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## **Occupational Exposure to Pesticides and the Incidence of Lung Cancer in the Agricultural Health Study**

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Running head: Pesticides and Lung Cancer Incidence

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## ABSTRACT

**Background:** Occupational pesticide use is associated with lung cancer in some, but not all, epidemiologic studies. In the Agricultural Health Study (AHS), we previously reported positive associations between several pesticides and lung cancer incidence.

**Objective:** We evaluated use of 43 pesticides and 654 lung cancer cases after ten years of additional follow-up in the AHS, a prospective cohort study comprised of 57,310 pesticide applicators from Iowa and North Carolina.

**Methods:** Information about lifetime pesticide use and other factors was ascertained at enrollment (1993-1997) and updated with a follow-up questionnaire (1999-2005). Cox proportional hazards models were used to calculate hazard ratios (HR) and 95% confidence intervals (CI), adjusting for smoking (smoking status and pack-years), gender, and lifetime days of use of any pesticides.

**Results:** Hazard ratios were elevated in the highest exposure category of lifetime days of use for pendimethalin (1.50; 95% CI = 0.98-2.31), dieldrin (1.93; 95% CI = 0.70-5.30), and chlorimuron-ethyl (1.74; 95% CI = 1.02-2.96), although monotonic exposure-response gradients were not evident. The HRs for intensity-weighted lifetime days of use of these pesticides were similar. For parathion, the trend was statistically significant for intensity-weighted lifetime days ( $p=0.049$ ) and borderline for lifetime days ( $p=0.073$ ). None of the remaining pesticides evaluated were associated with lung cancer incidence.

**Conclusions:** These analyses provide additional evidence for an association between pendimethalin, dieldrin, and parathion use and lung cancer risk. We found an association between chlorimuron-ethyl, a herbicide introduced in 1986, and lung cancer that has not been previously reported. Continued follow-up is warranted.

## INTRODUCTION

Lung cancer is the leading cause of cancer related-death in the United States (US) (American Cancer Society 2014) and the world (Torre et al. 2015). Lung cancer mortality and incidence is lower among farmers in the US than among the general population (Blair et al. 1993; Blair and Freeman 2009) potentially due to low prevalence of smoking among US farmers (Alavanja et al. 2004; Blair et al. 1992). Nonetheless, increased lung cancer mortality among licensed pesticide applicators has been reported (Barthel 1981; Becher et al. 1996; Blair et al. 1983; MacMahon et al. 1988; Pesatori et al. 1994), raising the possibility that exposure to certain pesticides may increase the risk of lung cancer among farmers. Only a few epidemiologic studies have assessed exposure to specific pesticides (Austin et al. 1989; MacMahon et al. 1988; Pesatori et al. 1994). MacMahon et al. (MacMahon et al. 1988) reported a slight increase in the lung cancer standardized mortality ratio (SMR) (SMR = 135; 90% Confidence (CI) = 114-158) among pesticide applicators and termite control operators exposed to chlordane and heptachlor. Blair et al. (Blair et al. 1983) also observed an excess of lung cancer among termite and other structural pest control applicators. Using banked serum samples from 919 residents of Charleston, SC, Austin et al. (Austin et al. 1989) did not find an association with serum DDT levels and respiratory cancer mortality among 19 cases. Pesatori et al. (Pesatori et al. 1994) in a small nested case-control study of structural pesticide workers in FL, observed suggestive positive associations for diazinon (Odds Ratio (OR) = 2.0; 95% CI = 0.7-5.5), carbaryl (OR = 4.2; 95%CI = 0.6-27.2), DDT (OR = 2.6; 95% CI = 0.5-14.3), and propoxur (OR = 12.4; 95% CI = 1.05-100.3); no associations were observed for malathion, chlorpyrifos, parathion, or chlordane. We previously reported positive associations between select pesticides and the occurrence of lung cancer in the Agricultural Health Study (AHS) (Alavanja et al. 2004). Of the

