Sustainability **2014**, *6*, 3552-3570; doi:10.3390/su6063552

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Perspective on Dietary Risk Assessment of Pesticide Residues in Organic Food

Charles M. Benbrook [1,†] and Brian P. Baker [2,†,*]

[1] Center for Sustaining Agriculture and Natural Resources, Washington State University, 90063 Troy Road, Enterprise, OR 97828, USA; Email: cbenbrook@wsu.edu

[2] Independent Consultant, PO Box 12256, Eugene, OR 97440, USA

† These authors contributed equally to this work.

* Author to whom correspondence should be addressed; E-Mail: bpb33@cornell.edu; Tel.: +1-541-228-0876.

Received: 11 January 2014; in revised form: 19 March 2014 / Accepted: 22 May 2014 / Published: 30 May 2014

Abstract: Previous studies have shown that organically produced food has lower risks of pesticide contamination than food that is not organically produced. However, organically produced food is not entirely free of pesticide residues. A large, high-quality U.S. Department of Agriculture database reports pesticide residues in several dozen organic and conventionally grown foods on an annual basis, and supports detailed analyses of the frequency of residues in conventional and organic food, the number of residues found in an average sample of food, residue levels, and potential dietary risk. These data are used to estimate pesticide dietary exposures and relative risk levels, and to assess the impacts of the current pesticide-related provisions of the National Organic Program (NOP) rule. Fraud appears to be rare based on the available data. Most prohibited residues found in organic produce are detected at levels far below the residues typically found in food grown with pesticides. Relatively high-risk residues are more common in imported foods—both organic and conventional—compared to domestically grown food. The authors conclude that incorporating relative dietary risk into the organic standard would be a more precautionary, risk-based approach than targeting enforcement to organic foods found to contain 5% or more of the applicable Environmental Protection Agency (EPA) tolerance.

Keywords: organic food; pesticides; contamination; residues; fruit; vegetables; dietary risk index

1. Introduction: Pesticide Residues in Organic Food

Organic food sales in the US have grown annually in double digits over the past 25 years to become a $28 billion industry as of 2012 [1]. While organic food is still seen as a niche market, in certain product categories market share for organic is significant. For example, organic salad mix accounted for 22% of all salad mix sales in 2012 [2], and organic fresh fruits and vegetables command over 10% of market share [3]. The growth in organic food is related to a number of factors. These include both altruistic and hedonistic reasons, ranging from concern for the environment and animal welfare to more personal reasons [4–6]. Ultimately the individual choice of whether to buy organic or non-organic food is part of an overall lifestyle decision [7].

"Health" is reported as the foremost reason why consumers purchase organic food in an overwhelming majority of studies reviewed [4,5,8–10]. While there is no consensus about the benefits of organic food, perhaps the strongest public health benefit from consumption of organic food is the reduction of pesticide exposure and the risk of cancer, neurodevelopmental deficits, and other adverse health outcomes that can be triggered, or made worse, by pesticide exposures [11–13]. Consumers who purchased organic food expressed significantly greater concerns about pesticides in food and the environment than shoppers as a whole [14]. In some markets, organic is the only label that consumers are willing to pay a premium for in order to reduce pesticide risk [15]. Data shows that organic foods are less likely to have pesticide residues, far less likely to have multiple residues of pesticides, and on average, pesticide levels in organic food are significantly lower [11,13,16,17]. Diets composed of predominantly organic foods significantly lower exposure to pesticides [10,18,19]. Even though organic farmers avoid the use of pesticides, some contamination is known to occur through various avenues discussed later.

However, organic food is not always free of pesticide residues for several reasons. Because ambient levels of pesticides are ubiquitous in the environment, some low-level contamination is often unavoidable. In addition, a relatively small number of pesticides are allowed for organic production. Most of these are non-synthetic, with a few exceptions made for pesticides determined to have little adverse impact on human health and the environment. Consumers who seek to avoid synthetic pesticides and lower health risks from dietary and other exposure routes can reasonably assume that organic food substantially accomplishes both goals. The US Department of Agriculture (USDA) organic standards and the policies to implement those standards were deliberately designed to prevent both the intentional and inadvertent risks posed by pesticides.

To protect consumers from fraudulent products, and to provide organic producers and handlers with a clear standard to meet market demand, Congress passed the Organic Foods Production Act (OFPA) as part of the 1990 Farm Bill. A primary motive driving passage of the OFPA was the perceived shortcoming of government actions to protect consumers from pesticide risk [20]. In Congressional debate over the OFPA, pesticide residue testing was a key issue of concern. Various stakeholders advocated for a program that assured periodic pesticide residue testing of shelf-ready organic products, pre-harvest testing of organic crops in the field, and soil testing for residual contamination.

The OFPA requires periodic residue testing by USDA accredited certification agents (ACAs) to determine if organic food contains "pesticide or other nonorganic residue or natural toxicants" and to report such violations to the appropriate health agencies [7 USC 6106(a)(6)]. Residue testing is to be used as an enforcement tool [7 USC 6511(a)]. The USDA may require ACAs to conduct pre-harvest tissue testing of any crop grown, or any soil suspected of harboring contaminants to assist with enforcement of the law [7 USC 6511(b)].

Food may not be certified nor sold as organic if intentionally treated with substances that are prohibited for organic production or handling [7 USC 6511(c)(2)(A)]. If an agricultural product sold or labeled as organic contains any "detectable pesticide or other non-organic residue or prohibited natural substance," NOP rules require ACAs to investigate and determine if the organic certification program has been violated. Residues of prohibited substances can be used as sufficient evidence to revoke organic certification, and ACAs, state organic programs and the USDA do not need to prove that the substance was intentionally applied. In such cases, producers or handlers may bear the burden of proof in showing that the detected, prohibited substance was not applied to the product [7 USC 6511(c)(1)]. Even if inadvertent contamination is beyond the producer's or handler's control, food that contains residues "present at levels that are greater than unavoidable residual environmental contamination" (UREC) cannot be sold or labeled as organically produced [7 USC 6511(c)(2)(B)]. In addition, organic food must also comply with pesticide-food tolerances applicable to all foods; any residue in an organic crop or food sample for which there is no current EPA tolerance, or an exemption from the requirement for a tolerance, would be considered "adulterated" and would not be eligible for sale either as organic or conventional.

