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Pesticide Residues

Reducing Dietary Risks

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Abstract

New data on pesticide residues, food consumption, and pesticide use reveal both the sources of consumers' dietary intake of pesticide residues and the benefits of research to develop safer alternatives to pesticide use. Consumers' dietary intake comes from four sources: onfarm pesticide use, post-harvest pesticide use, pesticides used on imported foods, and canceled pesticides that persist in the environment. Post-harvest uses account for the largest share of dietary intake of residues, but canceled and persistent chemicals appear among the highest risk indicators. Thus, research to develop onfarm pest control alternatives will not address all of the sources of these residues. While most pesticide uses do not result in detectable residues, higher levels of use do result in higher residues. The geographic source of residues can be identified.

Keywords: Pesticide residues, pesticide risk reduction

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Summary

Consumers' dietary intake of pesticide residues comes from four identifiable sources: onfarm pesticide use, post-harvest pesticide use, pesticides used on imported foods, and canceled pesticides (those with canceled registrations for use) that persist in the environment. This report shows how each of these sources contributes to dietary risk from pesticide residues and ranks pesticides according to their contribution to dietary risk.

The study is intended to identify sources of the largest risks, thereby contributing to USDA's ability to cost-effectively choose research and development projects to reduce risks. The study estimates consumers' dietary intake of pesticides. The dietary intake estimates are then used to develop risk indicators, expressing dietary intake as a percentage of safe levels. The indicators establish relative risks and their sources. For pesticides that are used mainly onfarm, the study shows how the development of alternatives could be targeted to particular regions and crops. However, the study also shows that research to develop onfarm pest control alternatives will not address all of the sources of pesticide residues in the diet.

Consumers' dietary intake is estimated using a new, large-scale survey of pesticide residues and recent consumption data. The residue data from the Pesticide Data Program (PDP) cover 10 commodities (apples, bananas, celery, green beans, grapefruit, grapes, lettuce, oranges, peaches, and potatoes) and 50 pesticides. For pesticides that are currently used in domestic onfarm production, the data help to show the geographic sources of residues and the extent to which use contributes to dietary intake risk. The data also show that the way in which food is marketed and the history of pest management techniques used on farms influence consumers' dietary intake of pesticide residues.

Consumption patterns also influence risks from pesticide residues. Correcting for differences in body weight, the average child consumes many more of some fruits and vegetables than does the average adult. For example, 1-year-old children eat eight times as many apples and four times as many green beans as adults.

Currently, most domestic onfarm use of pesticides with relatively high risk indicators is region specific. Produce from regions with higher use of particular chemicals has correspondingly higher residues.

Canceled but persistent chemicals appear among the highest risk indicators. DDT registrations were canceled in 1972, but it and its degradate DDE persist in the soil. Risks from such persistent and unused pesticides cannot be reduced simply by developing alternative practices. Research regarding how these persistent chemicals result in residues could indicate if it is possible to reduce these residues and resulting dietary intake.

Residue levels vary among domestic and imported commodities. For example, the United States both produces and imports grapes and peaches. Fungicide residues were generally higher on imported grapes. Finding differences between domestic and imported fruit shows, for example, children's intake of one fungicide comes largely from domestic apples and imported grapes. These findings underscore the value of actual residue data for setting research priorities, since imports may have residues that differ from those on domestic foods due to different production and handling practices.

Each commodity displayed different types of residues. For example, for bananas, grapefruit, and oranges, 98, 90, and 88 percent of residue detections respectively came from post-harvest treatments. Post-harvest residues were found on potatoes and fruit, but not on other vegetables.

Over time, scientists have learned to detect smaller and smaller amounts of pesticide residues. Thus, counting detections or measuring residues relative to legal tolerances are not good indicators of risks from dietary intake of pesticide residues. In general, the more frequently detected pesticides were not the chemicals that had the highest risk indicator values.

The numerical results of this study are consistent with other studies with different goals and methodologies, such as the FDA Total Diet Study. The results are consistent with a 1993 National Research Council report that argued that children's dietary pesticide residue intake should be examined separately; children consume more food per body weight and consume a less varied diet than adults. Estimated risk indicators from PDP data are relatively higher for children, but the small sample size for different children's age groups in the consumption survey used here means these results have greater uncertainty than risk indicators for adults. In addition, diets have been changing, particularly for children. Although our results suggest that health risks from pesticides are very low, our analysis underscores the need for better consumption data and more comprehensive residue data.

This broad view of risks does not allow much detail on pesticides' toxicology. Further, the indicators are not intended to measure the absolute size of risks because that is the function of regulatory agencies. Thus, the indicators in this study are not intended for use in risk assessment or as a basis for regulatory action. The indicators' purpose is for prioritizing research, but this is limited because dietary intake risks are not the only risks from pesticides. Some environmental and worker safety hazards may pose greater risks and less costly solutions than pesticide residues in food.

Glossary

Carcinogenic potency. The increase in cancer risk associated with a lifetime intake of 1 milligram of pesticide per kilogram of body weight per day. The potency factor used is usually estimated as the 95-percent upper-confidence interval of the slope of the dose response function. It is conventionally referred to as the "Q*."

Fraction of Negligible Risk Intake (FNRI). The dietary intake level of a given pesticide residue intake level divided by the negligible risk intake level for that pesticide.

Fraction of Reference Dose (FRD). The dietary intake level of a given pesticide divided by the EPA reference dose for that pesticide.

Limit of detection. The lowest residue level of a given pesticide that can be detected with a given laboratory technique.

Limit of quantitation. The lowest residue level of a given pesticide that can be measured with an acceptable level of certainty, using a given laboratory technique.

Negligible risk. A level of risk so low that it can be considered acceptable for some purposes. For example, a cancer risk level of 1 in a million (one extra cancer case per million individuals) is conventionally considered negligible.

Negligible risk intake level. A level of pesticide residue intake (per kilogram of body weight) that would lead to a negligible risk of cancer, given information about the carcinogenic potency of the pesticide and the level of consumption of commodities with residues of the pesticide.

Nonthreshold pesticide. A pesticide for which there is no level of intake with no risk of adverse health effects.

Reference dose. A level of pesticide residue intake that is believed to have no adverse health effects. The reference dose is estimated by EPA from animal testing data. The highest dose with no effects on animals is divided by an uncertainty factor to account for possible differences in susceptibility between humans and test animals, and for variability in susceptibility among individual humans. The uncertainty factors used range from 30 to 10,000, but are most often 100.

Threshold pesticide. A pesticide for which levels of intake below some threshold are believed to have no adverse health effects.

Tolerance. The legal limit for residues on food of a pesticide that is registered for legal use on the food or that results as a breakdown product from a pesticide registered for use on the food.

Pesticide Residues

Reducing Dietary Risks

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Introduction

Little is known about how to reduce risks from pesticide residues in food in a cost-effective manner. This report develops much of the information needed to focus research to reduce risks from dietary residue intake. A ranking of risks is needed to set priorities for development of alternative pest control methods or other measures to reduce risks from pesticide residues. Without an understanding of the relative importance of different risks, such efforts might waste resources or fail to actually reduce risks. For example, focusing publicly financed research on nonchemical alternatives for particular chemical uses that do not result in dietary risk will not reduce risk, but will divert resources from other agricultural research.

To set priorities, a broad and detailed perspective of dietary risks from pesticide residues is necessary, including the relative risks from different pesticides and foods consumed. We need to be able to rank the different risks, establish their sources, and measure how much risks would change with different research choices. The more precisely sources of risk are identified, the more research can be targeted to reduce risk.

This report draws on data from new large-scale surveys of pesticide use, pesticide residues, and food consumption to estimate dietary residue intake and risk indicators for 50 pesticide residues on 10 fruits and vegetables: apples, bananas, celery, green beans, grapes, grapefruit, lettuce, oranges, peaches, and potatoes. Risk indicators are then ranked for the average consumer and for consumer subpopulations with higher than average dietary intake of pesticide residues. Where these residues come from and how they link to farm and marketing production practices are examined to trace the sources of dietary risk.

The consumer subpopulation we focus greatest attention on is children. The 1993 National Research Council report, *Pesticides in the Diets of Infants and Children*, highlighted the greater vulnerability of children to health risks from pesticides in foods. Furthermore, children's and adults' diets have been changing over time, with possible consequences for dietary intake of pesticide residues.

The new data used in this report come from the Pesticide Data Program (PDP). Recognizing the need to improve the quality and quantity of information available on chemical residues, the Bush administration initiated the PDP in 1991 to complement the President's Food Safety Program begun in 1989. The PDP is designed to provide an improved database to respond more effectively to food safety issues. As part of the PDP, the National Agricultural Statistics Service (NASS) of USDA surveys chemical use on fruit and vegetable crops. The Agricultural Marketing Service (AMS) of USDA works with State laboratories to collect pesticide residue data, using state-of-the-art residue detection techniques. In 1992, AMS screened for 50 pesticide residues on 12 commonly consumed fruits and vegetables. These PDP activities provide data for government agencies to use in responding more effectively to food safety issues.

We estimate dietary intake of pesticide residues based on the AMS-PDP residue data in combination with USDA food consumption survey data. Dietary intake of each residue is estimated as the product of the quantities of different fruits and vegetables consumed and the quantity of residue on each fruit or vegetable. Indicators of potential health risks are then derived by comparing estimated intake with a safe intake value for threshold residues, or an intake level posing negligible risk for nonthreshold residues. These indicators make it possible to examine the relative contributions to dietary residue intake and risk of different commodities, estimating the relative contributions to dietary intake from imported and domestic commodities, from onfarm and post-harvest pesticide use, and from currently used and canceled pesticides (those with canceled registrations for use) that persist in the environment. Where residues result from domestic onfarm use, data on pesticide use from the NASS surveys make it possible to estimate how residue levels on various commodities change with pesticide use levels and location. In combination with the risk indicators, such information completes the picture for identifying potential research priorities to reduce risk. The final step in setting priorities for cost-effective risk reduction would be to compare risk indicators with the costs of risk reduction. This last step is beyond the scope of this report.

The risk indicators estimated here are not intended for use in risk assessment or as a basis for regulatory action. Several simplifying assumptions were made for consistency, as our analysis was carried out across nearly 500 pesticide uses (pesticide-commodity pairs). Furthermore, the commodities examined here are only a portion of the total diet. Risk estimates constructed as part of the regulatory process conducted by the Environmental Protection Agency (EPA), in contrast, typically focus on individual pesticides and a small number of uses. Their analyses can include total dietary intake from all sources and more detail on the toxicological properties of pesticides.

The objectives of this study are to:

1. Examine the distribution of residue levels on fresh fruits and vegetables and the sources of the residues: domestic onfarm pesticide use, post-harvest use, imported foods, and canceled pesticides that persist in the environment.

2. Link the levels of residues to pesticide use, showing how the regional intensity of use influences residues.

3. Examine differences in consumption patterns of adults and children and changes over time that may influence dietary intake of pesticide residues.

4. Estimate and rank indicators of health risk from dietary intake of residues for the average U.S. consumer, young children, and other population subgroups.

5. Determine the relative contributions to residue intake and health risk of different commodities and sources, including domestic onfarm use, post-harvest uses, imported foods, and canceled pesticides that persist in the environment.

Residue Detection Rates, Residue Averages, and Residue Sources

We examined data for 10 commonly consumed fruits and vegetables to ascertain the level of selected pesticide residue, the frequency with which residues were found, and the sources of the residues. The four sources of residues identified in the AMS data are domestic onfarm pesticide use, post-harvest use, imported foods, and canceled pesticides that persist in the environment. Although each source contributes to residues in food, not all pesticide use results in pesticide residue.

USDA Pesticide Residue Data

The AMS-PDP residue-testing program provides residue data for individual commodities that may significantly contribute to total residue intake, especially for children. Established in 1991, the AMS-PDP fills an important gap in the data available on pesticide residues in the diet. The Food and Drug Administration (FDA) Total Diet Study measures total dietary intake of pesticide residues but does not provide information about the specific commodity sources of residues. The FDA also measures residues on commodities directly through its regulatory monitoring, but this program focuses on detecting illegal residues rather than estimating the typical residue content of foods.

During 1992, the AMS-PDP measured residues on both domestic and imported samples of fresh fruits and vegetables, including apples, bananas, broccoli, celery, carrots, green beans, grapefruit, grapes, lettuce, oranges, peaches, and potatoes. (Broccoli and carrots were tested only during the final months of 1992 and were not included in this analysis.) Commodities were included in the PDP based on their level of consumption. The 10 commodities tested over the entire year represent approximately 56 percent of total U.S. fruit and vegetable consumption (by weight). AMS screened for 50 pesticides, including 14 fungicides, 6 herbicides, and 30 insecticides (table 1). AMS worked with EPA to develop a large portion of the list of pesticides, reflecting EPA's information needs. In addition to those pesticides requested by EPA, AMS contracting laboratories reported detections of other compounds that were detectable by the tests used to screen for the EPA pesticides.

The samples were drawn from terminal markets and supermarket distribution centers in six States: California, Florida, Michigan, New York, Texas, and Washington. These States were selected because they cover a large portion (about 40 percent) of the U.S. population, thereby ensuring that the data give a good estimate of the prevalence of the 50 selected pesticides in a portion of the food supply. Testing laboratories treated samples as consumers would: washing, peeling, and coring samples as appropriate before measuring residues.

Because the PDP covers a limited set of commodities and only a portion of the registered pesticides, it does not give us an exhaustive view of the extent of dietary intake of pesticides. However, the selected commodities

Table 1—Pesticides and commodities screened by AMS/USDA, 1992[1]

Herbicides/Growth regulators	Insecticides/Miticides	Fungicides	Commodities
2,4-D	Acephate	Anilazine	Apples
Atrazine	Azinphos-methyl	Benomyl	Bananas
Bromoxynil	Carbaryl	Captan	Celery
Chlorpropham	Chlorpyrifos	Chlorothalonil	Green beans
DCPA	Cypermethrin	Dicloran	Grapefruit
Trifluralin	DDT	Diphenylamine	Grapes
	Demeton	HCB	Lettuce
	Diazinon	Imazalil	Oranges
	Dichlorvos	Iprodione	Peaches
	Dicofol	Myclobutanil	Potatoes
	Dimethoate	o-Phenylphenol	
	Disulfoton	PCNB	
	Endosulfan	Thiabendazole	
	Ethion	Vinclozolin	
	Ethoprop		
	Fenamiphos		
	Lindane		
	Malathion		
	Methamidophos		
	Methidathion		
	Methoxychlor		
	Mevinphos		
	Omethoate		
	Ethyl parathion		
	Methyl parathion		
	Permethrin		
	Phorate		
	Phosalone		
	Phosmet		
	Propargite		

[1]Several pesticides were not tested for residues in all laboratories or in all of 1992. See the AMS-PDP report for 1992 for details.

and pesticides in PDP represent a substantial portion of fruit and vegetable consumption and pesticides used on those crops.

Detections, Residues, and Tolerances

Three outcomes are possible when testing for residues: A residue may (1) not be detected, (2) be detected but present in an amount insufficient to measure accurately, or (3) be detected and measured. The technology of detecting and measuring residues poses a problem for estimating average residue levels. Detection rates depend on the limits of detection, that is, the smallest amount that can be detected in residue testing. Scientists have made great advances in reducing limits of detection, and several of the 1992 PDP limits were no more than 1 part per billion. However, technology does not yet allow scientists to count individual molecules. Thus, many samples will show no detectable residues, and researchers will be uncertain how to interpret those findings in a quantitative sense. A finding of no detectable residue does not necessarily mean residues are zero. Undetected residues could be zero or any level up to just below the limit of detection.[1] Furthermore, some residues are detectable but cannot be measured with acceptable certainty. We followed EPA guidelines to estimate average residues, filling in values by assump-

[1]Table 2 shows the problem posed by undetected residues for estimating average residues. There was no case in which a pesticide was detected on all samples tested. Thus, we cannot calculate an average residue without making some assumptions about levels of residues too small to measure. Further, with only five pesticide-commodity pairs above the 50-percent detection rate, there are only a few pairs for which a median residue could be calculated directly from the data.

tion for the residues too small to accurately measure. Details of the estimation methods are in Appendix A.