50 pesticides evaluated, seven (dicamba, metolachlor, pendimethalin, carbofuran, chlorpyrifos, diazinon, and dieldrin) showed some evidence of positive associations with lung cancer incidence. Pesticide-specific analyses of diazinon (Jones et al. 2015) and metolachlor (Silver et al. 2015) use evaluating lung cancer risk, among other cancer sites, have been recently published from the AHS. Jones et al. (Jones et al. 2015) reported increased lung cancer incidence among male applicators with the highest exposure category of lifetime days of diazinon use (Rate Ratio (RR) =1.60; 95%CI = 1.11, 2.31;  $P_{\text{trend}}=0.02$ ) as well as with intensity-weighted lifetime days of diazinon use (RR=1.41; 95%CI = 0.98, 2.04;  $P_{\text{trend}}=0.08$ ). Silver et al. (Silver et al. 2015) found no association between either lifetime days or intensity-weighted lifetime days of metolachlor use.

We now use the AHS to investigate associations between lifetime use of 43 pesticides and the incidence of lung cancer with an additional 414 lung cancer cases and 10 years of follow-up beyond an earlier evaluation (Alavanja et al. 2004) and with updated information regarding more recent pesticide use and cigarette smoking status.

## METHODS AND MATERIALS

The AHS has been described previously (Alavanja et al. 1996). Briefly, we enrolled 57,310 restricted-use pesticides applicators residing in Iowa (commercial and private (farmer) = 36,792) and North Carolina (private applicators = 20,518) between 1993 and 1997. Vital status through December 31, 2011 was ascertained via linkage with state mortality files and the National Death Index. First primary, incident lung cancer cases that occurred between enrollment and December 31, 2010 in North Carolina and December 31, 2011 in Iowa were identified via linkage with the Iowa and North Carolina state cancer registries. Prevalent cancers ( $n=1,094$ )

and individuals who sought to obtain pesticide registration in Iowa or North Carolina, but did not reside in these states ( $n = 341$ ) were excluded from the analysis. Participants ( $n=1,113$ ) who moved out of Iowa or North Carolina were censored at the year they departed. All applicable Institutional Review Boards approved the protocol and all participants provided informed consent.

### *Exposure Assessment*

At enrollment, participants completed a self-administered questionnaire (<http://aghealth.nih.gov/collaboration/questionnaires.html>), indicating whether they had ever mixed or applied 50 specific pesticides. For 22 pesticides, the number of years and days per year the applicator personally mixed or applied a particular pesticide was also queried on the enrollment questionnaire. This detailed information about days and years of use for the remaining 28 other pesticides was obtained in a supplementary take-home questionnaire completed by approximately 44% of the cohort. In addition, the enrollment questionnaire gathered information on pesticide application methods, mixing, repair of pesticide application equipment, and the use of personal protective equipment (PPE). Smoking history, alcohol consumption in the past 12 months, fruit and vegetable consumption, other agricultural activities, non-farm occupational exposures, family history of cancer, medical conditions and medicines were also ascertained at enrollment. Blair and colleagues have previously shown that the reliability of reporting of pesticide use in the AHS questionnaire is similar to that for other factors routinely obtained by questionnaire for epidemiologic studies (Blair et al. 2002).

Lifetime exposure-days of use for each of the 50 pesticides was calculated from the questionnaire data as the product of the number of years a participant personally mixed or

applied each specific pesticide times the number of days in an average year that pesticide was used. In addition, we used an estimate of exposure intensity based on an algorithm developed from a comprehensive review of the literature by Dosemeci et al. (Dosemeci et al. 2002) and updated and supplemented by Coble et al. (Coble et al. 2011), which also used pesticide monitoring conducted in the AHS (Hines et al. 2008; Thomas et al. 2010) to calculate an intensity-weighted lifetime exposure-days score for each pesticide [exposure intensity x lifetime exposure-days]. The exposure intensity score weights aspects of pesticide use that may modify the intensity of exposure such as whether an applicator personally mixed pesticides for application, application methods used, repair of pesticide application equipment, and the use of PPE. Dermal absorption is generally considered the major route of exposure for many pesticides (Maroni et al. 2000). Pesticide monitoring in the AHS found that chemical-resistant glove use was a more important determinant of urinary, airborne and dermal levels of pesticides than initially assumed (Hines et al. 2008; Thomas et al. 2010). Consequently, the updated exposure intensity score more heavily weighted the use of protective gloves (Coble et al. 2011).