The National Organic Standards Board (NOSB) is the Federal advisory committee comprised of stakeholders with a legislatively mandated role to advise the USDA in setting organic certification standards. In Congressional debate on the OFPA, the Senate specifically stated the intent of the law was for residues to not exceed 10% of the EPA tolerance level, and that there was no intent to prohibit "minimal residue" that would be incidental to an organic farming operation [21]. The NOSB adopted the view that government funded, FDA residue testing could be done in a way that efficiently fulfilled the residue testing requirements of the OFPA, if supplemented with periodic sampling/residue testing of organic foods by ACAs [22]. Accepting the NOSB's recommendation [23], the USDA gave ACAs the authority to exclude from organic sale products containing pesticide residues that exceeded 5% of the corresponding EPA tolerance for a given pesticide [7 CFR 205.671]. The rule was silent on pesticide residues for legacy pesticides lacking active tolerances, as well as residues of pesticides on crops not covered by an existing tolerance.

Analytical chemistry has advanced over the past two-plus decades since the OFPA was passed and over the decade following implementation of the NOP. Technical and methodological advances in the conduct of residue testing have markedly lowered limits of detection, and have expanded the range of residues likely to be detected. These advances increase the likelihood of detection of both UREC residues and potential fraud.

The 5% of EPA tolerance provision is supposed to provide an extra margin of safety for consumers of organic food and also serves, when exceeded, as evidence of possible direct, intentional application of prohibited substances. As these policies were shaped and implemented, little effort was invested in analyzing how effective the policies were likely to be in achieving these stated goals, nor were alternative methods explored that might more cost-effectively fulfill these two purposes.

While the rule authorized ACAs to conduct periodic testing, it did not mandate it as intended by Congress. The Office of Inspector General (OIG) determined in an audit published in 2010 that the NOP regulations implemented part of the provisions of the OFPA, but "do not fully implement the requirement of section 2107 requiring certifying agents to perform periodic residue testing of products from organic operations" [24].

In response to the OIG audit, the NOP proposed an amended final rule for periodic residue testing on November 9, 2012 [77 FR 67239]. The amendment mandates ACAs to sample and test annually for pesticide residues from at least five percent of currently certified operations [7 CFR 205.670(d)]. The requirement is silent on the number of samples a given certified entity must test per operation and provides no guidance as to which crops should be sampled on a farm growing multiple organic commodities. The USDA conducted a pilot study to determine the levels of contamination of organic produce in the streams of commerce [25]. USDA agents analyzed 571 samples of apples, bell peppers, broccoli, potatoes, strawberries, and tomatoes in 2010 and 2011. All samples were collected at the retail level. The USDA's findings were consistent with previous residue studies, despite methodological differences. While the majority of samples analyzed did not contain detectable residues, 42.7% tested positive for at least one pesticide residue [25]. In 3.7% of those samples, a residue exceeded 5% of EPA tolerance.

Here we examine substantial USDA data on pesticide residues found in organic food following implementation of the USDA National Organic Program rule in 2002. From the data, we infer the likely sources of contamination, and place exposures and risk into perspective using a "Dietary Risk Index" (DRI) that takes into account both the levels of residues in individual samples and pesticide toxicity. The relative risks of eating organic foods are summarized with respect to dietary risk. Differences in risk levels and distributions are examined in domestically grown and imported organic food, with focus on fresh fruits and vegetables. The impacts of current NOP pesticide provisions are analyzed in terms of efficacy in reducing the frequency of possibly higher-risk residues in organic food. Policy reforms are recommended to better take advantage of new understanding of: (a) where and how residues of synthetic pesticides are finding their way into organic food; (b) residues that warrant investigation and possible interventions; and (c) changes in the NOP rule that can potentially further reduce pesticide-related risks in organic food (and keep them low), as well as further lessen farmworker risks and environmental impacts.

Data from the USDA's Pesticide Data Program (PDP) were analyzed to track and compare pesticide residues and risk levels for individual crops/foods, across pesticides, by country of origin, and over time. Risk metrics grounded in EPA dietary risk assessment procedures are used to explore in considerable detail the shares of risk by food or pesticide, or type of pesticide, the distribution of risks, and trends in risk levels and distributions over time.

2. Data and Methods

The USDA's Pesticide Data Program (PDP) has generated high quality and extensive data on pesticides in the US food supply [17]. Established in 1991 to support more accurate pesticide dietary risk assessments by the Environmental Protection Agency (EPA), the PDP annually selects a range of fresh and processed foods, focusing on those that make up a significant share of the diets of infants and children and which often contain pesticide residues. Samples are selected to be representative of market shares by country of origin, and within the U.S., by state. In addition, PDP sample records include the following market claims: "organic product," "pesticide free," "IPM-grown," and "no claim." The PDP annually reports the levels of all pesticide parent compounds, and selected metabolites and isomers, found above applicable limits of quantification (LOQs). The period of study of 2002–2011 was selected based on implementation of the final NOP rule in the last quarter of 2002. Operations were assumed to be largely in compliance with NOP-related pesticide use provisions for the entire year of 2002 prior to full implementation on 22 October. Supplemental Table 1 contains the raw data supporting this analysis. The table encompasses 1,168 pesticide residues detected in organic food samples tested by PDP between 2002 and 2011. Several data points appear in the Supplemental Table on each residue-food combination including the food group, year country of origin, whether the residue is a post-harvest fungicide, a legacy chemical, or organic allowed, the residue level reported, the tolerance level, the "Action Threshold" (5% of the tolerance), and dietary risk index values.

To assist in understanding the various major avenues by which pesticides can contaminate organic food, we assign all detected residues—which may be a parent compound, metabolite, or isomer—to one of the following four categories:

(1) Legacy contaminants;
(2) Post-harvest pesticides;
(3) Pesticides allowed for use in organic production under the NOP; and
(4) All other pesticides.

Most of the specific compounds in each of the first three categories above are covered in Table 1.

Table 1. Pesticides and other contaminants found in organic produce.

Pesticide Group	Compounds in the Group
Legacy Contaminants	Aflatoxin, Aldrin, Benzene Hexachloride (reported as "Hexachlorobenzene"), Cadmium, Chlordane, Chlordecone (Kepone), Dicofol (Kelthane), Dieldrin, DDE, DDT, Dimethylnitrosamine (Nitrosodimethylamine), Ethylene Dibromide (EDB), Heptachlor, Heptachlor Epoxide, Toxaphene, Lead, Lindane, Mercury, Methyl Alcohol, Mirex, Polychlorinated Biphenyls (PCBs), TDE
Post-harvest Pesticides	Bendiocarb, Chlorpropham, Diphenylamine (DPA), Fenhexamid, Fludioxonil, Imazalil, Iprodione, O-Phenylphenol, Pyrimethanil Tetrahydrophthalimide (THPI), Thiabendazole (TBZ)
Allowed for Organic	Azadirachtin, Pyrethrum, Spinosad (including metabolites)
Other	All pesticides not contained in the groups above

Most of the chemicals in the "Legacy Contaminants" category are organochlorine insecticides. These persistent organic pollutants are no longer actively used in agricultural production, but are still present in the soil and/or water and are taken up by some organic crops under certain conditions. Organochlorine pesticides have long been known to translocate into specific crops [26]. Most are no longer registered and do not have EPA tolerances, but are subject to FDA action levels. Contamination of soil on organic farms, residues of persistent pesticides in crops produced organically, and bioaccumulation in livestock fed contaminated crops is a long-standing concern of organic farmers [27]. The elemental substances cadmium, lead and mercury are also included as legacy contaminants, even though they are not necessarily the result of pesticide application.

