Food Additives and Contaminants, 2002, Vol. 19, No. 5, 427–446

Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets

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(Received 22 August 2001; revised 26 October 2001; accepted 30 October 2001)

An analysis of pesticide residue data was performed to describe and quantify differences between organically grown and non-organic fresh fruits and vegetables. Data on residues in foods from three different market categories (conventionally grown, integrated pest management (IPM)-grown/no detectable residues (NDR), and organically grown) were compared using data from three test programmes: The Pesticide Data Program of the US Department of Agriculture; the Marketplace Surveillance Program of the California Department of Pesticide Regulation; and private tests by the Consumers Union, an independent testing organization. Organically grown foods consistently had about one-third as many residues as conventionally grown foods, and about one-half as many residues as found in IPM/NDR samples. Conventionally grown and IPM/NDR samples were also far more likely to contain multiple pesticide residues than were organically grown samples. Comparison of specific residues on specific crops found that residue concentrations in organic samples were consistently lower than in the other two categories, across all three data sets. The IPM/NDR category, based on data from two of the test programmes, had residues higher than those in organic samples but lower than those in conventionally grown foods.

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Keywords: pesticide residues, organic foods, integrated pest management-grown foods, contaminants

Introduction

Reducing dietary exposure to pesticides—particularly in infants' and children's foods—is a major risk-management goal of government regulatory agencies, the food industries and the agricultural community, and many consumers prefer to buy foods with reduced residues (Hartman 1996, US EPA 1996). In the USA, passage of the Food Quality Protection Act (FQPA) in 1996 gave the Environmental Protection Agency (EPA) a mandate to review and strengthen safety limits for pesticide residues in foods. Recent and expected regulatory actions will restrict or phase out high-risk uses of and establish lower safe exposure levels for many pesticides (US EPA 2000a–c, Groth *et al.* 2001), which in turn will further stimulate interest in agricultural practices that can help achieve lowered exposure limits. In that context, quantitative measures of the effects of current production practices on residues should be widely useful.

Organic farming, which prohibits most synthetic pesticides and restricts the use of permitted natural pesticides, appears to offer foods essentially free of pesticide residues, and consumers perceive organic foods to be a lower-residue choice (Hartman 1996). In recent years, a new market sector consisting of produce marketed as produced with integrated pest management (IPM grown) and foods certified as containing 'no detectable residues' (NDR) has arisen, and currently competes with the organic category as a lower-residue alternative to conventionally grown fruits and vegetables.

However, few independent scientific studies have directly compared residues in these three market categories of foods. In part because of this lack of published data, public debate of this issue has been

Food Additives and Contaminants ISSN 0265–203X print/ISSN 1464–5122 online
http://www.tandf.co.uk/journals
DOI: 10.1080/02652030110113799

largely subjective and often uninformed. In particular, advocates who question organic techniques have often asserted that organic foods are as contaminated with pesticide residues as conventionally grown foods (Avery 2000, Stossel 2000, Milloy 2001).

In the past few years, EPA's FQPA implementation efforts and related residue-monitoring programmes at the US Department of Agriculture (USDA) have generated much new and more accurate data on dietary pesticide exposure (US EPA 2000d). Sufficient data currently exist to support rigorous comparison of residues in organic, IPM-grown/NDR and conventional foods.

Before presenting such an analysis, it is useful to define what we mean by 'organic', 'IPM', 'NDR' and 'conventionally grown' foods. For our purposes, conventionally grown foods are defined, by default, as those marketed with no claim that would qualify them for one of the other categories. While we recognize that many non-organic or conventional farmers to some extent use IPM and even organic pest-management techniques, we classified all produce not marketed with a label or point-of-sale claim that identifies it otherwise, as conventionally grown. If any misclassifications resulted from this assumption, they would tend to reduce apparent differences between conventionally grown produce and presumably lower-residue alternatives.

Pesticides used by conventional growers (and others) are subject to multiple layers of federal and state regulation, intended to protect farm workers, ensure food safety, and minimize ecological effects of pesticide applications. Pesticides must be registered with the EPA to be used on crops, and the EPA establishes tolerances (legal maximum concentration limits) for residues of each chemical on each crop for which it is registered. About 600 different pesticide active ingredients are registered with the US EPA, and about 10 000 food-use tolerances have been established. Pesticide use is regulated in terms of permitted crops that can be treated with any given chemical, amounts that may be applied, and timing of applications. Applications may be restricted to allow an interval between spraying and harvest, to allow residues to dissipate to safe levels before the treated food reaches the consumer.

'Organic' foods are defined by the USDA's recently published final standard of identity for this food category (USDA 2000a). National regulations were developed to bring consistency to more than 40 different existing state and private sets of standards. In general, organic agriculture produces food without use of synthetic chemicals. Some organic fruit and vegetable farmers, especially larger-scale producers, routinely apply certain natural pesticides derived from botanical and mineral sources, and biological preparations such as those containing the microbial insecticide *Bacillus thuringiensis*. (The national organic standard defines 'synthetic' pesticides rather precisely; pest-control substances outside those criteria are, essentially by definition, 'natural' pesticides.) Organic farmers producing small grains, dry beans, corn, soybeans and forage crops typically do not apply any pesticides. A few synthetic pesticides are permitted in organic agriculture; these are generally exempt from an EPA tolerance (legal limit on residues in foods) because of their low toxicity, expected lack of ecological or health risk, lack of expected dietary residues, or all of these reasons. The synthetic pesticides most commonly used in organic production include sulphur, copper-based fungicides, oil sprays, insecticidal soaps, and insect pheromones (Walz and Scowcroft 2000, OMRI 2001).

Organic farmers are allowed to use permitted pesticides only after non-pesticide interventions have failed to control pests. Organic standards generally restrict applications of botanicals and allowed synthetic pesticides, to minimize impacts on the environment and to reduce the likelihood of residues after harvest in edible plant parts (OMRI 2001).

The 'IPM' category encompasses many pest management technologies and systems now in use, which share a prevention-based approach. IPM systems rely heavily on scouting fields for pest population levels and linking pesticide applications or other interventions to empirical evidence of economic damage. IPM interventions include biological methods (such as natural predators, parasites and pathogens) to keep pest populations within tolerable limits and multiple tactics to promote vigorous crop growth and strong plant defence mechanisms (Benbrook *et al.* 1996). Current IPM systems range from some that are close to organic systems in their reliance on bio-intensive and cultural practices and avoidance of synthetic pesticides, to others that rely mainly on synthetic chemical biocides for pest management (Benbrook *et al.* 1996, Benbrook 2000, National Research Council 2000).

An increasing number of produce-labelling programmes aimed at environmentally concerned consumers market foods as 'IPM-grown'. Typically these programmes require farmers to use certain recognized, biologically based and prevention-oriented IPM practices (Benbrook 2000), and some strictly limit or prohibit the use of specific high-risk pesticides. Myriad 'green labels' have begun appearing on foods in recent years, and the potential for consumer confusion about the meaning and credibility of the different labels has increased as well. To address this concern, Consumers Union (CU, an independent consumer product-testing and publishing organization in the USA) has developed an Internet database with descriptions and evaluations of the standards and certification procedures behind various food ecolabels (Consumers Union 2001).

Other foods are marketed with a 'no detectable (pesticide) residues' (NDR) claim. NDR foods are tested to certify that pesticide residues fall below a set limit, usually 0.05 parts per million (ppm) (Scientific Certification Systems 2001). For this analysis, we considered NDR and IPM-grown claims substantially equivalent and combined them into a single category we call 'IPM/NDR'.

Materials and methods, and data sources

We analysed pesticide residue data from three testing programmes, comparing the frequency of detection and levels of pesticides found in foods produced with different farming systems. We obtained residue data from the USDA's Pesticide Data Program (PDP) (USDA 2000b), from the California Department of Pesticide Regulation (DPR's) Marketplace Surveillance Program (California EPA 1999), and from private tests on four selected foods carried out by CU (1998).

We obtained and analysed PDP residue data for tests done in 1994–99. The PDP tests a small and changing selection of foods each year and samples each food intensively, seeking accurately to represent the US market for the tested foods. Recent PDP tests have included a few samples each year identified at the point of sale as organically grown or carrying an IPM/NDR claim. In the 6 years of data obtained, the PDP tested 26 893 samples of fresh fruits and vegetables. Of those, 127 were identified as organically grown, and 195 were marketed with IPM/NDR claims; the rest (26 571 samples) carried no recorded market claim and were classified for our analysis as conventionally grown.