Only 5 of the nearly 500 pesticide-commodity pairs examined in PDP showed detection rates greater than 50 percent (table 2). Most detection rates were zero. The FDA's Regulatory Monitoring Program also provides information on pesticide residues on food products. AMS and FDA report results of similar tests, but the agencies have different information needs and therefore carry out testing in different ways. AMS focuses on detecting residues, no matter how small, while FDA's interest is in enforcement and in measuring residues that might violate legal tolerances. FDA's testing is necessarily limited because it must have test results quickly to stop foods with illegal residues from being marketed. These differences account in part for differences in detection rates found by the two programs.

AMS-PDP shows higher detection rates than the commodity-specific data from the FDA regulatory monitoring program. The PDP showed 61 percent of samples contained detectable residues. In 1992, FDA found no detectable residues on 51 percent of fruit and 69 percent of vegetable domestic surveillance samples. Similarly, no residues were found on 57 percent of fruit and 66 percent of vegetable import surveillance samples (DHHS, FDA, 1993). Although the detection rates measured by AMS and FDA differ, the percentage of PDP sample residues that exceed legal tolerances is similar to the level measured by FDA (approximately 1 percent). This implies that the real difference between the programs lies in the resources each devotes to measuring very small residues.

AMS found 10 "presumptive tolerance violations," or instances where residues apparently exceeded tolerances (USDA, AMS, 1994).[2] Five were on bananas, two each were on green beans and grapes, and one was on lettuce. The frequency with which AMS detected these types of violations was, like FDA, much lower than violations from residues with no tolerance. There were 55 violations (out of 5,750 samples) in which residues were found for which no tolerance exists (table 3).

[2]When AMS finds samples that it presumes violate tolerances, it informs FDA. Each violation is, at that point, presumptive because FDA decides whether a violation has occurred.

Table 2—Top 20 detection frequencies, by pesticide and commodity

Commodity	Pesticide	Detection frequency
		Percent
Oranges	Thiabendazole	63.8
Potatoes	Chlorpropham	59.3
Apples	Thiabendazole	56.5
Peaches	Iprodione	54.4
Grapefruit	Thiabendazole	54.0
Peaches	Dicloran	46.7
Celery	Permethrin	38.6
Bananas	Thiabendazole	37.5
Celery	Chlorothalonil	32.3
Apples	Azinphos-methyl	31.4
Apples	Diphenylamine	30.5
Oranges	Imazalil	29.3
Grapes	Iprodione	29.2
Grapes	Captan	27.9
Green beans	Methamidophos	27.7
Celery	Dicloran	27.6
Green beans	Endosulfan	27.0
Celery	Acephate	26.8
Green beans	Acephate	25.3
Grapes	Vinclozolin	23.6

Table 3—Residue findings for pesticides with no tolerance

Commodity	Pesticide	Findings
		Number
Apples	Chlorothalonil	1
	Chlorpropham	1
	Iprodione	1
	Vinclozolin	1
Celery	Chlorpyrifos	2
	DCPA	11
	Iprodione	2
	Quintozene	3
Green beans	Methamidophos	18
	Permethrin	3
Grapes	Diphenylamine	1
	Methamidophos	1
Lettuce	Chlorothalonil	1
	Chlorpyrifos	3
Peaches	Acephate	2
	Dimethoate	1
	Methamidophos	2
	Thiabendazole	1
Total		55

Only a few pesticide-commodity pairs show residues greater than 1 percent of tolerance (table 4). The residue average that stands out as larger than the rest, benomyl on bananas, is based on 3 detections out of 406 samples. Clearly, the three detections were larger as a percent of tolerance than most pesticide detections.

Sources of Pesticide Residues

The match between the set of 50 pesticides reported by AMS and the pesticides typically used on each fruit and vegetable is not perfect, but there is substantial overlap among these sets of pesticides. The AMS-PDP pesticides cover different percentages of pesticide use for each commodity, ranging from 75.5 percent of pre-harvest pesticides used on celery (by weight) to 11.4 percent of pre-harvest pesticides used on grapefruit (calculated from USDA, NASS, and ERS, 1992 and 1993). If sulfur were excluded from the pesticides used on grapefruit, AMS-PDP pesticides would cover 71.6 percent of pre-harvest pesticide use on grapefruit.

Many of the screened and detected pesticides are not currently used on farms in the United States. There are four sources, or uses, of pesticides that can be identified in the AMS data: domestic onfarm use, post-harvest treatments, imported foods, and canceled pesticides that persist in the environment. Each contributes to residues in food.

Residues from Domestic Onfarm Use and Post-harvest Treatments

Not all pesticide use results in residues because weather and exposure to the elements break down residues. The pesticides most frequently used on farms are detected, but at rates far smaller than their use would suggest. Chlorothalonil is one of the most frequently used fungicides on green beans. In 1992, 36 percent of the green bean acreage was treated with chlorothalonil an average of 3.4 times. Chlorothalonil was found (at any level) on 7.1 percent of green bean samples. Captan is the most heavily used fungicide on apples, with 52 percent of apple acreage receiving 7.3 treat-

Table 4—Tolerances, average residues, and average residue as a share of tolerance[1]

Commodity	Pesticide	Tolerance	Average residue	Share of tolerance
		ppm		*1.00 = 1 percent*
Bananas	Benomyl	0.20	0.024	12.03
Bananas	Thiabendazole	.40	.036	8.94
Bananas	Imazalil	.20	.015	7.35
Peaches	Chlorpyrifos	.05	.003	5.66
Bananas	Ethoprop	.02	.001	4.75
Green beans	Acephate	3.00	.131	4.38
Green beans	Methamidophos	1.00	.040	4.04
Apples	Thiabendazole	10.00	.351	3.51
Apples	Diphenylamine	10.00	.256	2.56
Grapes	Myclobutanil	1.00	.023	2.30
Peaches	Iprodione	20.00	.424	2.12
Peaches	Dicloran	20.00	.390	1.95
Green beans	Endosulfans	2.00	.034	1.71
Potatoes	Endosulfans	.20	.003	1.68
Potatoes	Chlorpropham	50.00	.835	1.67
Oranges	Thiabendazole	10.00	.165	1.65
Apples	Azinphos-methyl	2.00	.029	1.43
Grapes	Vinclozolin	6.00	.083	1.39
Grapes	Dimethoate	1.00	.014	1.36
Grapes	Omethoate	1.00	.012	1.24
Peaches	Azinphos-methyl	2.00	.024	1.18
Grapes	Chlorpyrifos	.50	.005	1.08
Peaches	Propargite	7.00	.070	1.00

ppm = Parts per million.

[1]Average residues below 1 percent of tolerance are not shown.

ments. Captan was found on 7.3 percent of apple samples. (This proportion also reflects post-harvest captan use and thus may overstate the importance of farm use.) One of the most frequently used insecticides in potato production is methamidophos, with 23 percent of acreage treated 1.8 times in 1992. Methamidophos was found on 1.1 percent of samples.

The small detection rates relative to use reinforce the well-known findings that time and exposure to the elements dramatically reduce many pesticide residues (Eichers, Jenkins, and Fox, 1971; Elkins, 1989; and Gonzalez and others, 1989). These findings also indicate why post-harvest uses are so important in detected residues. Five pesticide-commodity pairs yielded more than half the samples with positive findings; all five were the result of post-harvest pesticide uses (table 2). For some commodities, almost all the detected pesticide residues came from post-harvest treatments. For bananas, grapefruit, and oranges, 98, 90, and 88 percent of the residue detections, respectively, came from post-harvest pesticide uses (table 5).

Post-harvest uses occur at a relatively high frequency in residues because these pesticides are applied later than pesticides applied on-farm, and their residues are not usually exposed to rain, wind, high temperatures, sunlight, or alkali soils. Further, the post-harvest pesticides are applied directly to edible products, often in a wax to ensure that they remain in contact with fruit and vegetable surfaces.

Residues from Imported Foods

Among the 10 AMS-PDP commodities, only peaches and grapes had significant numbers of samples from

Table 5—Significance of post-harvest residues among AMS/USDA pesticide residue detections

Commodity	Pesticide	Residue detections	Residue detections potentially from post-harvest use	Post-harvest residues as a share of all residue detections
		- - - - Number	- - - -	*Percent*
Apples		1,096	518	47.3
	Captan		45	
	Diphenylamine		173	
	o-Phenylphenol		7	
	Thiabendazole		293	
Bananas		221	217	98.2
	Imazalil		23	
	Thiabendazole		194	
Celery		854	0	0.0
Grapefruit		332	298	89.8
	Imazalil		87	
	o-Phenylphenol		1	
	Thiabendazole		210	
Grapes		756	35	4.6
	Dicloran		35	
Green beans		576	0	0.0
Lettuce		297	0	0.0
Oranges		482	422	87.6
	Imazalil		167	
	o-Phenylphenol		5	
	Thiabendazole		250	
Peaches		677	364	53.8
	Dicloran		168	
	Iprodione		196	
Potatoes		530	387	73.0
	Chlorpropham		337	
	Thiabendazole		50	
Total		5,821	2,241	38.5

both domestic production and imports. This characteristic makes the commodities useful for contrasting the residues on domestic produce and imports.

In calculating average residues, assumptions must be made about the distribution of residues that are too small to measure accurately. We can bound what is physically possible for average residues by making two sets of assumptions to calculate averages that are as small and as large as the data permit. For a lower limit, we assume that all residues below the detection limit are zero and all samples below the limit of quantitation (the smallest amount which can be measured with an acceptable level of certainty) are at the limit of detection.[3] Those assumptions make the nonmeasured samples as small as possible and the calculated average residue as small as possible. For the upper limit, we assume that all residues below the detection limit are at the limit of detection and that all samples below the limit of quantitation are at the limit of quantitation. Average residues calculated under these assumptions yield estimates that are as large as possible. The smallest and largest possible averages were created for both domestically produced and imported grapes and peaches.[4]

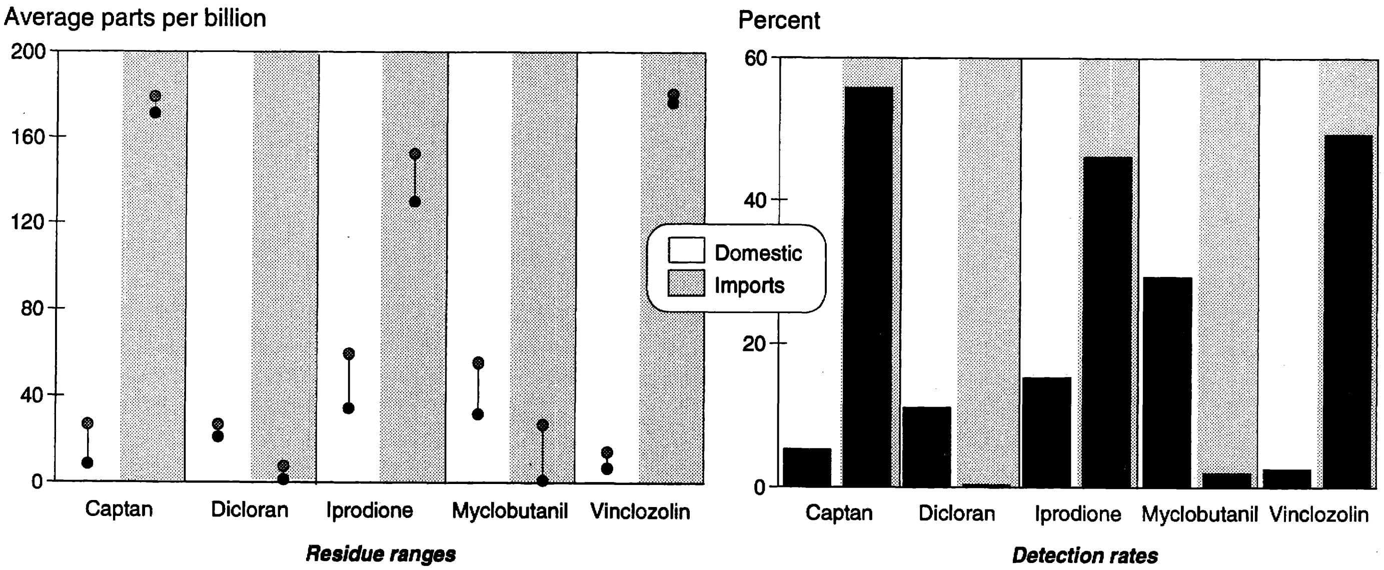
For fungicide residues on grapes, only seven fungicides were detected and, of those, diphenylamine and thiabendazole showed only one detection each on domestic grapes (fig. 1). On grapes, there are three fungicides (captan, iprodione, and vinclozolin) for which the smallest possible imported average residue value is larger than the largest possible domestic average residue value. Also, the differences are large compared with the range of physically possible average values. Captan residues on imported grapes range from 9 to 22 times higher than residues on domestic grapes. Iprodione residues are 2-4 times higher on imported grapes, while vinclozolin residues are 13-30 times higher on imported grapes. Dicloran and myclobutanil residues are higher on domestic grapes, but detection rates and average residue ranges are lower for both domestic and imported grapes than for the other three fungicide residues.

Although 12 different insecticides were detected on grapes, only 5 showed obvious differences between resi-

[3]If residues are not detected, they are not necessarily zero. They may be zero or any level less than detection limits. Similarly, residues that are detected but too small to measure accurately could actually take any value between the limit of detection and the limit of quantitation.

[4]A small number of these samples had residues that exceeded the legal limit. The number of such violations was too small for a useful statistical comparison of violations among imported and domestic samples within each pesticide-commodity combination.

Figure 1
Average fungicide residue ranges and detection rates for grapes, 1992



Example: Vinclozolin was found on 2.6 percent of domestic grapes with an average range of 6.6-14.1 parts per billion, while the fungicide was found on 49.4 percent of imported grapes with an average range of 176.4-180.5 parts per billion.
Source: Calculated by ERS from data compiled by USDA's Agricultural Marketing Service.

due averages (fig. 2). They also had the highest detection rates. However, the insecticide detection rates were far lower than the fungicide detection rates. Residues of chlorpyrifos, dimethoate, omethoate, and parathion are clearly larger on imported grapes. (Omethoate is not registered for use in the United States, but does have an established tolerance.) Only dicofol shows larger residues on domestic grapes.

Among the fungicides detected on peaches, dicloran residues on domestic peaches are 5.6 times higher than the residues on imported peaches (fig. 3). For iprodione, residue averages were larger for imported peaches. With the exception of propargite, the four paired average residue ranges presented in figure 4 are insecticides with the highest detection rates. Propargite was included because of the large variability surrounding the estimate of the average residue. One of the insecticides had higher residues on domestic samples, and two others had higher residues on imported samples.

The findings show that the pattern of residues differs between domestic and imported samples. Fungicide residues appear to be larger on imported grapes than on domestic grapes. Other generalizations are not apparent; some pesticide residues are larger on domestic fruit, while others are larger on imports.