The use of handling facilities such as packing houses, hydrocoolers, controlled atmosphere and cold storage rooms for both organic and non-organic crops can result in the contamination of crops with post-harvest pesticides, especially fungicides and plant growth regulators [17]. These substances are used primarily to preserve agricultural commodities, but may also include insecticides used in food handling establishments. The use of the same equipment to handle organic and non-organic produce can result in the transfer of pesticides to organic food when it moves through the same shed or processing line used to pack conventional produce. Examples include dicloran used as a post-harvest fungicide on sweet potatoes, thiabendazole used to pack bananas, ortho-phenylphenol as a citrus coating, and imazalil applied post-harvest to both bananas and citrus fruits. Some pesticides in storage can volatilize at low temperatures, particularly diphenylamine (DPA), a fungicide used to prevent scald in apples. These residues may come from dirty belts, bins that have not been properly cleaned, or storage facilities that lack proper air exchange. These aspects of post-harvest handling and processing are typically under the direct control of the handler and can be seen as "avoidable residual operational contamination" rather than "unavoidable residual environmental contamination".

Most pesticides allowed for organic production and handling are non-synthetic and most are among the least toxic materials registered for agricultural uses by the US EPA. Many are exempt from the requirement of establishing a tolerance, such as copper fungicides, horticultural oil, *Bacillus thuringiensis*, neem and pyrethrum. Tolerance exemptions are granted in cases where a pesticide is essentially non-toxic to mammals, as well as in cases where detectable residues on food at harvest are extremely unlikely because of the labeled rate of application, timing, method of application, and environmental fate of the pesticide. Non-synthetic pesticides are allowed in organic production by default, but some highly toxic, naturally occurring substances—such as nicotine and strychnine—are prohibited for use in organic production. The one notable exception is spinosad. Derived from actinomycetes, spinosad has a toxic mode of action for insects, but poses relatively low mammalian risks. Spinosad is unique among substances permitted in organic agriculture in that it is subject to a tolerance requirement by the EPA.

The remaining "other" group of residues stem from applications of the vast majority of synthetic pesticides with active, food-use registrations. Some anomalous residues appear in minor crops like herbs and specialty fruits and vegetables, for which there are limited registrations and tolerances, even for conventionally managed crops. Residues of these pesticides in organic food result either from incidental contamination from drift, runoff or carryover from a recent transition, mislabeling, or fraudulent applications.

Positive samples were grouped into Action Priorities of High, Medium or Low based on: (1) their relative health risks, (2) probability of fraud, and (3) a combination of these two factors. We consider positive samples as "High Action Priority" if they pose "High Dietary Risk" or are likely the result of "Suspected Direct" applications of pesticides not allowed on organic fields or food.

A Dietary Risk Index (DRI) can be used in many different ways to quantify the relative, potential health risk posed by one or more pesticides in food [28–31]. The DRI can be applied to:

- An individual residue in a single food sample;
- All residues found in a single sample;
- The mean level of the residues found of a particular pesticide in a set of samples of a given food (DRI-Mean, or DRI-M);
- Mean residue levels in a given food, taking into account the frequency of detections (Food Supply-DRI, or FS-DRI), calculated by multiplying the DRI-M by the percent of samples testing positive;
- Aggregate DRI-M or FS-DRI for a given food; and
- Aggregate DRI-M or FS-DRI across all foods, taking into account all the residues reported in each food.

Each of the different ways to calculate and apply the DRI is appropriate for certain applications, and inappropriate for others. For example, when the DRI is applied to a single food-chemical combination, the DRI value refers only to that one sample, and is not necessarily representative of other samples. The DRI-M assesses the relative risk of a given pesticide found in a given sample, but generally overstates the risk level in all samples, because it is based on the mean of the positive residue values reported in a set of samples, and ignores the frequency of positives. The FS-DRI adjusts for this bias by multiplying the DRI-M by the percent of samples that tested positive. FS-DRI is the form of the DRI that reflects most closely the way EPA analyzes chronic risks from long-term pesticide exposures. When aggregating risks across all pesticides found in a food, or across all foods, FS-DRI values should be used to avoid significant over-estimation of risk levels.

The resulting value reflects the relative risk for a person consuming the food regularly over many years, assuming a constant exposure to a given contaminant. The DRI-M provides a way to compare risk levels over time across different foods, production systems, in imports *versus* domestic production in a way that the FS-DRI does not. Because of the focus of this paper on residues and risk levels in individual samples of organic food, we used the DRI-M—the residue level reported by the PDP in a sample of organic food divided by the pesticide's chronic Reference Concentration (cRfC). All formulations of the DRI are based on current EPA policy regarding dietary risk and pesticide toxicology to calculate the dietary risk from average pesticide residue levels in a given food for people of known bodyweight, based on typical serving sizes.

The DRI is a function of a given pesticide's cRfC and the mean, or average, positive residue level found in a particular food. The $cRfC_{ij}$ is the maximum concentration of pesticide i that can be present in a daily serving or servings of food/beverage j, without exposing an individual of known weight to a dose of the pesticide that exceeds his or her personal, "reasonable certainty of no harm" specified by EPA in accord with the provisions in the 1996 Food Quality Protection Act (FQPA). Put simply, the cRfC is the ratio of the level of pesticide i in food j relative to the maximum amount that can be in the food, while still complying with the FQPA's standard of "reasonable certainty of no harm." However, risk is not simply a matter of the concentration. The dose also needs to be factored.

Chronic RfCs are expressed in mg pesticide per kg food and are calculated for each pesticide-food combination using the pesticide's: (1) Chronic Reference Doses (cRfDs) or, when set by EPA, its (2) Chronic Population Adjusted Doses (cPADs). EPA establishes a cPAD for pesticides in cases where an added safety factor—usually of 3× or 10×—is deemed necessary to implement the FQPA. A cPAD is a pesticide's cRfD divided by the additional safety factor EPA considers necessary for FQPA compliance; for pesticides lacking an additional FQPA safety factor, its cPAD equals its cRfD.