We obtained California DPR data for the test years 1989–98. DPR sampling in those 10 years included 1097 identified organic samples out of 67 154 total samples tested. The DPR programme does not identify samples with IPM or NDR market claims.

CU tested just four foods (apples, peaches, green peppers, tomatoes), but the tests were designed specifically to compare residue profiles of foods from the three market sectors. CU's tests included 67 organically grown samples, 45 IPM/NDR samples and 68 samples with no market claim.

Raw data were obtained from USDA, DPR, and CU and converted to Access data files keyed to unique sample numbers. A series of queries were then used to compute the number of samples, number with residues, number of residues per positive sample, mean residue levels in positive samples, and other results reported here. A statistician performed various analyses to determine the statistical significance of observed differences.

Detailed descriptions of the sampling and analytical methods used in the PDP and DPR testing programmes are available in published reports and on government web sites (California EPA 1999, US FDA 1999, 2000a, USDA 2000b, California DFA 2001). Discussion here focuses on selected characteristics of each data set most relevant to our analysis.

The PDP, established in 1990, is designed to provide estimates of pesticide residue levels and distribution in the US food supply, to support dietary exposure assessments by the EPA and other regulatory authorities. Fresh fruits and vegetables purchased at retail comprise $> 80\%$ of PDP samples. Analytical methods include standard multiresidue methods (MRMs) used to screen for families of chemicals, and selected single-residue methods for individual pesticides of interest not picked up by the MRMs. Positive findings are verified with appropriate confirming methods. The low limits of detection (LODs) and rigorous quality-assurance procedures of the PDP produce what the EPA regards as the best pesticide residue data available to support its risk assessments (US EPA 2000a–c).

PDP data differ markedly from 'farm gate' testing by the US Food and Drug Administration (FDA) and state departments of agriculture to enforce pesticide labels and tolerance limits (US FDA 2000b). LODs in enforcement testing are typically much higher than PDP LODs. The main goal of enforcement sampling is to detect residues over tolerance limits and divert foods with illegal residues from the human food supply. This requires rapid turnaround of samples and precludes using the highly sensitive methods and multiple layers of quality control built into the PDP. We relied on PDP data, and did not include FDA data, both because of the PDP's better detection sensitivity and more intensive sampling and because the FDA does not record market claims for the foods it samples.

The DPR data set, by contrast, is from the largest state enforcement programme in the US. As such, these data are subject to some of the limitations just described above for the FDA data. However, DPR has tested organic foods as a distinct market sector since 1989, and has more data on residues in organic samples than any other available source.

The DPR programme collects samples of produce at points of entry, packing sites, wholesale facilities, and in retail outlets. Sampling within a food commodity may be weighted based on relative intensity of pesticide use on a crop and on a history of violations from a region or particular supplier, and the number of imported samples tested is greater than imports' relative market share. Thus, the DPR sampling is not precisely representative of the market. Samples are analysed by a California Department of Food and Agriculture (CDFA) laboratory using CDFA's MRMs and selected single-residue methods for priority pesticides. Methodologies and procedures for detecting pesticide residues have improved in general over the years; and within the DPR data set, advances in analytical methodology, particularly in 1991 and 1996, increased the number of detectable pesticides and decreased LODs (California EPA 1999).

CU's tests were carried out by a contract laboratory whose analytical methods closely parallel those used by the PDP. Standard MRMs were used, and specific methods were added for the ethylene bis-dithiocarbonate (EBDC) fungicides and benomyl (another fungicide), on selected foods. The LODs for CU's tests were very similar to those reported by the PDP. CU's testing focused on exploring differences in residue patterns between organically grown, IPM/NDR-labelled and conventionally grown apples, peaches, green peppers and tomatoes. These four foods were chosen for testing because they are known to have a higher than average likelihood of containing pesticide residues. Samples were bought in a variety of retail outlets in five cities across the USA during summer and Fall of 1997 and shipped to the contract laboratory for analysis. In all, 60 samples of apples, 30 of peaches, 30 of peppers and 60 of tomatoes were tested. Roughly equal numbers of organic, IPM/NDR and conventional samples were tested for each food, although IPM/NDR-labelled peppers and peaches were in limited supply.

Each of these three sets of residue data has strengths and weaknesses. The PDP provides the highest quality data, and its extensive sampling best represents the US market for tested foods. But foods specifically identified as organically grown are underrepresented in the PDP data set, accounting for $< 0.5\%$ of all samples. Samples identified as IPM/NDR are only slightly more numerous. Small numbers of samples of specific foods sold as organic or IPM/NDR tested in any given year limit analytical possibilities. The PDP also does not test for some important residues included in CU's and DPR's testing—in particular, the EBDC fungicides.

The DPR programme also samples the market very broadly, although not precisely representatively. Within the DPR data set, the percentage of organic samples is closer to the estimated US market share for organic (about 2% of fresh produce according to USDA 2000a); however, DPR does not specifically identify samples with IPM/NDR claims. DPR analytical methods historically have had less sensitive detection limits, and have therefore detected fewer residues overall than methods used by PDP and CU.

The PDP and DPR data taken together provide a broad view across a wide array of different fruits and vegetables, purchased over a multi-year period and from a large, representative sample of locations within the USA and California, respectively. However, neither data set offers the depth of sampling needed for convincing comparisons of residues in individual foods as a function of market claim. The CU tests, in contrast, looked at just four foods purchased in a few locations over a short period. However, CU sampled each food from each market sector in comparative depth; the CU data generally include more organically grown and IPM/NDR samples of each tested food than the larger PDP and DPR data sets can provide.

Collectively, the three data sets offer enough breadth to support general comparisons of residue patterns across a wide range of different foods by market claim, and enough depth of sampling for a few foods to support confidence in the validity of observed differences in residue patterns in those specific foods.

One obvious gap in all three data sets is the lack of testing for residues of botanical insecticides, such as rotenone and pyrethrum, and for residues of other pesticides permitted for use on organic produce, such as copper-based fungicides. The EPA and FDA do not consider most pesticides used in organic production to pose residue-related health risks, and they are therefore not a priority to analyse. Botanical insecticides also tend to degrade rapidly in the environment into relatively non-toxic by-products. For these reasons, and perhaps also because of the relatively small (although rapidly growing) market share represented by organic foods in the USA, there has been little demand here for analytical methods for residues of the natural insecticides. Few or no confirmed methods are available for these residues; consequently, they are generally not tested for by programmes and laboratories that routinely monitor foods for pesticides.

Analyses and results

We analysed the three pesticide residue data sets to explore differences in the frequency and levels of pesticides in conventional, organic, and IPM/NDR foods. We tested three hypotheses.

- Organic produce is less likely to have detectable pesticide residues than either IPM/NDR or conventionally grown produce.
- Among samples with any residues, conventional and IPM/NDR foods are more likely to have multiple residues in a given sample than organic foods are.
- When present, residues in organic foods are likely to be at lower levels than those in non-organic foods.

When making residue comparisons, care must be taken in interpreting residues of persistent organochlorine (OC) insecticides banned many years ago. Examples include DDT, aldrin, dieldrin, heptachlor, chlordane and toxaphene (Edwards 1966). Carrots, potatoes and other root crops, cucurbits such as squashes and cucumbers, and selected leafy greens, such as spinach, tend to absorb OC residues from soils and to translocate them into edible crop tissues (Nash 1974, Mattina *et al.* 2000, Groth *et al.* 2001).

While farmers can do little to eliminate these persistent residues from soils, they can select crops that are less likely to accumulate OCs from contaminated fields. Additional steps can be taken as well. At least one organic certifier requires fields to be tested for OCs prior to certification (Oregon Tilth 1999) and applies standards based on relationships between OC residues in soils and in specific crops, to ensure that OC residues in harvested foods are below limits of detection (Tracy 1992, MacCormack *et al.* 1993). Nevertheless, OC residues are ubiquitous and will remain in soils and contaminate both conventional and organic produce for decades. Our analysis examined OC residues separately from other residues, to isolate this effect of general environmental contamination from differences associated with current production methods.

