HHS Public Access
Author manuscript
J Agromedicine. Author manuscript; available in PMC 2018 October 29.

Published in final edited form as:
J Agromedicine. 2018 ; 23(4): 327–335. doi:10.1080/1059924X.2018.1501451.

Pesticide use, allergic rhinitis, and asthma among US farm operators

Opal Patel[a,b], **Girija Syamlal**[b], **Paul K. Henneberger**[b], **Walter A. Alarcon**[c], and **Jacek M. Mazurek**[b]

[a]Association of Schools and Programs of Public Health (ASPPH)/Centers for Disease Control and Prevention (CDC) Public Health Fellowship Program, Washington, DC, USA

[b]Respiratory Health Division, National Institute for Occupational Safety and Health (NIOSH), CDC, Morgantown, WV, USA

[c]Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS), NIOSH, CDC, Cincinnati,OH, USA

Abstract

Objective: The objective of the study is to examine associations between use of specific pesticides and lifetime allergic rhinitis and current asthma in US primary farm operators.

Methods: The 2011 Farm and Ranch Safety Survey data from 11,210 primary farm operators were analyzed. Pesticide use on the farm was determined using an affirmative response to the question of whether the operator ever mixed, loaded, or applied pesticides on their farm in the 12 months prior to the interview. Operators who answered “yes” were further asked about the specific trade name and formulation identifiers of the product they used and personal protective equipment (PPE) used. Data were weighted to produce national estimates. Adjusted prevalence odds ratios (PORs) were calculated using logistic regression. The referent group included operators who did not use any pesticides in the 12 months prior to the interview.

Results: Of an estimated 2.1 million farm operators, 40.0% used pesticides, 30.8% had lifetime allergic rhinitis, and 5.1% had current asthma. Insecticide and herbicide use were significantly associated with lifetime allergic rhinitis and current asthma. The use of 2,4-dichlorophenoxyacetic acid (POR = 1.5; 95% CI 1.2–1.9) and carbaryl (POR = 2.3; 1.4–3.7) was significantly associated with lifetime allergic rhinitis. Of operators using pesticides, 64.9% used PPE the last time they mixed, loaded, or applied pesticides.

Conclusions: Pesticide use was associated with lifetime allergic rhinitis and current asthma among farm operators. Further studies are needed to clarify the dose–response relationship between pesticide use and adverse respiratory health effects.

CONTACT Jacek M. Mazurek, JMazurek1@cdc.gov, Respiratory Health Division, National Institute for Occupational Safety and Health (NIOSH), CDC 1095 Willowdale Road MS HG 908, Morgantown, WV 26505, USA.

Declaration of interests None declared.

Disclaimer
The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention or the Association of Schools and Programs of Public Health. Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

Keywords

Agriculture; allergic rhinitis; asthma; occupational exposure; pesticides

Introduction

Pesticides are substances or mixtures of substances intended to control pests in the environment.[1] Approximately 20,000 pesticide products, which include both active and inert ingredients, are marketed in the United States.[2–4] Active ingredients are categorized as conventional (synthetic chemicals), biological (natural materials), and antimicrobial.[3] Major pesticide classifications include herbicides, insecticides, fungicides, and fumigants.[3] In 2012, 1,006 million pound of conventional pesticides was used in the United States, and of those, 899 (89%) million pound was used in agriculture.[5] Exposure to pesticides has been associated with adverse health effects such as respiratory failure, neurotoxicity, dermatitis, and cancer.[1,6]

Adverse respiratory health outcomes among pesticide users, including allergic rhinitis and asthma, have previously been described.[7–18] In Greece, 51% of grape farmers who used pesticides reported allergic rhinitis (OR = 3.0).[7] Among pesticide applicators in the Agricultural Health Study, 67–74% reported current rhinitis, and 2% reported adult-onset asthma.[9,12,17] The authors found that specific pesticides used by pesticide applicators were significantly associated with current rhinitis and adult-onset asthma.[8,9,12,17] For example, use of 2,4-dichlorophenoxyacetic acid (2,4-D) was associated with current rhinitis[12] (OR = 1.3) and adult-onset atopic asthma[9] (OR = 1.6). Also, permethrin used on animals was significantly associated with an increased number of rhinitis episodes,[17] and parathion use was associated with allergic asthma[9] (OR = 2.1).

A recent review of studies concluded that occupational pesticide exposure in farmers was associated with respiratory health effects.[11] Associations between pesticide exposures, such as organophosphates and carbamates, and chronic cough, wheeze, and asthma, as well as decreased respiratory function measured by spirometry tests, have also been found in studies of agricultural workers.[11] One study in this review found that rhinitis was more frequent in greenhouse workers compared to office workers. Pesticide use was considered a potential exposure for these greenhouse workers, but it was not evaluated separately for an association with rhinitis.[19]

While pesticides are beneficial in protecting food supply and controlling disease vectors, respiratory health effects are not fully understood.[6,7,11] The Agricultural Health Studies reported on the associations between pesticide use and respiratory health among US farmer and commercial licensed pesticide applicators and their spouses in two states. This study advances the previous research by examining the associations between specific pesticides and lifetime allergic rhinitis and current asthma among primary farm operators, regardless of their certification.