Information on pesticide use was updated between 1999 and 2005 with the use of a computer-assisted telephone interview (CATI). Participants were asked to report all pesticides used in the year prior to the interview as well as the frequency of use. Because only 36,342 applicators (63%) completed both the baseline and the follow-up questionnaires, we used multiple imputation with logistic regression and stratified sampling to impute missing pesticide exposure information on 20,968 applicators who did not complete the follow-up interview (Heltshe et al. 2012).

In addition to updating pesticide use information between 1999 and 2005 with the CATI, smoking status (current, past, never), but not pack-years, was also updated. To update pack-years of cigarette smoking among current smokers ( $n = 7,637$ ), we applied the number of cigarettes smoked reported in the enrollment questionnaire and multiplied it by the number of intervening years between the enrollment and follow-up interview. These additional pack-years of cigarette smoking were then added to the total pack-years calculated from the enrollment questionnaire to update total pack-years of cigarette smoking. For participants who reported being current smokers on the enrollment questionnaire, but reported being former smokers on the follow-up interview ( $n = 1,712$ ), the number of cigarettes smoked per day reported at enrollment were applied and the years of smoking during the intervening time period was estimated to be half the time period. This same algorithm was used for participants who reported being former smokers at enrollment, but reported smoking currently on the follow-up interview ( $n = 573$ ). For participants missing information on smoking on the enrollment and the follow-up interview ( $n = 1,051$ ), pack-years of smoking was not imputed. Similarly, as a small proportion of participants ( $n = 1,033$ ) was missing information on the number of cigarettes smoked per day (enrollment questionnaire), pack-years of smoking was not imputed. In addition, participants missing information on other potential confounders (e.g., age, gender, total lifetime pesticide days ( $n = 4,338$ )) were also excluded. In total, 7,498 participants were excluded, leaving 49,812 (89%) participants for the statistical analyses of pesticide exposure.

### *Statistical Analyses*

We used Cox Proportional Hazards to estimate hazard ratios and 95% confidence limits, using age at risk as the time scale, to assess potential associations between pesticide use and the

incidence of lung cancer. We evaluated 43 specific pesticides here. Diazinon (Jones et al. 2015) and metolachlor (Silver et al. 2015) were not evaluated because results of the evaluation of these pesticides have recently been published. In addition, five other pesticides (trichlorfon, carbon tetrachloride/carbon disulfide, aluminum phosphide, ziram, and 2,4,5-TP) were not evaluated because there were fewer than 15 exposed lung cancer cases; too few for meaningful analyses. Lifetime days of exposure and intensity-weighted lifetime exposure-days were both categorized into quartiles based on the distribution among the lung cancer cases to assess exposure-response gradients, where possible. For seven pesticides (aldrin, captan, carbofuran, coumaphos, dieldrin, heptachlor, and toxaphene) tertiles were used because of the relatively small number of exposed lung cancer cases. In addition to assessing cumulative lifetime exposure-days, we also conducted analyses in which lifetime exposure-days were lagged five and 15 years.

*A priori* covariates used in our previous report (Alavanja et al. 2004), included age, gender, pack-years of smoking separately for current and former smokers, and total lifetime days of pesticide use. We further evaluated potential confounding from cigarette smoking by including pack-years of cigarette smoking as continuous variable; these two approaches yielded comparable risk estimates. We also assessed the potential for confounding by other covariates (education, body mass index, family history of lung cancer, race, state of residence, fruit and vegetable intake, alcohol consumption, and raising poultry and livestock, which is associated with reduced lung cancer incidence among farmers in the AHS (Beane Freeman et al. 2012)); none of these variables meaningfully influenced the estimates of relative risk. In addition to adjusting for total lifetime days of pesticide application, we also conducted additional analyses adjusting for lifetime days of diazinon, dieldrin, and pendimethalin use because these pesticides

were previously associated with lung cancer incidence in the AHS. Our final models included the *a priori* covariates only.

