FINAL PROJECT REPORT
WTFRC Project Number: CP 06-601 **WSU Project # 13C-3643-7387**

Project Title: Reinstating integrated mite control in apple orchards

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Other funding Sources

Agency Name: Washington State Commission on Pesticide Registration
Amount awarded: $12,560 (2006): $12,373 (2007)

Total Project Funding: *Year 2006:* 34,841 *Year 2007:* 36,730

Budget History:

Item	**Year 1:** 2006	**Year 2:** 2007
Salaries	9,374	9,754
Benefits	904	917
Wages	7,800	8,400
Benefits	780	0
Equipment	0	0
Supplies	1,500	1,500
Travel	1,923	2,820
Miscellaneous	0	0
Total	22,281	24,357

Significant Findings

1. A consistent association was found between the insecticides Assail, Calpyso, and Rimon and increased levels of mites in large scale commercial orchard blocks over three years. The severity and extent of the outbreaks varied widely from year to year.

2. An additive effect in causing mite outbreaks was found between Assail, Calpyso, and Rimon when used in a program with the blossom/fruit thinning materials lime-sulfur and carbaryl; however, there were elevated mite levels in the Imidan+lime-sulfur+carbaryl treatment, as well.

3. Bioassays with spider mites and *T. occidentalis* demonstrated clearly that lime-sulfur and ATS are acutely toxic on contact to all three mite species, while dry flowable sulfur has little or no effect.

4. Lime-sulfur and ATS caused severely reduced prey consumption in *T. occidentalis* when exposed only to residues and contaminated prey; dry flowable sulfur had no effect. The effect of lime-sulfur occurred even at reduced rates, and with or without the addition of petroleum oil. In general, when prey consumption went down, fecundity was also suppressed.

Results and Discussion

Large scale commercial trial. This trial was conducted for three years in commercial orchards from Bridgeport to the Royal Slope. The treatments consisted of three newer codling moth insecticides (Assail, Calypso, and Rimon) compared to an OP standard (either Guthion or Imidan) applied to 1-4 acre blocks. The same treatments were applied to the same blocks in successive years. Mite populations in 2005 (Fig. 1a) were high in only one orchard out of five. The highest levels occurred in the Rimon treatment followed by Assail and Calypso. Very few differences were found in rust mite or predatory mite levels among the various treatments.

In 2006, mite populations were much higher overall in the test orchards (Fig. 1b). Five out of six orchards had high mite populations. Rimon caused an elevated tetranychid mite level in five orchards, Assail in two, and Calypso in three. There was one orchard which had a very high peak of mite in the OP plot. However, this orchard had high mite levels overall in 2006, following high levels in 2005. Trends in predatory mite densities were less clear, although in several blocks the recovery in the population was too late to affect the outbreak of mites during the mid-season. When orchards were used as replicates in ANOVA, there were no statistical differences found among treatments for either tetranychid or predatory mites. Rust mites varied considerably among orchards; there were statistically more rust mites in the Assail treatment, but this was based primarily on two orchards (data not shown).

Mite populations in 2007 were overall much lower than the previous year (Fig. 1c), with peak populations of about six mites/leaf (as opposed eighty mites/leaf in 2006). Only two of five orchards sampled experienced a moderate increase in spider mite levels, with high levels occurring in the Rimon treatment in one orchard, and Assail and Calypso in another. Slightly elevated levels of spider mites also occurred in the OP check in one orchard. Predatory mite levels were higher in two orchards, one apparently in response to increased spider mite densities, and one in response to rust mite densities (data not shown).