Frequency of positive samples

Our first hypothesis is that organically grown food samples should have detectable pesticide residues less often than do conventionally grown or IPM/NDR samples. The data in tables 1–4 were analysed using Cochran–Mantel–Haenszel (CMH) methods to determine whether there were statistically significant differences in the frequency of detection of residues among the three market categories of foods.

Table 1 shows the number and per cent of samples of fresh fruits and vegetables found to contain one or more pesticide residues in PDP tests from 1994 to 1999, arrayed by crop and market claim. PDP tested 26 571 samples of conventionally grown (no market claim) fresh fruits and vegetables in those 6 years. Of these, 73% contained at least one pesticide residue; 82% of fruit samples; and 65% of vegetables contained one or more residues. Celery, pears, apples, peaches and strawberries all had residues $> 90\%$ of their samples.

Over the same period, the PDP tested 195 samples of fresh fruit and vegetables marketed with an IPM or NDR claim; 47% contained one or more residues, with modest differences between fruits and vegetables. The difference in overall per cent positive between conventional and IPM/NDR samples is highly statistically significant ($p < 0.001$). A total of 193 distinct pesticide residues (including metabolites and isomers)

Table 1. Frequency of pesticide residues in fresh fruits and vegetables by market claim: Pesticide Data Program, 1994–99.

	Organic			IPM/NDR			No market claim		
	Number of samples	Number of positives	Per cent positive	Number of samples	Number of positives	Per cent positive	Number of samples	Number of positives	Per cent positive
Fruits									
Apples	1	0	–	20	10	50	2294	2150	94
Bananas	1	0	–	11	4	36	1134	658	58
Cantaloupe	3	1	33	0	0	–	1242	603	49
Grapes	4	1	25	12	4	33	1891	1481	78
Oranges	7	1	14	13	7	54	1899	1616	85
Peaches	2	1	50	10	5	50	1107	1035	93
Pears	4	1	25	0	0	–	1777	1689	95
Strawberries	8	2	25	5	5	100	1268	1160	91
All fruit	30	7	23	71	35	49	12 612	10 392	82
Vegetables									
Broccoli	2	1	50	18	7	39	674	171	25
Carrots	18	4	22	21	7	33	1874	1359	73
Celery	2	1	50	4	2	50	173	166	96
Cucumbers	10	2	20	1	0	–	723	533	74
Green beans	3	0	–	24	10	42	1169	689	59
Lettuce	3	1	33	21	8	38	860	428	50
Potatoes	4	1	25	20	10	50	1386	1117	81
Spinach	19	9	47	7	7	100	1645	1380	84
Sweet bell peppers	11	1	9	0	0	–	722	500	69
Sweet potatoes	6	1	17	1	1	100	1557	999	64
Tomatoes	10	0	–	5	4	80	1971	1254	64
Winter squash	9	1	11	2	0	0	1205	497	41
All vegetables	97	22	23	124	56	45	13 959	9093	65
All fresh foods	127	29	23	195	91	47	26 571	19 485	73

'IPM/NDR' includes 'No Detectable Residues' samples with the market claims 'PDP No Pesticides Detected', 'PDP Pesticide Free', 'Speciality No Pesticides Detected' and 'Speciality Pesticide Free'. These market claims are typically accompanied by a requirement that integrated pest management systems also be used.
'Organic' includes samples with the market claims 'PDP Organic' and 'Speciality Organic'.

were found in the 91 positive samples of IPM/NDR foods; 73 residues were at levels below the typical NDR standard of 0.05 ppm. Accordingly, about two-thirds of the residues found in IPM/NDR foods sampled by PDP do not meet the most common standard for 'NDR', although some might meet different criteria applied by various IPM-labelling programmes.

Only 23% of PDP organic samples contained one or more residues. In this data set, organically grown samples contained residues about one-third as often as conventional samples did, and half as often as IPM/NDR samples did. Both of these differences are highly statistically significant ($p < 0.001$).

Differences in percents positive between organic and conventional samples of apples, grapes, oranges, peaches, pears, strawberries, carrots, celery, cucumbers, green beans, potatoes, spinach, peppers, sweet potatoes and tomatoes were all also statistically significant, despite the small number of organic samples for each individual food. The frequency of residues in IPM/NDR samples was statistically significantly lower than in conventional samples for 10 of these 15 foods—all but strawberries, cucumbers, spinach, sweet potatoes and tomatoes.

If persistent organochlorine pesticides are removed from the comparison, the results change dramatically, particularly for vegetables. Table 2 repeats the comparisons of PDP data in table 1, but with residues of banned OCs excluded. Banned OCs accounted for about 40% of positive organic samples in table 1. With those contaminants excluded, the positive fraction of organic vegetables drops to 9%. IPM/NDR and conventionally grown vegetable samples show only slight declines in per cent positive, and the per cent of positive fruit samples changes little in any market category when OC residues are excluded. Overall, excluding OC residues decreases the fraction of positive organic samples from 23 to 13%. As in table 1, the differences among market claim categories shown in table 2 are all highly statistically significant ($p < 0.001$).

As a practical matter, OC residues in organic foods do deserve to be counted, especially from the consumer's perspective. However, this analysis suggests the extent to which the residues detected in many organic foods are associated with persistent environmental contamination, independent of contemporary production methods.

Table 3 compares the frequency of residues detected in organic and conventional foods sampled by the California DPR testing programme from 1989 to 1998. Because the DPR tests a very large number of different foods, only aggregated data, arranged by test year, are displayed. Over the 10 years analysed, DPR tested 66 057 samples of conventional produce, of which 31% contained at least one residue. Only 6.5% of 1097 DPR organic samples tested positive. This difference is highly statistically significant ($p < 0.001$). The higher LODs in DPR testing are the primary reason why the percents positive are so much lower here than in the PDP data, but the relative frequencies of detection in the two categories are highly comparable.

Table 3 also shows an apparent trend toward increasingly frequent detection of residues in both organic and conventional samples in recent years. Advances in analytical methodology used by DPR, particularly in 1991 and 1996, decreased LODs for many residues

Table 2. Frequency of pesticide residues in fresh fruits and vegetables by market claim, excluding the residues of banned organochlorines: Pesticide Data Program Results, 1994–99.

	Organic			IPM/NDR			No market claim		
	Number of samples	Number of positives	Per cent positive	Number of samples	Number of positives	Per cent positive	Number of samples	Number of positives	Per cent positive
Fruits									
Apples	1	0	–	20	10	50	2294	2150	94
Bananas	1	0	–	11	4	36	1134	658	58
Cantaloupe	3	1	33	0	0	–	1242	514	41
Grapes	4	1	25	12	4	33	1891	1477	78
Oranges	7	1	14	13	7	54	1899	1616	85
Peaches	2	1	50	10	5	50	1107	1035	93
Pears	4	1	25	0	0	–	1777	1689	95
Strawberries	8	2	25	5	5	100	1268	1148	91
All fruit	30	7	23	71	35	49	12 612	10 287	82
Vegetables									
Broccoli	2	1	50	18	7	39	674	170	25
Carrots	18	0	0	21	7	33	1874	1137	61
Celery	2	1	50	4	2	50	173	166	96
Cucumbers	10	1	10	1	0	–	723	499	69
Green beans	3	0	–	24	10	42	1169	684	59
Lettuce	3	1	33	21	8	38	860	426	50
Potatoes	4	1	25	20	10	50	1386	1078	78
Spinach	19	2	11	7	7	100	1645	1212	74
Sweet bell peppers	11	1	9	0	0	–	722	500	69
Sweet potatoes	6	1	17	1	1	100	1557	986	63
Tomatoes	10	0	–	5	2	40	1971	1253	64
Winter squash	9	0	–	2	0	0	1205	354	29
All vegetables	97	9	9	124	54	44	13 959	8465	61
All fresh foods	127	16	13	195	89	46	26 571	18 752	71

See notes to table 1.
Residues of long-banned organochlorine insecticides and their metabolites are not included: DDT, DDE, DDD, heptachlor epoxide, hexachlorobenzene, aldrin and dieldrin.

Table 3. Frequency of residues in organic and conventional samples tested by the Calfornia Department of Pesticide Regulation, 1989–98.