We used PROC MIANALYZE (SAS 9.3) to account for our multiple imputation approach. For the pesticides dieldrin, 2,4,5-TP, parathion, chlordane, DDT, heptachlor, and toxaphene there was no variability between the five imputed sets because their registrations had been cancelled prior to the conduct of the Phase 2 interview. Therefore, standard proportional hazards models were used. *P*-values for trend were calculated by using the log-transformed version of the continuous exposure variables while adjusting for the covariates. We conducted analyses stratified by smoking status to assess potential effect measure modification. In addition, we conducted analyses by lung cancer histologic type (adenocarcinoma vs. non-adenocarcinoma). These analyses are presented in supplemental tables (S2 and S3) only because the small number of lung cancer cases among strata limited precision and interpretation.

## RESULTS

Since our previous report (Alavanja et al. 2004), 414 additional first primary, histologically confirmed incident lung cancer cases have occurred. In total, 654 first primary incident lung cancer cases were included in this current report with an average follow-up of 14.8 years since AHS enrollment. Selected characteristics are depicted in Table 1. As expected, a higher proportion of lung cancer cases as compared with non-cases was observed with older age and higher pack-years of cigarette smoking. The proportion of lung cancer cases was slightly higher among non-Whites, among those residing in North Carolina and among those having a history of chronic lung disease. We did not find differences with gender or family history of

lung cancer. Lung cancer cases were less likely to regularly consume fruits, vegetables and alcohol than were non-cases.

Table 2 presents the HRs for lifetime days of use and intensity-weighted lifetime days for 13 pesticides and lung cancer. Results were included if they had been previously associated with lung cancer in the AHS (dicamba, pendimethalin, carbofuran, chlorpyrifos, and dieldrin), (Alavanja et al. 2004) other epidemiologic studies (malathion (Pesatori et al. 1994), parathion (Pesatori et al. 1994), carbaryl (Pesatori et al. 1994), chlordane (MacMahon et al. 1988), DDT (Austin et al. 1989), and heptachlor (MacMahon et al. 1988)), or otherwise showed an association with lung cancer in this evaluation (chlorimuron-ethyl). Supplemental Table S1 depicts the hazard ratios for the remaining 30 pesticides; none of which were positively associated with lung cancer. Lifetime days of chlorimuron-ethyl were associated with statistically significant increased risk in the highest exposure category only (HR = 1.74; 95% CI = 1.02-2.96), but did not show an exposure-response trend ( $P_{\text{trend}} = 0.180$ ). The highest quartile of lifetime days of pendimethalin use also showed a positive association with lung cancer (HR = 1.50; 95% CI = 0.98-2.31). We further divided the 4<sup>th</sup> quartile at its median of lifetime days of pendimethalin. The HR for the lower 50% of the 4<sup>th</sup> quartile was 1.26 (95% CI = 0.65-2.46) and the HR for those in the upper 50% of the 4<sup>th</sup> quartile was 2.52 (95% CI = 1.31-4.83), although the  $p$  for trend was not significant ( $P_{\text{trend}} = 0.283$ ). Lifetime days of dieldrin use also showed a positive association in the highest exposure tertile (HR = 1.93; 95% CI = 0.70-5.30), as did the HR for the intensity-weighted lifetime exposure-days metric (HR = 2.06; 95% CI = 0.95-4.43). The lowest and highest quartiles of lifetime days of DDT use showed a slight excess in risk, although a monotonic exposure response gradient was not evident ( $P_{\text{trend}} = 0.695$ ). Similarly, the highest quartile of lifetime days of malathion use showed a slight excess risk (HR = 1.35; 95%