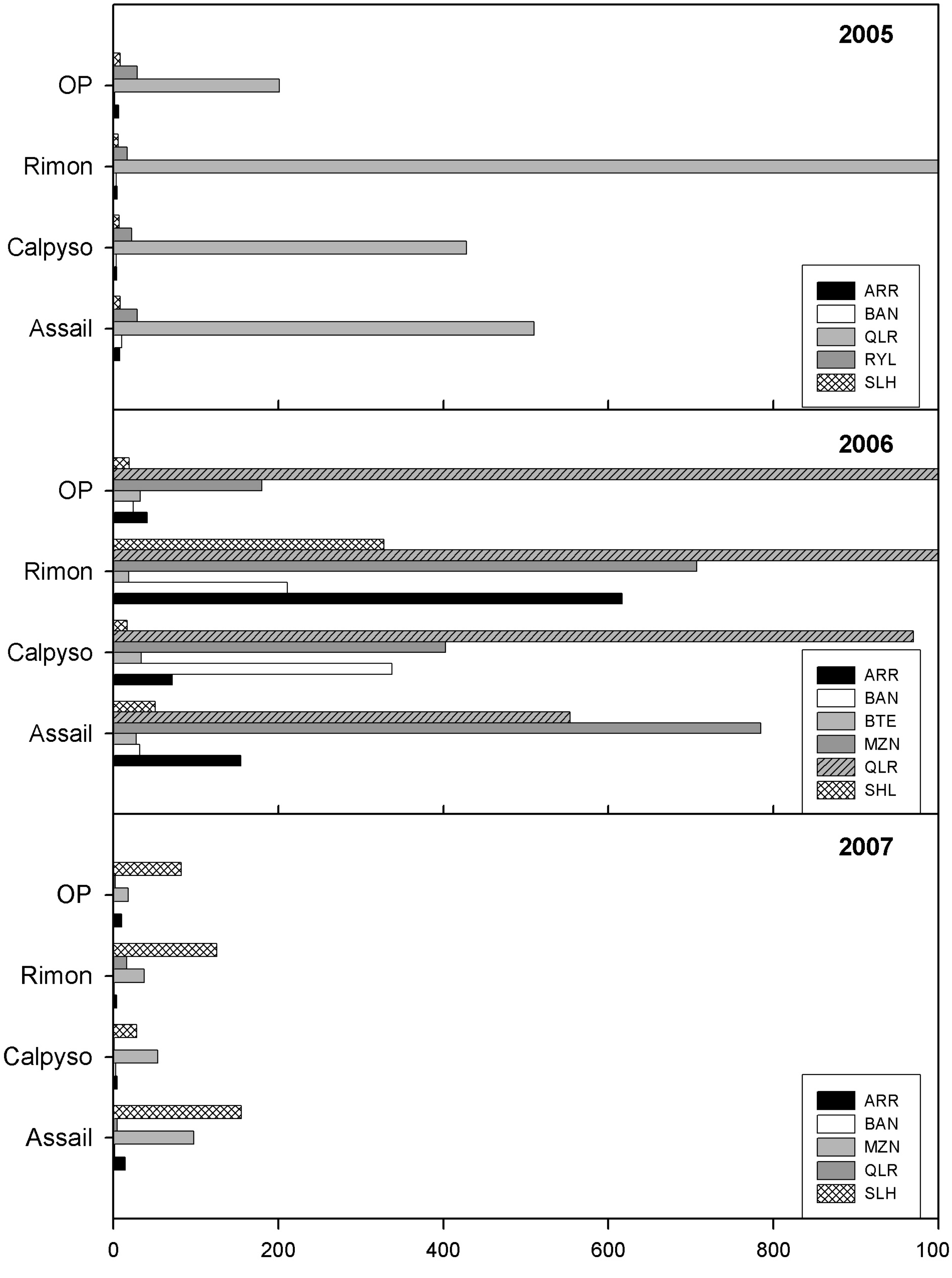

Fig. 1. Tetranychid cumulative mite days resulting from applications of Assail, Calypso, Rimon, and an OP to large commercial orchard blocks, 2005 (1a), 2006 (1b), and 2007 (1c).

Medium plot replicated trials.

Test 1. This experiment examined the additive effects of seasonal programs of two thinning materials, lime-sulfur and Sevin, with four different codling moth materials. The codling moth insecticides (Assail, Calpyso, Rimon and Imidan) were applied either alone, preceded by lime-sulfur, or with lime-sulfur followed by Sevin. All materials were used at typical timings (lime-sulfur at bloom; Sevin at 10 mm fruit; codling moth materials at first and second cover).

The results from this trial were very striking; none of the treatments containing just the codling moth materials caused a mite flareup; only those incorporating all three groups (lime-sulfur, carbaryl, and the codling moth insecticide) caused a flare-up (Fig. 2). In this test, even Imidan caused a moderate increase in mites. Assail and Rimon (+LS+carbaryl) had the highest peaks, and Calypso+LS+carbaryl had the lowest peak. Predatory mites (data not shown) were highest in the Imidan and Assail treatments, and lowest in the Rimon treatments. Apple rust mite populations were highest in the Assail and Imidan treatments, but Rimon appeared to have a detrimental effect on rust mites. Fruit damage by codling moth was higher in some of the Assail treatments, and lower in the Rimon and Imidan treatments, although most of the damage was in the form of stings. There was also a non-significant trend for woolly apple aphids to be lowest in the Imidan treatments, and highest in the neonicotinyl treatments, with Rimon intermediate.