Methods

Data source

In 2011, the National Institute for Occupational Safety and Health supported the Farm and Ranch Safety Survey to collect information on farm exposures, injuries, and health among primary farm operators in the United States (OMB No. 0535–0235). This telephone survey was conducted by the US Department of Agriculture's National Agricultural Statistics Service (NASS). Of the 25,000 farm operations selected for the survey, 11,210 (44.8%) were active farms and agreed to participate. The remaining operations either refused to participate (5,103; 20.4%), were not actively farming (1,190; 4.8%), or could not be contacted (7,497; 30.0%). Data were self-reported by the farm operator or the farm operator's spouse. The adjusted survey response rate, excluding noncontacts, was 70.8%.

Definitions

Primary farm operators were those responsible for running the farm and making daily management decisions.[20] Farm operators with lifetime allergic rhinitis were those who had ever been told by a doctor, nurse, or other health professional that they had hay fever, seasonal allergies, or allergic rhinitis. Farm operators with current asthma were those who had ever been told by a doctor, nurse, or other health professional that they had asthma and still had asthma at the time of the interview.

Pesticide use on the farm was determined using an affirmative response to the question, "In the past 12 months, have you/the farm operator ever mixed, loaded, or applied pesticides on your farm?" Operators who answered "yes" were further asked, "The last time you/the farm operator did this, what was the specific trade name of the product used including formulation identifiers." Those who used pesticides were also asked whether they wore personal protective equipment (PPE) the last time they mixed, loaded, or applied pesticides on the farm. Operators were asked about the type of PPE worn (i.e., chemical-resistant boots or over boots, chemical-resistant gloves, protective eyewear or a face shield, a chemical-resistant suit over clothing, a chemical-resistant apron, or a respirator).

The need for medical care because of a pesticide exposure was assessed using an affirmative response to the question, "In the past 12 months, have you/the farm operator become sick or had any reaction that led you/them to seek medical care because of pesticide exposure?" Information about specific adverse health effects or the pesticide used prior to the reaction was not collected.

Farms were classified based on the largest source of revenue for the farm. Livestock farms reported largest source of revenue from swine, dairy, beef cattle, sheep or goats, equine, poultry, aquaculture, and other animals. Crop farms reported largest source of revenue from grains, tobacco, cotton, vegetables, fruits or nuts, nursery or greenhouse, cutting Christmas trees, and other crops or hay.

Pesticide use coding

Verbatim responses on the specific pesticide trade name and formulation identifiers were reviewed by two authors (O.P. and J.M.M.). Active ingredients in pesticide products were identified and assigned a code to be used for analyses. To identify and code active ingredients, the product research page from the National Pesticide Information Center (http://npic.orst.edu/NPRO/) was consulted. Guidelines from the US Environmental Protection Agency were used to classify specific pesticides as herbicides, insecticides, fungicides, fumigants, rodenticides, or other.[21] The authors coded verbatim responses separately, compared results, and discussed and reconciled coding discrepancies. Pesticide use was coded as "unknown" when operators could recall neither the specific trade name nor the active ingredient, or the authors could not identify the reported pesticide because of insufficient information. Information on operators use of each specific pesticide in the 12 months prior to the interview was categorized as "yes" (i.e., operator used this specific pesticide), "no" (i.e., operator used other pesticides), "unknown" (i.e., specific pesticide use was unknown), and "did not use any pesticides."

Statistical analyses

NIOSH calculated survey weights using NASS stratification of farms within census regions and by farm value of sales to produce nationally representative estimates. Analyses were done using SAS version 9.4 (SAS Institute, Cary, NC) survey procedures. Proportions with corresponding 95% confidence intervals (CIs) were estimated. Estimates with a relative standard error ≥30% were excluded from further analysis.

Multivariable logistic regression models to examine the associations between specific pesticides and lifetime allergic rhinitis and current asthma in farm operators were developed. First, the Rao-Scott chi-square test of independence to separately examine associations between demographic, farm characteristic, and farm-related exposures with lifetime allergic rhinitis or current asthma was used; variables associated with lifetime allergic rhinitis or current asthma at $P < .2$ were selected for inclusion in two initial base models. Backward elimination was used to develop the two final base models that included variables significantly associated with lifetime allergic rhinitis or current asthma.[22] Smoking and other exposures were evaluated for potential confounding and their inclusion in the models did not substantially change the effect estimates of interest. The final base model for lifetime allergic rhinitis included age group (16–39, 40–64, and 65–99 years), sex, farm value of sales (≤$9,999, $10,000–99,999, and ≥$100,000), and region (Midwest, North, South, and West). The final base model for current asthma included sex and region. Specific pesticides associated ($P < .2$) with lifetime allergic rhinitis or current asthma were added separately to each final base model. All tests were two-sided with $P < .05$ considered significant. The referent group included operators who did not use any pesticides in the 12 months prior to the interview.