Residues from Canceled and Persistent Pesticides

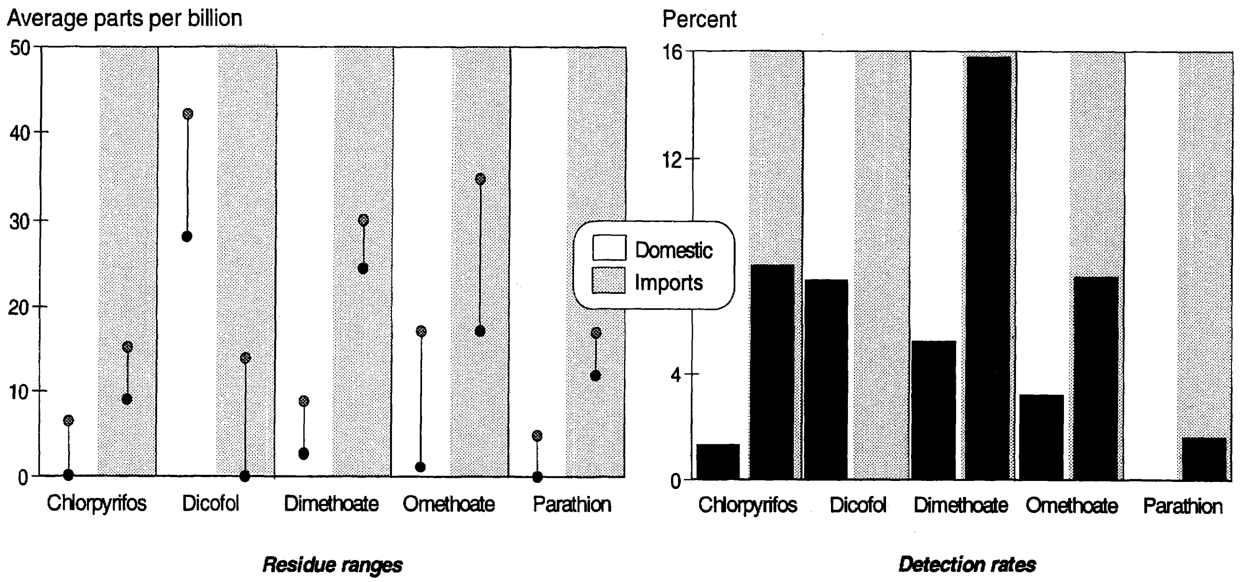
Some of the chemicals for which AMS screened, namely anilazine, DDT, demeton, and HCB, are no longer used. AMS also screened for two degradation products of DDT: DDE and TDE. DDT is the only possible source of these two residues. TDE residues were not detected in the 10 commodities. Although legal use of DDT ended in 1972, both DDT and DDE were found in samples of celery, lettuce, and potatoes. DDE residues were found in apples and green beans, and DDT residues were found in peaches. These detections could be the result of use that occurred up to 50 years ago.

The largest number of DDT and DDE detections among the 10 commodities were in potatoes. These two persistent chemicals accounted for 12 percent of residue detections in potatoes, similar to the 15 percent of detections from pesticides currently used on farms; 73 percent of detections were from currently used postharvest chemicals.

Residue Detections and Residue Levels in the Diet

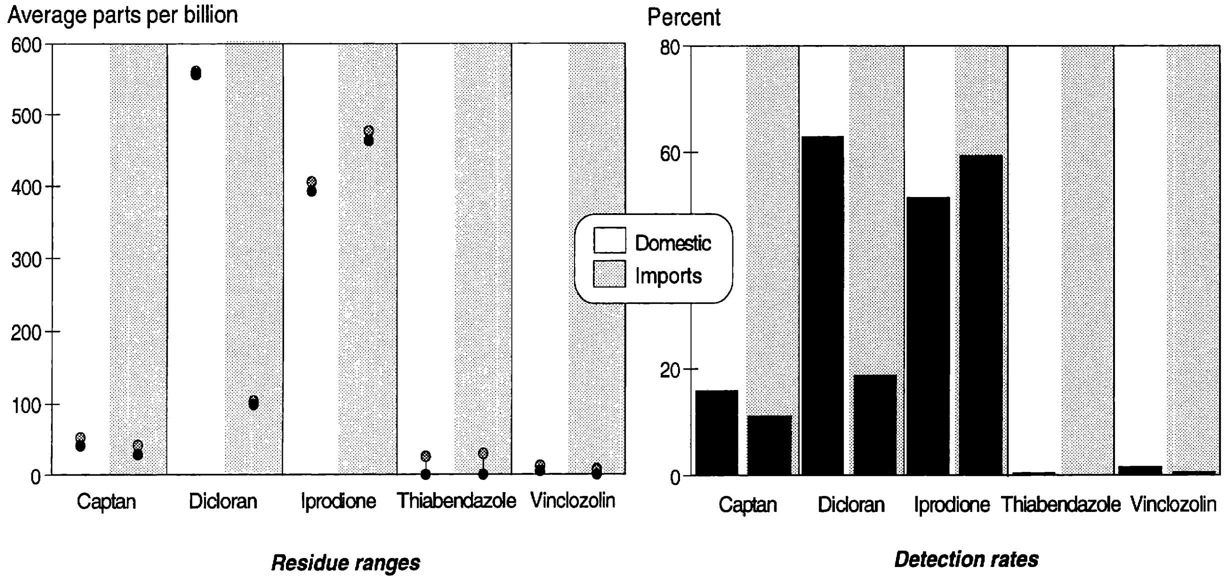
There is little relation between average residue and average residue as a percent of tolerance (table 4). Even when a pesticide residue average is relatively large, average residue may be a small fraction of the legal

Figure 2
Average insecticide residue ranges and detection rates for grapes, 1992



Example: Dimethoate was found on 5.2 percent of domestic grapes with an average range of 2.7-8.8 parts per billion, while the insecticide was found on 15.8 percent of imported grapes with an average range of 24.4-30.0 parts per billion.
Source: Calculated by ERS from data compiled by USDA's Agricultural Marketing Service.

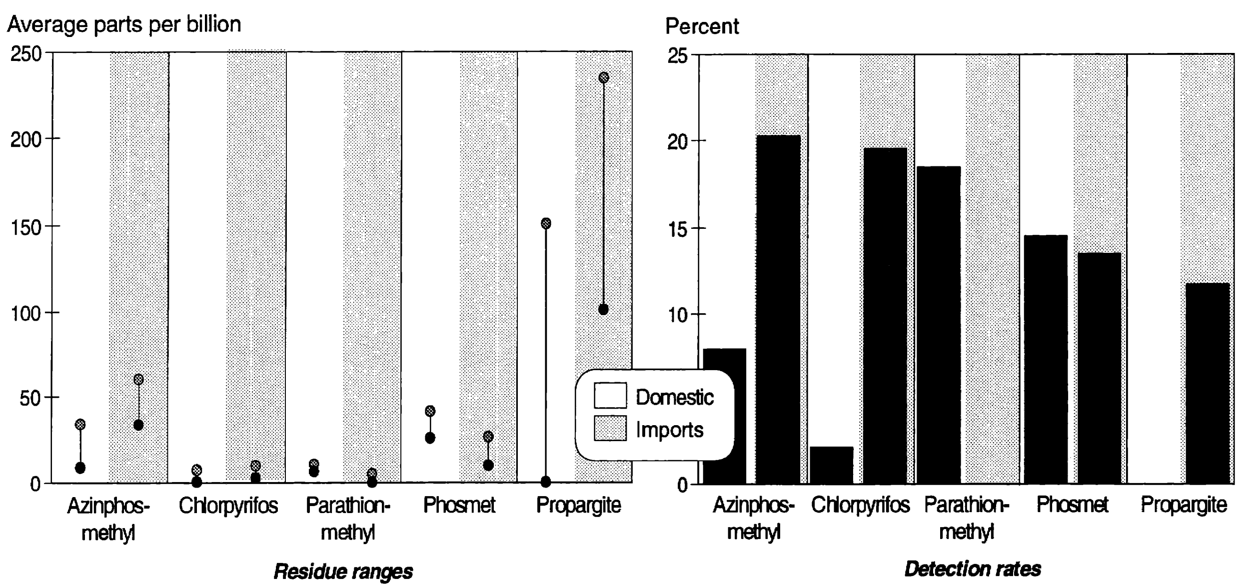
Figure 3
Average fungicide residue ranges and detection rates for peaches, 1992



Example: Dicloran was found on 63.0 percent of domestic peaches with an average range of 557.8-561.0 parts per billion, while the fungicide was found on 18.8 percent of imported peaches with an average range of 98.3-103.6 parts per billion.

Source: Calculated by ERS from data compiled by USDA's Agricultural Marketing Service.

Figure 4
Average insecticide residue ranges and detection rates for peaches, 1992



Example: Chlorpyrifos was found on 2.2 percent of domestic peaches with an average range of 0.4-7.1 parts per billion, while the insecticide was found on 19.5 percent of imported peaches with an average range of 2.5-9.6 parts per billion.

Source: Calculated by ERS from data compiled by USDA's Agricultural Marketing Service.

tolerance. Comparing the rankings in tables 2 and 4, we see that there is some relation between detection frequency and average residue. Pesticides that are frequently detected are often those with relatively high average residues. However, none of these descriptive statistics characterize the risks from pesticides in the diet.

The potential for adverse health effects from a chemical depends on the amount ingested and the chemical's toxicity (Chaisson, Petersen, and Douglass, 1991). Examining detection frequencies and average residues tells nothing about toxicity and does not address dietary intake. Consumption differs among consumer subpopulations, and that variance influences residue intake.

Dietary Patterns and Implications for Pesticide Residue Intake

Consumption influences dietary intake of pesticide residues. For risk rankings to be meaningful, consumption estimates need to reflect changing dietary patterns and variations among subpopulations. Consumption patterns have been changing over time. Even if fruits and vegetables carried identical residue levels year to year, increases in fruit and vegetable consumption could lead to increases in dietary intake of pesticides. Consumption also varies among subpopulations. The 1993 National Research Council report, *Pesticides in the Diets of Infants and Children*, noted that young children consume much larger amounts of some foods per unit of body weight than adults because their diets are less diverse and because they consume more calories per kilogram of body weight.[5]

Furthermore, there are also differences in consumption patterns among adult consumers. Some adults consume relatively large amounts of fruits and vegetables, as recommended by the DHHS/USDA Dietary Guidelines for Americans and the National Cancer Institute "5 A Day for Better Health" campaign (USDA and DHHS, 1990). These consumers, compared with the average consumer, could have a significantly higher dietary intake of pesticide residues from fruits and vegetables.

General Changes in Consumption Patterns from 1977/78 to 87/88

Food consumption estimates are based on household consumption surveys, but it is useful to put such estimates in context by comparisons with trends in disappearance data.[6] Household consumption surveys were conducted in 1977/78 and again in 1987/88. Disappearance data suggest that consumption patterns changed significantly over 1977-87. Total per capita food disappearance increased, with the diet shares of animal and crop products shifting in relative importance (Putnam and Allshouse, 1994). Most of that change occurred in the mid-1980's. Per capita red meat disappearance fell 12 percent, per capita egg disappearance fell 5 percent, and per capita fat disappearance increased 18 percent (Putnam and Allshouse, 1994).

Disappearance data are available for only some of the 10 commodities in the AMS-PDP data, but these data show dramatic changes in the mix of fruit and vegetable consumption by form and commodity during 1977-87. Fresh fruit consumption increased 21 percent and vegetable consumption increased 17 percent, even though total fruit and vegetable consumption increased only 5 percent (Putnam and Allshouse, 1994). Several commodities showed much more dramatic increases. Consumption of apples in all forms increased 53 percent, and fresh apple consumption increased 26 percent. Consumption of fresh grapes increased 100 percent. Fresh broccoli consumption increased 154 percent, and fresh carrot consumption increased 54 percent.

Changing consumption patterns during 1977-87 reflect changes in many of the underlying determinants of consumption, including relative prices, consumer income, and tastes and preferences (Lutz and others, 1992; Senauer, Asp, and Kinsey, 1991). In addition to economic trends, changing demographics, growing awareness of the links between diet and health, and increased demand for food away from home all played a role in shifting consumption patterns.

Data and Methodology for Commodity Consumption Estimates

Estimates of commodity consumption are based on the 1987-88 Nationwide Food Consumption Survey (NFCS), conducted by the USDA Human Nutrition Information Service (HNIS).[7] Foods as consumed were converted to raw agricultural commodity equivalents using TASDIET™ software developed by TAS, Inc. This conversion allows us to examine consumption of

[5]Consumption is estimated on a per kilogram of body weight basis because possible health implications of pesticide residues relate to dietary intake of residues per kilogram of body weight.

[6]Food disappearance is equal to production plus imports less exports. While some food appearing in disappearance statistics is wasted rather than consumed, changes in disappearance are associated with changes in consumption as long as wastage rates do not change dramatically (Lutz and others, 1992).

[7]The survey was conducted by the USDA Human Nutrition Information Service, which was reorganized as the Food Consumption Laboratory within the USDA Agricultural Research Service.

the commodity from a variety of dietary sources, including foods consumed as part of processed mixtures. For example, a meal including pizza is converted to the equivalent consumption of tomatoes, wheat, olives, and other ingredients.[8] Each individual's total consumption of each raw agricultural commodity is then derived for all foods consumed. This conversion is necessary because research to develop alternative pest control methods would be carried out on agricultural crops or commodities, rather than on the myriad foods available in the marketplace.

The 1987/88 NFCS is the seventh and most recent decennial survey conducted by USDA to describe food consumption behavior and to assess the nutritional content of American diets. Food consumption data were collected on 3 consecutive days from a sample of about 10,000 individuals, selected in a self-weighting, multistage, stratified sampling design.

The 1987/88 survey has been criticized for its small number of respondents (10,172) compared with the previous 1977/78 survey (30,770). A Government Accounting Office (GAO) report has claimed that the 1987/88 survey was inadequate for use in intake estimates (USGAO, 1991). The 1987/88 survey's low response rate raised the possibility of nonresponse bias, although GAO could not establish the existence of such bias.[9]

In its own study of the nonresponse problem, HNIS concluded:

> "Results of a study of attrition suggested that the regression weighting may correct nonresponse bias. The study showed that differences between respondents and nonrespondents in eating behavior were predictable because they were caused by known socioeconomic variables, which can be adjusted for by weighting, and were not caused by some other unknown and nonrandom, and thus unpredictable, response propensity. Also, a comparison of NFCS 1987-88 with the NFCS 1977-78 and the 1985 and 1986 Continuing Survey of Food Intakes by Individuals revealed that differences in results appeared to be caused by the differences in methodology, design, and target samples rather than by nonresponse. Despite the low response rate, the NFCS 1987-88 provides better estimates of current dietary intake than does the NFCS 1977-78." (Guenther and Tippett, 1993)

The expert panel convened by HNIS to evaluate the potential for nonresponse bias concluded, like GAO, that it could neither establish the presence of bias nor prove its nonexistence. The panel concluded that between-group comparisons are possible, but demanded recognition that the respondents may not be entirely representative of the subgroups. Estimates of consumption of specific foods and upper percentiles of intake may be questionable. HNIS argues that its procedures to weight the responses have minimized the potential nonresponse problem. While nonresponse bias is usually less a problem for subgroups because subgroups are more homogeneous than larger populations, the smaller sample size results in larger variances for small subgroups. This is especially relevant for this study, which focuses on consumption of young children in five 1-year cohorts (1-year-olds, 2-year-olds, 3-year-olds, 4-year-olds, and 5-year-olds), each with a very small sample size of 100-200 individuals.

While the smaller sample size of the 1987/88 survey does not allow analysts to estimate consumption patterns as precisely as the previous 1977/78 survey, the 1987/88 survey is the most current food consumption survey that can be aggregated to the commodity level. Because consumption patterns and underlying consumption determinants have changed, the more recent survey is appropriate for this analysis.

Children's Consumption Patterns and Changes in Consumption

Here we compare consumption per kilogram of body weight of 10 fruits and vegetables for the whole U.S. population with that for 1-year-old children; we also examine changes in commodity consumption. We focus on young children because this group's consumption patterns differ more from the U.S. average than any other clearly defined subpopulation. We examined consumption patterns for several other population subgroups, divided by season, region, ethnicity, income, age, and gender.[10] Some groups consume as much as 80 percent more of some commodities than the U.S. average. Differences for young children are much larger, however, because they consume many more calories per body weight, and because their diets are more specialized.

[8]TASDIET™ allows for use of concentration factors, for example, allowing tomato paste to be converted to an unconcentrated equivalent.