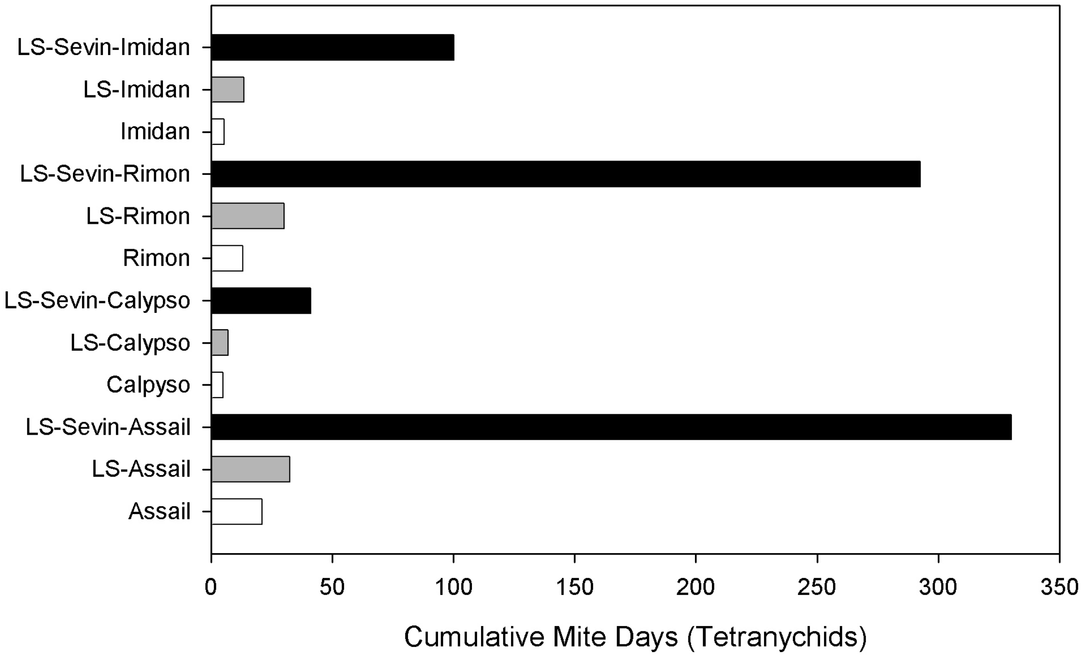

Fig. 2. Additive effect of codling moth programs, lime-sulfur (LS) and carbaryl (Sevin) in an orchard trial.

Test 2. A second test examined the relative effect of ATS vs. lime-sulfur (with or without a Sevin application at 10 mm fruit), in the absence of any of the above-mentioned codling moth materials. Mite populations were low throughout the test, with no significant differences among treatment (data not shown).

Test 3. This test examined the relative effects of one vs. two applications of lime-sulfur and Sevin vs. NAA, all followed by two applications of Assail for the first generation of codling moth, with a "mite-neutral" check (NAA and Intrepid). In this trial (data not shown) there was a slight trend for higher tetranychid mite populations in treatments containing lime-sulfur, but this occurred only on a few count dates during the peak mite population. There was some increase of mites in the check, also. No significant treatment differences in cumulative mite days for tetranychid or predatory mites.

Test 4. This test looked at the additive effect of Sevin, Assail, and Surround, a kaolin clay material known to flare mite populations. Little treatment effect was seen in this trial; there was a modest mite increase in the plots, but the highest level was in the check (least disruptive) (data not shown).

Test 5. This test targeted the effect of sulfur-containing pesticides on apple rust mite and predatory mites. Either a single or a triple application of lime-sulfur, ATS, or dry flowable sulfur was applied in late June to a high rust mite population, being fed on by low to moderate levels of predatory mites. Lime sulfur had the greatest detrimental effect on rust mites, with flowable sulfur intermediate, and ATS with the least effect (Fig. 3a). All treatments suppressed rust mites in relation to the check. There was no difference between single and triple applications, perhaps because of the population crash due to hot weather. All treatments suppressed predatory mites in relation to the check, and to about the same degree (Fig. 3b). Tetranychid mite populations were low throughout the test, and no stimulation occurred due to the sulfur treatments.