The cRfC for a given food-pesticide combination is derived from the equation:

$$cRfC_{ij} = W \cdot \frac{cPAD_i}{S_j} \quad (1)$$

where W is the bodyweight of an individual measured in kg and S_j is the daily average serving size of food *j*. The cRfC calculations in the present analysis are based on the diet of a child weighing 16 kg. The selection of 16 kg approximately corresponds to the 50th percentile of growth children around 3.5 years old at the based on the Centers for Disease Control and Prevention (CDCP) growth chart [32]. At around age 3.5 years, children are consuming their largest portions of individual foods per kilogram of body weight. Other bodyweights could be used, but this parameter does not change the relative values of DRIs for one pesticide-food combination in contrast with others.

The mean of the residue levels reported for all positive samples for a given food-pesticide combination, in a given year, is the basic exposure metric used in the DRI formula. The mean of the positive residues ($\bar{R}_{ij}$) of pesticide *i* found in food *j* is calculated via Equation (2), where *n* equals the number of positive residues reported:

$$\bar{R}_{ij} = \frac{\sum_{i>0} R_{ij}}{n} \quad (2)$$

The DRI for a given pesticide and food combination is a function of exposure expressed as the average positive residue and the chronic Reference Concentration (Equation (3)).

$$DRI_{ij} = \frac{\bar{R}_{ij}}{cRfC_{ij}} \quad (3)$$

The residue data used in DRI calculations are from the USDA's Pesticide Data Program (PDP) [17]. Sometimes multiple chemical forms contribute to the dietary risk associated with the residues of a given pesticide, such as endosulfan including endosulfan I, endosulfan II and endosulfan sulfate. In such cases, DRI scores are computed for the parent chemical and all breakdown products, and then added together to represent the total risks associated with all of the reported residues resulting from an application of a single pesticide. This approach fails to capture the cumulative risk potential of exposures to pesticides within a family, like pyrethroids, or those that pose human risks through the same biochemical mode of action, such as carbamates and organophosphates.

DRI values are computed for each food-pesticide combination, for a set of samples collected during a specified time period (usually one year). The FQPA directs the EPA to take into account all foods in which a given pesticide residue is present in determining whether the FQPA's "reasonable certainty of no harm" standard is satisfied. Since few, if any pesticides are found in more than 10 servings of foods that a given person might eat in a day, DRI values of 0.1 or less for a single food-pesticide combination are regarded as posing acceptable risks under the FQPA. In the present analysis, possibly High Dietary Risk samples are those with a DRI value greater than 0.1.

In addition, food-pesticide combinations with DRI values less than 0.1 were classified as High Priority from the perspective of organic integrity when the mean residue level found in the organic samples exceeded 10% of the mean residue level of the same pesticide reported in samples with no market claim, and assumed to be conventionally produced and handled. In either a conventionally grown or organic field, residues detected at relatively low levels, e.g., 0.1 or less of the mean of positive samples from conventionally managed farms, are probably the result of drift, carry over, or some exposure route other than a typical in-season application at or near rates typical on conventional farms. Relatively high residues in conventional or organic food—e.g., residues well above the mean residue level across all positive, conventional samples—probably result from in-season applications at unusually high rates, multiple applications, late season applications, or persistent, systemic pesticides that have built up over time in soil or irrigation water.

The model assumes that pesticides detected in conventional samples are directly applied, thus $\bar{R}_{ij}$ provides an expected "mean of the positives" value for given crop-pesticide data pair. Pesticides quantified at or below 10% of the mean of the positives from conventional samples were classified as incidental amounts with a low action priority (A). Samples with pesticides above the incidental amount were classified as medium action priority up to the point where the levels were equivalent to $\bar{R}_{ij}$. Those samples with levels above $\bar{R}_{ij}$ were classified as having a high priority for action (Equation (4)).

$$\begin{aligned} &\boldsymbol{R \leq \bar{R}_{ij} \cdot 0.1,} && \boldsymbol{A = Low} \\ &\boldsymbol{\bar{R}_{ij} \cdot 0.1 < R \leq \bar{R}_{ij}} && \boldsymbol{A = Medium} \\ &\boldsymbol{R > \bar{R}_{ij}} && \boldsymbol{A = High} \end{aligned} \tag{4}$$

Organic samples contaminated at levels greater than the $\bar{R}_{ij}$ are likely the result of a direct, intentional application. Such findings are evidence of possible fraud, even when the risk index is low. Some of the samples above 10% of $\bar{R}_{ij}$ were for pesticides not registered for the crop, which more often relates to drift from a neighboring field growing a crop where the pesticide is registered. The two criteria for High Action Priority are not mutually exclusive. Pesticides that met both criteria were not double counted.

Food-pesticide combinations with a DRI of less than 0.1 were classified as Medium Action Priority. Organic samples the mean of the positive residues in the organic samples was equal to or greater than 10% of $\bar{R}_{ij}$ in samples grown under conventional management were also classified as Medium Action Priority.

Other food-pesticide combinations with DRI values less than 0.1 and mean residues in the organic samples less than 10% of $\bar{R}_{ij}$ in conventional samples were classified as Low Action Priority, as were samples that tested positive for the few pesticides that are permitted in organic agriculture. In many cases, all or most of the detected residues in organic samples were at or near the LOD, a finding consistent with incidental contamination from ambient levels in agricultural ecosystems. Samples that tested positive for pesticides permitted in organic production were also considered to be "low risk" as long as their DRI did not exceed 0.1.

The Action Threshold (AT) is defined as 5% of the existing EPA tolerance governing residues in a given food-pesticide combination. The NOP requires that an ACA to investigate and possibly suspend or revoke an operator's certification if they find or are made aware of residues above the AT.

3. Results and Discussion

The data were prepared and analyzed using Microsoft Access and Microsoft Excel. Parametric statistics were not considered appropriate because of the non-normal distribution of the data.

3.1. Results

Table 2 provides an overview of the distribution of residues found in organic samples in PDP testing over the period from 2002 to 2011. Residues of specific pesticides are categorized into the above-described four groups in three ways: domestically grown samples, imported samples, and all samples combined.

Table 2. Positive organic samples by origin and group, 2002–2011.

Pesticide Group	**Domestic Positives**		**Imported Positives**		**Total Positives**	
	# Positive	**% Positive**	**# Positive**	**% Positive**	**# Positive**	**% Positive**
Legacy	162	17.9	1	0.5	163	15.0
Post-Harvest	281	31.1	34	18.4	315	28.9
Organic Allowed	197	21.8	42	22.7	239	21.9
Other	265	29.2	108	58.4	373	34.2
Total Positive	**905**	**100.0**	**185**	**100.0**	**1090**	**100.0**

Source: Residue data from the USDA Pesticide Data Program, 2002–2011.