[9]Nonresponse bias could be a problem if the pattern of nonresponses were systematic and unrecognized as systematic. If nonresponse bias is recognized, data may be weighted to reduce the bias.

[10]We also examined the regional distribution of commodities to determine whether consumers in some regions could have a higher intake of pesticide residues in the diet because of higher pesticide use in that region. The Western region is the only region with a high percentage of fruits and vegetables produced and consumed within the region.

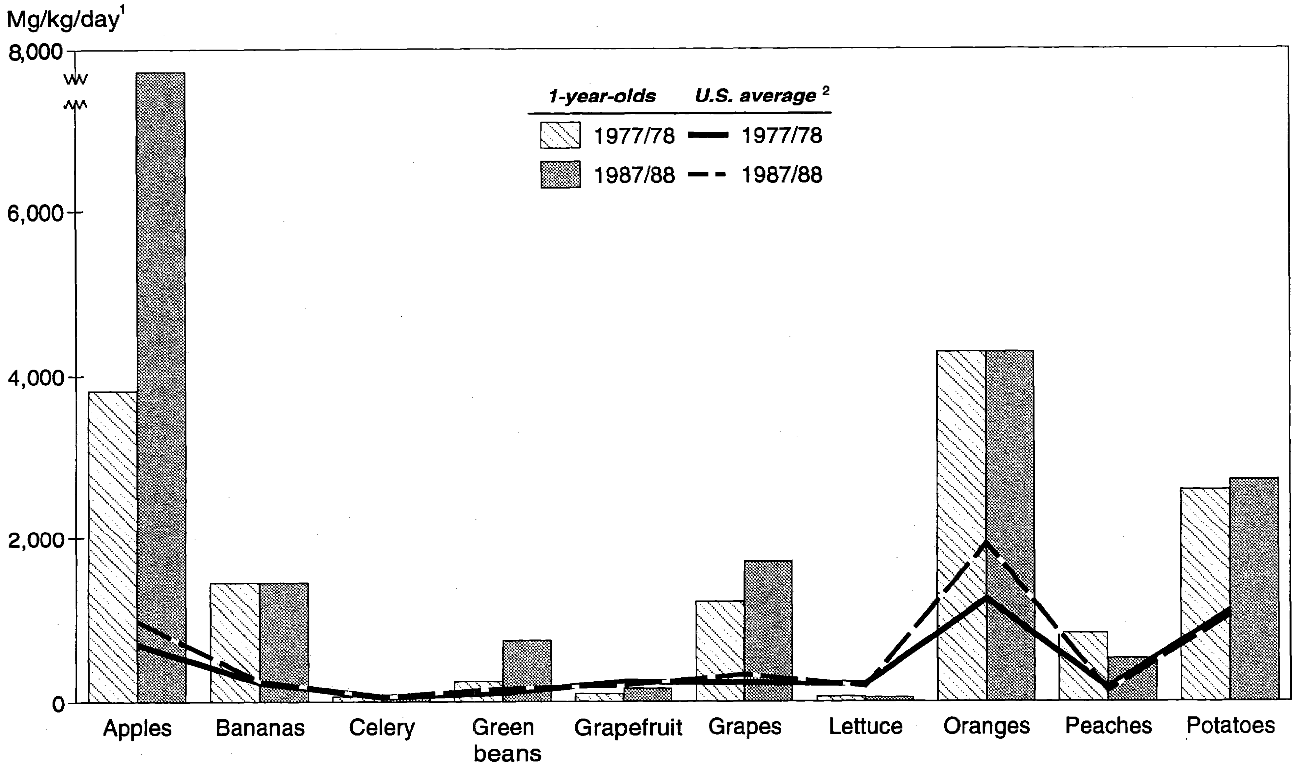
For many of the AMS-PDP commodities, children's consumption per kilogram of body weight is several times the U.S. average.[11] Per kilogram of body weight, 1-year-olds consume nearly 8 times as many apples as the average population, nearly 6 times as many bananas, 5 times as many grapes, 4 times as many green beans and peaches, and over twice as many oranges and potatoes (fig. 5). Further, young children's consumption of several of these commodities has increased more rapidly than the U.S. average since 1977/78. Consumption of apples by 1-year-olds doubled, and consumption of grapes tripled, while, for the population as a whole, consumption of these commodities increased about 40 percent. Green bean consumption decreased by 21 percent for the population as a whole, but increased by 58 percent for 1-year-old children.

[11]Body weights are self-reported for adults and reported by parents for children.

Adults with High Consumption of Fruits and Vegetables

Another subpopulation that could have higher pesticide intake is adults who consume relatively large amounts of fruits and vegetables. This group could include vegetarians as well as other individuals with high fruit and vegetable consumption. Consumption patterns and intake levels of this subpopulation are important to understand because government and private sector information programs are promoting increased fruit and vegetable consumption. The "5 A Day for Better Health" program, jointly promoted by the National Cancer Institute and the Produce for Better Health Foundation, representing the fruit and vegetable industry, is the first

Figure 5
Change in consumption per kilogram of body weight of selected fruits and vegetables, 1977/78-87/88



[1] Consumption in milligrams per kilogram of body weight per day in 1987/88. Data are estimated on an individual basis. Average body weight varies by commodity because only individuals who consume the commodity are counted. The average body weight for all individuals in the CSFII sample was 158 pounds. Body weights are self-reported or, for children, reported by parents.
[2] Includes individuals in the 48 contiguous States; of all ages, genders, ethnic groups, and religions; and includes all seasons.

Source: Based on Nationwide Food Consumption Surveys 1977/78 and 1987/88, aggregated from foods as consumed to raw commodity equivalents using Diet System Software by TAS, Inc.

national health promotion program to focus on the benefits of daily fruit and vegetable consumption (DHHS, 1991). The program's goal is to increase per capita consumption of fruits and vegetables to five servings daily by the year 2000 based on the Dietary Guidelines for Americans issued jointly by DHHS and USDA. It attempts to increase public awareness of the health benefits of five servings daily of fruits and vegetables and to provide consumers with information about incorporating more servings into daily eating patterns. This message is also incorporated into the Food Guide Pyramid, a graphic tool used to increase consumer awareness of the importance of having diets high in fruits and vegetables and following Government dietary guidelines (USDA and DHHS, 1990, and USDA, HNIS, 1992).

As consumers attempt to control disease through diet, they may expose themselves to more pesticides. If dietary intake risk from pesticide residues were great enough, consumers might have to balance one risk against another and limit their fruit and vegetable consumption. We compared fruit and vegetable consumption by adults in the upper percentiles of the consumption distribution with consumption by young children to determine whether this group of adults may also warrant special consideration in determining priorities for research to reduce pesticide residue risk.

Estimates for the upper percentiles of the consumption distribution for each of the 10 commodities are 3-day averages based on the 1987/88 NFCS, including consumers who did not consume the commodity during the 3 survey days. Foods as consumed are converted to raw agricultural commodities using TASDIETTM software developed by TAS, Inc. We can compare these consumption levels to the average levels of 1-year-old children, the demographically defined consumer subpopulation having the highest or near highest consumption per kilogram of body weight for all the AMS-tested commodities (fig. 6).

Consumption by the 85th percentile of adults (a consumer subpopulation defined by consumption patterns) exceeds consumption by 1-year-olds for only celery and lettuce. However, less than 15 percent of adults actually consume more lettuce and celery than 1-year-olds (per kilogram of body weight) over the long run. The distribution of individual 3-day averages gives upwardly biased estimates of the upper percentiles of the longrun average intake, called the "usual intake" (Carriquiry, Jensen, and Nusser, 1991).[12]

[12]The upper percentile estimates are biased upward because the variance of the 3-day average is always higher than the variance of consumption averaged over a longer period. The methodology for estimating the distribution of usual intake for foods from data on a small number of days per individual is still under development.

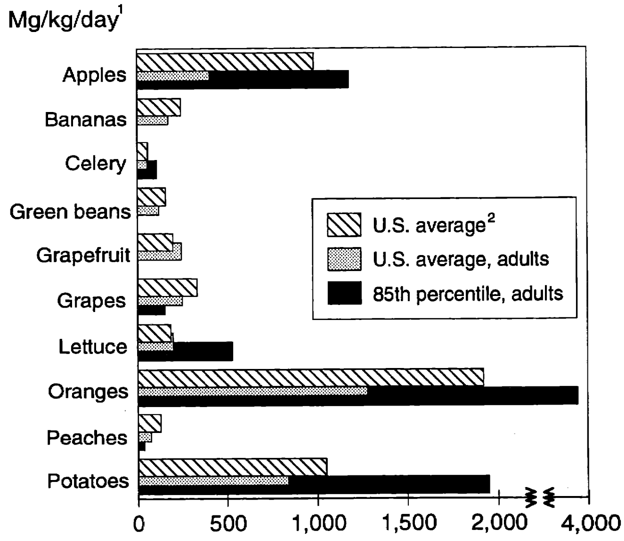
In sum, population subgroups have different consumption patterns, which could lead to differences in pesticide residue intake. For some groups, such as young children, these differences are greatly magnified by differences in body weight. Differences between children's and adults' consumption patterns are large enough to warrant special consideration of children's diets in examining priorities for research to reduce pesticide residue risks. Further, these differences have increased since the late 1970's.

Dietary Residue Risk Indicators

We estimated dietary intake of pesticide residues as a fraction of dietary intake levels recognized as safe or posing only negligible risk to derive two pesticide residue risk indicators: Fraction of Negligible Risk Intake (FNRI) and Fraction of Reference Dose (FRD). Dietary pesticide residue intake is calculated as the product of estimated average residue and estimated consumption. Indicators by pesticide are calculated for consumer

Figure 6

Adult consumption per kilogram of body weight of selected fruits and vegetables, 1987/88



[1] Consumption in milligrams per kilogram of body weight per day in 1987/88. Data are estimated on an individual basis. Average body weight varies by commodity because only individuals who consume the commodity are counted. The average body weight for all individuals in the CSFII sample was 158 pounds. Body weights are self-reported or, for children, reported by parents.
[2] Includes individuals in the 48 contiguous States; of all ages, genders, ethnic groups, and religions; and includes all seasons.

Source: Based on Nationwide Food Consumption Surveys 1977/78 and 1987/88, aggregated from foods as consumed to raw commodity equivalents using Diet System Software by TAS, Inc.

subpopulations defined by consumer income, ethnicity, age, and level of fruit and vegetable consumption. Additionally, we estimated the contribution of each commodity to the total indicator value for each pesticide.

Note that these indicators are not intended as estimates of the potential health impacts of these pesticides and cannot be used to draw regulatory conclusions. Rather, they are intended for use in comparing pesticides and identifying the sources of dietary pesticide residue risk. As a tool for comparing pesticides, the indicators have strengths and weaknesses. The indicators incorporate some information about potential adverse health impacts of dietary intake of pesticide residues because they reveal for which pesticides intake is largest relative to recognized safe levels. These findings help us prioritize research to reduce risks better than estimates of dietary intake alone because pesticides differ in toxicity. However, they do not identify the precise health consequences of dietary intake and, by default, treat all health consequences identically. Ranking the importance of various health outcomes would be a subject for public policy debate; this question is unresolved.

Indicator Definitions

We estimated the FNRI for pesticides believed to have no risk-free intake level. These "nonthreshold" pesticides are probable human carcinogens or, in some cases, possible human carcinogens.[13] The numerator of the FNRI is the dietary pesticide residue intake per kilogram of body weight. The denominator of the FNRI, referred to here as the "negligible-risk intake level," is the maximum level of dietary intake per kilogram of body weight that would lead to a negligible risk of cancer. This level is derived for this study using EPA data on the carcinogenic potency of the pesticide and is based on a common definition of negligible risk, which is a 1-in-a-million probability of cancer over a 70-year lifetime. The FNRI is then simply the ratio of the estimated dietary intake to the negligible-risk intake level. The calculations behind the derivation of the negligible-risk intake levels and FNRI estimates are summarized in appendix B.

We estimated the FRD for pesticides for which very low levels of intake (up to a threshold level) cause no ill effect (threshold pesticides). These pesticides have potential noncancer health effects such as tissue damage and neurochemical changes. The FRD is derived by dividing dietary residue intake per kilogram of body weight by the reference dose established by EPA (EPA, 1994). (See Glossary for definition of reference dose.) The 1993 National Research Council report argued that reference doses should be modified to account for children's unique susceptibility to adverse developmental effects. Toxicological research is ongoing and data for all pesticides is not available. Thus, we rely on current reference doses for all consumers.

The estimates of pesticide residue intake use residue data on raw commodities but use consumption data on commodities in both raw and processed forms. While residue data on processed commodities are available from other testing programs, they are very limited in coverage. To apply residue averages on raw foods to foods in both raw and processed forms, we were required to assume that processed forms would carry equivalent residue levels. We accounted for differences in residue concentration only due to removal of water in processing.

Raw and processed forms often have very different levels of residues, however. Many residues are degraded or reduced in processing, while others can be created as breakdown products from some processes. Further, pesticide use can be very different on some commodities destined for the processed market, with the potential for varying residues even before processing.[14] These assumptions do not have a consistent bias, since residues of a particular pesticide could be either greater or less in the raw form of a commodity than in a processed form. Further research will be required to refine dietary intake estimates to account for differences in residues between raw and processed foods. Because young children consume raw and processed foods in different proportions than adults do, differences in residues are especially important to explore further.

Estimates of dietary pesticide residue intake are also sensitive to the methods used to estimate average pesticide residue concentrations (see appendix A), and, for this reason, the assumptions used have been refined as much as possible with current data. Indicator values of less than 1 indicate that dietary intake from the 10 AMS-PDP commodities is below levels generally recognized as safe. However, the utility of the indicators presented here is for the rankings they allow, rather than for their numerical values. The rankings can also help identify pesticide-commodity combinations for which more detailed processed-form residue data should be obtained.

[13] For regulatory purposes, the designator "probable" indicates greater evidence of carcinogenicity than does "possible."

[14] Comparing total pounds of active ingredient applied, pesticide use data show (at conventional levels of statistical significance) that insecticide and fungicide use is larger in fresh green bean production than in production intended for the processing market. On the other hand, potatoes for processing receive more fungicides, herbicides, growth regulators, and soil fumigants than potatoes destined for the fresh market.

Indicator Estimates and Rankings

We estimated the FNRI for 10 nonthreshold residues, including 9 pesticides (DDT, benomyl, captan, chlorothalonil, dichlorvos, lindane, o-phenylphenol, permethrin, and propargite) and one degradation product (DDE). We also estimated the FRD for the remaining threshold residues.[15]

Indicators were estimated for several income groups, ethnic groups, and age groups.[16] Subpopulations defined by ethnicity and income have qualitatively similar pesticide indicator values and rankings since consumption varies little among these subpopulations. Indicator values are higher for young children, and rankings are different for some residues. These differences in magnitude reflect children's higher consumption per kilogram of body weight of many commodities. Therefore, only indicators for the average U.S. consumer and young children are reported here.

[15]Toxicologists have classified some of the threshold pesticides as possible human carcinogens, but for which cancer risk estimates are not considered appropriate (Engler, 1993). These pesticides are considered safe below their reference dose. In the AMS-PDP, pesticides with this characteristic include acephate, bromoxynil, cypermethrin, dicifol, dimethoate, parathion, and phosmet. The lists of pesticides evaluated for threshold and nonthreshold risks change with new scientific information.

[16]Indicators for infants less than 1 year old are not reported here because they typically do not consume fruits and vegetables during the first few months of life.

Indicators for the average U.S. consumer are based on the 1987/88 average consumption level of the 10 commodities consumed, over a 70-year lifetime. Indicators for young children are based on average consumption levels for each age group, and cover only 1 year (see appendix B for further explanation of indicator construction). Pesticides are reported if any one of the subpopulations analyzed was found to have an FNRI value greater than 0.10 (intake greater than 10 percent of the negligible risk intake level).