Laboratory bioassays.

A series of laboratory bioassays was done on European red mite, twospotted spider mite, and *Typhlodromus occidentalis*, with emphasis on the latter. The bioassays provided a more detailed examination of the effect of sulfur-containing pesticides than was provided by the field tests.

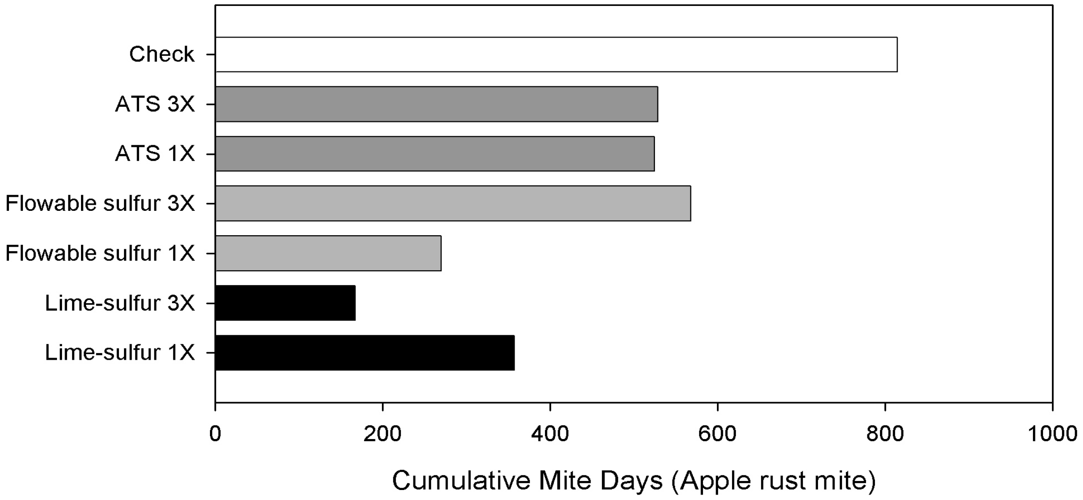

Fig. 3a. Effect of sulfur pesticides on apple rust mite, field experiment.

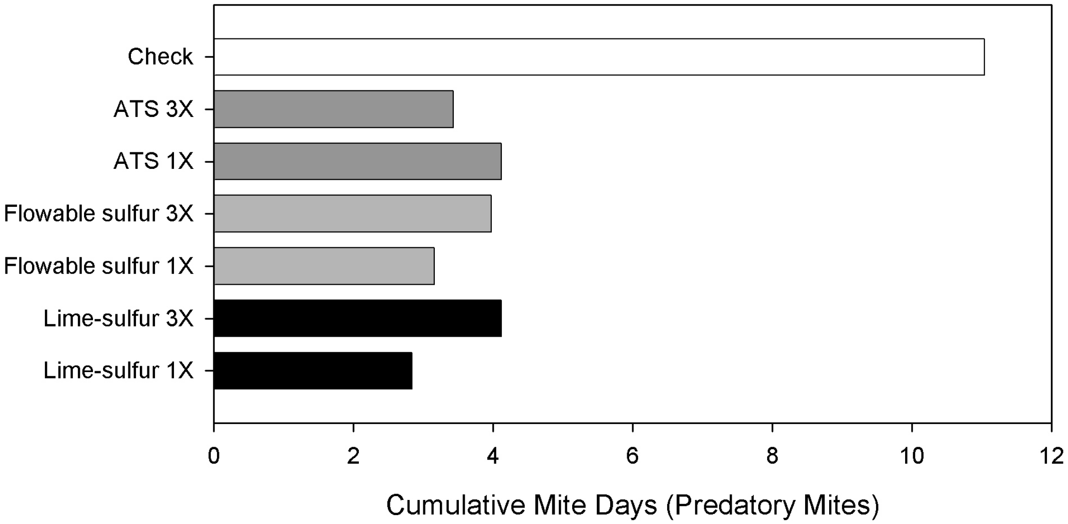

Fig. 3b. Effect of sulfur pesticides on predatory mites, field experiment.

Exposure routes included contact, residual, and contaminated prey; effects measured included direct mortality, and the sublethal effects of prey consumption and fecundity.