The coefficient of variation (CV) was calculated for prevalence odds ratios (PORs) to evaluate reliability. Using the estimated POR and the CI, it was shown that CI = $\exp[\ln(\text{POR}) \pm 1.96 \times \text{SE}(\ln(\text{POR}))]$; therefore, $\ln(\text{CI}) = \ln(\text{POR}) \pm 1.96 \times \text{SE}(\ln(\text{POR}))$. SE(ln(POR)) was calculated using either the upper or lower bound of the CI. Computing the

SE(POR) was done using the Delta Method in which SE(POR) = SE(ln (POR)) × POR. The CV was calculated using the formula CV = [SE(POR)/POR] × 100.

A survey of respirator use and practices among private sector employers found differences in respirator use by establishment size, i.e., larger establishments (≥500 employees) had substantially higher rates of respirator use than smaller establishments (<20 employees).[23] To address potential differences in respirator use by farm size, we evaluated associations between specific pesticides and lifetime allergic rhinitis by farm size (≤100 and ≥101 acres). In addition, we evaluated the associations by farm type (crop and livestock). Similar analyses for associations with current asthma were not done because the numbers of operators with current asthma who used specific pesticides were small and related estimates were unreliable.

Results

Of an estimated 2.1 million farm operators, 40.0% mixed, loaded, or applied pesticides on their farm in the 12 months prior to the interview. An estimated .9% of farm operators who mixed, loaded, or applied pesticides became sick or had a reaction that led them to seek medical care because of pesticide exposure in the 12 months prior to the interview. The highest proportion of pesticide use was among operators who were aged 16–30 years (51.4%), male (42.5%), located in the West (45.7%), operated farms ≥1,000 acres (54.9%), had farm value of sales ≥$100,000 (54.5%), and had crop farms (43.0%) (Table 1). Most operators used pesticides outdoors (95.7% applied and 92.2% mixed or loaded pesticides).

Farm operators reported up to seven different pesticides that they used in the 12 months prior to the interview. Among operators using pesticides, 54.1% used one, 10.5% used two, and 4.3% used three or more pesticides. A total of 161 specific pesticides were identified. Of these, herbicides accounted for the largest class of pesticides (42.9%), followed by insecticides (28.6%) and fungicides (18.0%).

Farm operators most commonly used herbicides (58.8%), followed by insecticides (9.8%) and fungicides (2.4%). By specific pesticide, the most commonly used was glyphosate (41.7%), followed by 2,4-D (17.8%) and triclopyr (5.4%). Overall, 30.7% (35.5% in the South, 29.9% in the North, 27.8% in the Midwest, and 25.3% in the West) of operators using pesticides could recall neither the specific trade name nor the active ingredient.

An estimated 30.8% of operators had lifetime allergic rhinitis and 5.1% had current asthma. The prevalence of lifetime allergic rhinitis was 38.2% in the South, 29.0% in the West, 25.2% in the North, and 24.1% in the Midwest; the prevalence of current asthma was 6.6% in the West, 5.4% in the North, 5.2% in the South, and 4.3% in the Midwest. By pesticide class, insecticide and herbicide use were significantly associated with lifetime allergic rhinitis and current asthma (Tables 2 and 3). By specific pesticide, 2,4-D and carbaryl were significantly associated with lifetime allergic rhinitis. Operators who could not recall the specific trade name nor the active ingredient of pesticides used had higher odds of having lifetime allergic rhinitis (POR = 1.5; 95% CI 1.2–1.8) or current asthma (POR = 1.6; 95% CI

1.1–2.3) compared with those who did not use any pesticides in the 12 months prior to the interview.

Among operators managing farms ≤100 acres, significant associations with lifetime allergic rhinitis were observed for herbicides and insecticides, and specifically for use of 2,4-D, carbaryl, and triclopyr (Table 4). Among operators managing farms ≥101 acres, only insecticide use was associated with lifetime allergic rhinitis; no specific pesticides were significantly associated with lifetime allergic rhinitis. Tests for the interaction of farm size with pesticide use were not statistically significant.

Among operators with livestock farms, significant associations with lifetime allergic rhinitis were observed for herbicides and insecticides, and specifically for use of 2,4-D (Table 5). Among operators with crop farms, lifetime allergic rhinitis was significantly associated with overall insecticide use, and with use of the permethrin. Tests for the interaction of farm size with pesticide use were not statistically significant.

Among operators who used pesticides, an estimated 64.9% used at least one form of PPE the last time they mixed, loaded, or applied pesticides: 55.5% used chemical-resistant gloves; 27.9% used protective eyewear or face shield; 16.3% used chemical-resistant boots; 11.5% used a chemical-resistant suit; 10.3% used a respirator (5.7% used a filtering face piece/dust mask style respirator and 4.4% used a cartridge respirator); and 2.7% used a chemical-resistant apron. Of operators who used pesticides and had lifetime allergic rhinitis, 9.9% used a respirator. A significantly higher proportion of pesticide using operators used respirators on crop than livestock farms (11.4% vs. 9.1%; $P = .04$) and operating farms ≤100 acres than farms ≥101 acres (11.3% vs. 8.9%; $P = .02$). No significant association was observed between respirator use and lifetime allergic rhinitis; however, respirator use was significantly associated with farm size and farm type.

