

# Measuring IPM Impacts in California and Arizona

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## Abstract

Integrated pest management (IPM) is a method of reducing economic, human health, and environmental risks from pests and pest management strategies. There are questions about the long-term success of IPM programs in relation to continued use of pesticides in agriculture. Total pounds of pesticides applied is a mis-measure of the impact of IPM in agriculture. A more complete measurement of the long-term impact of IPM includes consideration of changes in agricultural production practices and productivity, toxicity of the pesticides used, risks from human exposure to pesticides, and environmental sampling for pesticides in air and water resources. In recent decades, agricultural IPM programs have evolved to address invasive pests, shifts in endemic pest pressures, reductions in pest damage tolerance in markets, and increases in crop yields. Additionally, pesticide use data from Arizona and California revealed reduced use of pesticides in some toxicity categories but increased use of pesticides in a couple of categories. Data from federal and California programs that monitored pesticide residue on food have documented low pesticide risk to consumers. Environmental monitoring programs documented decreased pesticide levels in surface water resources in agricultural watersheds in the western United States and low levels of pesticides in air resources in agricultural areas in California. The focus of IPM assessment should be on reducing economic, human health, and environmental risks, not on pounds of pesticides applied. More broadly, IPM programs have evolved to address changes in pests and agricultural production systems while continuing to reduce human health and environmental risk from pesticides.

**Key words:** IPM, agriculture, evaluation, metrics

Funding agencies and the general public are requesting greater evaluation and documentation of the impact of integrated pest management (IPM) programs in the United States. Many IPM projects and programs focus on short-term (change in knowledge) or medium-term (change in behavior) impacts and have documented greater knowledge of and adoption of IPM practices (Farrar et al. 2016). However, there are questions about the long-term success of IPM in relation to constant or increasing pesticide use. Epstein and Zhang (2014) stated that IPM programs are promoted to the public as a method to reduce agricultural pesticide use. A 2001 report found that while IPM had been adopted on about 70% of U.S. crop acreage, chemical pesticide use had increased between 1992 and 2000, and there was only a slight decrease in the amount of the riskiest pesticides used in the same period (U.S. Government Accountability Office 2001). Maupin and Norton (2010) used economic models to document that IPM programs lead to a slight increase in pesticide use in corn and cotton systems. They suggest pesticide use is primarily related to fixed environmental factors.

IPM is a method of reducing economic, human health, and environmental risks from pests and pest management strategies. As stated in the IPM Roadmap (2013), the goals of IPM are to “prevent

unacceptable levels of pest damage by the most economical means, while minimizing risk to people, property, resources, and the environment.” Thus, the long-term goal of IPM in agriculture is mis-measured by considering only amount of pesticide use. Because risk from pesticides is a function of hazard (toxicity of the chemical) times the likelihood of exposure, reduction in total pounds of pesticides as a surrogate for reduced-risk does not consider pesticide toxicity, pesticide specificity, or mitigation measures to reduce exposure. Also, aggregate pesticide use does not consider changes in other factors, such as invasive pests, increases in endemic pest pressures, reductions in pest damage tolerance in markets, changes in crops produced (Fig. 1), and increases in yields. In the western United States, recent introductions of spotted winged Drosophila, bagrada bug, and brown marmorated stink bug and increases in endemic brown stink bug levels have significantly affected existing IPM programs. As an example of changes in pest damage tolerance, almond processors in California have reduced acceptable navel orangeworm damage levels from 4% to 1% or less (B. Higbee, personal communication).

We examined California and Arizona data on pesticide use, pesticide residue on food, pesticide contamination of surface water



Fig. 1. Pistachio acreage has increased in the past 20 yr in California.

resources, and pesticides in air resources in an effort to address the long-term impacts of IPM. These long-term impacts, termed “change in condition” in logic models (<http://www.uwex.edu/ces/pdande/evaluation/evallogicmodel.html>, accessed 9 September 2016) are due to many factors, including adoption of IPM. Some of the information in this article appears in a larger report, *Adoption and Impacts of Integrated Pest Management in Agriculture in the Western United States* (Farrar et al. 2015), available at <http://westernipm.org/index.cfm/about-the-center/publications/special-reports/adoption-and-impact-of-ipm-in-western-agriculture/>, accessed 9 September 2016. We did not address economic risks in this analysis since these risks are continually being addressed by research and extension programs.