		Organic			No market claim		
Year	Total number of samples	Number of samples	Number of positives	Per cent positive	Number of samples	Number of positives	Per cent positive
1989	9387	196	7	3.6	9191	2060	22.4
1990	8275	194	5	2.6	8081	1660	20.5
1991	7443	82	5	6.1	7361	1856	25.2
1992	7307	40	4	10.0	7267	2271	31.3
1993	6056	22	0	0.0	6034	2165	35.9
1994	5465	45	2	4.4	5420	1838	33.9
1995	5498	41	3	7.3	5457	1943	35.6
1996	6070	144	20	13.9	5926	2190	37.0
1997	5635	155	15	9.7	5480	2025	37.0
1998	6018	178	10	12.8	5840	2402	41.1
All years	67 154	1097	71	6.5	66 057	20 410	30.9

and increased the number of detectable pesticides. This enhanced analytical sensitivity, rather than changes in pesticide use or other variables, is the most likely explanation for the observed increase in the frequency of detectable residues.

We also analysed the DPR data with residues of banned organochlorines excluded. Results were similar to those seen in table 2. Crops that accumulate OCs from soil occasionally had these residues, whether organic or conventional. Excluding the OCs reduced the per cent positive for the organic samples more noticeably than for the conventional samples. Because of the higher LODs in the DPR tests and the smaller initial per cent of positive samples, the exclusion of OCs here had less effect than in the PDP data, but the overall picture was quite consistent.

Table 4 displays the frequency of residues found in the four crops tested by Consumers Union. For all four foods combined, 79% of conventional samples, 51% of IPM/NDR samples and 27% of organic samples had one or more residues. These overall differences are highly statistically significant ($p < 0.001$). Differences between the percents positive for organic and conventionally grown samples of all four individual foods were also statistically significant. The differences between conventional and IPM/NDR samples were significant for peppers and tomatoes, but not for apples and peaches. Positive percentages for conventionally grown individual foods in CU's limited sampling were very similar to those found by the PDP with much larger, geographically and temporally more representative sampling of these foods.

Table 4. Frequency of residues in fresh apples, peaches, peppers and tomatoes by market claim: Consumers Union testing.

	Organic			IPM/NDR			No market claim		
	Number of samples	Number of positives	Per cent positive	Number of samples	Number of positives	Per cent positive	Number of samples	Number of positives	Per cent positive
Apples	20	7	35	20	19	95	20	20	100
Peaches	12	4	33	5	3	60	13	11	85
Total fruit	32	11	34	25	22	88	33	31	94
Peppers	10	0	0	6	0	0	14	10	71
Tomatoes	25	7	28	14	1	7	21	13	62
Total vegetables	35	7	20	20	1	5	35	23	66
Total for the four foods	67	18	27	45	23	51	68	54	79

Multiple residues

Multiple pesticide residues are commonly detected in several widely consumed fruits and vegetables. Samples of many foods commonly contain two, three or four different residues, and much higher numbers are not uncommon. For example, DPR testing found 14 residues in a single green pepper sample; the PDP has found as many on one spinach sample and 13 residues in a sweet bell pepper sample. US-grown apples tested by PDP in 1996 were more likely to have four or more residues than they were to have three or less, and were more than three times as likely to have seven or more residues as they were to have no residues. Multiple residues are also routinely encountered on peaches, spinach, strawberries, pears, green peppers, cucumbers and celery, based on PDP results.

Following a mandate of the FQPA, EPA has been assessing cumulative exposures to pesticides that share a common mechanism of toxic action, such as the organophosphate (OP) insecticides. A recent dietary exposure assessment for the OPs compiled by the US EPA (2000c) reported that 998 (44%) of 2289 samples of apples tested by PDP from 1994 to 1996 contained at least one OP residue. Of the positive samples, 419 (42%) had two OP residues, 67 (7%) had three, and seven (0.7%) had four. Overall, $> 20\%$ of apple samples contained two or more OP residues. The same EPA analysis found that multiple OP residues were even more prevalent in canned and frozen green beans, and in wheat grain, than in apples.

Our second hypothesis posits that when residues are present, organically grown samples are less likely to contain multiple residues than conventionally grown or IPM/NDR samples are. Table 5 compares the frequency of samples with multiple residues in each market category by each of the three test programmes. Numbers of residues in distinct samples of 20 different foods (summarized in table 6) were analysed using CMH methods and a linear mixed model, to determine whether there were statistically significant differences in the average number of residues in samples of each market category for each food.

In the PDP tests, 46% of conventional samples, 24% of IPM/NDR samples and just 7% of organic samples had multiple residues. DPR found multiple residues in 12% of conventional samples and about 1% of organic samples. CU found multiple residues in 62% of conventional, 44% of IPM/NDR and only 6% of its organic samples. These differences are all highly statistically significant ($p < 0.001$).

Further detail on numbers of residues in specific foods is provided in table 6. PDP tests found 3.0 residues on average in conventional apples, 2.9 residues on conventionally grown peaches, 2.6 residues on conventional celery, strawberry, and sweet bell pepper samples, and 2.3 residues on conventional pears. Organic samples had no residues or a single residue in 15 of 20 cases. One sample of 'organic' sweet bell peppers imported from Mexico contained six residues. (This sample was clearly mislabelled, and not organically grown; see table 7). The IPM/NDR samples, while intermediate between organic and conventionally grown produce in the odds of having any residues at all, had almost as many residues in positive samples as conventional samples did for most foods, and in a few cases, had more. The lower overall frequency of multiple residues in the IPM/NDR category relative to conventional produce appears to reflect the lower overall per cent positive for this sector, more than fewer residues per positive sample.

Table 5. Samples containing multiple residues by market claim in three datasets.

	Organic			IPM/NDR			No market claim		
Data set	Number of samples	Samples with multiple residues	Per cent samples multiple residues	Number of samples	Samples with multiple residues	Per cent samples multiple residues	Number of samples	Samples with multiple residues	Per cent samples multiple residues
PDP (20 crops)	127	9	7.1	195	46	23.6	26 571	12 102	45.5
DPR (19 crops)	609	8	1.3	n.a.	n.a.	n.a.	34 003	4 055	11.9
CU (four crops)	67	4	6.0	45	20	44.4	68	42	62

n.a., Not applicable.

Table 6. Number of pesticide residues found by market claim and average number of residues in fresh foods tested by the USDA's Pesticide Data Program, 1994–99.

	No. of samples tested	No. of positive samples	No. of unique residues found	Residues per sample tested	Residues per positive sample
Apples					
No market claim	2294	2150	6967	3.0	3.2
Organic	1	–	–	–	–
IPM/NDR	20	10	38	1.9	3.8
Bananas					
No market claim	1134	658	728	0.6	1.1
Organic	1	–	–		
IPM/NDR	11	4	4	0.4	1.0
Broccoli					
No market claim	674	171	190	0.3	1.1
Organic	2	1	1	0.5	1.0
IPM/NDR	18	7	7	0.4	1.0
Cantaloupe					
No market claim	1242	603	940	0.8	1.6
Organic	3	1	1	0.3	1.0
IPM/NDR	–	–	–		
Carrots					
No market claim	1874	1359	2655	1.4	2.0
Organic	18	4	4	0.2	1.0
IPM/NDR	21	7	10	0.5	1.4
Cucumbers					
No market claim	723	533	1421	2.0	2.7
Organic	10	2	4	0.4	2.0
IPM/NDR	1	–	–		
Celery					
No market claim	173	166	449	2.6	2.7
Organic	2	1	1	0.5	1.0
IPM/NDR	4	2	3	0.8	1.5
Grapes					
No market claim	1890	1481	3536	1.9	2.4
Organic	4	1	1	0.3	1.0
IPM/NDR	12	4	8	0.7	2.0
Green beans					
No market claim	1169	689	1504	1.3	2.2
Organic	3	–	–		
IPM/NDR	24	10	33	1.4	3.3
Lettuce					
No market claim	860	428	792	0.9	1.9
Organic	3	1	1	0.3	1.0
IPM/NDR	21	8	10	0.5	1.3
Oranges					
No market claim	1899	1616	2996	1.6	1.9
Organic	7	1	1	0.1	1.0
IPM/NDR	13	7	13	1.0	1.9
Peaches					
No market claim	1107	1035	3233	2.9	3.1
Organic	2	1	1	0.5	1.0
IPM/NDR	10	5	12	1.2	2.4