CI = 0.93-1.97). Although parathion was only slightly associated with the risk of lung cancer in the highest quartile (HR=1.17; 95% CI=0.51-2.68) for lifetime days and (HR=1.20; 95% CI=0.58-2.47) for intensity-weighted lifetime days), the test for trend was statistically significant for intensity-weighted lifetime days ( $p=0.049$ ) and borderline for lifetime days ( $p=0.073$ ). The lowest exposure category of lifetime days use for maneb/mancozeb had a statistically significant increased risk of lung cancer (HR = 3.27; 95% CI = 1.54-2.20), but the highest exposure category was not elevated and there was no evidence of an exposure response gradient ( $P_{\text{trend}} = 0.939$ ) nor were any of the other exposure categories significantly increased. Carbaryl, carbofuran, chlordane, chlorpyrifos, and heptachlor were not associated with the incidence of lung cancer. Dicamba showed a statistically significant inverse exposure response trend, although the lowest risks were seen in the lower quartiles of exposure. Generally, the hazard ratios for the intensity-weighted lifetime days for these pesticides were similar to the lifetime-days metric (table 2).

Table 3 shows the results of lagging lifetime days of exposure 5 and 15 years. The HRs from lagging lifetime exposure-days by 5 and 15 years were somewhat lower than those from unlagged analyses for pendimethalin and chlorimuron-ethyl. The association between dieldrin and lung cancer incidence was not influenced because use had ceased before either of these lag periods. No obvious pattern emerged from the lagged analysis of parathion.

## DISCUSSION

With an additional ten years of follow-up and 414 additional first primary, histologically confirmed incident lung cancer cases, we reevaluated the associations between lifetime days and intensity-weighted lifetime days for 43 pesticides and relative risk for lung cancer. Independent

AHS pesticide -specific analyses for diazinon (Jones et al. 2015) and metolachlor (Silver et al. 2015) were not included here because these results have been published. For pendimethalin and dieldrin, we found evidence of positive, albeit imprecise, associations with lung cancer. These two pesticides had elevated HRs in the highest exposure category, but the exposure-response gradients were neither monotonic, nor statistically significant. Parathion showed some evidence of increased risks for lung cancer, but the trends were not monotonic, nor were the excesses the largest in the highest quartile of exposure. We observed an increased hazard ratio with use of chlorimuron-ethyl in the highest exposure category. Chlorimuron-ethyl use was not associated with lung cancer in a previous AHS analysis (Alavanja et al. 2004). None of the other pesticides (chlorpyrifos, carbofuran, or dicamba) was associated with lung cancer risk in this reevaluation.

Pendimethalin has been shown to induce thyroid follicular cell adenomas in rats and is classified as a possible human carcinogen (Group C) by the US EPA (United States Environmental Protection Agency 1997). Previous analyses of pendimethalin in the AHS (Alavanja et al. 2004; Hou et al. 2006), however, have been inconsistent. There is limited experimental evidence linking pendimethalin to genotoxicity (Dimitrov et al. 2006) or carcinogenicity in rodents ([Anonymous] 2002). To our knowledge, no epidemiologic studies other than the AHS have investigated pendimethalin use and lung cancer risk. We see only weak evidence for an association from a borderline statistically significant association with lifetime days of use and intensity-weighted lifetime days. The lung cancer excess with pendimethalin use was largely limited to the upper half of the upper quartile, but the exposure response trends were not statistically significant.

Dieldrin is an organochlorine insecticide that was banned from agricultural use in 1970 by the U.S. EPA, although its use as a termiticide was permitted by the U.S. EPA between 1972 and 1987 (Stern 2014). There are concerns about ongoing low-level exposure because dieldrin is commonly found in hazardous waste sites and is relatively resistant to environmental degradation (Stern 2014). As with the previous analyses of the AHS cohort (Alavanja et al. 2004; Purdue et al. 2007), dieldrin was positively associated with lung cancer, but mainly in the highest tertile of use. Dieldrin has been demonstrated to induce liver tumors in mice, but not in other rodents (Cancer 1987). The small number of dieldrin exposed lung cancer cases complicates interpretation here.