Group 1. This series of bioassays examined mortality and fecundity of the three mite species when exposed via contact to lime-sulfur, ATS, and dry flowable sulfur. Two bioassay formats were used, one using synchronous cohorts to provide female mites of the same age, or mites taken at random from the orchard or a laboratory colony. Data were collected daily for 5 d; however, the 48 h data provided the best compromise between check mortality and treatment effect. Lime-sulfur and ATS were acutely toxic to western predatory mite, European red mite and twospotted spider mite, causing high levels of mortality (60-100%) 48 h after treatment (Fig. 4). Dry flowable sulfur showed no acute toxicity with the exception of European red mite, where an intermediate level of toxicity was found. For the most part, sublethal effects on fecundity were not detected; evidently, if the mites survived, they could reproduce normally. The one exception was ATS, which caused a slight reduction in egg production of twospotted spider mite in one bioassay, but no differences occurred in other bioassays. There was no apparent difference in results between bioassays using synchronous cohorts versus those using mites of unknown ages.

Group 2. This series of bioassays (and all subsequent ones) focused on mortality and prey consumption by *T. occidentalis* exposed to contaminated prey and residues on leaf surfaces (residual bioassay). Lime-sulfur at both 8% and 4% caused a significant reduction in prey consumption at 24 and 48 h (Fig. 5); there were no differences in mortality (data not shown). Dry flowable sulfur caused no suppression of prey consumption or mortality. ATS caused a slight increase in mortality (48 h), but there was a measurable decrease in prey consumption at both rates in relation to the check.

Group 3. This bioassay used the three sulfur containing materials at a constant rate of sulfur (the previous tests had rates that were based on field rates). When all three sulfur products were applied at the same rate of S/ml solution (equal to the high rate of dry flowable sulfur), both ATS and lime sulfur caused a reduction in prey consumption at 48 h. In this test, lime-sulfur had a significantly greater effect than ATS. Fecundity was also severely suppressed in these two treatments. There was no difference in mortality at 24 h, which was low in all treatments.

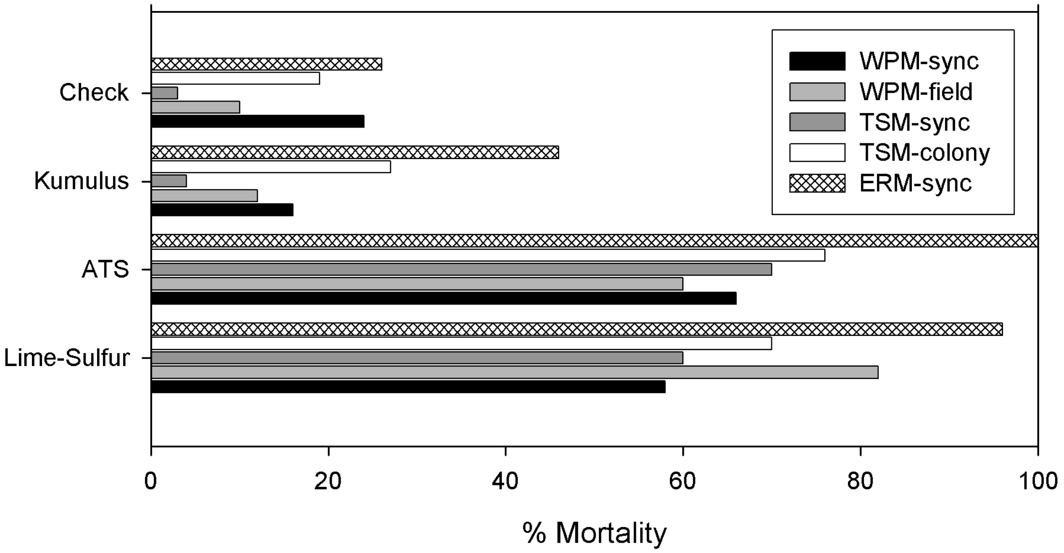

Fig. 4. Percentage mortality after 48 h resulting from contact bioassays with lime-sulfur, ATS, and dry flowable (Kumulus) sulfur (WPM, *T. occidentalis*; TSM, twospotted spider mite; ERM, European red mite).

Group 4. This bioassay looked at the effect of the two rates of lime-sulfur commonly used by the industry (8% and 2%), either alone or in combination with petroleum oil. This is one of the few tests where significant mortality occurred in one or more treatments, specifically, lime-sulfur at 2% (both with and without oil), and lime-sulfur 8% with oil. Prey consumption was dramatically reduced by all lime-sulfur treatments, regardless of rate or addition of oil (Fig. 6). Oil alone caused an intermediate reduction in prey consumption. Fecundity was not different than the checks in any treatment.