The highest U.S. average FNRI for a nonthreshold pesticide is 0.38 for DDE (table 6). In other words, estimated intake of DDE residues from 10 fruits and vegetables is 38 percent of the negligible risk intake level, assuming no loss or creation of residues in processing and similar pesticide levels on commodities destined for fresh and processed markets. This intake is a result of the persistence of DDT (and its degradation products).

The FNRI estimates for propargite must be considered provisional, as results were derived from a relatively small sample on a single commodity. In 1993, AMS testing for propargite included seven commodities. The U.S. average FNRI values are all below 1, which is consistent with other evidence about the safety of the Nation's food supply.[17]

[17]See "Implications for Data Needs and Interpretation" in this report for a discussion of the FDA Total Diet Study.

Table 6—Fraction of Negligible Risk Intake (FNRI) and Fraction of Reference Dose (FRD) for selected consumer subpopulations

Pesticide	U.S. average	1-year-olds	2-year-olds	3-year-olds	4-year-olds	5-year-olds	Adult average	85th percentile of adults
Nonthreshold								
Benomyl	0.10	0.65	0.46	0.41	0.26	0.24	0.05	0.11
Captan	.18	1.06	.79	.70	.55	.39	.11	.16
Chlorothalonil	.08	.20	.12	.16	.15	.11	.08	.15
DDE	.38	1.19	1.14	.79	.90	.73	.29	.50
DDT	.20	.54	.43	.24	.50	.32	.15	.34
o-Phenylphenol	.04	.18	.19	.15	.11	.09	.02	.06
Permethrin	.19	.19	.13	.16	.23	.16	.20	.43
Propargite	.29	1.10	.39	.18	.96	.38	.17	.02[1]
Threshold								
Azinphos-methyl	.03	.19	.15	.13	.09	.07	.01	.03
Dimethoate	.06	.31	.23	.21	.15	.12	.04	.14
Ethion	.03	.19	.16	.14	.09	.07	.01	.30
Methamidophos	.16	.59	.26	.26	.29	.34	.12	.29
Thiabendazole	.08	.38	.37	.30	.22	.17	.05	.10

[1]Results for propargite are provisional, based on a limited sample and a small number of detections.

The highest FNRI of the indicators for young children is for DDE for 1-year-olds (1.19). DDE was also the top-ranked indicator for the U.S. average. Captan appears as the number three residue in the list for 1-year-olds, while it was number five for the U.S. average. Again, while all the indicator values for children suggest dietary intake close to or well below negligible risk intake levels, data gaps and the imprecision in consumption and residue data make these estimated values inexact.

FRD values were estimated for the five top-ranking threshold AMS-PDP pesticides. Pesticides were reported if any one of the subpopulations analyzed showed an FRD value greater than 0.10 (intake greater than 10 percent of the reference dose). For the average U.S. consumer, the largest FRD is for methamidophos, with an indicator value of 0.16 (table 6). Values for young children are higher, reflecting their greater consumption per kilogram of body weight of many commodities; rankings for threshold pesticides are the same for 1-year-old children as for adults. Methamidophos is the top-ranked threshold pesticide for 1-year-old children, with an estimated FRD of 0.59.

Like the indicators for the nonthreshold pesticides, the FRD estimates are below 1, consistent with other findings that dietary intake of pesticide residues falls far below EPA reference doses (DHHS, FDA, 1993). Again, however, the ranking of these indicators is of interest rather than the values themselves.

Adults in Upper Percentiles of Pesticide Residue Intake

A small fraction of adults consume a larger quantity of fruits and vegetables than young children, per kilogram of body weight. While the higher fruit and vegetable consumption of these adults means higher intake of some pesticide residues, it does not mean that intake levels are above negligible risk intake levels or reference doses. Nor is it necessarily true that pesticides would be ranked differently for adults in the upper percentiles of fruit and vegetable consumption or of residue intake than for the general population.

We compared indicator rankings and values for adults in the 85th percentile of the pesticide residue intake distributions for each pesticide to those of young children to examine whether diets of these adults may also warrant special consideration in setting priorities for research to reduce residue risk. These percentiles are based on the distribution of all adults in the survey, including those with no intake of a given pesticide residue from the 10 commodities during the 3 survey days. The estimates probably overstate the longrun average intake at the 85th percentile of the longrun average pesticide residue intake, as discussed above. The percentiles of pesticide residue intake include different individuals from the corresponding percentiles of commodity consumption. Further, the percentiles for one pesticide include different individuals than percentiles for intake of another pesticide.

The highest ranked nonthreshold pesticide is DDE, just as it is for 1-year-olds. The ranking of the remaining pesticides differs somewhat from the ranking for children. Permethrin appears as the second-ranked pesticide for the 85th percentile of adults, while it was close to the bottom of the list for young children. This difference arises from dietary differences between adults and children. Permethrin residues were found by AMS primarily on celery and lettuce, which is consumed in small amounts by children but in large amounts by some adults.

The top-ranking threshold pesticide for the 85th percentile group is ethion. This differs from the ranking for 1-year-old children and the U.S. average, in which methamidophos is the top-ranked threshold pesticide. The FRD value is also higher for these adults than for 1-year-old children. Other pesticides ranked similarly for upper percentile adults as for 1-year-olds. While rankings are different for children and adults in upper percentiles, indicator values (except for ethion) are all lower for adults in the 85th percentiles than for 1-year-old children.

Comparing rankings for adults and children provides insight into whether some adults may warrant special consideration in priorities for research to reduce residue risk. For most pesticides, dietary intake for adults with greatest exposure is less than intake for 1-year-old children, and special consideration for children's diets would probably protect other individuals in the population as well.

Potential Residue Intake from Five Servings of Fruits and Vegetables per Day

PDP data make it possible to consider the implications of a diet providing five servings of fruits and vegetables per day. FNRI and FRD indicators are estimated here for individual servings of the 10 fruits and vegetables tested by AMS in 1992. Indicators are then estimated for hypothetical diets that provide five servings per day of the AMS-tested fruits and vegetables (tables 7 and 8). Note the DDT estimate for peaches is based on few detections and would likely vary significantly with different samples.

We estimated pesticide residue intake from different combinations of fruits and vegetables. Since the average adult consumption of the 10 commodities studied here adds up to 2.3 servings daily, a diet providing

Table 7—FNRI for nonthreshold pesticides, lifetime average of one serving daily of selected fruits and vegetables[1,2]

Commodity	Serving size (Grams/day)[3]	DDE	Permethrin	DDT	Captan	o-Phenylphenol	Benomyl[4]	Chlorothalonil
Apples	180	0.13	0.00	0.00	0.16	0.04	0.15	0.01
Bananas	140	.00	.00	.00	.00	.00	.20	.00
Celery	40	.02	.34	.02	.00	.00	.00	.49
Green beans	55	.09	.04	.00	<.01	.00	.06	.12
Grapefruit	277	.00	.00	.00	.00	.00	.00	.00
Grapes	60	.00	.00	.00	.25	.00	.00	.00
Lettuce	28	.01	.28	.01	.00	.00	.00	<.01
Oranges	252	.00	.00	.00	.00	.04	.00	.00
Peaches	175	.00	.33	1.11	.36	.00	.00	.00
Potatoes	112	.45	.02	.19	.00	.00	.00	.00

[1]Propargite is omitted because residues were found on only one commodity. [2]Values are rounded to two decimal places after all calculations are completed. [3]Serving sizes are based on serving size data from "Handbook 8," *Composition of Foods: Fruits and Fruit Juices* and *Composition of Foods: Vegetables and Vegetable Products* (USDA, 1982, and USDA, 1984). [4]Screening for benomyl occurred only on three commodities.

Table 8—FRD for threshold pesticides, lifetime average of one serving daily of selected fruits and vegetables[1]

Commodity	Serving size[2]	Methamidophos	Thiabendazole	Dimethoate	Azinphos-methyl	Ethion
Apples	180	0.00	0.09	0.05	0.05	0.06
Bananas	140	.00	.01	.03	.00	.00
Celery	40	.03	.00	<.01	<.01	.00
Green beans	55	.62	.00	.05	<.01	<.01
Grapefruit	277	.00	.03	.00	.00	.01
Grapes	60	.02	<.01	.06	<.01	.00
Lettuce	28	<.01	.00	.01	.00	.00
Oranges	252	.00	.06	.01	.00	.01
Peaches	175	.04	<.01	.01	.04	.00
Potatoes	112	.02	.01	<.01	<.01	.00

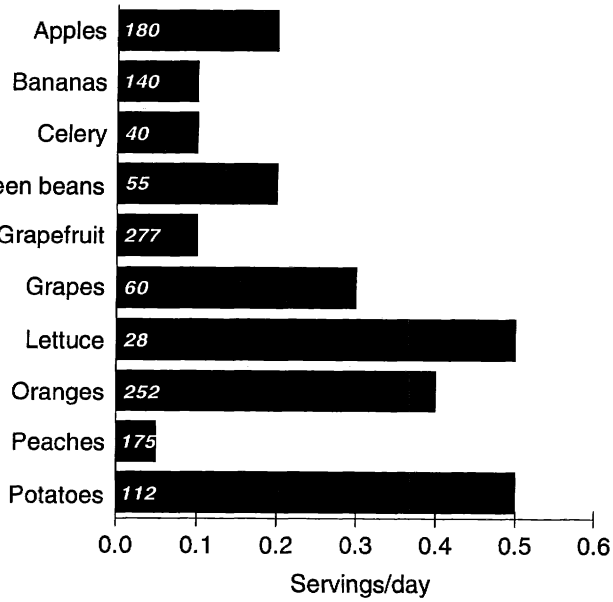
[1]Values are rounded to two decimal places after all calculations are completed. [2]Serving sizes are based on serving size data from "Handbook 8," *Composition of Foods: Fruits and Fruit Juices* and *Composition of Foods: Vegetables and Vegetable Products* (USDA, 1982, and USDA, 1984).

5 servings daily from these commodities in the same proportions would roughly double the current average consumption of each commodity (fig. 7). The first hypothetical diet is comprised of five total servings of fruits and vegetables daily in the same proportion as current consumption (table 9). The proportions of raw and processed forms of each food are assumed to remain constant as well.

The second set of hypothetical diets consists of one serving of each of the five commodities with the highest average residues per serving for each pesticide. These diets illustrate the highest possible residue intake levels from diets meeting the objective of five servings of different fruits and vegetables per day. Note that the second set of diets consists of the same five fruits and vegetables daily for a lifetime; thus, any such estimated indicators would be unrealistically high.

While numerical values should be treated with caution, the results suggest that increasing fruit and vegetable

Figure 7
Number of servings of AMS commodities consumed per day, U.S. adults



Total = 2.3 servings per day.
Note: Numbers in bars are serving sizes in grams per day based on serving size data from "Handbook 8" (USDA, 1982, and USDA, 1984).

Source: Per capita servings consumed based on Nationwide Food Consumption surveys 1977/78 and 1987/88, aggregated from foods as consumed to raw commodity equivalents using Diet System Software by TAS, Inc.

consumption to meet health recommendations should not cause concern about dietary intake of pesticide residues. All indicators from the illustrated diet of five servings in current proportions are below 1, meaning that nonthreshold residues are all below negligible risk intake levels and threshold residues are below reference doses (table 9).

The benefits of increasing fruit and vegetable diet shares probably exceed the potential effects of slight increases in pesticide residue intake. Epidemiological studies have shown that incidence of many cancers is lower by a factor of two or more for consumers with high fruit and vegetable consumption than for those with low consumption (Block, Patterson, and Subar, 1992). Thus, reducing pesticide residue intake could only improve the already enormous benefits of high fruit and vegetable consumption. Overall, indicator values support other evidence of the safety of the food supply. While the absolute levels of the numerical values should be treated with caution, the indicator rankings show which pesticides pose the greatest risks for specific consumer subpopulations and where benefits of reduced dietary intake would be largest.

Sources of Dietary Intake of Residues

While information on dietary pesticide residue intake suggests where the larger benefits of reduced dietary

Table 9—FNRI and FRD for simulated diets providing five servings of fruits and vegetables per day[1]

Pesticide	Current adult diet	Lifetime average of five servings per day of AMS commodities in same proportions as currently consumed	Lifetime average of one serving each of five commodities with highest residues per serving
Nonthreshold[2]			
DDE	0.29	0.62	0.71
Permethrin	.20	.44	.97
DDT	.15	.32	1.33
Captan	.11	.24	.76
Chlorothalonil	.08	.17	.63
Benomyl	.05	.11	.41
o-Phenylphenol	.02	.05	.08
Threshold			
Methamidophos	.12	.26	.73
Thiabendazole	.05	.10	.20
Dimethoate	.04	.09	.19
Ethion	.01	.03	.08
Azinphos-methyl	.01	.02	.09

[1]Values are rounded to two decimal places after all calculations are completed. [2]Propargite is omitted because residues were found on only one commodity.

intake are, it does not give much guidance on achieving those benefits. Knowing the sources of higher indicator values could help set priorities for research efforts to develop alternative pest control measures because pesticide use, as well as nonpesticide alternatives, is typically defined by treated commodities and treatment location.

Dietary intake of pesticide residues results from pesticide use in food production and marketing. Residues in the AMS data set come from domestic onfarm use, domestic post-harvest use, use on imported foods, and past use of canceled chemicals that persist in the environment. However, the link between use and residues is often tenuous because many residues break down and disappear with time and exposure to the elements.

In this section, we analyzed chemicals with FNRI or FRD indicators greater than 0.10 for at least one consumer subpopulation, based on residue data from the AMS-PDP. This group includes eight chemicals posing nonthreshold risks: DDE, propargite, captan, benomyl, DDT, permethrin, chlorothalonil, and o-phenylphenol. Among chemicals posing threshold risks, methamidophos, thiabendazole, dimethoate, azinphos-methyl, and ethion meet the selection criteria. In addition, acephate is discussed because its degradate methamidophos is selected, and acephate use is a potential source of residues from this chemical.

In examining sources of risk, we focus on indicators for 1-year-olds because the FNRI and FRD estimates are relatively larger in this subpopulation. For example, the FNRI for DDE is 1.19, with 59 percent of that value coming from potatoes and 34 percent from apples (table 10).

Children's residue intake is often primarily from one or two commodities, reflecting their less varied diet. Peaches are the only source of propargite residues considered here because residue testing was limited to one commodity. Apple consumption by 1-year-olds represents approximately half of captan- and benomyl-intake levels. Grapes are the other principal source of captan residue intake; bananas account for most other benomyl intake. Potatoes and apples account for 93 percent of DDE residue intake for 1-year-olds. Green

Table 10—Sources of threshold and nonthreshold dietary intake risk

Pesticide	1-year-olds' FNRI	Principal commodity dietary source (Percent)	Principal pesticide use source	U.S. regions where pesticide is used
Nonthreshold				
DDE	1.19	Potatoes (59) Apples (34)	Canceled	N/A
Propargite	1.10	Peaches (100)	Imports	N/A
Captan	1.06	Apples (45) Grapes (47)	Farm/post-harvest Imports	East, North Central
Benomyl	.65	Apples (69) Bananas (23)	Farm Imports	East, North Central
DDT	.54	Potatoes (57) Apples (43)	Canceled	N/A
Chlorothalonil	.20	Green beans (51)	Farm	All
Permethrin	.19	Peaches (36)	Farm	East, North Central
o-Phenylphenol	.18	Apples (68) Oranges (31)	Post-harvest	N/A
Threshold				
Methamidophos	.59	Green beans (87)	Farm	Southeast (Used as acephate)
Thiabendazole	.38	Apples (71)	Post-harvest	[1]
Dimethoate	.31	Apples (46) Grapes (38)	Farm Imports	East, North Central
Azinphos-methyl	.19	Apples (87)	Farm	All
Ethion	.19	Apples (93)	Farm	West

N/A = Not applicable.

[1]Not region-specific.

bean consumption accounts for most of the dietary intake of methamidophos residues. Apples are the principal source of residues for the other selected threshold risk chemicals.