### Pesticide Use Data

One barrier to evaluating the effectiveness of IPM programs is the difficulty in accurately measuring pesticide use. Pesticide use is often estimated based on pesticide sales and other data. At the federal level, estimated pounds of active ingredient applied nationwide have declined from a high in the early 1980s, and the environmental persistence, rate of application, and toxicity of pesticides used has declined in comparison with the same measurements in the 1970s (Fernandez-Cornejo et al. 2014). Arizona and California have state pesticide-use reporting requirements, and therefore have high-quality use data.

In Arizona, many types of agricultural pesticide applications are reported to the state, as required by state law. This includes all

for-hire applications (i.e., custom), all aerial applications, some applications of products in Section 18 exemptions or 24c registrations, and applications of all pesticides to the soil that are listed on Arizona’s Department of Environmental Quality’s Groundwater Protection List (Arizona Department of Environmental Quality 2013). Reported data—including crop name, location (township, range, and section), product applied, pounds applied, rates, and target pest—are entered into the state pesticide use reporting database. The Arizona Pest Management Center (APMC) of the University of Arizona augments the data with additional information (e.g., U.S. Environmental Protection Agency [EPA] product information, pesticide label data, and mode of action tables) and invests significant resources in verifying data and correcting errors. The result is the APMC Pesticide Use Database, a historical database (1991 to present) of Arizona pesticide use records that is used for research, education, addressing pesticide registration questions and needs, and evaluating the impact of Arizona IPM programs (U.S. Government Accountability Office 2010). Although submitted data do not represent 100% of agricultural applications, data are representative of most standard practices with respect to key insect pests (P. C. Ellsworth, A. Fournier, and J. Palumbo, unpublished data).

Pesticide risk in Arizona cotton is lower than 1995 due to reduction in insecticide use and transition to more selective insecticides. The amount of insecticide active ingredient applied to Arizona cotton has declined by 1.16 million pounds, down 90% compared to 1995 levels. By 2011, 76% of all cotton insecticides used were selective, meaning they are safer to use and help preserve beneficial

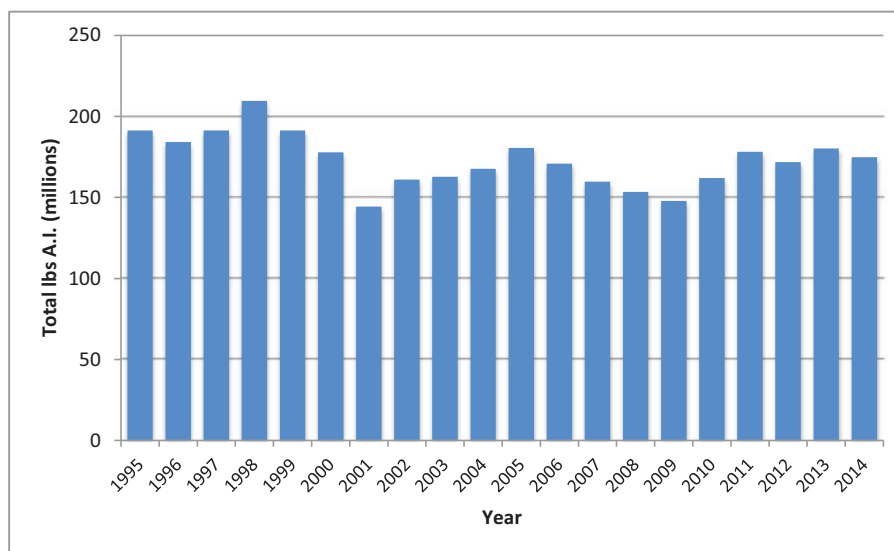
insects in the cotton system. Arizona cotton growers have reduced use of broadly toxic insecticides use by 74% compared with pre-2005 levels (Arizona Pest Management Center 2014).