(*continued*)

Table 6—concluded

	No. of samples tested	No. of positive samples	No. of unique residues found	Residues per sample tested	Residues per positive sample
Pears					
No market claim	1777	1689	4091	2.3	2.4
Organic	4	1	2	0.5	2.0
IPM/NDR	–	–	–		
Potatoes					
No market claim	1386	1117	1806	1.3	1.6
Organic	4	1	1	0.3	1.0
IPM/NDR	20	10	20	1.0	2.0
Spinach					
No market claim	1645	1380	3193	1.9	2.3
Organic	19	9	16	0.8	1.8
IPM/NDR	7	7	18	2.6	2.6
Strawberries					
No market claim	1268	1160	3326	2.6	2.9
Organic	8	2	3	0.4	1.5
IPM/NDR	5	5	12	2.4	2.4
Sweet bell peppers					
No market claim	722	500	1854	2.6	3.7
Organic	11	1	6	0.5	6.0
IPM/NDR	–	–	–		
Sweet potato					
No market claim	1557	999	1324	0.9	1.3
Organic	6	1	1	0.2	1.0
IPM/NDR	1	1	1	1.0	1.0
Tomatoes					
No market claim	1971	1254	2938	1.5	2.3
Organic	10	–	–		
IPM/NDR	5	4	4	0.8	1.0
Winter squash					
No market claim	1205	497	783	0.6	1.6
Organic	9	1	1	0.1	1.0
IPM/NDR	2	–	–		

Residue levels

Our third hypothesis states that when residues are present in organically grown foods, they should be at lower concentrations than the residues typically found in conventionally grown and IPM/NDR foods. This hypothesis is difficult to test using most statistical methods, because the relative rarity of residues in organic foods leaves few degrees of freedom to test significance. One practical approach is to compare the same residues on the same crops (e.g. chlorpyrifos on tomatoes) across market categories. We call any given comparison of this sort a crop–pesticide data pair (CPDP). While comparing residues of conventional pesticides on organic foods (typically the result of inadvertent contamination or mislabelling) with the same residues on conventional or IPM/NDR crops (typically the result of deliberate crop treatment) might seem biased toward finding lower residues in organic produce, it is in fact the most practical way to compare residues, since the data on residues in organic foods are essentially all for residues of conventional pesticides.

Excluding OC residues, there are 22 organic-conventional CPDPs in the PDP data, 25 in the DPR data and seven in the CU data. The PDP data provide only eight organic-IPM/NDR CPDPs, but there are 70 IPM/NDR-conventional PDP CPDPs. The CU data set contains five organic-IPM/NDR CPDPs, and five IPM/NDR-conventional CPDPs. Across all three

Table 7. Comparison of organic and no market claim mean residues found in 22 crops, USDA data.

Food	Active ingredient	No market claim		Organic samples		Ratio no market claim to organic mean
		Number of positives	Mean residue (ppm)	Number of positives	Mean residue (ppm)	
Broccoli	DCPA	142	0.014	1	0.007	2.0
Cantaloupe	methamidophos	64	0.050	1	0.021	2.4
Celery	oxamyl	28	0.087	1	0.11	0.8
Cucumber	endosulphan I	319	0.023	1	0.008	2.9
Grape	iprodione	746	0.233	1	0.14	1.7
Grape	vinclozolin	197	0.147	1	0.2	0.7
Orange	formetanate HCL	86	0.422	1	0.3	1.4
Peach	endosulphans	49	0.029	1	0.01	2.9
Pear	diphenylamine	340	0.094	1	0.017	5.5
Pear	*o*-phenylphenol	327	0.845	1	0.037	22.8
Potato	chlorpropham	892	1.59	1	1.6	1.0
Spinach	DCPA	30	0.011	1	0.007	1.5
Spinach	methamidophos	43	0.009	1	0.072	0.1
Spinach	omethoate	225	0.069	1	0.008	8.6
Spinach	permethrin	946	1.920	1	0.49	3.9
Strawberry	iprodione	287	0.552	1	0.079	7.0
Strawberry	methomyl	162	0.440	1	0.19	2.3
Strawberry	chlorpryifos	5	0.006	1	0.007	0.9
Sweet bell pepper	endosulphan I	148	0.030	1	0.008	3.8
Sweet bell pepper	methamidophos	260	0.092	1	0.68	0.1
Sweet bell pepper	diazinon	6	0.012	1	0.061	0.2
Sweet potato	*o*-phenylphenol	14	0.031	1	0.017	1.8

data sets, typically just one or a very few organic or IPM/NDR samples contained a particular residue, so mean residues in the organic and IPM/NDR samples often reflect a single value. In contrast, the number of positive conventional samples with a given residue is generally larger.

Small numbers of organic and IPM/NDR samples with specific residues limit the statistical power of comparisons for individual CPDPs. However, statistically meaningful conclusions can be extracted from the data as a whole. The data in tables 7–10 were analysed using two types of statistical tests. Residue concentrations were directly compared using log-transformed concentrations or ranks, or using a linear mixed model controlling for crop, year or data set as appropriate. Tests were also performed for equality of proportion of pairs where conventional samples had a higher concentration, using Friedman's Rank test, exact tests for proportions, and χ^2-tests.

Table 7 presents the 22 organic-conventional CPDPs in the PDP data set. Residues in organic samples were lower in 15 cases (68%). This difference falls just short of being statistically significant ($p = 0.067$). Of the eight organic-IPM/NDR CPDPs in the PDP data (not shown in table 7), the IPM/NDR samples had higher residues in five cases (62%). This difference is not significant.

Table 8 compares residues in IPM/NDR samples with those in corresponding conventional samples in the PDP data set. IPM/NDR samples are much more likely to contain residues than organic samples are, and there are 70 of these CPDPs. Residues in IPM/NDR samples were lower than those in the conventional samples in 48 cases (69%). This difference is highly statistically significant ($p = 0.002$).

Table 9 shows 25 conventional-organic CPDPs in the DPR data set; organic samples had lower residues in 15 cases (60%). This difference is of borderline statistical significance ($p = 0.059$). In interpreting table 9, it should be recalled that the LODs of the DPR analytical methods are higher than those of the other two data sets. Since the DPR tends to detect only comparatively higher residues, the odds that an organic sample would have a much lower residue than might occur in a conventional sample are reduced from the outset.

Table 8. Comparison of 'IPM/NDR' claim sample means to 'no market claim' samples in 70 crop pesticide data pairs tested by the USDA's Pesticide Data Program.