DDT residues, and residues from its degradate DDE, in the AMS-PDP sample are a result of DDT use before 1972. Thiabendazole and o-phenylphenol are used only in post-harvest applications on apples and oranges. We have little additional information about these residue sources.

Imported peaches, grapes, and bananas are a source of dietary residue intake for some of these chemicals. All of the estimated intake of propargite results from residues on imported peaches. Most of the intake of captan residues on grapes is a result of residues found on imported samples. Grape consumption accounts for 47 percent of the captan FNRI, and captan residues on imported grapes are at least 9 times greater than on domestic grapes. All banana samples were imported and 23 percent of the benomyl FNRI comes from banana consumption.[18] A major component (38 percent) of the dimethoate FRD comes from grape consumption, and imported grapes carry at least 3 times as much dimethoate as domestic production.

The other sources of dietary intake of pesticide residues are primarily the result of onfarm use. A few chemicals, like captan, are registered for both onfarm and post-harvest use, and thus the source of residues cannot be distinguished. Of the 14 chemicals selected, 9 have onfarm uses: acephate, azinphos-methyl, benomyl, captan, chlorothalonil, dimethoate, ethion, methamidophos, and permethrin.

Pesticide use in different regions influences residue detections.[19] Appendix C provides further statistical analysis confirming that regions with greater pesticide use realize greater residues and higher rates of detection. Large portions of dietary intake of captan, benomyl, dimethoate, and ethion are from apple consumption, and these pesticides are used on apples in specific producing regions. Use of captan and benomyl in apple production is concentrated in the Eastern and Lake States (Michigan, New York, Pennsylvania, Virginia, North and South Carolina, and Georgia); there is little use in the Western apple-producing States (Washington, Oregon, California, and Arizona). Dimethoate is used on apples primarily in the Mid-Atlantic and Lake States (North Carolina, Virginia, Pennsylvania, New York, and Michigan). Washington is the only major apple-producing State with quantifiable ethion use. Use even in Washington is fairly rare, with 2 percent of the acreage treated an average of 1.2 times. This suggests that while the FRD for ethion on apples is still far below 1, any measurable increase in ethion use on Washington apples could be associated with a substantially higher FRD.

Most other dietary intake of residues is also largely due to region-specific pesticide use on particular commodities. Green bean consumption is the source of the largest share of FNRI from chlorothalonil. While green beans are produced across the United States, chlorothalonil is important to green bean production only in the South: North Carolina (83 percent of acreage treated), Georgia (76 percent), and Florida (44 percent). Its use is modest outside the South, with 16 percent of acreage treated in California and less in other States.

The calculated FRD for acephate is 0.02 for 1-year-olds, indicating that its dietary intake is a very small portion of the reference dose. However, one of its degradation products is methamidophos with an FNRI of 0.59, mostly coming from green bean consumption. Methamidophos has no registration for use on green beans. Acephate use on fresh green beans is important to production only in the South: Florida (39 percent of acreage treated) and Georgia (36 percent).[20]

Of the domestic onfarm pesticides with relatively high FNRI or FRD values, only azinphos-methyl use on apples and permethrin use on lettuce, green beans, celery, and peaches do not have region-specific use patterns. The insecticide azinphos-methyl is one of the few pesticides used in all apple-producing regions. Apples are the major contributor to azinphos-methyl FRD for 1-year-olds. The pesticide is applied 2.5-6.5 times per acre on 57-90 percent of apple acreage in major producing States. It is a major contributor to insect control on apples across the United States. Permethrin is also used throughout the United States. Peaches, green beans, celery, and lettuce all contribute to the permethrin

[18]Recall that the residue average was based on few detections. For pesticide-commodity pairs with few detections, the assumed values for values below the limit of detection and between the limits of detection and quantitation have a larger influence on the calculated average residue.

[19]Risk indicators could not be calculated on a regional basis because pesticide residue data are not robust enough to provide average residue estimates on a regional basis. AMS data show that terminal markets draw their supplies from all regions. All regions consume more of their own fruits and vegetables than they would if all produce were evenly distributed, but there is substantial product mobility.

[20]It is also used frequently in California and the North Central and Lake States on green beans destined for processing. We have no residue estimates for products destined for the processed market.

These results indicate that risks from dietary intake of pesticide residues could be reduced by altering usage practices or finding alternatives for a fairly limited set of pesticide uses. However, onfarm pesticide use is not the only, or even the most important, source of children's dietary intake of pesticide residues. Imported foods and chemicals that persist in the environment contribute a substantial portion of the dietary risk from the 10 PDP commodities, and are the primary sources of 1-year-olds' dietary intake of chemicals with FNRI above 1.00.

Implications for Data Needs and Interpretation

Residue data, consumption data, and risk indicators are important for ranking and characterizing dietary risks. Commodity-specific residue data can complement other kinds of data in understanding risks.

Residue Data

Residue data derived from samples taken as close as possible to consumption will most accurately represent dietary intake of pesticide residues. Without such data, we must assume that all commodities carry residues at the legal limit. Tolerances, however, are much larger than the typical residues to which consumers are exposed. Assuming residues at tolerance not only greatly overstates risks, but leads to very different rankings of risks.

Tolerances are enforcement tools and are set at levels far higher than expected residues on foods. Tolerances are set so that enforcement officials can be certain that pesticides were misused if they find residues above tolerances. (See Saunders and Petersen, 1987, for a discussion of the dietary intake information used to set tolerances.) Few samples reported by either FDA or AMS-PDP violate tolerance levels, first because a chemical is seldom used by all producers of the crop as frequently as allowed or as close to harvest as allowed, and second, because many residues degrade over time, with exposure to the elements.

We estimate dietary intake under the extreme assumption that residues are at tolerance levels to demonstrate how such estimates differ from those based on the AMS-PDP residue data. Risk indicators are estimated from dietary intake of pesticides detected on apples and oranges, chosen because they are important in children's diets. We assumed that residues would be at tolerances for all pesticides, and that processed products would carry residues at the tolerance level, implying that processing would not reduce or concentrate residues (except through the addition or reduction of water content in foods). Pesticides chosen were those that showed risk indicator values greater than 0.1 for one or more age groups among young children.

If all residues were assumed at tolerance levels, estimates of the average consumer's dietary intake of most pesticides on a single commodity alone would exceed recognized safe levels. Dietary intake on each commodity would exceed the negligible risk intake level or the reference dose, each of which is based on residue intake from all commodities (tables 11-12). Intake levels are larger for 1-year-old children, and FNRI and FRD exceed the standard or reference doses by orders of magnitude. In comparison, the FNRI and FRD based on actual residues are either zero or close to zero.

The ranking of risk indicators based on tolerances bears little relation to that based on actual residues. For nonthreshold risks from orange consumption, most pesticides show zero risk based on actual residue. The only pesticide in this group that has a positive FNRI value based on actual residues is o-phenylphenol. Yet its FNRI value based on tolerance is least among the pesticides used on oranges. These examples show that without actual residues, pesticide risks can be overestimated. Further, a perverse ranking of risks is likely, with numerous undetected pesticides assumed to pose the greatest risks. Actual residue data are essential for characterizing and ranking dietary intake risks.

Consumption Data

Consumption patterns have changed substantially from 1977 to 1987. Dietary risks can change with consumption, and ignoring these changes will result in incorrect risk rankings. With imprecise data, consumption will sometimes be underestimated, leading to underestimated or unidentified dietary risks. Sometimes consumption will be overestimated, leading researchers to focus on hazards that do not exist and thereby diverting resources away from controlling real hazards.

Pesticide dietary intake for almost all pesticides and almost all consumer subpopulations is a small fraction of intake levels recognized as safe. However, pesticide and commodity coverage here is incomplete. More reliable consumption estimates and more complete residue information may reveal the presence of nontrivial risks.

Risk Indicators

Neither detection frequency nor residues as a percent of tolerance are good indicators of risks from dietary intake of pesticide residues. To rank risks, dietary intake must be compared with intake levels that are considered safe or of negligible risk. Counting detections would be use-

Table 11—FNRI comparing actual residues and residues at tolerances

		Apples		Oranges	
Pesticide	Consumers	Residues assumed at tolerance	Actual residues	Residues assumed at tolerance	Actual residues
Propargite	U.S. average	91.70	Not tested	298.38	Not tested
	1-year-olds	715.26	Not tested	699.05	Not tested
Captan	U.S. average	88.74	0.06	173.25	.00
	1-year-olds	692.19	.48	405.90	.00
DDE	U.S. average	33.52	.05	65.45	.00
	1-year-olds	261.49	.41	153.34	.00
DDT	U.S. average	33.52	.00	65.45	.00
	1-year-olds	261.49	.00	153.34	.00
Benomyl	U.S. average	28.99	.06	80.85	.00
	1-year-olds	226.12	.45	189.42	.00
Chlorothalonil	U.S. average	0.00	<.01	.00	.00
	1-year-olds	0.00	.03	.00	.00
Permethrin	U.S. average	.89	.00	.00	.00
	1-year-olds	6.92	.00	.00	.00
o-Phenylphenol	U.S. average	54.23	.02	42.35	.02
	1-year-olds	423.01	.12	99.22	.05

Note: The action level for combined DDT + DDE + TDE was used for these calculations. No tolerance exists for DDT or DDE. DDE and DDT were treated as if they were each at the action level.

Table 12—FRD comparing actual residues and residues at tolerances

		Apples		Oranges	
Pesticide	Consumers	Residues assumed at tolerance	Actual residues	Residues assumed at tolerance	Actual residues
Methamidophos	U.S. average	0.00	0.00	0.00	0.00
	1-year-olds	.00	.00	.00	.00
Thiabendazole	U.S. average	.99	.03	1.93	.03
	1-year-olds	7.69	.27	4.51	.07
Dimethoate	U.S. average	9.86	.02	19.25	<.01
	1-year-olds	76.91	.14	45.10	.01
Azinphos-methyl	U.S. average	1.52	.02	2.96	.00
	1-year-olds	11.83	.17	6.94	.00
Ethion	U.S. average	3.94	.02	7.70	.01
	1-year-olds	30.76	.18	18.04	.01

ful in estimating risks from a hazard for which any exposure, no matter how small, would quickly be fatal. Pesticide residues do not fall into this category. For most pesticides, toxicologists have calculated threshold intake levels below which no adverse health effects occur. With state-of-the-art testing capability, even the most frequently detected pesticides can have dietary intake levels that are orders of magnitude less than threshold levels.

For pesticides without threshold levels (primarily cancer-causing chemicals), toxicologists assume that risks grow linearly with dietary intake. Again, detection numbers are irrelevant to addressing the potential health impacts; some measurement of dietary intake is necessary for comparison with intake levels that would pose negligible risks.

Similarly, comparing residues with legal tolerances is also irrelevant to characterizing risks. Risks assuming tolerance-level residues are unrealistically large. The finding that residues are a small portion of tolerances is not informative about risk. Thus, risk indicators of the kind developed in this report are needed to adequately characterize and rank risks.

Commodity-Specific Residue Data and "Market Basket" Data

From a risk management perspective, the PDP provides unique information. We can examine the contributions to dietary intake risks from specific pesticide-commodity pairs. To some extent, we can link regional pesticide use to residues. This information can help meet a goal of developing safer alternatives for the riskiest pesticide uses. Geographic-, pesticide-, and commodity-specific PDP data are useful because any set of potential alternative practices will be at least that specific. IPM programs and nonchemical pest management practices have been designed to function for specific pest problems on particular commodities. Often, such programs are specific to particular agroclimatic regions.

The usefulness of PDP is limited by its coverage. With a limited set of pesticides and a small set of commodities, it may not cover the largest risks or those most easily reduced. Other information puts findings from the PDP in perspective. The FDA Total Diet Study examines dietary intake of a wide class of pesticide residues in foods consumers purchase. The study measures residues in both fresh and processed foods in order to estimate total dietary intake of pesticide (and other) residues. Processed foods are composed of many raw agricultural products. The Total Diet Study results cannot identify the agricultural source of residue, which is the unique contribution of the PDP.

FDA provides data showing pesticide dietary intake for several consumer subpopulations (DHHS, FDA, 1993). FDA intake estimates examined here are based on 1986-91 results from the FDA Total Diet Study. These intake estimates can be converted to FNRI and FRD indicators.

Because the FDA Total Diet Study includes processed foods, it more accurately reflects the effects of processing on residues than the PDP data. Further, the FDA data reflect residue estimates from a nearly complete diet, as opposed to the small number of commodities included in the AMS testing. At the same time, the FDA data have limitations. The 1986-91 residue intake estimates are based on dietary composition data that are over 16 years old and may no longer reflect actual changes in consumption patterns.[21] Further, the diet composition relies on representative foods rather than all commodities consumed. Differences in limits of detection and assumptions for residue estimates would also lead to differences in conclusions from the two data sources.[22]

None of the FRD estimates derived from FDA dietary intake data are greater than 1.00 for any subpopulation (table 13). Most show dietary intake is 1 percent (or less) of the reference dose. These findings are qualitatively similar to findings from the AMS-PDP data. In the FDA-derived FRD estimates, methamidophos appears at the top of the list, just as it does in the ranking of AMS-PDP estimates. The main difference is that FRD estimates from the FDA data are generally lower than the estimates derived from AMS-PDP data. The lower index estimates from the FDA data may reflect lower residues in many processed foods compared with the fresh commodities measured by AMS-PDP, differences in dietary patterns underlying these two sets of estimates, or differences in methods for estimating average residues.

By contrast, several pesticides show FNRI values greater than 1.00 in the FDA-derived FNRI estimates (table 14). Many are larger than those estimated from AMS-PDP data, probably because FDA data accounted for the whole diet. FDA-derived FNRI values exceed 1.00 for DDT, heptachlor, propargite, HCB, chlordane, and per-

[21]The FDA Total Diet Study results cited here (1986-91) used the representative diets developed in 1982 based on the 1977/78 USDA Nationwide Food Consumption Survey and the National Center for Health Statistics Second National Health and Nutritional Examination Survey, 1976-80. The Total Diet Survey 1992 was based on revisions to the diets using the 1987/88 National Food Consumption Survey.

[22]Residue intake estimates for the Total Diet Study substitute zero for undetected and "trace" detections. In this analysis of AMS-PDP residue data, positive values are substituted for non-detects and "trace" detections. (See Appendix A).

Table 13—FRD for various age/sex subpopulations, based on FDA Total Diet Study

Pesticide	6-11 months	2 years	14-16 years, female	14-16 years, male	20-25 years, female	20-25 years, male	60-65 years, female	60-65 years, male
Methamidophos	0.23	0.40	0.23	0.21	0.33	0.28	0.45	0.36
Dimethoate	.07	.03	.01	.01	.04	.03	.02	.02
Ethion	.03	.04	.01	.01	.01	.01	.01	.01
Azinphos-methyl	.01	.02	<.01	.01	<.01	<.01	.01	<.01
Endosulfan	.01	.01	<.01	<.01	<.01	<.01	<.01	<.01
Thiabendazole	<.01	.01	<.01	<.01	<.01	<.01	<.01	<.01
Acephate	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Aldicarb	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01

Table 14—FNRI for various age/sex subpopulations, based on FDA Total Diet Study

Pesticide	6-11 months	2 years	14-16 years, female	14-16 years, male	25-30 years, female	25-30 years, male	60-65 years, female	60-65 years, male
Dieldrin	91.20	115.20	41.60	48.00	40.00	44.80	43.20	43.20
DDT	15.23	14.89	4.69	6.43	3.60	4.32	3.06	3.54
Heptachlor	8.10	11.25	3.15	4.50	3.15	4.05	2.25	3.15
Propargite	8.72	6.85	1.21	1.51	1.19	.84	1.47	1.27
HCB	1.87	3.57	1.02	1.53	1.02	1.36	.85	1.02
Chlordane	1.04	2.08	.91	.91	1.04	1.04	1.04	1.17
Permethrin	.84	1.27	.64	.75	1.02	.83	1.05	1.07
Captan	.08	.17	.05	.04	.05	.03	.10	.09
Folpet	.01	.01	<.01	<.01	<.01	<.01	.01	.01
Chlorothalonil	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Tetrachlorvinphos	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01

methrin for at least one age group. Of these chemicals, only propargite and permethrin are still in use. Propargite has an FNRI of 8.72 for children 6-11 months old and 6.85 for 2-year-old children; the FNRI for permethrin is slightly greater than 1.0 for 2-year-old children.