Discussion

Overall, 40% of farm operators mixed, loaded, or applied pesticides on farms in the 12 months prior to the interview, similar to previous studies reporting pesticide use by 45–53% of farmers.[24,25] More than half of operators reported using only one pesticide and herbicides were the predominant type of pesticide. Farm operators using herbicides or insecticides had a higher odds of having lifetime allergic rhinitis and current asthma compared with operators who did not use any pesticides in the past 12 months. The Agricultural Health Study of pesticide applicators and their spouses from Iowa and North Carolina found significant associations between adultonset allergic asthma and 2,4-D (OR = 1.5; 95% CI 1.1–2.1), glyphosate (OR = 1.3; 95% CI 1.0–1.7), carbaryl (OR = 1.4; 95% CI 1.1–1.8), permethrin (OR = 1.7; 95% CI 1.0–2.9), and malathion (OR = 1.6; 95% CI 1.2–2.1) among farm women.[8] However, the authors found no association between these pesticides and adult-onset asthma for male farmers.[9] Among male and female pesticide applicators, wheeze was associated with the use of malathion (OR = 1.1; 95% CI 1.0–1.3).[14]

In the current study, glyphosate was the most commonly used pesticide. However, there was no significant association between glyphosate use and lifetime allergic rhinitis or current asthma among farm operators. Previous findings among pesticide applicators have shown that glyphosate was associated with current rhinitis[12] (OR = 1.3; 95% CI 1.1–1.6), adult-onset atopic asthma in farm women[8] (OR = 1.3; 95% CI 1.0–1.7), and allergic (OR = 1.6; 95% CI 1.2–2.0) and non-allergic wheeze (OR = 1.2; 95% CI 1.1–1.4) among male farmers.[10] The differences in finding between this study and the Agricultural Health Study might be explained, in part, by the differences in methodologies. Although this study and the Agricultural Health Study relied on self-reported exposures and health outcome, the Agricultural Health Study devoted many more questions to pesticide use, which may have yielded a more robust assessment of pesticide exposure.

The second most commonly used pesticide by operators was 2,4-D. Farm operators who used 2,4-D had a higher odds of having lifetime allergic rhinitis compared to operators who did not use any pesticides. Similar results were found among pesticide applicators for an association between 2,4-D use and current rhinitis[12] (OR = 1.3; 95% CI 1.1–1.6), adult-onset atopic asthma in farm women[8] (OR = 1.5; 95% CI 1.1–2.1), and allergic wheeze (OR = 1.5; 95% CI 1.2–1.8) among male farmers.[10]

In this study, farm operators who used carbamates (carbaryl) or pyrethroids (permethrin) had a higher odds of lifetime allergic rhinitis.[1,6,26] In previous studies, carbamate use was associated with allergic rhinitis (OR = 3.0; 95% CI 1.4–6.5) among Greek farmers, and allergic asthma (OR = 1.5; 95% CI 1.1–1.9) and farmers lung (OR = 1.3; 95% CI 1.0–1.7) among US farmers.[7,8,13] Among US pesticide applicators, the use of carbaryl was associated with allergic wheeze (OR = 1.7; 95% CI 1.3–2.2), and permethrin use was associated with allergic wheeze (OR = 1.4; 95% CI 1.1–1.8) and non-allergic wheeze (OR = 1.4; 95% CI 1.2–1.6) among male farmers.[10] When permethrin used for crops and animals was evaluated separately, permethrin used on animals was associated with wheeze (OR = 1.3; 95% CI 1.1–1.6) among farmers[15] and an increased number of rhinitis episodes among private pesticide applicators.[17]

A third of operators could recall neither the specific pesticide trade name nor the active ingredient. These operators were found to have higher odds of having lifetime allergic rhinitis or current asthma compared with those who did not use any pesticides. These findings underscore the need for increased awareness of pesticides used on the farms and associated health risks.

Farm operators on smaller farms who used certain pesticides had higher odds of lifetime allergic rhinitis compared with operators on larger farms. The attenuation of results among operators on larger farms may be explained, in part, by differences in roles of primary farm operators on larger versus smaller farms. An Australian study on farm safety practices by farm size found that smaller farms were less likely to own safety equipment than larger farms.[27] Also, farm operators with livestock farms had a higher odds of lifetime allergic rhinitis for most pesticides compared to operators on livestock farms who did not use any pesticides. A past study in US farmers suggested that livestock farmers may be exposed to more agricultural chemicals than crop farmers.[28] Further research is needed to identify whether pesticide handling knowledge and practices among operators differ by farm size and type.