		No market claim		IPM/NDR		
Food	Active ingredient	Number of positives	Mean residue (ppm)	Number of positives	Mean residue (ppm)	Ratio no market claim mean residue to IPM/NDR
Apple	azinphos methyl	1148	0.0568	1	0.0200	2.84
Apple	benomyl	67	0.1047	5	0.1064	0.98
Apple	captan	287	0.1160	1	0.0700	1.66
Apple	chlorpyrifos	514	0.0255	2	0.0050	5.09
Apple	dicofol	32	0.3005	1	0.1400	2.15
Apple	dimethoate	126	0.0470	2	0.0300	1.57
Apple	diphenylamine (DPA)	1370	0.7973	9	0.7078	1.13
Apple	methomyl	61	0.0358	2	0.0675	0.53
Apple	omethoate	94	0.0241	2	0.0400	0.60
Apple	oxamyl	93	0.0325	1	0.0500	0.65
Apple	phosmet	127	0.0500	1	0.0100	5.00
Apple	propargite	526	0.3944	4	0.4375	0.90
Apple	thiabendazole	1100	0.8389	7	0.5176	1.62
Banana	thiabendazole	577	0.0927	4	0.0938	0.99
Broccoli	DCPA	142	0.0141	7	0.0131	1.08
Carrot	acephate	4	0.0110	1	0.0060	1.83
Carrot	captan	11	0.0191	1	0.0200	0.95
Carrot	iprodione	525	0.0455	1	0.1000	0.45
Carrot	trifluralin	733	0.0524	5	0.0228	2.30
Celery	chlorothalonil	117	0.0889	2	0.3250	0.27
Celery	permethrin	50	0.0769	1	0.1800	0.43
Grape	captan	678	0.1621	3	0.3467	0.47
Grape	dimethoate	256	0.0624	1	0.0180	3.46
Grape	iprodione	746	0.2334	3	0.1397	1.67
Grape	omethoate	243	0.0428	1	0.0900	0.48
Green bean	acephate	247	0.2623	5	0.2576	1.02
Green bean	benomyl	73	0.3048	3	0.1980	1.54
Green bean	carbaryl	41	0.2492	3	0.4267	0.58
Green bean	carbofuran	2	0.0200	1	0.0100	2.00
Green bean	chlorothalonil	177	0.0911	6	0.0502	1.82
Green bean	DCPA	54	0.0449	2	0.0940	0.48
Green bean	dimethoate	69	0.1576	2	0.4500	0.35
Green bean	endosulphans	305	0.1387	3	0.0493	2.81
Green bean	iprodione	21	0.3220	1	0.1000	3.22
Green bean	methamidophos	234	0.1046	5	0.0618	1.69
Green bean	omethoate	43	0.0405	2	0.0950	0.43
Lettuce	acephate	116	0.0306	1	0.0080	3.83
Lettuce	endosulphans	140	0.0426	5	0.0216	1.97
Lettuce	methamidophos	54	0.0092	1	0.0090	1.02
Lettuce	mevinphos	76	0.0469	1	0.0250	1.87
Lettuce	permethrin	95	0.3796	2	0.1165	3.26
Oats, rolled	malathion	17	0.0054	1	0.0050	1.07
Orange	ethion	32	0.0112	1	0.0020	5.58
Orange	formetanate HCL	86	0.4216	1	0.0850	4.96
Orange	imazalil	1051	0.1297	5	0.1958	0.66
Orange	thiabendazole	1056	0.2026	6	0.2323	0.87
Peach	azinphos methyl	288	0.0792	1	0.0500	1.58
Peach	benomyl	187	0.4160	3	0.4100	1.01
Peach	captan	135	0.1539	1	0.0100	15.39
Peach	carbaryl	167	0.4062	1	0.1200	3.39
Peach	dicloran	411	0.7614	2	0.0160	47.59
Peach	iprodione	779	0.8885	3	0.3533	2.51

(*continued*)

Table 8—concluded

Food	Active ingredient	No market claim: Number of positives	No market claim: Mean residue (ppm)	IPM/NDR: Number of positives	IPM/NDR: Mean residue (ppm)	Ratio no market claim mean residue to IPM/NDR
Peach	parathion methyl	302	0.0548	1	0.0480	1.14
Potato	chlorpropham	892	1.5910	8	1.1570	1.38
Potato	endosulphans	216	0.0143	5	0.0056	2.56
Potato	*o*-phenylphenol	44	0.1724	1	0.0250	6.90
Potato	thiabendazole	290	0.4253	5	0.3168	1.34
Spinach	dimethoate	100	0.2726	1	0.0180	15.14
Spinach	endosulfans	86	0.1161	1	0.0100	11.61
Spinach	omethoate	225	0.0686	2	0.0885	0.78
Spinach	permethrin	946	1.9199	7	0.8556	2.24
Strawberry	captan	761	1.1084	1	0.1200	9.24
Strawberry	iprodione	584	0.5787	3	0.3820	1.51
Strawberry	malathion	162	0.0324	3	0.0427	0.76
Strawberry	methomyl	322	0.4176	1	0.9100	0.46
Strawberry	myclobutanil	263	0.0954	2	0.1380	0.69
Strawberry	vinclozolin	167	0.4774	2	0.1390	3.43
Sweet potato	dicloran	898	0.3536	1	0.3200	1.10
Tomato	chlorthalonil	158	0.0875	2	0.0425	2.06
Tomato	piperonyl butoxide	13	0.2923	2	0.0840	3.48

Table 9. Comparison of organic and no market claim mean residues found in 25 crop pesticide data pairs tested by the California Department of Pesticide Regulation, 1994–98.

Crop	Active ingredient	No market claim: Number of positives	No market claim: Mean of positives (ppm)	Organic: Number of positives	Organic: Mean of positives (ppm)	Ratio no market claim mean to organic mean
broccoli	DCPA	9	0.05	1	0.06	0.83
cabbage	chlorpyrifos	4	0.14	1	0.17	0.82
cabbage	dimethoate	2	0.15	1	0.10	1.45
cabbage	methamidophos	6	0.19	2	0.22	0.89
cucumber	endosulphan	308	0.12	2	0.05	2.66
grape	endosulphan	7	0.06	1	0.31	0.18
grape	iprodione	41	0.64	1	1.76	0.36
grape	methomyl	29	0.41	1	0.14	2.90
lettuce	chlorothalonil	4	0.10	1	0.11	0.89
lettuce	DCPA	13	0.13	3	0.03	4.21
lettuce	endosulphan	29	0.32	1	0.04	7.94
lettuce, leaf	DCPA	22	0.06	1	0.19	0.32
onion, green	chlorothalonil	29	0.55	1	0.05	10.90
orange	chlorpyrifos	304	0.14	1	0.10	1.44
pear	methyl parathion	4	0.03	1	0.04	0.73
pepper	carbaryl	59	0.75	1	0.10	7.46
pepper	chlorothalonil	3	0.12	1	0.07	1.71
pepper	endosulphan	168	0.15	2	0.12	1.28
pepper	methamidophos	642	0.20	1	0.54	0.36
pepper	methomyl	41	0.21	1	0.35	0.59
spinach	DCPA	5	0.21	1	0.06	3.43
spinach	permethrin	261	1.69	2	1.26	1.34
squash, summer	endosulphan	248	0.10	2	0.02	6.77
tomato	chlorothalonil	106	0.49	1	0.11	4.46
tomato	methamidophos	425	0.11	1	0.10	1.07

Table 10. Comparison of organic and IPM/NDR mean residues to no market claim mean residues in seven and five crop pesticide data pairs tested by the Consumers Union.

Crop	Active ingredient	No market claim: Number of positives	No market claim: Mean of positives (ppm)	IPM/NDR: Number of positives	IPM/NDR: Mean of positives (ppm)	Organic: Number of positives	Organic: Mean of positives (ppm)	Ratio IPM/NDR to organic mean	Ratio no market claim to organic mean	Ratio IPM/NDR to no market claim mean
Apple	azinphos methyl	10	0.103	21	0.073	3	0.032	2.3	3.2	0.71
Apple	carbaryl	2	0.055	0		2	0.029		1.9	
Apple	thiabendazole	10	0.804	5	0.125	2	0.042	3.0	19.1	0.16
Apple	benomyl	5	0.076	14	0.077	2	0.078	1.0	1.0	1.01
Peach	phosmet	4	0.63	2	0.147	1	3.3	0.0	0.2	0.23
Peach	benomyl	4	0.067	0		2	0.051		1.3	
Tomato	benomyl	8	0.078	1	0.06	6	0.064	0.9	1.2	0.77

Table 10 summarizes CPDPs from the CU data. Organic samples had lower residues in five of seven organic-conventional pairings (71%). Organic samples had lower residues than IPM/NDR samples in two of five cases (40%), and IPM/NDR samples had lower residues than conventional samples in four of those five CPDPs (80%). Because of the small number of cases in this data set, none of the differences in table 10 are statistically significant.

Overall, a clear picture emerges from the CPDP comparisons across all three data sets. In each case, residues in organic samples were lower than the same residues in conventional samples about two-thirds of the time. While these differences within each individual data set failed to achieve statistical significance at the $p < 0.05$ level, aggregating the three data sets improves the power of the analysis. The combined data sets include 54 conventional-organic CPDPs; the organic samples had lower residues in 37 cases (69%), a result that is statistically significant ($p = 0.029$).

The comparison of IPM/NDR-conventional CPDPs includes 70 from the PDP data set, and an additional five from CU's data. Combining the two sets yields a total of 53 cases on which the residues are lower in IPM/NDR samples (71%), and modestly increases statistical confidence in this result ($p = 0.001$).

Discussion

The three data sets offer test results obtained by government agencies and by an independent consumer organization, none of which have any commercial or institutional interest in organic, IPM/NDR or other market claims. The data support robust, objective comparisons of pesticide residues in foods produced with different agricultural methods and marketed with various claims. Our analysis shows convincingly that organic samples are much less likely to contain detectable pesticide residues than conventionally grown or IPM/NDR foods are. Organic samples with residues are also far less likely to have multiple residues than are conventional or IPM/NDR samples. These differences are clear-cut, consistent across data sets, and highly statistically significant.

