly in wind tunnel tests, but the technique needs further improvement.

Objective 2. Evaluate other parasitoids that are mass-reared in Guatemala for biological control of olive fruit fly, and determine the response of these parasitoids to non-target hosts to acquire importation permits

Testing olive fruit fly and non-target fruit fly species with parasitoids in the Petapa Quarantine Laboratory, in Guatemala is under review by the Guatemala government. USDA-APHIS-PPQ Letters of No Permit Required have been obtained to allow export of olive fruit fly, walnut husk fly, cherry fruit fly, seedhead fly, and cape ivy fly to the Petapa Quarantine Laboratory, Guatemala. A proposal was submitted to the Guatemala Ministry of Agriculture for entry of these fruit fly species into the Petapa Quarantine Laboratory, and is pending.

Research collaborations during this project were developed with other workers. Dr. Brian Federici, Univ. Calif. Riverside, discovered a poison gland in *P*. cf. *conolor*. Dr. Xingeng Wang, Univ. Calif. Kearney, Parlier, studied rates of parasitism between *P*. cf. *conolor* reared from sterile versus fertile Medfly. Dr. Spencer Walse, USDA-ARS, Parlier, and Dr. Joceyln Millar, Univ. Calif. Riverside, discovered potential attractants from olive fruit fly exudates produced by adults reared on diet in our lab. Dr. Frank Zalom, Univ. Calif. Davis, evaluated olive fruit fly that were collected at parasitoid release sites for resistance to GF-120.

CONCLUSIONS

The parasitoid, *Psyttalia* cf. *concolor*, was successfully mass-produced in Guatemala using newly developed procedures and imported into California for biological control of olive fruit fly. The parasitoid showed potential to become established on olive fruit fly in certain areas of the state where high populations of the pest re-occur annually. Potential establishment was greatly enhanced in 2008 by the release of large numbers of parasitoids, and conditions in release sites that supported the persistence of infested fruit in trees. Comparative studies in one location showed a 59% reduction of olive fruit fly in fruit exposed to parasitism. These findings support the potential effectiveness of the biological control program.

FUNDING SOURCES

External Funds: California Olive Committee
Internal Funds: USDA-ARS-SJVASC, Parlier, CA; and USDA-APHIS-PPQ-CPHST, Guatemala; and the Moscamed Program, USA-Mexico-Guatemala

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