In this study, over 60% of operators used some type of PPE when they mixed, loaded, or applied pesticides on the farm, and 10% wore a respirator. Previous research on private sector employees, including those in mining, construction, and agriculture, has shown that larger establishments were associated with higher respirator use compared to smaller establishments.[23] A greater proportion of operators in the current study used respirators on smaller farms and crop farms compared to operators on larger farms and livestock farms, respectively. This may be explained by use of enclosed cabs by operators on larger farms, which would eliminate need for respirators when applying pesticides. Differences in respirator use by region may be explained by farm type, farm size, and regional variations in pesticide training and pesticides used on the farm.25,28,29

The Farm and Ranch Safety Survey is the largest national survey of agricultural pesticide use that collected detailed information on pesticide and PPE use on the farm. However, these data have some limitations. The estimates were based on self-reported data from a cross-sectional survey; diagnoses of allergic rhinitis or asthma could not be validated and temporality could not be established. Some operators might have developed allergic rhinitis or asthma in the past, prior to their use of pesticides, or past pesticide exposure may have contributed to allergic rhinitis or asthma. Associations between pesticide use and respiratory health effects among operators may be influenced by exposures early in life (i.e., the hygiene hypothesis); however, no information was available on childhood exposures.[30,31] In addition, while previous research has found different associations between males and females, most associations between pesticides and rhinitis or asthma, overall and by gender, could not be evaluated because of small sample sizes resulting in unstable estimates. Also, information on the proxy responses was not available; thus, it was not possible to assess potential bias. Studies have shown that proxy and selfreported responses may differ and potentially affect the direction of associations.[32,33] Moreover, no data on frequency of pesticide use or past pesticide use were collected, and we were unable to account for multiple pesticide exposures and inert ingredients found in pesticide products. Results of additional analyses (results not shown) of associations between health outcomes and specific pesticide exposures for operators who reported using only one specific pesticide (i.e., only 2,4-D) were similar, with wider CIs of point estimates for health outcomes due to smaller sample sizes. Finally, the healthy worker effect could result in lack of observed associations.[34–36]

Up-to-date training, education, and safe pesticide handling is critical to prevent pesticide-related illnesses. This includes compliance with instructions on pesticide product labels for recommended PPE. Research should examine the association between pesticide use and respiratory health effects by farm type, and whether pesticide handling knowledge and practices, and PPE use among operators differs on smaller versus larger farms. In addition, future studies should conduct cumulative risk assessments of agricultural pesticide exposures because pesticide exposure typically occurs in mixtures with other pesticides.[37]

Conclusion

This study adds to the limited knowledge on pesticide use and its association with respiratory diseases among primary farm operators. To inform prevention, further studies are needed to clarify temporality and the dose (frequency and duration of exposure)–response relationship between pesticide use and respiratory health.

Acknowledgments

The authors thank Kitty J. Hendricks, MA, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, for her active role as the Project Officer for the Farm and Ranch Safety Survey and Michael E. Goldcamp, PhD, and Larry A. Layne, MA, National Institute for Occupational Safety and Health, CDC, for their assistance in Farm and Ranch Safety Survey planning, questionnaire development, and data collection and preparation for public use.

Funding

This study was supported by Cooperative Agreement Number 6 NU36OE000002 from the Centers for Disease Control and Prevention and the Association of Schools and Programs of Public Health and by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

References

1. Costa LG. Toxic effects of pesticides In: Klaassen C, Watkins JB, III, eds. Casarret & Doull’s Essentials of Toxicology. 2nd ed. New York: The McGraw-Hill Medical; 2010:309–322.
2. CDC. Pesticide illness & injury surveillance. https://www.cdc.gov/niosh/topics/pesticides/. Accessed July 24,2017.
3. EPA. Basic information about pesticide ingredients. https://www.epa.gov/ingredients-used-pesticide-products/basic-information-about-pesticide-ingredients. Accessed July 24, 2017.
4. CDC. NIOSH pesticide poisoning monitoring program protects farmworkers. December 2011. DHHS (NIOSH) Publication Number 2012–108. https://www.cdc.gov/niosh/docs/2012-108/. Accessed July 24, 2017.
5. Atwood D, Paisley-Jones C Pesticides industry sales and usage, 2008–2012 market estimates. https://www.epa.gov/sites/production/files/2017-01/documents/pesticides-industry-sales-usage-2016_0.pdf. Accessed August 4, 2017.
6. Pesticides Harbison R.. In: Raymond D, Harbison RD, Bourgeois MM, Johnson GT, eds. Hamilton & Hardy’s Industrial Toxicology. 6th ed. Hoboken, NJ: John Wiley & Sons, Inc.; 2015:855–926.
7. Chatzi L, Alegakis A, Tzanakis N, Siafakas N, Kogevinas M, Lionis C. Association of allergic rhinitis with pesticide use among grape farmers in Crete, Greece. Occup Environ Med. 2007;64:417–421. [PubMed: 17182637]
8. Hoppin JA, Umbach DM, London SJ, et al. Pesticides and atopic and nonatopic asthma among farm women in the agricultural health study. Am J Respir Crit Care Med. 2008;177(1):11–18. [PubMed: 17932376]
9. Hoppin JA, Umbach DM, London SJ, et al. Pesticide use and adult-onset asthma among male farmers in the agricultural health study. Eur Respir J. 2009;34 (6):1296–1303. [PubMed: 19541724]
10. Hoppin JA, Umbach DM, Long S, et al. Pesticides are associated with allergic and non-allergic wheeze among male farmers. Environ Health Perspect. 2017;125 (4):535–543. doi:10.1289/EHP315. [PubMed: 27384423]
11. Mamane A, Baldi I, Tessier JF, Raherison C, Bouvier G. Occupational exposure to pesticides and respiratory health. Eur Respir Rev. 2015;24:306–319. [PubMed: 26028642]
12. Slager RE, Poole JA, LeVan TD, Sandler DP, Alavanja MC, Hoppin JA. Rhinitis associated with pesticide exposure among commercial pesticide applicators in the Agricultural Health Study. Occup Environ Med. 2009;66:718–724. [PubMed: 19289390]
13. Hoppin JA, Umbach DM, Kullman GJ, et al. Pesticidesand other agricultural factors associated with self-reported farmer’s lung among farm residents in the Agricultural Health Study. Occup Environ Med. 2007;64(5):334–341. [PubMed: 17182642]
14. Hoppin JA, Umbach DM, London SJ, Alavanja MC, Sandler DP. Chemical predictors of wheeze among farmer pesticide applicators in the Agricultural Health Study. Am J Respir Crit Care Med. 2002;165:683–689. [PubMed: 11874814]