Pesticide risk in Arizona lettuce is lower due to reduction in insecticide use and transition to more selective insecticides, and pesticide risk scores in ipm Pesticide Risk Mitigation Engine (ipmPRiME) quantify that risk reduction. In Arizona lettuce, the amount of broad-spectrum insecticide applied has declined by 72% and the average number of pesticide applications decreased from an average of >10 sprays in 1995 to an average of <2.4 sprays in 2011. The use of safer, reduced-risk insecticides in Arizona lettuce has increased 14-fold over the same period. Safety to aquatic and other organisms has been progressively and significantly improved by >80% from 1991 to 2011, based on a comprehensive spatial analysis of lettuce pesticide use and calculation of pesticide risk scores using the ipmPRiME (Arizona Pest Management Center 2014). In both Arizona cotton and lettuce, insecticide risk has been reduced through reduction in frequency of insecticide sprays, pounds of insecticide applied and reduction in the toxicity of the pesticides used.

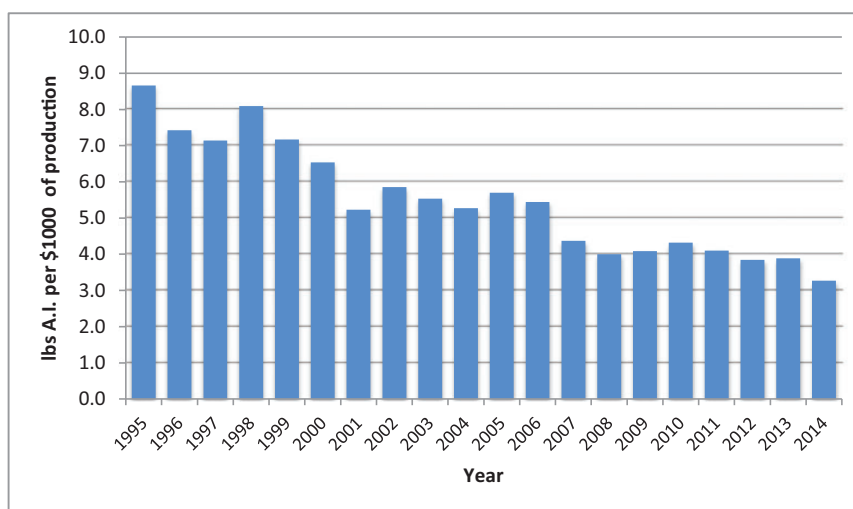
In California, all agricultural pesticide use is reported to county agricultural commissioners for submission to the California Department of Pesticide Regulation, which releases an annual report of all nonhomeowner pesticide use in the state. Total pounds of pesticide active ingredient in agricultural production and postharvest fluctuates year to year based on weather patterns and shifts in crop production, but has decreased from ~191 million pounds (86.6 million Kg) in 1995 to ~175 million pounds (79.4 million Kg) in 2014, an 8% decrease (Fig. 2; California Department of Pesticide Regulation 2015a). However, that decrease occurred while the state's agricultural production increased sharply. California's agricultural gross cash income increased from US\$22.1 billion on 29.3 million acres (11.8 million hectares) in 1995 to US\$53.5 billion on 25.5 million acres (10.3 million hectares) in 2014—a 142% increase in income and a 12.9% decrease in area (California Department of Food and Agriculture 2015). For comparison, the cumulative rate of inflation during that period was 55% (United States Bureau of Labor Statistics 2016). Contributing to the increase in gross cash income