AMS-PDP data show higher risks than the FDA data only for captan. The FDA-derived FNRI for captan shows indicators all less than 1.00. AMS-PDP data show indicators that are less than 1.00 for all but one subpopulation (1-year-old children). Thus, the FDA intake estimates indicate that the highest dietary risks from pesticides come from pesticides that have lost registrations and are no longer used. AMS did not detect dieldrin residues in any of the 1992 sample commodities, but FDA detected these residues at a level leading to an FNRI of 115 for 2-year-olds and over 40 for adults.[23] DDT residues detected by the Total Diet Study lead to FNRI values of approximately 15 for young children and over 3 for adults.

Although the AMS-PDP data and the FDA data are very different, their results are qualitatively similar. Most indicators are less than 1.00; a few indicators are greater than 1.00, mostly from banned and persistent chemicals. Where the AMS and FDA data covered the same chemicals, the rankings of risk are similar.

[23]Laboratory techniques used by PDP could have detected dieldrin, but limits of detection and quantitation have not yet been determined.

The information provided by the PDP is uniquely useful for ranking risks and identifying risk sources. Current efforts underway in USDA to improve consumption data, especially for children, and to vary PDP coverage to include commodities important in children's diets will render more useful information to set priorities for risk reduction.

Conclusions and Implications for Risk Reduction

This report presents risk indicators for dietary intake of pesticides using a new, large-scale survey of pesticide residues and up-to-date consumption estimates. The newly available data from the Pesticide Data Program (PDP) cover 10 commonly consumed fruits and vegetables and 50 pesticides. The analysis here makes two unique contributions toward setting priorities for research to reduce dietary risks from pesticide residues. First, risk indicators are used to rank relative risks. Second, the sources of risk are identified through disaggregation of the indicators by commodity and type of pesticide use. This information can be used to direct research to develop alternative pest control methods or other measures to reduce dietary risks from pesticide residues.

Indicators were constructed for chemicals posing threshold risks by comparing residue intake estimates to intake levels that are recognized as safe. For nonthreshold risks, intake estimates were compared with intake recognized as posing only negligible risk. The resulting indicators are greater than 1.00 when estimated dietary intake exceeds intake levels recognized as safe or posing only negligible risk. Indicators representing intake from the PDP commodities were estimated and ranked for the average U.S. consumer and consumer subpopulations defined by age, income, ethnicity, and for consumers eating five servings per day of fruits and vegetables. The risk indicators estimated in this report are not intended for use in risk assessment or as a basis for regulatory action.

The results presented here show that pesticide residue detections, average residues relative to tolerance, and tolerance violations are not good indicators of risks from dietary intake of pesticide residues. In general, the more frequently detected pesticides were not the chemicals that had the highest indicator values. Similarly, average residues as a percent of tolerance tend to rank very differently than risk indicator values, as risks depend on the level of dietary intake and the toxicological properties of the particular chemical.

The magnitudes of the risk indicators reported here are similar to those from other studies with different goals and methodologies, such as the FDA Total Diet Study; such similarities suggest that risks for the average consumer are very low or nonexistent. A 1993 National Research Council report highlighted the need to examine children's dietary intake of residues separately because children consume more food per kilogram of body weight and consume a less varied diet than adults. Estimated risk indicators from PDP data are relatively higher for children, but the small sample size for 1-year-olds, for example, in the consumption survey used here means these results have greater uncertainty than risk indicators for adults. In addition, diets have been changing, particularly for children. The results here underscore the need for better data, particularly fruit and vegetable consumption data, to evaluate those risks.

A disaggregation of sources for the top-ranked children's indicators helps to identify research that could reduce dietary intake of residues. The PDP data are unique in that they allow us to trace the sources of pesticide residues from four categories: domestic pesticide use in agricultural production; domestic post-harvest use; use on imported foods (whether in foreign production or post-harvest); and canceled chemicals that persist in the environment. Imported foods and canceled but persistent chemicals contribute a substantial portion of dietary intake of pesticide residues posing nonthreshold risks; onfarm uses are the principal sources of threshold risk pesticide residues.

Among the 10 commodities, only grapes and peaches had large samples from both domestic and imported origins. Comparing residue levels from the two sources showed that several fungicide residues on imported grapes were found more frequently and at greater levels than on domestic grapes. For example, captan is a fungicide with a top-ranked risk indicator for children. Most of the dietary intake comes from apples and grapes. Captan residues on grapes were largely from imported grapes. These findings underscore the value of actual residue data for setting research priorities, since imports may have residues that differ from domestic foods due to different production and handling practices.

DDT and its degradate, DDE, were among the relatively high-risk indicators. DDT registrations were canceled in 1972, but it persists in the soil. Clearly, risks from persistent and unused pesticides cannot be reduced by development of alternative practices. Research regarding how these persistent chemicals result in residues would be useful to determine if it is possible to reduce these residues and their resulting dietary intake.

Most current domestic onfarm use contributing to relatively higher risk indicators is region-specific. Produce from regions with higher use of particular chemicals has correspondingly higher residues. The development of onfarm pest control alternatives to reduce dietary intake risk could therefore be targeted specifically to particular regions and crops. Examples of region-specific use include methamidophos, a breakdown product of acephate, used on green beans in the South, and captan and benomyl, used on apples in the East and North Central regions.

The risk indicators and information provided by the PDP are useful in ranking research priorities for risk reduction. This kind of ranking is essential in directing research resources to significantly reduce risk. Current efforts underway in USDA to improve consumption data, especially for children, and to vary PDP coverage to include additional commodities important in children's diets will render more useful information to set priorities for risk reduction.

However, the results of this study also show that research to develop onfarm pest control alternatives will not address all of the sources of these residues. Furthermore, these risk indicators are only one of several criteria that could be used to set priorities for development of alternative pest control techniques. Environmental impacts, water quality, and worker safety play important roles. Other hazards may pose greater risks and less costly solutions than pesticide residues in food.

References

Block, Gladys, Blossom Patterson, and Amy Subar. "Fruit, Vegetables, and Cancer Prevention: A Review of the Epidemiological Evidence," *Nutrition and Cancer.* Vol. 18, No. 1, 1992, 1-29.

Carriquiry, A.L., Helen H. Jensen, and S.M. Nusser. "Modeling Chronic Versus Acute Human Health Risk from Contaminants in Food," *Economics of Food Safety*. Julie A. Caswell, ed. New York: Elsevier Science Publishing Co., Inc., 1991.

Chaisson, Christine F., Barbara Petersen, and Judith S. Douglass. *Pesticides in Food—A Guide for Professionals*. American Dietetic Association, Chicago, IL, 1991.

Code of Federal Regulations, Title 40, Part 180, July 1992.

Eichers, Theodore, Robert Jenkins, and Austin Fox. *DDT Used In Farm Production.* U.S. Dept. Agr., Econ. Res. Serv., AER-158, July 1971.

Elkins, Edgar R. "Effect of Commercial Processing on Pesticide Residues in Selected Fruits and Vegetables," *Journal of the Association of Official Analytical Chemists.* Vol 72, No. 3, 1989, 533-5.

Engler, Reto. "List of Chemicals Evaluated for Carcinogenic Potential," Memorandum, Office of Prevention, Pesticides, and Toxic Substances, Environmental Protection Agency, Aug. 31, 1993.

Gonzalez, A.R., D.R. Davis, E.R. Elkins, and E.S. Kim. "Reduction of Ethylenethiourea Residues in Canned Spinach," *Hortscience.* Vol. 24, No. 6, 1989, 990-2.

Guenther, Patricia M., and Katherine S. Tippett, eds. "Abstract." *Evaluation of Nonresponse in the Nationwide Food Consumption Survey, 1987-88.* Washington, DC: U.S. Dept. Agr., Human Nutrition Information Service. NFCS Rep. No. 87-M-2. Sept. 1993.

Helsel, Dennis R., and Timothy A. Cohn. "Estimation of Descriptive Statistics for Multiply Censored Water Quality Data," *Water Resources Research.* Vol. 24, No. 12, 1989, 1997-2004.

Lutz, Steven M., David M. Smallwood, James R. Blaylock, and Mary Y. Hama. *Changes in Food Consumption and Expenditures in American Households During the 1980's.* U.S. Dept. Agr., Econ. Res. Serv., and Human Nutrition Information Service, SB-849, Dec. 1992.

National Research Council. *Pesticides in the Diets of Infants and Children,* Washington DC: National Academy Press, 1993.

Putnam, Judith Jones, and Jane E. Allshouse. *Food Consumption, Prices, and Expenditures, 1970-93.* U.S. Dept. Agr., Econ. Res. Serv., SB-915, Dec. 1994.

Saunders, D. Stephen, and Barbara J. Petersen. *An Introduction to the Tolerance Assessment System.* U.S. Environmental Protection Agency, Office of Pesticide Programs, Hazard Evaluation Division, Toxicology Branch, Mar. 1987.

Senauer, Ben, Elaine Asp, and Jean Kinsey. *Food Trends and the Changing Consumer*. St. Paul, MN: Eagan Press, 1991.

U.S. Department of Agriculture, Agricultural Marketing Service. *Pesticide Data Program (PDP) Summary of 1992 Data*. Apr. 1994.

U.S. Department of Agriculture, Human Nutrition Information Service. *The Food Guide Pyramid*. Home and Garden Bulletin No. 252, Aug. 1992.

U.S. Department of Agriculture, Human Nutrition Information Service, Consumer Nutrition Center. *Composition of Foods: Fruits and Fruit Juices*. AH-8-9, rev. 1982.

U.S. Department of Agriculture, Human Nutrition Information Service, Nutrition Monitoring Division. *Composition of Foods: Vegetable and Vegetable Products*. AH-8-11, rev. 1984.

U.S. Department of Agriculture, National Agricultural Statistics Service and Economic Research Service. *Agricultural Chemical Usage—1992 Vegetables Summary*. Ag Ch 1(93), June 1993.

________. *Agricultural Chemical Usage—1991 Fruits and Nuts Summary*. Ag Ch 1(92), June 1992.

U.S. Department of Agriculture, National Agricultural Statistics Service. "1992 Vegetable Chemical Use Survey Data Documentation Manual." Mimeo, July 1992.

________. "Fruit and Nut Chemical Use Surveys—Interviewer's Manual." Mimeo, Sept. 1991a.

________."Fruit and Nut Chemical Use Surveys—Supervising and Editing Manual." Mimeo, Sept. 1991b.

U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Nutrition and Your Health: Dietary Guidelines for Americans*. 3rd ed. Home and Garden Bulletin No. 232, Nov. 1990.

U.S. Department of Health and Human Services, Food and Drug Administration. *Food and Drug Administration Pesticide Program—Residue Monitoring—1992*. 1993.

U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health. *Eat More Fruits & Vegetables—5 A Day for Better Health*. NIH Pub. No. 92-3248, Oct. 1991.

U.S. Environmental Protection Agency. "Exposure Assessment Guidelines," *Federal Register*. Vol. 57, No. 104, May 29, 1992, 22915.

U.S. Environmental Protection Agency, Office of Pesticide Programs. "Office of Pesticide Programs Reference Dose Tracking Report." Mimeo, Apr. 18, 1994.

U.S. General Accounting Office. "Pesticides: Food Consumption Data of Little Value to Estimate Some Exposures." Report to the Chairman, Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, House of Representatives, RCED-91-125, May 1991.

Appendix A: Estimating Residue Averages

To calculate an average residue intake in the diet, assumptions must be made about the detections and levels that cannot be measured accurately. We cannot calculate a residue average without the entire set of residues. Similarly, variance estimates cannot be calculated directly, thereby ruling out any ability to suggest a degree of confidence in any measure of central tendency.

Scientists and engineers have proposed many solutions to this data problem (Helsel and Cohn, 1989). Here we estimate average residues for each pesticide-commodity pair following EPA guidelines, imputing values for residues too small to detect or measure precisely (EPA, 1992). In practice, this implied the following:

1. If a pesticide was not detected on a given sample, a value equal to half the limit of detection (limits of detection varied by laboratory and by pesticide) weighted by the percentage of U.S. crop acreage treated with the pesticide was imputed.

2. If there were no detections of a pesticide on any sample of a crop, all samples were treated as if residues were zero.

3. Where pesticide use data were not available, all of the crop was assumed to be treated with the pesticide. This includes imported samples and samples with detections of post-harvest pesticides.

4. For detected but unmeasurable residues, the average of the limit of quantitation and the limit of detection was substituted.

Following these substitutions, we derived a simple average from the sample results for each pesticide-commodity pair.

For many pesticides, constraining the estimated average to zero when there are no detections is reasonable. Most of the pesticides with no detections on a given commodity are never actually used on the commodity. However, this assumption may lead to underestimated residues of persistent pesticides, like DDT, which has not been used in a generation but still finds its way into the food supply.

Pesticides on imported foods and post-harvest pesticides are assumed to be used on the entire crop because we have no information about the extent of pesticide use outside the United States or beyond the farm gate. Given the relatively high frequency with which post-harvest pesticides are detected, the 100-percent post-harvest use assumption is reasonable.

The substitutions made for samples with no detectable residues will bias estimates upward somewhat because the mean of residue levels below the limit of detection is probably well below half the limit of detection. The rankings of average residues and indicators are also sensitive to these assumptions because pesticides have different rates of detection. It is because of this sensitivity to assumptions that we have refined the assumptions as much as possible with current data. Further research is needed to incorporate information about the distribution of residues into estimates of average residues, overcoming problems caused by differences in limits of detection and differences in information on acres treated across pesticides.

The use of pesticide residue averages derived from tests on fresh commodities to estimate intake from fresh and processed forms of the commodities implies two additional assumptions. First, pesticide use patterns must be the same for commodities destined for fresh and processed markets. Second, residues must not be reduced or altered by processing and cooking, except for changes in concentration due to the removal of water. Further research is needed to account for different pesticide residue levels on fresh and processed products.

Appendix B: Calculating the Fraction of Negligible Risk Intake for Nonthreshold Pesticides

We define the Fraction of Negligible Risk Intake ($FNRI_{ik}$), for pesticide *i* and individual *k*, as follows:

$$FNRI_{ik} = \frac{\text{Dietary intake per kilogram of body weight}_{ik}}{\text{Negligible risk intake}_{i}}. \quad (1)$$

For individual *k*, dietary intake per kilogram of body weight of pesticide *i* from several commodities indexed as *j* is estimated as:

$$\frac{\sum_{j} (\text{Average residue}_{ij} \times \text{Average daily consumption}_{jk})}{\text{Body weight in kilograms}_{k}}. \quad (2)$$

Nonthreshold health effects considered in this study include only carcinogenic effects. Because there is assumed to be no threshold below which there are no effects, negligible risk intake for the average population is defined as the intake that would lead to a 1×10^{-6} (1/1,000,000) probability of cancer over a 70-year lifespan. For children in 1-year cohorts, the 1-year risk level is considered more appropriate and negligible risk is derived as 10^{-6} divided by a 70-year lifespan. This results in a 1-year cancer probability of 14×10^{-9}, or 14 in a billion individuals. The 1-year negligible risk intake is then the intake that would lead to that probability of cancer in 1 year.