15. Hoppin JA, Umbach DM, London SJ, Lynch CF, Alavanja MC, Sandler DP. Pesticides and adult respiratory outcomes in the Agricultural Health Study. Ann N Y Acad Sci. 2006;1076:343–354. [PubMed: 17119214]
16. Hoppin JA, Umbach DM, London SJ, Lynch CF, Alavanja MC, Sandler DP. Pesticides associated with wheeze among commercial pesticide applicators in the Agricultural Health Study. Am J Epidemiol. 2006;163:1129–1137. [PubMed: 16611668]
17. Slager RE, Simpson SL, Levan TD, Poole JA, Sandler DP, Hoppin JA. Rhinitis associated with pesticide use among private pesticide applicators in the Agricultural Health Study. J Toxicol Environ Health A. 2010;73:1382–1393. [PubMed: 20818537]
18. Faria NM, Facchini LA, Fassa AG, Tomasi E. Pesticides and respiratory symptoms among farmers. Rev Saude Publica. 2005;39:973–981. [PubMed: 16341409]
19. Zuskin E, Schachter EN, Mustajbegovic J. Respiratory function in greenhouse workers. Int Arch *Occup Environ Health*. 1993;64:521–526. [PubMed: 8482594]
20. USDA. Economic research service. Farm household well-being: Glossary. https://www.ers.usda.gov/topics/farm-economy/farm-household-well-being/glossary.aspx#farmoperator. Accessed August 4, 2017.
21. EPA. Types of pesticide ingredients. https://www.epa.gov/ingredients-used-pesticide-products/types-pesticide-ingredients. Accessed August 4, 2017.
22. Wang F, Shin HC SAS model selection macros for complex survey data using proc surveylogistic/surveyreg. Midwest SAS users group 2011 conference proceedings. Statistics, Data Mining, and Analysis https://www.mwsug.org/proceedings/2011/stats/MWSUG2011-SA02.pdf. Accessed August 4, 2017.
23. Doney BC, Groce DW, Campbell DL, et al. A survey of private sector respirator use in the United States: an overview of findings. J Occup Environ Hyg. 2005;2(5):267–276. [PubMed: 15814381]
24. Carpenter WS, Lee BC, Gunderson PD, Stuel and DT. Assessment of personal protective equipment use among Midwestern farmers. Am J Ind Med. 2002;42:236–247. [PubMed: 12210692]
25. Schenker MB, Orenstein MR, Samuels SJ. Use of protective equipment among California farmers. Am J Ind Med. 2002;42:455–464. [PubMed: 12382259]
26. Toynton K, Luukinen B, Buhl K, Stone D Permethrin general fact sheet. National Pesticide Information Center, Oregon State University Extension Services. http://npic.orst.edu/factsheets/PermGen.html. Accessed August 8, 2017.
27. Bailey J, Dutton T, Payne K, Wilson R, Brew BK. Farm safety practices and farm size in New South Wales. J *Agromedicine*. 2017;22:229–234. [PubMed: 28402192]
28. Lee E, Burnett CA, Lalich N, Cameron LL, Sestito JP. Proportionate mortality of crop and livestock farmers in the United States, 1984–1993. Am J Ind Med. 2002;42:410–420. [PubMed: 12382254]
29. Kearney GD, Xu X, Balanay JA, Allen DL, Rafferty AP. Assessment of personal protective equipment use among farmers in eastern North Carolina: a cross-sectional study. J Agromedicine. 2015;20:43–54. [PubMed: 25635742]
30. Eriksson J, Ekerljung L, Lötvall J, et al. Growing up on a farm leads to lifelong protection against allergic rhinitis. Allergy. 2010;65(11):1397–1403. [PubMed: 20497148]
31. Douwes J, Travier N, Huang K, et al. Lifelong farm exposure may strongly reduce the risk of asthma in adults. Allergy. 2007;62(10):1158–1165. [PubMed: 17845585]
32. Gilpin EA, Pierce JP, Cavin SW, et al. Estimates of population smoking prevalence: self-vs proxy reports of smoking status. Am J Public Health. 1994;84 (10):1576–1579. [PubMed: 7943473]
33. Nelson LM, Longstreth WT, Jr, Koepsell TD, Checkoway H, van Belle G. Completeness and accuracy of interview data from proxy respondents: demographic, medical, and life-style factors. Epidemiology. 1994;5:204–217. [PubMed: 8172996]
34. Schenker MB, Farrar JA, Mitchell DC, et al. Agricultural dust exposure and respiratory symptoms among California farm operators. J Occup Environ Med. 2005;47(11):1157–1166. [PubMed: 16282877]
35. Dumas O, Le Moual N, Siroux V, et al. Work related asthma. A causal analysis controlling the healthy worker effect. Occup Environ Med. 2013;70 (9):603–610. [PubMed: 23759534]