were shifts in crops produced from lower-value to higher-value crops and increases in crop yields. Examples of shifts in crop production were a decrease in cotton acreage from 1,175,800 acres (71,100 hectares) in 1995 to 210,000 acres (85,000 hectares) in 2014 and an increase in pistachio acreage from 60,300 acres (24,400 hectares) in 1995 to 221,000 acres (89,400 hectares) in 2014 (California Department of Food and Agriculture 2015). An example of increasing crop yields is the increase in processing tomato yields from an average of 33.4 tons per acre (74.8 megagrams per hectare) in 1995 to an average of 48.5 tons per acre (108.6 megagrams per hectare) in 2014—and yields of >60 tons per acre (134.4 megagrams per hectare) are not uncommon (Geisseler and Horwath 2013). An examination of the pesticide use data in relation to the value of agricultural production revealed that California growers applied 8.7 pounds (3.9 Kg) of pesticide active ingredients for every US\$1,000 of agricultural product in 1995. In 2014, they applied 3.3 pounds (1.5 Kg) per US\$1,000 of agricultural product (Fig. 3). Therefore, measured in terms of production value, pounds of pesticide active ingredient applied per US\$1,000 of agricultural production has decreased 62% from 1995 to 2014. Integration of pesticide data with crop production statistics indicates that pesticide use has decreased slightly while crop yield and economic value have increased significantly.

In 2009, California began reporting pesticide use by human and environmental toxicity category and extended the data back to 2000 (California Department of Pesticide Regulation 2010 and 2015b). Their assignment of pesticides to specific toxicity classes provides greater detail about pesticide risk than aggregate-use data. The data show pesticide use reductions in some risk categories and pesticide use increases in others. For chemicals known to cause reproductive toxicity, use has declined from 28.6 million pounds (13 million Kg) in 2000 to 8.2 million pounds (3.7 million Kg) in 2014, a 71% decrease. Use of cholinesterase-inhibiting pesticides has dropped from 11.6 million pounds (5.3 million Kg) in 2000 to 4.6 million pounds (2.1 million Kg) in 2014, a 60% decrease. The use of pesticides designated as having the potential to pollute groundwater has declined from 2.5 million pounds (1.1 million Kg) in 2000 to 690,000 pounds (313,000 Kg) in 2014, a 72% decrease. For pesticides identified by the U.S. EPA as B2 carcinogens or on California's



**Fig. 2.** Total pounds of active ingredient applied in agricultural production and postharvest fumigation in California from 1995 to 2014. Data obtained from California Department of Pesticide Regulation (2015).



**Fig. 3.** Average pounds of active ingredient applied per US\$1,000 value of agricultural production from 1995 to 2014. Data obtained from Pesticide Use Annual Summaries (California Department of Pesticide Regulation) and California Agricultural Statistics Review (California Department of Food and Agriculture).

Proposition 65 list of chemicals that are “known to cause cancer,” use has increased from 25.5 million pounds (11.6 million Kg) in 2000 to 30 million pounds (13.6 million Kg) in 2014, an 18% increase. The California Department of Pesticide Regulation notes that pesticide oils are classified as carcinogens and that their use is included in these figures, even though some of those oils may not be carcinogenic due to their high degree of refinement and oils displace use of other more toxic pesticides (California Department of Pesticide Regulation 2015). The use of toxic air contaminants has increased from 38.5 million pounds (17.5 million Kg) in 2000 to 44.1 million pounds (20 million Kg) in 2014, a 15% increase (California Department of Pesticide Regulation 2015). It should be noted that some pesticides are on multiple toxicity lists. For example, 1-3 dichloropropene, metam-potassium, and mancozeb are potential carcinogens and toxic air contaminants; methyl-bromide is a reproductive toxin and toxic air contaminant; and metam-sodium is a reproductive toxin, carcinogen, and toxic air contaminant (California Department of Pesticide Regulation 2015).