Parathion was recently designated by IARC as possibly carcinogenic to humans (group 2B); largely based on experimental evidence (Guyton et al. 2015). To our knowledge, no previous epidemiologic studies (Pesatori et al. 1994), including our previous report (Alavanja et al. 2004), have found associations for parathion use with lung cancer specifically, although melanoma was associated with parathion use in the AHS (Dennis et al. 2010). In chronic feeding studies, parathion has been demonstrated to be carcinogenic to Osborne-Mendel rats and to increase the incidence of alveolar/bronchiolar adenomas in B6C3F1 mice (National Toxicology Program 1979). Furthermore, parathion has been demonstrated to damage DNA in human peripheral lymphocytes (Undeger and Basaran 2005). In our study, the small number of exposed cases and the lack of a monotonic exposure-response gradient complicated interpretation. While these data do not provide strong evidence to support an association, nearly all the exposure categories had excess risks and are deserving of continued investigation for a potential association between parathion and lung cancer. In addition, malathion (Guyton et al. 2015) and DDT (Loomis et al. 2015) also were evaluated and classified as probably carcinogenic to humans (group 2A), largely

based on sufficient evidence in animals. The evidence in humans, however, was deemed limited and the lung was not a site observed to be associated with either malathion or DDT use in the epidemiologic studies assessed. Further epidemiologic investigation of both malathion and DDT are warranted.

This is the first report from the AHS in which chlorimuron-ethyl and maneb/mancozeb have been associated with lung cancer incidence. However, these new findings may be chance occurrences because they are based on relatively small numbers of exposed cases. Chlorimuron-ethyl is a herbicide introduced in 1986 for use on soybeans. It was previously associated with wheeze among commercial applicators in the AHS (Hoppin et al. 2006). The US EPA classifies chlorimuron-ethyl as “not likely to be carcinogenic to humans”

([http://npic.orst.edu/chemicals\\_evaluated.pdf](http://npic.orst.edu/chemicals_evaluated.pdf)). To our knowledge, there are no published epidemiologic reports on the relationship between chlorimuron-ethyl exposure and cancer.

Maneb/mancozeb has been observed to potentiate cancer in rodents (Belpoggi et al. 2002) and to be genotoxic in cultured human lymphocytes (Srivastava et al. 2012). The US EPA classifies these fungicides as probable human carcinogens (group B2)

([http://npic.orst.edu/chemicals\\_evaluated.pdf](http://npic.orst.edu/chemicals_evaluated.pdf)). However, maneb/mancozeb use in our current analysis was associated with lung cancer only in the lowest exposure category and did not display an exposure response gradient.

To our knowledge, no epidemiologic studies outside of the AHS, have investigated dicamba and lung cancer risk. In contrast to previous AHS evaluations, we see no evidence of an association between dicamba and lung cancer in this analysis with larger numbers, although *in vitro* evidence suggests that dicamba may be genotoxic (Gonzalez et al. 2006, 2007). Contrary

to earlier AHS publications, we also see no evidence of an association between lung cancer and chlorpyrifos (Alavanja et al. 2004; Lee et al. 2004) or carbofuran (Alavanja et al. 2004; Bonner et al. 2005) use. There is experimental mechanistic evidence that chlorpyrifos can induce oxidative stress and oxidative DNA damage (Ojha and Srivastava 2014; Zafiroopoulos et al. 2014) and carbofuran may be genotoxic (Mladinic et al. 2012). The proportion of AHS cohort members using either chlorpyrifos or carbofuran has declined since enrollment (Hoppin et al. 2012). Our analysis focused on the active ingredients of formulated mixtures of commercial products. These formulations contain both active ingredients and so called ‘inert ingredients’ and we cannot rule out the possibility that changes in the formulated mixtures associated with dicamba, chlorpyrifos, and carbofuran products are associated with changes in observed associations. Conversely, previous associations observed between these chemicals and lung cancer with fewer cases may have been due to chance.