For domestically grown organic samples, two-thirds of the detectable residues stemmed from post-harvest pesticides, legacy contaminants, or pesticides allowed for organic production. Organic farmers have very little control over residues of post-harvest fungicides and legacy chemicals—two groups accounting for close to one-half of all detected residues. In the case of imported organic foods, residues of legacy chemicals and post-harvest fungicides accounted for only 19% of all detected residues, compared to 49% in the case of domestically grown organic foods.

Table 3 includes pesticides grouped by action priority. "Suspected Direct" cases are those where the mean residue level reported in domestically grown or imported organic samples exceeds 10% of the mean residue level in conventionally grown samples of the same food grown in the US or imported. Pesticides in organic food with both DRIs over 0.1 and mean residues above 10% of the mean level of residues in conventionally grown samples were not double counted in the totals.

Table 3. Positive pesticide samples of all organic food by pesticide risk level: 2002–2011.

Pesticide Group	**Domestic Positives**		**Imported Positives**		**Total Positives**	
	# Positive	**% Positive**	**# Positive**	**% Positive**	**# Positive**	**% Positive**
All Food						
High Priority						
High risk	44	4.9%	12	6.5%	32	2.9%
Suspected Direct	98	10.8%	13	7.0%	57	5.2%
Possibly both	20	2.2%	43	23.2%	141	12.9%
Subtotal High Priority	*122*	*13.5%*	*44*	*23.8%*	*166*	*15.2%*
Medium Priority						
Legacy	139	15.4%	1	0.5%	140	12.8%
Post-harvest	135	14.9%	12	6.5%	147	13.5%
Other	111	12.3%	51	27.6%	162	14.9%
Subtotal Medium Priority	*385*	*42.5%*	*64*	*34.6%*	*449*	*41.2%*
Low Priority						
Incidental	201	22.2%	35	18.9%	236	21.7%
Organic Allowed	197	21.8%	42	22.7%	239	21.9%
Subtotal Low Priority	*398*	*44.0%*	*77*	*41.6%*	*475*	*43.6%*
Total	**905**	**100.0%**	**185**	**100.0%**	**1090.0**	**100.0%**

Source: Residue data from the USDA Pesticide Data Program, 2002–2011.

3.1.1. Positive Samples by Food Category

The samples were further subdivided into fresh fruits and vegetables. The findings for fruit appear in Table 4.

Table 4. Positive pesticide samples of organic fruit by pesticide risk level: 2002–2011.

Food Group/Priority	**Domestic Positives**		**Imported Positives**		**Total Positives**	
	# Positive	**% Positive**	**# Positive**	**% Positive**	**# Positive**	**% Positive**
High Priority						
High risk	10	5.6%	6	11.8%	16	7.0%
Suspected Direct	10	5.6%	6	11.8%	16	7.0%
Possibly both	23	12.8%	15	29.4%	38	16.5%
Subtotal High Priority	*23*	*12.8%*	*15*	*29.4%*	*38*	*16.5%*
Medium Priority						
Legacy Chemicals	0	0.0%	0	0.0%	0	0.0%
Post-harvest pesticides	21	11.7%	5	9.8%	26	11.3%
All others	14	7.8%	9	17.6%	23	10.0%
Subtotal Medium Priority	*35*	*19.6%*	*14*	*27.5%*	*35*	*15.2%*
Low Priority						
Incidental	88	49.2%	20	39.2%	108	47.0%
Organic Allowed	33	18.4%	2	3.9%	35	15.2%
Subtotal Low Priority	*121*	*67.6%*	*22*	*43.1%*	*143*	*62.2%*
Total	**179**	**100.0%**	**51**	**100.0%**	**230**	**100.0%**

Source: Residue data from the USDA Pesticide Data Program, 2002–2011.

With domestically grown organic fruit, over two-thirds of the residues detected fall in the "Low Priority" group, while 12.8% are "High Priority." By contrast, almost 30% of imported samples contain "High Priority" residues. Not surprisingly, since no fruits tested by the PDP form and mature underground, none of the fruit samples tested positive for legacy contaminants. Over 60% of the combined positive samples fell into the Low Action Priority category.

The findings for organic vegetable samples are summarized in Table 5.

Table 5. Positive pesticide samples of organic vegetables by pesticide risk level: 2002–2011.

Food Group/Priority	Domestic Positives		Imported Positives		Total Positives	
	# Positive	% Positive	# Positive	% Positive	# Positive	% Positive
High Priority						
High risk	7	1.8%	5	4.1%	12	2.4%
Suspected Direct	32	8.4%	6	4.9%	38	7.6%
Possibly both	36	9.5%	22	18.0%	58	11.6%
Subtotal High Priority	*61*	*16.1%*	*23*	*18.9%*	*84*	*16.8%*
Medium Priority						
Legacy Chemicals	62	16.4%	1	0.8%	63	12.6%
Post-harvest pesticides	16	4.2%	4	3.3%	20	4.0%
All others	65	17.2%	40	32.8%	105	21.0%
Subtotal Medium Priority	*78*	*20.6%*	*45*	*36.9%*	*123*	*24.6%*
Low Priority						
Incidental	61	16.1%	14	11.5%	75	15.0%
NOP Permitted	114	30.1%	40	32.8%	154	30.7%
Subtotal Low Priority	*175*	*46.2%*	*54*	*44.3%*	*229*	*45.7%*
Total	**379**	**100.0%**	**122**	**100.0%**	**501**	**100.0%**

Source: Residue data from the USDA Pesticide Data Program, 2002–2011.

Domestically-grown organic vegetables had a lower percentage of samples with DRIs greater than 0.1 than organic fruit samples—1.8% compared to 5.6% in the case of domestically grown organic fruit. "High Risk" residues with DRI values over 0.1 were more than twice as common in imported organic vegetables compared to domestically grown vegetables.

Vegetables accounted for all samples found to contain legacy contaminants, mainly in root crops such as carrots and potatoes. It is interesting to note that legacy chemicals accounted for 16.4% of all residues detected in domestically-grown organic foods, yet only one sample in imported samples (0.8% of the total number of positive samples in imported, organic vegetables).

3.1.2. Impact of the NOP 5% of Tolerance "Action Threshold"

Samples identified as "High Dietary Risk" on account of DRI values over 0.1 were checked for whether they also violate the current action threshold for organic food of 5% of EPA Tolerance, or 5% of the applicable FDA Action Level for pesticides that have no EPA tolerance. The results are presented in Table 6.