36. Le Moual N, Kauffmann F, Eisen EA, Kennedy SM. The healthy worker effect in asthma: work may cause asthma, but asthma may also influence work. Am J Respir Crit Care Med. 2008;177:4–10. [PubMed: 17872490]

37. Hernández AF, Parrón T, Tsatsakis AM, Requena M, Alarcón R, López-Guarnido O. Toxic effects of pesticide mixtures at a molecular level: their relevance to human health. Toxicology. 2013;307:136–145. [PubMed: 22728724]

Table 1.

Characteristics of primary farm operators and proportion of operators using pesticides.

Characteristic	Operators % (95% CI)	Proportion of primary farm operators using pesticides % (95% CI)
Total	100.0	40.0 (38.8–41.3)
Age group (years)		
16–39	5.3 (4.7–5.9)	51.4 (45.9–56.9)
40–64	59.6 (58.3–60.8)	43.3 (41.6–45.0)
65–99	35.1 (33.9–36.3)	33.3 (31.3–35.3)
Sex		
Male	83.7 (82.8–84.7)	42.5 (41.2–43.9)
Female	16.3 (15.3–17.2)	27.0 (24.1–30.0)
Marital status		
Married	83.5 (82.6–84.5)	41.5 (40.1–42.9)
Not married[a]	16.5 (15.5–17.4)	33.3 (30.4–36.3)
Smoking status[b]		
Current smoker	9.4 (8.6–10.2)	39.0 (34.7–43.3)
Former smoker	30.3 (29.1–31.5)	41.4 (39.0–43.8)
Never smoker	60.3 (59.0–61.5)	39.7 (38.1–41.2)
Second job[c]		
Yes	48.3 (47.0–49.6)	40.4 (38.5–42.3)
No	51.7 (50.4–53.0)	39.8 (38.1–41.5)
Region[d]		
Midwest	36.5 (35.4–37.7)	38.6 (36.5–40.7)
North	6.5 (6.2–6.8)	29.4 (27.5–31.2)
South	42.0 (40.8–43.2)	40.8 (38.6–43.0)
West	15.0 (14.4–15.6)	45.7 (43.7–47.7)
Farm size (acres)		
≤100	63.7 (62.8–64.6)	37.1 (35.4–38.9)
101–999	30.5 (29.6–31.4)	43.2 (41.3–45.2)

	Operators	Proportion of primary farm operators using pesticides
Characteristic	% (95% CI)	% (95% CI)
≥1,000	5.8 (5.4–6.1)	54.9 (51.1–58.7)
Farm value of sales ($)		
<9,999	55.0 (54.0–56.2)	35.6 (33.6–37.6)
10,000–99,999	27.5 (26.7–28.4)	39.7 (38.1–41.4)
≥100,000	17.4 (16.7–18.1)	54.5 (52.3–56.7)
Farm type[e]		
Livestock	51.1 (49.8–52.3)	37.2 (35.5–39.0)
Crop	48.9 (47.7–50.2)	43.0 (41.2–44.8)

[a]Widowed, divorced, separated, or single/never married.

[b]Current smokers were those who smoked at least 100 cigarettes in their lifetime and smoked cigarettes either every day or some days at the time of the survey. Former smokers were those who smoked at least 100 cigarettes in their lifetime but do not smoke anymore. Never smokers were those who smoked less than 100 cigarettes in their lifetime.

[c]Operators were asked, “Do you have a second job in addition to your farming to supplement the farm income?”

[d]Midwest: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin; North: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont; South: Alabama, Texas, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Virginia, and West Virginia; West: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

[e]Farms were classified based on the largest source of revenue for the farm. Livestock farm type includes swine, dairy, beef cattle, sheep or goats, equine, poultry, aquaculture, and other animals. Crop farm type includes grains, tobacco, cotton, vegetables, fruits or nuts, nursery or greenhouse, cutting Christmas trees, and other crops or hay.

Table 2.

Adjusted PORs for lifetime allergic rhinitis among pesticide users versus non-users[a].