Epstein and Zhang (2014) analyzed California pesticide use report data for 49 active ingredients that were used in cumulative state-wide quantities of 22,000 pounds (10,000 Kg) or more in either 1993 or 2000 and appeared on at least one of the five toxicity lists: reproductive toxins, carcinogens or probable carcinogens, cholinesterase-inhibiting pesticides, groundwater protection program compounds, and toxic air contaminants. Of the 49 active ingredients analyzed between 1993 and 2010, three are no longer in use and 40 have declined in use, two have increased in use, and one was newly added to the toxicity list (Epstein and Zhang 2014).

These data document that use of pesticides classified as reproductive toxins, cholinesterase inhibitors, and potential groundwater contaminants is decreasing and use of pesticides classified as carcinogens and toxic air contaminants is increasing. Therefore, potential human and environmental risk based only on use is decreasing for some categories and is increasing for others. Assignment of pesticides to toxicity categories provides additional information but does not address the potential for exposure, an important part of the risk equation. Anecdotally, increased use of plastic tarps, and more recently totally impermeable film tarps, has reduced potential exposure (Fig. 4). However, there are no data documenting adoption of these specific practices.

## Pesticide Residues on Food

Consumers are exposed to pesticide residues on food. To manage this risk and prevent misuse of pesticides, the EPA establishes pesticide tolerances. Pesticide tolerances are the amount of pesticide residue allowed on a commodity. The Pesticide Data Program within the USDA Agricultural Marketing Service (AMS) collects fresh and processed food from distribution centers and conducts pesticide residue analysis. The specific commodities change from year to year, and fresh produce samples are washed in running water for 15–20 s to mimic consumer practices. Samples are then analyzed for >300 pesticides, metabolites, degradates, and isomers in an analysis designed to detect the smallest possible amount of pesticide residues with limits of detection in parts per billion (USDA AMS 2014).

The percentage of samples with pesticide residue exceeding the EPA-established tolerance was 0.5% or less in each of the past 10 yr, and the majority of samples exceeding pesticide tolerance levels were imported, not domestic. The percentage of samples with residue of a pesticide for which there is no tolerance on that commodity—contamination that may be the result of pesticide drift—was 5.2% or less in each of the past 10 yr, and the residues were present at very low levels that did not exceed the tolerances established for similar commodities (USDA AMS 2014).

The Pesticide Residue Monitoring Program within the California Department of Pesticide Regulation collects raw fruits and vegetables from the channels of trade for pesticide residue analysis. In contrast to the federal Pesticide Data Program, the California program does not change commodities each year and does not include processed food. The Pesticide Residue Monitoring Program analysis methods are continually improved and now detect >300 pesticides or breakdown products (California Department of Pesticide Regulation 2014).

Most samples have either no detectable residue or pesticide residues within legal tolerances, usually <10% of the legal tolerance level. The percentage of samples with pesticide residue exceeding the EPA-established tolerance is 1% or less in each of the past 10 yr. The percentage of samples with residue of a pesticide for which there is no tolerance on that commodity is 4% or less in each of the past 10 yr, and most of the samples for which there is no tolerance on that commodity have residues in the fractions of parts per million. Data from 2010 to 2013 documents that 97.8% or more of the



Fig. 4. Use of totally impermeable film and gluing overlapping tarp edges during soil fumigation.

fruit and vegetables grown in California are in compliance with EPA-established pesticide residue tolerances (California Department of Pesticide Regulation 2014).

Winter and Katz (2011) examined the dietary exposure to pesticide residues from the commodities on the Environmental Working Group's 2010 Dirty Dozen list (celery, peaches, strawberries, apples, blueberries, nectarines, bell peppers, spinach, cherries, kale, potatoes, and grapes [imported]). They analyzed exposures to the 10 most common pesticide residues on each of the 12 commodities. One hundred nineteen of the 120 exposure estimates were 1% or lower than the chronic reference dose for the pesticide, with 113 at 0.1% or lower. Methamidophos on bell peppers was at 2% of chronic reference dose. Chronic reference dose is an estimate of the amount of pesticide that a person could ingest every day for a lifetime without appreciable risk of harm.