Fewer data exist to permit direct comparisons of residue levels in organic and non-organic samples of a given crop, because of the small number of organic samples in any data set that have a specific pesticide on a specific food. However, here, too, when data are examined from all three data sets, a consistent pattern emerges: organic samples in paired comparisons had lower residues about two-thirds of the time. This pattern was consistently observed across a wide range of different foods tested by all three programmes, suggesting that it is quite likely generally true for organic foods as a whole.

The two data sets that include IPM/NDR food samples as an identifiable market sector also support the conclusion that, despite the heterogeneous nature of the category, samples that carried an IPM or NDR claim generally were less likely to contain residues and had lower residues than were found in conventionally grown samples. The IPM/NDR samples also had more frequent and generally higher residues than those in organic samples.

Current risk assessment methodologies cannot definitively quantify the possible public-health implications of pesticide residues in the diet. A consensus now exists, at least within the USA, that dietary pesticide residues are a significant public health concern, particularly for young children (National Research Council 1993). Nevertheless, the available evidence falls short of associating specific harm to individuals with routine exposure to dietary pesticide residues.

Despite these irreducible scientific uncertainties, risks are relative, and exposure to fewer and lower dietary residues should translate into smaller risks. Our analysis therefore supports the conclusion that the risks posed by organically grown fruits and vegetables are substantially smaller than comparable risks from foods grown using conventional pest management systems. Foods produced under an IPM or NDR labelling regime appear to fall in between conventional and organic foods in terms of residues and risks.

There is a significant gap in this qualitative risk comparison, related to the possible contribution to total risk of residues of natural pesticides. This category includes the botanical insecticides, such as rotenone, pyrethrum and pyrethrins, sabadilla and neem; bio-based insecticides such as *Bacillus thuringiensis*; and mineral-based products, including horticultural oils and sulphur and copper-based fungicides. While such natural pest management tools are commonly associated with organic farming, many are also used by conventional farmers and IPM practitioners. The lack of residue data noted earlier in this paper, and the lack of complete toxicological data for most botanical insecticides, have seriously limited ability to carry out risk assessments for these pest-management products. These constraints affect not only assessments of risks associated with organic foods, but also assessments of any similar risks posed by use of these products in conventional and IPM-based farming.

Some commentators, in particular habitual US critics of organic agriculture, have suggested that unmeasured, toxicologically untested, theoretical residues of natural pesticides in organically grown foods render organic foods as 'hazardous' in terms of residue-related health risks as conventionally grown foods (D. T. Avery 2000, A. Avery 2001, Stossel 2000, Milloy 2001). This claim is neither supported by empirical data nor scientifically credible, but it has been widely spread through the mass media, such that questions related to natural pesticides have become something of a cloud accompanying the generally accepted silver lining of fewer conventional pesticide residues in organically grown foods.

Several lines of indirect evidence suggest that residues of natural pesticides are rarely present or pose minimal health concerns in any market category of foods on which they might be used. As noted in our description of organic foods earlier in this paper, organic farming rules require that any pesticides used are applied minimally, and only as a last resort, and application rates allowed on organic farms are typically lower than those allowed on conventionally grown crops (Meister 1999). In a survey of pesticide use by the Organic Farming Research Foundation, 52% of organic growers said they 'never' used botanical insecticides, another 21% reported using these products 'rarely', and only 9% said they used them 'frequently or regularly'. Even fewer organic farmers use sulphur or copper-based fungicides or horticultural oils, with 60%, 66% and 65% saying they 'never' use these products, respectively (Walz 1999, Walz and Scowcroft 2000).

Most of the popular natural pesticides are used primarily because they pose minimal ecological threats to farming systems. Other natural but highly toxic pesticides, such as nicotine, cryolite, strychnine and lead arsenate, are banned from organic production and rarely used by farmers in other categories. Sulphur and copper compounds, horticultural oils and insecticidal soaps are far less toxic and considered safe based on long experience. Most pesticides commonly used on organic farms are exempt from EPA tolerances (i.e. no safety-based residue limits are deemed necessary), because of low toxicity or a low probability of detectable residues in foods, or both. (Banned natural pesticides are covered in 7 CFR 602. The exempt status of sulfur and related natural fungicides are listed in 40 CFR 180.2; petroleum oils in 40 CFR 180.1001(b)(3). Copper compounds are exempted from EPA tolerances in 40 CFR 180.1001(b)(1) and exempted are permitted for use in organic farming in 7 CFR 205.601(i)(1). Pyrethrum and pyrethrins are exempted from tolerances in 40 CFR 180.1001(b)(6); rotenone, derris or qube roots in 40 CFR 180,1001(b)(7); sabadilla in 40 CFR 180.1001(b)(8); and azadirachtin, the active constituent of neem, in 40 CFR 180.1119.) The botanical insecticides generally break down quickly in the environment. For example, rotenone degrades rapidly in sunlight (Mandava 1985), and pyrethrum and its derivatives also decompose rapidly (Casida 1973). The belief that most botanicals rapidly break down explains both the lack of EPA tolerances and the lack of analytical methods for residues; the EPA has concluded that residues of these compounds are unlikely to be present in foods.

Recent research has suggested that rotenone, injected directly into rats, has neurotoxic effects (Betarbet *et al.* 2000). The EPA has assessed the possible carcinogenicity of pyrethrum and concluded that this natural insecticide (derived from chrysanthemums) may pose some cancer risk for humans (Avery 2001). It seems essential that the widely used botanicals be more completely tested for the full range of toxic effects that conventional pesticides are currently tested for. Expanded efforts to collect data on possible residues of the natural pesticides in organic and non-organic foods are also needed. Better toxicity data and residue data will improve the basis for risk assessments of these pest-management tools. If future research verifies health concerns related to certain of the botanicals, for example, their continued use—in both organic and non-organic farming—would need to be re-evaluated. Ultimately, debate over the theoretical risks of these pesticides is likely to persist until a solid body of empirical data clearly resolves the issue.

For the present, however, there is no basis to conclude that residues of natural pesticides in any foods, organic or conventional, pose risks remotely comparable to those represented by residues of conventional (synthetic) pesticides. The toxicity of the organophosphate and carbamate insecticides, for example, has been quite thoroughly tested. Upper limits of 'safe' exposure have been defined by regulatory authorities, based on risk assessments with extensive peer review and comments from interested parties (Groth *et al.* 2001). The presence of frequent residues of many of the widely used synthetic insecticides in foods has been well documented, and residue levels often approach or exceed official 'safe' doses (Groth *et al.* 2000, 2001). In contrast, there are simply no credible scientific data to indicate either that significant residues of natural pesticides are present in foods, or that residues of these substances that might be present pose a meaningful public health risk. Nevertheless, these are certainly interesting questions, and it is in everyone's interest to see better scientific answers developed.

Returning to a topic on which we have data, virtually all the residues detected in organic foods (and other market categories of foods) by the three test programmes are residues of conventional, synthetic pesticides. How and why do residues of synthetic pesticides get into organic foods? Many of these residues do not violate organic standards, which recognize that small amounts of residues from sources beyond farmers' control are unavoidable. The US National Organic Program (NOP) standard for unavoidable contamination is 5% of the applicable EPA tolerance. Most residues detected in positive organic samples in all three of our data sets were well below this level and would not have disqualified the tested samples from being accurately labelled and sold as organic under that standard.

A few positive organic samples, however, contained more significant residues. For example, one sample of peaches labelled organic, tested by CU, contained 3.3 ppm of phosmet, explainable only as the result of spraying shortly before harvest. An imported organic sweet bell pepper sample tested by the PDP in 1999 contained high residues of methamidophos, diazinon, methyl parathion and endosulphan. Methamidophos was found in this sample at 0.68 ppm, compared with a mean level of 0.092 ppm in 260 positive conventional pepper samples (table 7). These two samples may have been mislabelled as organic where they were sold, or perhaps misidentified as organic in data-entry errors within the test programmes.