Over one-half of the residues in organic food with a DRI greater than 0.1—therefore classified as "High Risk"—fall below the USDA-NOP Organic Action Threshold of 5% of the EPA Tolerance.

Moving to a risk-based system for the targeting of pesticide-residue-related enforcement actions would clearly reduce pesticide dietary risks more effectively in organic foods than the current Action Threshold. Options to do so follow in the "Discussion" section.

Table 6. Current organic action thresholds for organic samples with a high dietary risk index: 2002–2011.

Action Threshold	Domestic Positives		Imported Positives		Total Positives	
	# > AT	**% > AT**	**# > AT**	**% > AT**	**# > AT**	**% > AT**
DRI>0.1						
Above AT	21	46.7%	5	38.5%	26	44.8%
Below AT	24	53.3%	8	61.5%	32	55.2%
Total Residues > AT	*45*	*100.0%*	*13*	*100.0%*	*58*	*100.0%*

Source: Residue data from the USDA Pesticide Data Program, 2002–2011.

3.1.3. Inadvertent Contamination and Risk

Organic samples occasionally contain residues that can be regarded as inadvertent, because they can be reasonably assumed to be the result of circumstances over which the organic farmer has little or no control. For the purpose of this study, an "inadvertent" residue in an organic food is defined as a residue that:

- Is present at an incidental level less than 10% of the mean of the positives for the same pesticide in conventionally grown samples;
- Has no tolerance established by EPA covering residues in organic or conventionally grown crops; or
- Is a legacy contaminant.

Over 95% of the residues that could be classified as inadvertent had DRIs less than 0.1. Table 7 gives the percentage of samples in each category of inadvertent residues with DRIs greater than 0.1. Fifteen samples of domestic and 12 samples of imported organic produce that tested positive for pesticides had no EPA established Maximum Residue Level (MRL).

Table 7. Positive organic food samples classified as inadvertent with a high dietary risk index: 2002–2011.

	Domestic Positives		Imported Positives		Total Positives	
Category	**# DRI > 0.1**	**% DRI > 0.1**	**# DRI > 0.1**	**% DRI > 0.1**	**# DRI > 0.1**	**% DRI > 0.1**
Incidental	1	4.2%	1	25.0%	2	7.1%
No tolerance	0	0.0%	3	75.0%	3	10.7%
Legacy	23	95.8%	0	0.0%	23	82.1%
Total Inadvertent	*24*	*100.0%*	*4*	*100.0%*	*28*	*100.0%*

Source: Residue data from the USDA Pesticide Data Program, 2002–2011.

Consistent with the hypothesis that contamination is low risk, only about 5% of the positive samples fell into the category, mostly with legacy contaminants. Only two samples that tested positive and were below 10% of the mean of the positives in conventional samples had a DRI of greater than

0.1, indicating low levels of contamination by highly toxic residues. The three positive samples with DRIs greater than 0.1 and no EPA tolerance were all imported, and thus not subject to EPA labeling laws for pesticide application.

3.2. Discussion

Our results raise questions about the effectiveness of current NOP pesticide provisions, especially if a primary goal of these provisions is to markedly reduce, if not eliminate, pesticide risk in certified organic foods. While organic food significantly reduces pesticide exposure and thus potential health risks from pesticides, organic farming does not eliminate pesticide risk. Risk levels arising from pesticide residues in organic food differ by over 1000-fold, with most posing very modest risks and a limited number associated with possibly worrisome risks as measured by the DRI. In order to sustain consumer confidence in organic food, the NOP and organic community needs to act decisively in the rare cases when residues in organic food are associated with possibly worrisome risks. The NOP, in partnership with organic farmers and food companies and certifying agents, must also tap the best available science in assuring consumers on an ongoing basis that pesticide risks in organic food, both domestically grown and imported, are well understood, effectively targeted through timely enforcement actions, and relatively small compared to risks in conventionally grown food.

Only 10.8% of domestically grown organic samples fall in the "High Priority" group, and likely over one-half of these samples fall into this category because of suspected direct application rather than possibly high dietary risks. Some 44% of samples detected in US-grown organic food fall in the "Low Priority" group. Given that the NOP currently has no way to distinguish between the 10.8% of domestic samples posing possibly worrisome risks *vs.* the 44% posing little or no risk, it is inevitable that current NOP pesticide residue enforcement procedures are inefficiently targeting those organic foods worthy of attention.

The NOP could encourage certifiers to target ongoing organic food sampling toward sources of foods with a history of relatively high-risk residues (e.g., DRI > 0.1). After receiving residue testing results from a certifier, the NOP could send an alert to the certify highlighting any samples with a residue level associated with a DRI > 0.1. The data required to determine which samples exceed this threshold could be built into the NOP's residue dataset and used to flag relatively high-risk samples. Conversely, the NOP could offer periodic guidance to certifiers flagging food-pesticide combinations that may arise periodically, but do not warrant intensive focus because of consistently, very low DRI values (e.g., post-harvest fungicide residues in tree fruit).

One vital cluster of challenges arises around the occasional presence of UREC residues in organic food. The primary source of UREC is presumed to be pesticide drift, while carry over in soil, contaminated compost or organic soil amendments, and irrigation water are emerging as more frequent and sometimes very difficult problems to contend with. Drift is a widely recognized environmental problem. Aerial application, air blast sprayers, and micro-droplets are application technologies that increase the risk of drift and off-farm damage to non-target vegetation.

Presence of a pesticide is not proof of an intentional application, but a direct application of a pesticide will in the vast majority of cases result in a higher level of residues than inadvertent contamination. The dynamics of drift are complicated and depend on atmospheric conditions. Factors such as how application equipment is operated, the particle or droplet size of the pesticide, the velocity of the pesticides being released, and surrounding vegetation all play a role. Pesticide levels tend to diminish with distance by predictable amounts, all other things being equal [33,34]. The highest levels will be on vegetation where pesticides were directly applied.

Measures that organic farmers are expected to take to avoid drift includes notification of neighboring conventional farms, establishment of clear borders and buffer zones, and planting of hedgerows that can trap pesticides transported from conventional farms by drift, runoff and other means. These measures entail costs imposed on organic farmers. Even when farmers take precautions, their crops can still be contaminated. Some courts now recognize that organic farmers need to be protected from drift and should not be expected to bear the full cost of avoiding pesticide contamination that is caused by other farmers and the pesticide applicators that they hire [35].

The greatest difference between domestic and imported crops is with persistent pollutants. Legacy pesticides are 162-times more likely to occur in domestic than in imported products. This outcome may reflect several factors. Legacy pesticides may have been used less in other countries by operations that were exporting to the US [36]. Additionally, crops and livestock products that accumulate persistent pesticides are unlikely to be imported, while most imported crops generally are not accumulators. Finally, such pesticides may degrade more rapidly under the tropical conditions where many imported fresh fruits and vegetables are grown. Given that environmental contamination is known to be present, the question then becomes what is avoidable? If so, how can the organic standards address avoidable contamination?