Group 5. This bioassay compared the effect of exposure to Sevin either topically (plus residues) or to residues only, in comparison to a water check. Mortality was zero in all treatments. There were no significant treatment differences in prey consumption, fecundity, or viability of *T. occidentalis* eggs.

Discussion

Field Experiments. Given the format of the trial (commercial orchards widely scattered across the state with varying histories), there was a relatively clear and consistent pattern of disruption by all three of the codling moth insecticides used in this trial. The effect of Assail and Calypso was noted in earlier experiments (Beers et al. 2005). No effect of Rimon was noted in small-plot trials, however, this association, first reported by anecdotal evidence, has been confirmed in these experiments. The occasional high population in the OP standard indicates that mite outbreaks can also occur where these compounds are used; it is primarily a question of frequency. OP resistance in *T. occidentalis* from Washington has been documented for decades, with ca. 100-fold resistance levels in comparison to a susceptible population (Croft and Jeppson 1970; Babcock and Tanigoshi 1988).

While the three-year period of this study is insufficient to predict long-term patterns, it seems apparent that year-to-year variation is an important factor. The mechanism underlying this variation is not clear, however, it is likely that temperatures during some key period of development play a role. This variation tends to obscure what are likely real effects of pesticide programs on integrated mite control.

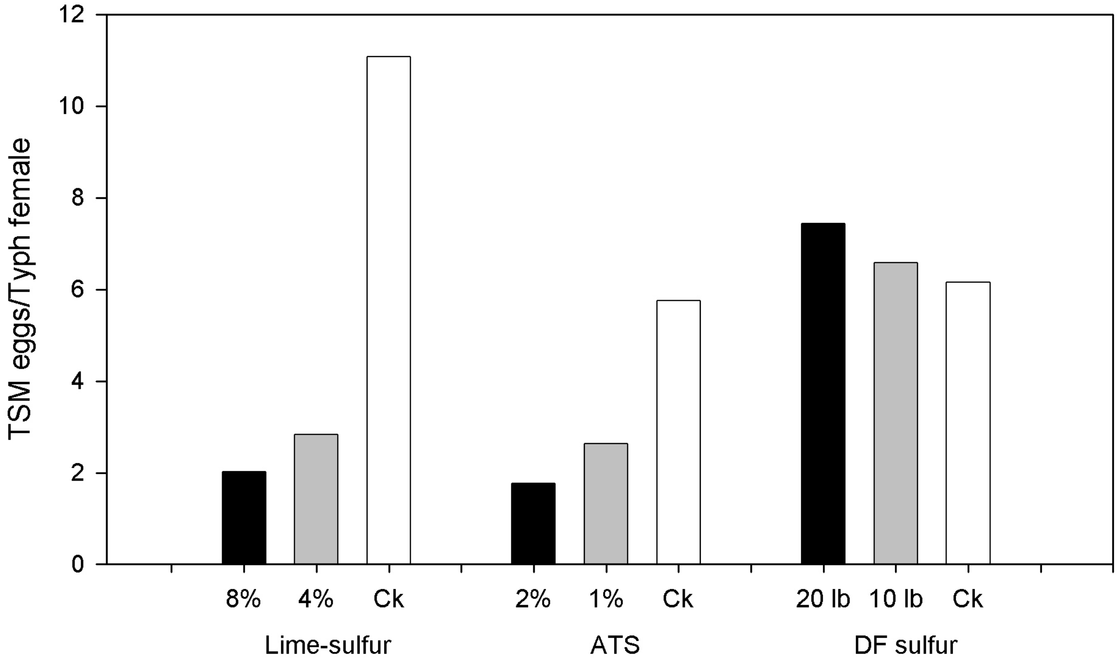

Fig. 5. Sublethal effects of sulfur pesticides on prey consumption by *T. occidentalis* exposed to residues.

The principle of additive effects is demonstrated in the small plot trials, that is, that the probability of a mite outbreak increases with the number of disruptive compounds. Some of the materials currently used for thinning (lime-sulfur, ATS, and carbaryl) have a history of disrupting integrated mite control, mainly through direct toxicity to either *T. occidentalis* or its alternate prey, apple rust mite (Hoyt 1969). These detrimental effects have become codified in the WSU Crop Protection Guide over the years (e.g., Smith et al. 2007), appearing as early as the 1960s (Hoyt 1965). Despite this knowledge, these compounds have been used for decades in Washington orchards, and mostly without causing mite outbreaks. It is likely that increased numbers of applications, coupled with use of more disruptive codling moth programs, has resulted in the higher regional incidence of mite outbreaks.