Mislabelling of organic samples can result from wilful fraud or an inadvertent lapse in chain-of-custody accounting. To the consumer, the reason matters little. Such incidents appear rare, from data examined here. Nevertheless, the organic community, particularly certifying agents and government enforcement agencies, needs to develop effective procedures for investigating and rectifying even isolated high-residue incidents.

Some other positive organic samples seem likely to reflect post-harvest contamination of organically grown samples. For example, many of the organic tomato samples tested by CU had benomyl residues comparable to those in conventionally grown samples. Residues could have resulted from fungicide treatment during transport or storage, or mixing of treated and untreated produce somewhere between farm and retail, as well as from possible mislabelling.

Pesticide residues in foods sold as organic are grounds for a fraud investigation under the US NOP rule. We reviewed data from such investigations related to some of the 71 organic samples found to contain residues in the California DPR data. Firm conclusions could not be reached in any given case, but fraud, chain-of-custody errors by the grower or shipper, or laboratory error may explain some relatively high positive samples. In about half the cases, however, residues were very low and consistent with unavoidable environmental contamination because of drift, persistent residues in the soil, or contaminated irrigation water supplies.

Implementation of the NOP final standards should further reduce the frequency and levels of conventional pesticides in organic foods. The new regulations prohibit use on organic crops of all synthetic pesticides that have EPA tolerances, and limit unavoidable contamination to 5% of the EPA tolerance. Foods with residues exceeding these limits may not legally be sold as organic. New national standards for accreditation of private and state organic certifiers should increase the consistency of industry practices, help avoid detectable residues and enhance the likelihood that mislabelled foods will be detected and dealt with. Farmers will also face greater sanctions and penalties for mislabelling of food as organic. Certifiers have a mandate to collect samples for pesticide analysis, and when crops contain residues above acceptable limits, certifiers must investigate and impose sanctions. Future accreditation of certifiers will depend, at least in part, on how effectively they enforce these provisions.

Our analysis shows that food samples marketed with IPM/NDR claims consistently had fewer and lower pesticide residues than conventionally grown samples, but more frequent and higher residues than organic samples. In this case, the presence of residues of conventional synthetic pesticides is expected, since IPM and conventional systems employ largely overlapping arsenals of chemicals. Nevertheless, some residues detected in IPM/NDR samples may indicate either mislabelling or unavoidable environmental contamination, as for organically grown samples.

Are IPM/NDR-labelled foods more like ‘organic’, more like ‘conventional’, or a distinctive category in their own right? Based on data from the CU and PDP tests, IPM/NDR foods are intermediate between the other two categories in terms of frequency of residues. With respect to multiple residues, positive IPM/NDR samples are very much like positive conventional samples. In terms of the relative residue levels, the median ratio for organic-conventional CPDPs and the median ratio for IPM/NDR-conventional CPDPs are highly similar (1.50 and 1.58, respectively). Overall, IPM/NDR foods may be an attractive alternative for consumers interested in reducing their exposure to pesticide residues. At this point, IPM/NDR is an eclectic and relatively new category, whose precise market share is not well documented. The many labelling programmes in this category have different criteria for certification and different degrees of rigour in their requirements, making the credibility of individual programmes difficult for consumers to assess. Confusion over proliferation of ‘green labels’ on foods may eventually generate pressure for uniform US national standards, as have evolved for organically grown foods.

Conclusions, research needs and policy implications

The present analysis shows convincingly, using three distinct measures applied to three separate data sets, that organically grown foods contain fewer pesticide residues than conventional or IPM-grown foods, and that residues, when present, are lower in organic foods. We hope this objective analysis of reliable empirical data will help resolve some questions about differences in pesticide residue profiles between organic and non-organic foods. We have also shown less striking but similar differences between conventional foods and IPM/NDR labelled produce, and between IPM/NDR and organic foods.

The data suggest that consumers who seek to reduce their exposure to pesticide residues can do so reliably by choosing organic produce, and to a lesser degree by choosing IPM/NDR-labelled fruits and vegetables. However, none of the choices available on the market is completely free of pesticide residues. Organically grown produce contains some residues of synthetic pesticides, consistent with unavoidable contamination for the most part. Some small fraction of foods sold as organic also appears to be mislabelled conventionally grown produce. Unavoidable residues and occasional mislabelling and the often-higher prices of organic foods are factors consumers can weigh as they make food purchase decisions.

More data are needed to refine and update these comparisons. Sampling of both organic and IPM/NDR foods tested by the major pesticide monitoring agencies should be expanded, to better represent the presence of these foods in the marketplace. There is a particular need for data on possible residues of botanical and other natural pesticides on both organic and non-organic produce. The hypothesis that such residues *might* be present and could offset to a degree the comparative lack of synthetic pesticide residues in organic produce should be either confirmed or rejected on the basis of robust empirical data.

The relative lack of synthetic pesticides in organic produce shown by the data presented here makes intuitive sense, since such foods are not supposed to have such chemicals applied to them. Residues that 'should not be there' (excluding unavoidable environmental residues of the OC insecticides) were detected in 13% of the organic samples tested by the PDP. Reducing this level of contamination will be a significant challenge for the organic agricultural sector. On one hand, most of the residues found reflect the capacity of wind, rain, fog, and irrigation water to move pesticides beyond the fields where they were applied. On the other hand, better procedures and clearer policies are needed to help ensure that the new US organic regulations can achieve their stated purpose of making organically grown foods essentially free of detectable residues.

One possible policy mechanism for strengthening the capacity of the organic community to isolate and eliminate residues in organic food would be to set up a national alert system. The USDA NOP could receive a notice from the PDP and state laboratories whenever an organic sample was found to contain a residue. The NOP, certifiers and enforcement agencies could then track down and rectify the source of the problem.

Active management to limit crops grown on soil contaminated with persistent organochlorine pesticides can significantly reduce that source of contamination. Effective strategies have been documented (Oregon Tilth 1999) but are not included in the NOP rule and need to be more widely adopted. Farmers who grow crops such as carrots, winter squash, spinach, and other foods known to accumulate organochlorine pesticides may need to take special precautions, including testing their fields for soil-bound OC residues. Mandating such steps, at least for organic food, may well be justified from a public health perspective and should be added to organic industry quality control procedures.

The IPM/NDR category is still quite young, and growing rapidly. It appears that consumer demand for low-pesticide foods significantly exceeds the current capacity of organic farming in the USA, and that both organic and IPM/NDR categories may continue to grow vigorously as long as minimizing residue exposure remains a consumer concern. To earn consumer confidence over the long-term, IPM/NDR Labeling programmes need to develop rigorous and transparent standards and certification procedures. Whether national standards for IPM/NDR Labeling will ultimately be required may depend on how successfully the industry can address these needs and coordinate disparate programmes without federal regulation.

For conventional farmers in both the USA and in countries that export fruits and vegetables to the USA, continued implementation of the FQPA will increase pressures to eliminate or to markedly reduce residues of high-risk pesticides in foods, especially foods that are prominent in children's diets. If the FQPA goal of an increased safety margin is met, residues in conventionally grown foods will trend downward toward levels currently found in some IPM/NDR foods. Tighter residue limits and reduced pesticide use by conventional growers should also reduce drift incidents and other sources of unavoidable environmental contamination. These factors may prompt organic producers to make even greater efforts to avoid residues, so that the organic label can maintain its distinctive promise of relatively lower pesticide exposure and risk.

The market shares for both organic and IPM/NDR produce seem likely to continue to grow in coming years. These trends, coupled with growing reliance on biological interactions and prevention-based pest management systems, should reduce both overall pesticide use and residues in food and water, with concomitant reductions in risks to farm workers and agricultural ecosystems. Consumers and all who work within the food system should share the benefits.

Acknowledgements

The authors thank W. Keith Newsom-Stewart, Senior Statistician, Consumers Union, for his many insights and invaluable contribution in carrying out statistical analyses of the data. The authors also recognize the contribution of Cynthia J. Langlois, formerly a Project Leader in the Public Service Projects department at the Consumers Union (and currently with the Weinberg Group, San Francisco), who led the CU test project in 1997. They are grateful to Terry Schmer of the California EPA, Department of Pesticide Regulation, and Martha Lamont, Pesticide Data Branch Chief, USDA Pesticide Data Program, for their cooperation and assistance in helping the authors obtain and interpret the DPR and PDP data, respectively. Any errors of interpretation are the authors' alone.

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