Pesticide	POR (95% CI)	*P* value
Pesticide use	**1.4 (1.2, 1.6)**	**<001**
Herbicides	**1.3 (1.1, 1.5)**	**.001**
Phenoxy[b]	**1.5 (1.2, 1.9)**	**<.001**
2,4-D	**1.5 (1.2, 1.9)**	**<.001**
Glyphosate	1.1 (1.0, 1.3)	.13
Pyridines[c]	**1.4 (1.1, 2.0)**	**.03**
Triclopyr	1.4 (1.0, 2.1)	.08
Aminopyralid	.9 (.5, 1.9)	.86
2,4-D and glyphosate	1.3 (.9, 1.8)	.19
2,4-D and triclopyr	1.3 (.8, 2.1)	.27
Insecticides	**2.1 (1.6, 2.7)**	**<.001**
Carbamates[d]	**2.3 (1.4, 3.7)**	**<.001**
Carbaryl	**2.3 (1.4, 3.7)**	**<.001**
Pyrethroids[e]	**2.4 (1.5, 3.9)**	**<.001**
Organophosphates[f]	1.3 (.7, 2.5)	.34

Adjusted for age, sex, value of sales, region. Boldface indicates P < .05.

[a]Operators who mixed, loaded, or applied pesticides in the 12 months prior to the interview versus operators who did not.

[b]Phenoxy herbicides include 2,4-D, 2,4,5-T, MCPA, MCPP, and fenoxaprop.

[c]Pyridine herbicides include aminocyclopyrachlor, aminopyralid, clopyralid, picloram, fluroxypyr, pyroxsulam, and triclopyr.

[d]Carbamate insecticides include carbaryl, thiodicarb, and fenoxy.

[e]Pyrethroid insecticides include permethrin, cyfluthrin, bifenthrin, cypermethrin, tefluthrin, lambacyahalothrin, and tau-fluvalinate.

[f]Organophosphate insecticides include chlorpyrifos, diazinon, dichlorvos, malathion, endosulfan, dimethoate, and acephate.

Table 3.

Adjusted PORs for current asthma among pesticide users versus non-users[a].

Pesticide	POR (95% CI)	*P* value
Any pesticide use	**1.5 (1.1, 1.8)**	**.003**
Herbicides	**1.3 (1.0, 1.8)**	**.04**
Phenoxy	1.4 (.9, 2.2)	.17
2,4-D	1.3 (.8, 2.1)	.24
Glyphosate	1.3 (.97, 1.8)	.08
Insecticides	**2.0 (1.2, 3.3)**	**.009**

Adjusted for sex and region. Boldface indicates $P < .05$.

[a]Operators who mixed, loaded, or applied pesticides in the 12 months prior to the interview versus operators who did not.

Table 4.

Adjusted PORs for lifetime allergic rhinitis among pesticide users versus non-users[a], by farm size.

	≤100 acres	≥101 acres
Pesticide	**POR (95% CI)**	**POR (95% CI)**
Herbicides	**1.4 (1.1, 1.7)**	1.2 (.9, 1.4)
Phenoxy	**1.6 (1.2, 2.2)**	1.3 (1.0, 1.7)
2,4-D	**1.6 (1.2, 2.2)**	1.3 (1.0, 1.8)
Glyphosate	1.2 (1.0, 1.5)	1.0 (.8, 1.3)
Pyridines	**1.8 (1.1, 2.9)**	1.0 (.7, 1.6)
Triclopyr	**1.8 (1.1, 3.1)**	1.0 (.6, 1.7)
2,4-D and glyphosate	1.2 (.7, 2.0)	1.3 (.8, 2.1)
Insecticides	**2.3 (1.6, 3.3)**	**1.7 (1.1, 2.5)**
Carbamates	**2.3 (1.3, 4.1)**	—[b]
Carbaryl	**2.4 (1.3, 4.2)**	—
Pyrethroids	—	1.7 (.9, 3.0)

Adjusted for age, sex, value of sales, region. Boldface indicates *P* < .05.

[a]Operators who mixed, loaded, or applied pesticides in the 12 months prior to the interview versus operators who did not.

[b]Estimate unreliable.

Table 5.

Adjusted PORs for lifetime allergic rhinitis among pesticide users versus non-users[a], by farm type.

	Livestock	Crop
Pesticide	**POR (95% CI)**	**POR (95% CI)**
Herbicides	**1.4 (1.1, 1.7)**	1.2 (.9, 1.4)
Phenoxy	**1.3 (1.0, 1.8)**	**1.7 (1.2, 2.4)**
2,4-D	**1.3 (1.0, 1.8)**	—[b]
Glyphosate	1.2 (1.0, 1.5)	1.1 (.9, 1.3)
Pyridines	**1.6 (1.1, 2.3)**	1.2 (.7, 2.0)
Triclopyr	1.5 (.9, 2.4)	—
2,4-D and glyphosate	.9 (.5, 1.6)	1.7 (1.1, 2.8)
2,4-D and triclopyr	1.3 (.7, 2.4)	1.3 (.6, 2.9)
Insecticides	**2.8 (1.8, 4.3)**	**1.7 (1.2, 2.5)**
Carbamates	—	1.7 (.9, 3.1)
Carbaryl	—	1.6 (.9, 3.1)
Pyrethroids	—	**2.6 (1.5, 4.6)**

Adjusted for age, sex, value of sales, region.

Boldface indicates $P < .05$.

[a]Operators who mixed, loaded, or applied pesticides in the 12 months prior to the interview versus operators who did not.

[b]Estimate unreliable.