To derive these intake levels, we make use of the conventional cancer risk equation and carcinogenic potency estimates from EPA (Engler, 1993):

$$\text{Cancer risk}_{ik} = \text{Dietary intake per kilogram of body weight}_{ik} \times \text{Potency}_{i}. \quad (3)$$

Carcinogenic potency is estimated as the 95-percent upper bound of the dose-response slope from animal studies and is measured in tumors per milligram of toxin per kilogram of body weight consumed daily over a lifetime (National Research Council, 1993). This lifetime potency value is conventionally referred to as Q*. The 1-year potency would then be Q*/70. From these potency values, the negligible-risk intake level for a lifetime and for 1 year can be solved for as the relevant negligible-risk probability level divided by the potency:

$$\text{Negligible risk intake (lifetime)}_{i} = \frac{1 \times 10^{-6}}{Q_i^*}. \quad (4)$$

$$\text{Negligible risk intake (1-year)}_i = \frac{14 \times 10^{-9}}{(Q_i^* / 70)}. \tag{5}$$

The FNRI for nonthreshold effects over a lifetime would then be:

$$\text{FNRI (lifetime)}_{ik} = \frac{\text{Dietary intake per kilogram of body weight}_{ik}}{\text{Negligible risk intake (lifetime)}_i} \tag{6}$$

$$= \frac{(\sum_j \text{Average residue}_{ij} \times \text{Average daily consumption}_{jk}) \times Q_i^* \times 10^{-6}}{\text{Body weight in kilograms}_k}.$$

Similarly, for children, the 1-year FNRI for nonthreshold effects would be:

$$\text{FNRI (1-year)}_{ik} = \frac{\text{Dietary intake per kilogram of body weight}_{ik}}{\text{Negligible risk intake (1-year)}_i} \tag{7}$$

$$= \frac{(\sum_j \text{Average residue}_{ij} \times \text{Average daily consumption}_{jk}) \times (Q_i^*/70) \times (14 \times 10^{-9})}{\text{Body weight in kilograms}_k}$$

Note that the transformations of intake into lifetime and 1-year FNRI yield the same numerical results because the 70 years cancels in the numerator and denominator of the 1-year negligible risk intake level. The difference in interpretation between lifetime and 1-year FNRI, however, is that the 1-year FNRI may reveal the portion of consumers' lifetimes in which relatively large contributions to lifetime risks occur. Thus, pesticides with a 1-year FNRI for children greater than 1 and a lifetime FNRI less than 1 represent cases where contributions to lifetime risk are concentrated in early years, even if they do not exceed negligible risk over a lifetime.

Appendix C: Estimating the Linkage Between Use and Residues

From the nine onfarm-use pesticides examined in "Sources of Dietary Intake of Residues," we found a set of commodities for which residue detections showed sufficient variation that we could estimate functions relating pesticide residue levels to pesticide use. Measured residue levels can be modeled as a function of pesticide use, but, because residue levels cannot be measured below limits of quantitation, the use-residue linkage is best explored by treating measured residues as a limited dependent variable. The probability distribution of positive residues is a conditional distribution (conditional on finding measurable residues). Thus, we estimate Tobit models for several pesticides and classes of pesticides used on various crops, classifying residues first as measurable or not (zero or one) depending on whether the residue was below or at least as great as the limit of quantitation. Then, for the strictly positive quantifiable residues, measured residue levels are included as additional information in the dependent variable.

USDA Pesticide Use Data

The PDP fruit and nut surveys and vegetable surveys were initiated as a series of commodity-specific national surveys to create cross-sectional and time-series data on the farm use of pesticides. These surveys are designed to provide reliable State-level estimates of applications of individual active ingredients, treated acreage, and application rates. States and crops are selected for the survey based on the importance of each crop in terms of acreage and production, and the State's contribution to total acreage. Surveys have covered more than 80 percent of total U.S. acreage in each target crop.

The data for our analysis come from the 1991 Fruit and Nut Chemical Use Survey and the 1992 Vegetable Chemical Use Survey. The fruit and nut survey was conducted in Arizona, Florida, Georgia, Michigan, New York, North Carolina, Oregon, Pennsylvania, South Carolina, Texas, Virginia, and Washington. Growers were personally interviewed to obtain information on chemical applications. USDA's National Agricultural Statistics Service (NASS) collected the chemical use and production practices information beginning in October 1991. Information on a full year of applications was collected after the 1991 harvest through the 1992 harvest. Information was collected separately for bearing and nonbearing acreage. During 1992, the vegetable chemical use survey was conducted in Arizona, Florida, Illinois, Michigan, Minnesota, New Jersey, New York, North Carolina, Oregon, Texas, Washington, and Wisconsin. Each sampled unit was contacted during fall 1992 to obtain production and chemical use data. (Details of survey methodologies are in USDA, NASS, 1992; USDA, NASS, 1991a; and USDA, NASS, 1991b.)

The California State government collected equivalent use information for agricultural production in California, and we included that information to represent pest control practices in California. The California and USDA equivalent use data were merged for estimating statistics we reported below. Because State regulations require growers in California periodically to report all of their pesticide use to the State Environmental Protection Agency, California growers were not asked to provide pesticide use data in the version of the survey we used. Instead, growers supplied their CalEPA ID numbers for reporting pesticide use, and NASS used those numbers to find and extract each farm's pesticide use data from State administrative records. All other input use, practices, output, and economic data were collected by personal interview.

Fruit, nut, and vegetable crops are grown on approximately 2 percent of the total U.S. crop acreage, and production is widely dispersed. Sampling from an area frame would have desirable statistical properties, but, given the mobility of vegetable and small fruit production, is not feasible. Instead, NASS draws samples from a list frame, stratified by State and within States by crop, acreage, farm size, and the number of growers. The main weakness of the list frame is coverage: population inferences from list frame samples are only as accurate as the list is complete, and changes in crops planted, farm operator and operation status will affect the ability of the list to capture the population. The quality of the list frame is maintained by NASS staff in State offices around the country, who update list information annually. The primary criteria used to project final sample size was the ability to provide accurate estimates of chemical use at the State level.

We summarized use data by Agricultural Statistical District (ASD), creating averages for percent of acres treated of each pesticide applied (per ASD) and for the number of times each pesticide was applied per acre (per ASD) during the year. We chose these two variables to represent the extent of use (percent of acres treated) and intensity of use (number of treatments per acre). Both variables were calculated based on practices of the set of pesticide users within an ASD. For example, the percent of apple acres treated with captan in an ASD refers to the set of farms within the ASD that reported using captan on apples. From that subset of farms, we calculated the percent of apple acreage receiving one or more captan treatments. Similarly, the number of applications was calculated from the subset of farms that reported using captan.

The practical importance of subsetting the data in this manner is that the statistics we calculate answer the following question: If captan is used, how much typically remains on apples? Further, we deleted data for which use and residues were both zero, since those observations dominate the data set and, if included, would introduce statistical bias into our estimates.

The date on which pesticides were applied is available for fruit crops not included in the California survey. We constructed a dummy variable for each pesticide, equal to one if any farmer in an ASD applied the pesticide in September or later in the calendar year. If all farmers in the ASD applied the pesticide earlier than September, the variable was set equal to zero. (Data are available only for apple farms.)

Many surveys carried out by NASS are stratified by ASD. With approximately nine ASD's per State, using this stratification controls for some of the locational variation in production practices. We hypothesized that pest pressure and pesticide use would be relatively homogeneous within an ASD.

The mapping of average percent of acres treated, number of acre treatments, and time of last application by ASD onto residue measurements generates a relatively large number of observations. It is, however, a second-best option for linking use and residues. Optimally, fruit and vegetables from a large number of fields or orchards (each homogeneously treated with regard to pesticide use) would have been sampled and residues would have been measured at each stage in the food distribution and marketing system. However, the use- and residue-data programs were carried out independently. Thus, the data will not support a precise estimate of the linkage between use and residues.

Regression Results

Among the nine pesticides selected for estimation (acephate, azinphos-methyl, benomyl, captan, chlorothalonil, dimethoate, ethion, methamidophos, and permethrin), there were five commodities for which detection frequency was high enough to map ASD average-use estimates onto detections. Commodities included apples, celery, green beans, lettuce, and peaches. For most commodity-pesticide pairs, residues were all below the limits of quantitation and detection; these pairs were unsuitable for our estimations.

Results of two types of regressions are presented in appendix tables 1-5. First, linkages between individual pesticide use patterns and pesticide residues for three commodities are presented. These include azinphos-methyl, captan, and benomyl on apples; acephate, chlorothalonil, and permethrin on celery; and methamidophos on green beans. For each commodity, the nine pesticides were aggregated and the residues of nine individual pesticides were regressed on the use of nine pesticides. This latter regression is presented for each commodity.

Measured residues are denoted "concent." Percent of acres treated is denoted "pct_trt" and average number of treatments is "a_times." Time of last application is denoted "time_app." Each regression model is of the following form:

$$\begin{aligned} Concent &= B_0 + B_1(pct\_trt) + B_2(a\_times) + B_3(time\_app) \\ &\quad + U_i \text{ if } concent \geq LOQ \\ &= 0 \text{ otherwise.} \end{aligned} \tag{8}$$

We assumed a normal distribution for the error term U_i. LOQ is the quantitation limit, the smallest amount of each pesticide that could be accurately measured. LOQ varied among the seven testing laboratories and by pesticide.

Log likelihood estimates indicate each regression is highly significant. The p-values for the log likelihood show the probability of incorrectly rejecting the null hypothesis that no parameters differ from zero. All log likelihood p-values are reported as 0.0001, indicating uniformly strong relations between pesticide use variables and concentration levels at all conventional levels of significance. (Note the data for the apple and peach regressions all come from NASS surveys. The vegetable regressions are NASS data blended with California reporting data.)

For each of the five regressions mapping use of the nine pesticides onto concentration, each of the parameter estimates is highly significant. The largest p-value among all the parameter estimates in the five regressions is 0.0326. Parameter p-values indicate the probability of incorrectly rejecting the null hypothesis that the parameter is zero. Expected parameter signs are positive, and only one estimated parameter is negative. The single unexpected sign shows that the linkage is strong, but does not yield perfect predictions.

Compared with regressions including the nine pesticides together, regressions of individual pesticides onto concentration levels have a smaller sample size. While values of p for log likelihood values indicate the use-residue linkage is strong, the pattern of estimated individual parameter signs and significance levels is less compelling than for nine pesticides together. Three individual parameters have negative signs, although none of these is different from zero at the 5-percent significance level. For the benomyl and captan regressions, only the application timing variable fails to take a positive sign and is not significant.

Does pesticide use influence pesticide residues? Positive parameter estimates and p-values that are small relative to conventional significance levels are evidence that use does influence residue detections and residue levels. However, this evidence does not say how much residues might change with changes in pesticide use. To address the latter issue, we calculated elasticities of residue

Appendix table 1—Results from apple regressions

	Nine pesticides		Azinphos-methyl		Benomyl		Captan	
Variable	Estimate	p-value	Estimate	p-value	Estimate	p-value	Estimate	p-value
Intercept	1.0764	0.0001	3.7259	0.0001	2.6060	0.0001	0.3493	0.2902
pct_trt	.0007	.0264	.0007	.5423	.0020	.0113	.0009	.0196
a_times	.5694	.0002	-.4893	.0922	.7029	.0001	1.0893	.0001
time_app	1.3630	.0001	-.0108	.9602	-.3297	.1815	.2356	.4655
Log likelihood	-3,482.9	.0001	-536.5	.0001	-199.0	.0001	-580.9	.0001
Sample size	2,163		398		275		390	

Appendix table 2—Results from celery regressions

	Nine pesticides		Acephate		Chlorothalonil		Permethrin	
Variable	Estimate	p-value	Estimate	p-value	Estimate	p-value	Estimate	p-value
Intercept	1.6555	0.0001	1.3252	0.0225	2.0704	0.0001	2.4088	0.0009
pct_trt	.0017	.0001	.0065	.0013	.0028	.1662	.0014	.1855
a_times	.1176	.0001	.1177	.7553	.0874	.0002	.2685	.5173
Log likelihood	-3,161.7	.0001	-699.7	.0001	-740.0	.0001	-670.9	.0001
Sample size	1,756		383		425		412	

Appendix table 3—Results from green bean regressions

	Nine pesticides		Methamidophos	
Variable	Estimate	p-value	Estimate	p-value
Intercept	2.0373	0.0001	0.9096	0.2734
pct_trt	-.0141	.0001	.0034	.8204
a_times	.1589	.0001	.4610	.0027
Log likelihood	-1,635.2	.0001	-338.3	.0001
Sample size	960		175	

Appendix table 4—Results from lettuce regressions

	Nine pesticides	
Variables	Estimate	p-value
Intercept	0.7206	0.0001
pct_trt	.0042	.0001
a_times	.1211	.0001
Log likelihood	-4,071.6	.0001
Sample size	2,810	

Appendix table 5—Results from peach regressions

	Nine pesticides	
Variable	Estimate	p-value
Intercept	0.5126	0.0326
pct_trt	.0045	.0005
a_times	.7809	.0001
Log likelihood	-303.9	.0001
Sample size	190	

levels with respect to percent of acres treated and average number of treatments per acre. Elasticity is defined as:

$$\frac{\partial log(y)}{\partial log(x)} = \frac{\partial y}{\partial x} \frac{E(x)}{E(y)}. \qquad (9)$$

In our case, elasticity with respect to percent of acres treated (average number of treatments) is the percentage increase in residue concentration from a 1-percent increase in percent of acres treated (average number of treatments). Two elasticities were calculated for each commodity and each pesticide (or set of nine pesticides) as follows:[24]

$$Elasticity_{pct\_trt} = \hat{B}_1 \frac{Average\ pct\_trt}{\bar{y}} \qquad (10)$$

$$Elasticity_{a\_times} = \hat{B}_2 \frac{Average\ a\_times}{\bar{y}}$$

where E(y) is approximated by:

$$\bar{y} = \hat{B}_0 + \hat{B}_1\ pct\_trt + \hat{B}_2\ a\_times.$$

In this case, the regression accounts for the adjustment to the mean value made when only a small percentage of observed concentration values are above LOQ. These elasticities show how large a percentage increase in residues could be expected from a 1-percent change in the measures of average use.

As one would expect, all the elasticities are less than 1.0 (app. table 6). An elasticity of 1.0 would imply, for example, that a 1-percent increase in the number of acre treatments would increase concentration levels by 1 percent. Elasticities less than 1.0 indicate that not all the additional pesticide applied finds its way into the food supply. In fact, 10 of the 24 estimated elasticities are 0.1 or less, indicating pesticide concentration levels change by less than 10 percent of increased use. Only three estimated elasticities are greater than 0.5. These low elasticities reflect the generally low levels of detections relative to use.

The strength of the linkage between use and residues is underestimated by the regression diagnostics reported here. There are no variables that directly interconnect the use and residue surveys. The ASD averages we calculated imprecisely connect the surveys. Because we used ASD averages rather than farm-level pesticide measures, some information had to be discarded. For some AMS samples, recorded detections could not be matched to pesticide use within the ASD. This occurs because small samples of farms within each ASD make it possible to miss sampling all the farms that use some pesticides. So long as information is discarded, we know that the linkage has not been fully established.

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[24]Note that these elasticities are not adjusted for the probability of a positive residue concentration. Thus, they refer only to the portion of the relationship where residue concentrations are positive.

Appendix table 6—Elasticities of residue levels with respect to pesticide use variables

Commodity	Pesticide	Elasticity with respect to percent of acres treated	Elasticity with respect to average number of treatments per acre
Apples	Nine pesticides	0.0254	0.3650
	Azinphos-methyl	.0418	-.1841
	Benomyl	.0079	.2199
	Captan	.0557	.7573
Celery	Nine pesticides	.1776	.0828
	Acephate	.3616	.0565
	Chlorothalonil	.2238	.0861
	Permethrin	.1384	.0950
Green beans	Nine pesticides	-.2079	.2148
	Methamidophos	.0605	.5409
Lettuce	Nine pesticides	.3169	.1051
Peaches	Nine pesticides	.1354	.6407