Pesticide residue data from the Pesticide Data Program at USDA and the Pesticide Residue Monitoring Program in California document that most pesticide residues are below the pesticide tolerance established by EPA. Dietary exposure analysis documents that human risk from pesticide residue on food is low, even for those fruits and vegetables identified as most likely to have pesticide residue.

### Pesticides in the Environment: Water and Air Resources

Environmental risk from pesticides can be considered based on residues in water and air resources. The U.S. Geological Survey

compared pesticide residues in streams draining agricultural, mixed use and urban surface waterways for the years 2002 to 2011 against the same data for 1992 to 2001 (Stone et al. 2014). Stream classification was based on the dominant land-use in the watershed drained, and 49 of the 182 streams in the report are in the western United States. The percentages of assessed streams with at least one pesticide that exceeded aquatic-life benchmarks decreased slightly for agricultural streams, from 69% in 1992–2001 to 61% in 2002–2011. Mixed-use streams had similar levels of contamination, 45% in 1992–2001 and 46% in 2002–2011, while urban-stream contamination increased sharply from 53% in 1992 to 2001 to 90% in 2002 to 2011 (Stone et al. 2014). During 1992 to 2001, 17% of agricultural streams and 5% of mixed-use streams had pesticide concentrations that exceeded human-health benchmarks. During 2002 to 2011, human-health benchmarks were exceeded for atrazine in one agricultural stream (Stone et al. 2014).

Since 2011, California Department of Pesticide Regulation has conducted air monitoring to determine concentrations of pesticides likely to be found in air. Sampling locations are near the towns of Salinas, Shafter, and Ripon, which were selected based on proximity to pesticide use, demographic data, and availability of other exposure and health data. Samples were collected for one 24-h period each week of the year. California Department of Pesticide Regulation monitored for 32 pesticides and 5 pesticide breakdown products and conducted 5,966 analyses in 2014. Of these, 5,471 analyses (91.7%) had no detectable concentration, 498 analyses (8.3%) had detectable concentrations, and in 225 analyses (3.8%) the concentrations were quantifiable. Fourteen of the 37 pesticides

and pesticide breakdown products were not detected. Of the 23 pesticides and pesticide breakdown products detected, 12 were in trace concentrations just above the limits of detection and 11 were in quantifiable concentrations. Of the 23 pesticides and pesticide breakdown products detected, 22 did not exceed screening targets. 1,3-Dichloropropene at Shafter was detected at average concentrations that are calculated to increase cancer risk 1.7 times over a 70-yr lifetime of exposure. The sampling locations, number of pesticides and pesticide breakdown products analyzed, number of analyses, percent detections, and quantifiable detections were similar in the preceding three years. The exceptions were chloropicrin detections in Salinas and Shafter in 2013, which were at levels calculated to increase cancer risk 1.4 and 3.47 times, respectively, over a 70-yr lifetime of exposure.

In the environment, risk from pesticides in surface water in agricultural watersheds is decreasing and is correlated with local pesticide use. In air, based on four years of monitoring in three California locations—all selected as likely to have high airborne pesticide concentrations—the risk from pesticides in air sources is low.

## Possible Solutions

IPM is a method of reducing economic, human health, and environmental risks from pests and pest management strategies. Pesticide applications are a component of IPM programs, but total pounds of pesticide applied is a poor measure of the impact of IPM. IPM programs should be measured by evaluation of economic, human health, and environmental risks from pests and pest management practices. Metrics of the impacts of IPM programs need to incorporate pesticide toxicity, potential for exposure, and environmental risks in the context of agricultural productivity.

Over the past two decades, IPM programs have contributed to increasing agricultural productivity and have reduced some human health and environmental risks from pesticide applications due to decreases in use in Arizona and California. Risks from potential carcinogens and toxic air contaminants may have increased due to increased applications, although data on exposure are lacking. Additional research and extension focus on IPM programs for the pests targeted by these applications is warranted. Continued support for IPM research and extension programs is necessary to address new invasive pests and changes in agricultural production systems.

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