Bioassays. The bioassays provide confirmatory evidence of toxic effects observed in the field trials. Overall, the residual exposure bioassays confirm the results of the contact/residual bioassays (Group 1); viz., that lime-sulfur and ATS have a significant effect, while dry flowable sulfur has little or none. Lime-sulfur and ATS have significant contact toxicity to all mite species, including *T. occidentalis*, while exposure to residues reduces either prey consumption, fecundity, or both. The net effect of these multiple toxic outcomes is likely to be moderate to severe, at least in the period immediately following application; the longer term impacts are yet to be investigated. In the small-plot field test, flowable sulfur, as well as ATS and lime-sulfur had some effect on *T. occidentalis*, but this may have been mediated through reduction of its prey, apple rust mite. In addition, temperature may have an effect on the toxicity of elemental sulfur, thus dry sulfur may in fact be more toxic at the higher temperatures in the field vs. the laboratory tests. Interestingly, the population of *T. occidentalis* used in this bioassay has developed complete tolerance to carbaryl, which was formerly quite toxic, and considered a major disruptant of integrated mite control (Hoyt 1965, 1969). However, tolerance on the part of *T. occidentalis* has been selected for over time, and was present in Washington *T. occidentalis* populations since the 1960s (Croft and Jeppson 1970, Babcock and Tanigoshi 1988). This underscores the dynamic nature of pesticide susceptibility in arthropod populations. Conversely, we have been using lime-sulfur for over 100 years in Washington, and while we have no baseline data, it is still acutely toxic to mites. There are some compounds that, by virtue of mode of action, have little chance of causing selection in the target population. The caustic nature or breakdown products of these materials may prove to be an insurmountable barrier for development of a resistance mechanism both in pest and beneficial species.

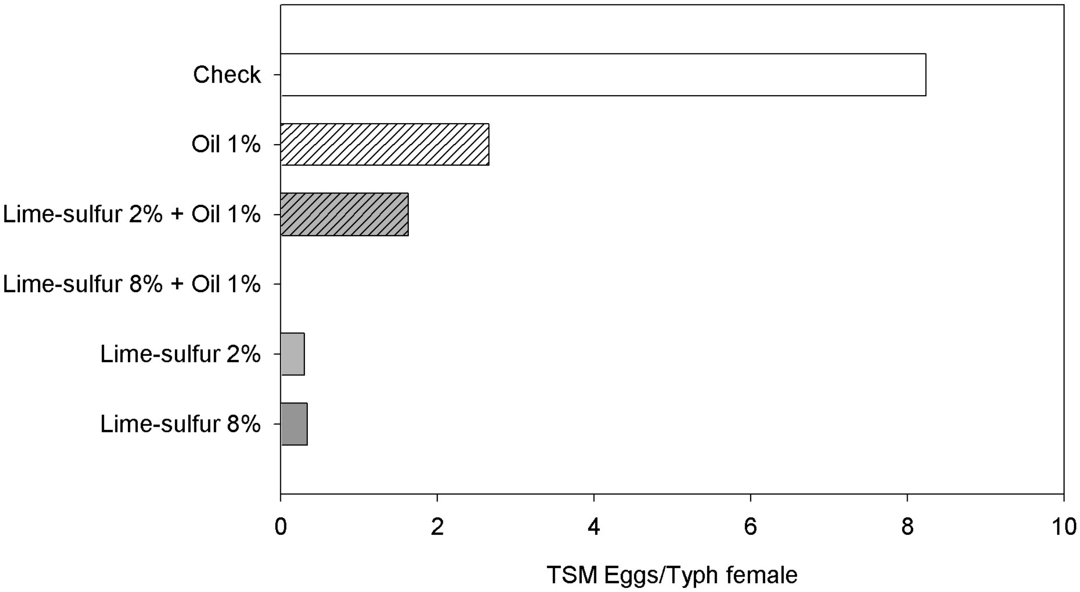

Fig. 6. Sublethal effects of lime sulfur with or without oil on prey consumption by *T. occidentalis* exposed to residues.

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