While the answer is site-specific and depends on the structure and management of farming operations, contamination that is caused by the application, storage, or use of a prohibited substance by the organic operator should be rare and avoidable. Not much can be done in the immediate future about legacy contaminants, although organic farmers can avoid problems by planting crops not prone to the uptake of legacy chemicals bound to the soil.

With post-harvest pesticides, research and/or policy reform may be able to further reduce pesticide risk in organic food over the long run. This problem, though, could be solved reliably by growth in demand for organic fruits and vegetables sufficient to support organic-only processing facilities and distribution channels.

Some contaminants other than fungicides are present as the result of post-harvest handling. Most prominent is the plant growth regulator chlorpropham, which is used to inhibit sprouting in potatoes. Various insecticides are used to control ants, roaches, and other pests both in packing, storage and retail facilities. Only those that are exclusively registered for non-food use are included in the post-harvest pesticide category.

The USDA organic standard requires handlers to use non-chemical means such as exclusion, removal of pest habitat, food sources and breeding areas; and management of environmental factors to prevent pest-induced damage. Handlers who have such systems in place but require control may also use mechanical or physical methods like traps, light, or sound. Non-synthetic substances and synthetic substances consistent with the National List may also be applied.

These substances need to be included in the operation's organic system plan. The plan "must include a list of all measures taken to prevent contact of the organically produced products or ingredients with the substance used." Other pesticides may be used "as required by Federal, State, or local laws and regulations" as long as "measures are taken to prevent contact of the organically produced products or ingredients with the substance used" [7 CFR 205.271(f)].

The USDA organic standards do not require facilities dedicated solely to handling organic product. While post-harvest pesticides below 5% of EPA tolerances are generally accepted without consequence in organic foods, the intent of both the statute and the rule are to prevent contact and possible contamination. Positive tests for post-harvest pesticides within the handlers' control may be indicative of inadequate procedures for separation and cleaning required in the post-harvest handling requirements of the standards.

Finally, there is the issue of residues associated with, but not derived from permitted substances used in organic production. While such cases are relatively rare, organic farmers have management options to reduce pesticide risks if they are testing positive for these pesticides. The presence of piperonyl butoxide (PBO) in some of the samples, notably in some imported products, may be correlated with the use of other permitted substances. While PBO is prohibited under the NOP, it is commonly used as a synergist with pyrethrum and other pesticides permitted for organic production. It is recognized to have biocidal properties and is labeled as an active ingredient in the US. PBO may also be used as an inert ingredient in some botanical pesticides, and would be prohibited for use as an inert ingredient under the USDA Organic regulation [37]. However, in some countries the presence of PBO may be concealed from producers in products that appear to meet standards for organic production. Such adulteration may be true for other formulated pesticides used outside the US as well.

4. Conclusions

Advances in analytical chemistry, sampling, models to evaluate risk from pesticides, and investigation capacity have given organic agriculture some powerful new tools that can be used to protect consumers and the integrity of the organic label. The LOQs for many pesticides have fallen progressively since 1991, in step with advances in analytical chemistry methods. As a result, the modern PDP and other residue testing programs detect more pesticide residues in organic foods that are either not authorized for organic production but covered by a tolerance, or not covered by a tolerance on conventional grown crops. This latter problem arises with several minor crops, which have few pesticides registered and few MRLs established.

The primary purpose of the USDA NOP is to enforce truth in labeling. The USDA organic seal on food labels carries with it certain expectations. One is protection from fraud. Another is avoidance of food containing residues of pesticides prohibited by the NOP standard. Incorporation of dietary risk into the organic standard would be a more precautionary, risk-based approach than targeting enforcement to organic foods found to contain 5% or more of the applicable EPA tolerance.

Most pesticides in organic food tested by the USDA's PDP were detected at very low levels and can be safely assumed to be incidental and low risk. Presumably, most low-level residues are also inadvertent. Legacy contaminants can be assumed as incidental because they are present in soil, and without testing the soil it is not possible to predict what levels of contaminants will occur in crops. Pesticides for which there are no tolerances can be assumed to be inadvertent in most cases because they are not generally labeled for, or applied directly to the crops. This assumption may not hold true for imported crops where EPA pesticide label requirements are not in effect.

Based on the data analyzed in this paper and our collective experience, we believe that fraud is rare and that most prohibited residues in organic produce are not the result of willful application. Presumably the risk and cost of losing certification and the organic premium would be a sufficient deterrent. Low levels of contamination will occur and need to be monitored, but also tolerated, unless organic farming is to be limited to rare and exceptionally isolated regions. However, our findings show that there is still room for improvement. The NOP can help protect the public by providing risk-driven, clear and binding guidance to ACAs regarding the choice of crops to be tested, the frequency of testing, and number of samples collected on a given operation. Such strong guidance will enhance the value of the program and the return-on-investment in residue testing by the organic community as a whole.

Organic food offers consumers a choice that dramatically reduces dietary exposure to pesticide and thus potential pesticide-related health risks. Dietary risks in organic food can be further reduced by the adoption of policies that are based on scientific advances in the detection of residues, coupled with quantification of relative pesticide risk levels, but doing so will require the NOP and all stakeholders in the organic community to embrace both policy and scientific innovation.

Acknowledgments

The authors acknowledge the assistance of Martha Lamont, Karie Knoke, Nicholas Potter and four anonymous reviewers.

Author Contributions

The dietary risk index was created by Benbrook, as well as the pesticide residue dataset used in this project. Both authors contributed to the research design and Baker carried out detailed analyses. Both authors shaped the final tables, agreed upon key results, wrote the paper, and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

1. Greene, C. Growth patterns in the U.S. Organic Industry. Available online: http://www.ers.usda.gov/amber-waves/2013-october/growth-patterns-in-the-us-organic-industry.aspx#.U367uHbywUg (accessed on 22 May 2014).
2. Hornick, M. Organic salad growth, share prompt push for promotions. *The Packer*, 4 November 2013. Available online: http://www.thepacker.com/fruit-vegetable-news/marketing-profiles/230511011.html (accessed on 22 May 2014).
3. Organic Trade Association (OTA). *Organic Trade Association's 2011 Organic Industry Survey*; OTA: Brattleboro, VT, USA, 2011.
4. Hartman Group. *Organic Consumer Profile*; Hartman Group: Bellevue, WA, USA, 2000. Available online: http://www.hartman-group.com/publications/reports/the-organic-consumer-profile (accessed on 22 May 2014).

5. Hartman Group. *Organic 2006: Consumer Attitudes & Behavior, Five Years Later & Into the Future*; Hartman Group: Bellevue, WA, USA, 2006. Available online: http://www.hartman-group.com/publications/view/19 (accessed on 22 May 2014).
6. Zanoli, R.; Naspetti, S. Consumer motivations in the purchase of organic food: A means-end approach. *Br. Food J.* **2002**, *104*, 643–653.
7. Von Essen, E.; Englander, M. Organic food as a healthy lifestyle: A phenomenological psychological analysis. *Int. J. Qual. Stud. Health Well-Being* **2013**, *8*, 20559.
8. Lockie, S.; Lyons, K.; Lawrence, G.; Grice, J. Choosing organics: a path analysis of factors underlying the selection of organic food among Australian consumers. *Appetite* **2004**, *43*, 135–146.
9. Hughner, R.S.; McDonagh, P.; Prothero, A.; Shultz, C.J.; Stanton, J. Who are organic food consumers? A compilation and review of why people purchase organic food. *J. Consum. Behav.* **2007**, *6*, 94–110.
10. Oates, L.G.; Oates, L. Health, Wellness and Organic Diets. Ph.D. Thesis, RMIT University, Melbourne, Australia, 2013.
11. Baker, B.P.; Benbrook, C.M.; Groth, E., III; Benbrook, K.L. Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: Insights from three US data sets. *Food Addit. Contam.* **2002**, *19*, 427–446.
12. *US President's Cancer Panel Reducing Environmental Cancer Risk: What Can We Do Now?* US Department of Health and Human Services: Washington, DC, USA, 2010.
13. Smith-Spangler, C.; Brandeau, M.L.; Hunter, G.E.; Bavinger, J.C.; Pearson, M.; Eschbach, P.J.; Sundaram, V.; Liu, H.; Schirmer, P.; Stave, C.; *et al*. Are Organic Foods Safer or Healthier Than Conventional Alternatives? A Systematic Review. *Ann. Intern. Med.* **2012**, *157*, 348–366.
14. Wilkins, J.L.; Hillers, V.N. Influences of pesticide residue and environmental concerns on organic food preference among food cooperative members and non-members in Washington State. *J. Nutr. Educ.* **1994**, *26*, 26–33.
15. Bazoche, P.; Combris, P.; Giraud-Héraud, E.; Seabra Pinto, A.; Bunte, F.; Tsakiridou, E. Willingness to pay for pesticide reduction in the EU: Nothing but organic? *Eur. Rev. Agric. Econ.* **2013**, doi:10.1093/erae/jbt011.
16. Winter, C.K.; Davis, S.F. Organic Foods. *J. Food Sci.* **2006**, *71*, R117–R124.
17. US Department of Agriculture (USDA). *Agricultural Marketing Service, Pesticide Data Program Pesticide Data Program Annual Reports*; USDA: Washington, DC, USA, 1992.
18. Curl, C.L.; Fenske, R.A.; Elgethun, K. Organophosphorus pesticide exposure of urban and suburban preschool children with organic and conventional diets. *Environ. Health Perspect.* **2003**, *111*, 377–382.
19. Lu, C.; Toepel, K.; Irish, R.; Fenske, R.A.; Barr, D.B.; Bravo, R. Organic diets significantly lower children's dietary exposure to organophosphorus pesticides. *Environ. Health Perspect.* **2006**, *114*, 260–263.
20. Organic Foods Production Act of 1990. Available online: http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5060370 (accessed on 26 May 2014).
21. US Congress. *Senate: Report on the 1990 Farm Bill*; US Government Printing Office: Washington, DC, USA, 1990.

22. National Organic Standards Board. Available online: http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=stelprdc5058863 (accessed on 26 May 2014).
23. Minutes of the National Organic Standards Board. Available online: http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5065328 (accessed on 26 May 2014).
24. *USDA Office of Inspector General Oversight of the National Organic Program*; USDA: Washington, DC, USA, 2010.
25. 2010–2011 Pilot study: Pesticide Residue Testing of Organic Products: Available online: http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5101234 (accessed on 26 May 2014).
26. Edwards, C.A. Insecticide Residues in Soils. In *Residue Reviews*; Gunther, F., Ed.; Reviews of Environmental Contamination and Toxicology; Springer: New York, NY, USA, 1966; Volume 13, pp. 83–132.
27. Rodale, J. *Encyclopedia of Organic Farming*; Rodale: Emmaus, PA, USA, 1970.
28. US Environmental Protection Agency (US EPA). *Office of Inspector General Measuring the impact of the Food Quality Protection Act: Challenges and Opportunities*; US EPA: Washington, DC, USA, 2006.
29. US Environmental Protection Agency (US EPA). *Office of Inspector General Supplemental Report: Details on Dietary Risk Data in Support of Report No. 2006-P-00028, Measuring the Impact of the Food Quality Protection Act: Challenges and Opportunities*; US EPA: Washington, DC, USA, 2006.
30. Benbrook, C. *The Organic Center's "Dietary Risk Index"—Tracking Relative Pesticide Risks in Food and Beverages*; The Organic Center: Boulder, CO, USA, 2011.
31. Benbrook, C. *Impacts of Changing Pest Management Systems and Organic Production on Tree Fruit Pesticide Residues and Risk*; Washington State University, Center for Sustaining Agriculture and Natural Resources: Leavenworth, WA, USA, 2012.
32. US Department of Health and Human Services, Centers for Disease Control and Prevention. *2000 CDC Growth Charts for the United States: Methods and Development*; US Government Printing Office: Washington, DC, USA, 2002.
33. Thompson, N.; Ley, A.J. Estimating spray drift using a random-walk model of evaporating drops. *J. Agric. Eng. Res.* **1983**, *28*, 419–435.
34. Salyani, M.; Cromwell, R. Spray drift from ground and aerial applications. *Trans. Am. Soc. Agric. Eng.* **1991**, *35*, 1113–1120.
35. Jacobs Farm/Del Cabo, Inc. v. Western Farm Service, Inc., 190 Cal.App.4th 1502. Available online: http://www.mpplaw.com/files/upload/JacobsFarm_DelCabo,Inc.V.WesternFarmService,Inc.%282010%29190Cal.App.4th1502.pdf (accessed on 26 May 2014).
36. Wright, A. Rethinking the circle of poison: The politics of pesticide poisoning among Mexican farm workers. *Lat. Am. Perspect.* **1986**, *13*, 26–59.
37. *Organic Materials Review Institute Generic Materials List*; Organic Materials Research Institute: Eugene, OR, USA, 2013.