We observed a number of inverse associations with lagged exposures, particularly for the 15-year exposure lag. We cannot explain these inverse associations in our data. None of these inverse associations are supported by biologic evidence, however. Rather, the limited evidence that does exist suggests carcinogenic potential as previously noted with, for example, dicamba, chlorpyrifos, and maneb/mancozeb.

Several limitations are evident in our current analysis. In spite of an additional 10 years of follow-up and substantial accrual of lung cancer cases, the number of lung cancer cases exposed to some pesticides remains small and continues to hamper study precision and our ability to evaluate risk by histologic type of lung cancer and to explore effect modification by smoking, especially for chemicals for which patterns of use information were collected only on the take-

home questionnaire. In addition, the analysis relies on imputed pesticide use data for a substantial fraction of the cohort.

We cannot rule out the possibility for chance or multiple comparisons to explain some of our results. Although approaches to adjust for multiple comparisons exist, a number of authors have warned against using such measures in epidemiological studies (Rothman 1990; Savitz and Olshan 1995; Goldberg and Silbergeld 2011). Our goal is to describe the magnitude of associations between specific pesticides and lung cancer risk. As such, we prefer to let other epidemiological studies and other relevant evidence (e.g., toxicological data) help sort out the likely reality of the findings.

Although the reliability of information on pesticide use obtained from farmers is quite good and comparable to that from other factors commonly obtained by questionnaire in epidemiologic studies such as smoking and alcohol consumption (Blair et al. 2002), some exposure assessment error undoubtedly occurs. In this prospective cohort study, exposure misclassification is likely to diminish estimates of relative risk and mute any real exposure-response relationships (Blair et al. 2011).

Although information on smoking was included in the statistical models, the possibility of residual confounding by active smoking and secondhand smoke exposure should be considered. This seems unlikely, however, because there was no evidence of a link between smoking and pesticide use. It certainly was not evident with many pesticides because use of most pesticides did not result in an increase in the relative risk of lung cancer. Thus, any residual confounding would have to be chemical specific. We evaluated a number of factors, including other pesticide use (diazinon, pendimethalin, dieldrin, and chlorimuron-ethyl) that might potentially confound

associations between specific pesticides and lung cancer, none of which meaningfully influenced the risk estimates on our analyses. Exposure to secondhand smoke was not ascertained in the AHS, however, any confounding due to ETS is likely to be small in comparison to direct smoking.

There is the possibility that a healthy worker survivor effect (HWSE) may have attenuated or reversed the reported associations. Unfortunately, we cannot carefully evaluate for a HWSE because time-dependent exposure information prior to enrollment was not collected. Nonetheless, the likelihood of a HWSE is low in the AHS cohort because the participants are predominately farm owners/operators who have a sizable economic investment in their operation, providing an incentive to continue farming.

This study has a number of strengths. It is a large population of farmers and commercial pesticide applicators who can provide detailed and reliable information regarding their pesticide use history (Blair et al. 2002). Information on pesticide use, application practices and other information was obtained prior to onset of cancer diminishing the chances of case-response bias. Loss to follow-up is minimal due to use of high quality state cancer registries and vital records and low residential mobility of this cohort. An algorithm that incorporated several exposure determinants that predicted urinary pesticide levels was used to develop an intensity-weighted exposure metric in our study (Coble et al. 2011). Information on potential confounders, such as smoking, or the use of other pesticides was available and could be evaluated and controlled in the analysis.

## CONCLUSION

Several epidemiologic studies have found associations between pesticides and lung cancer (Alavanja and Bonner 2012). In our continuing survey within the AHS, we find that no specific class of pesticide is associated with lung cancer. Although not entirely consistent, we did observe some evidence of associations with pendimethalin, and dieldrin. In addition, we found possible new associations between chlorimuron-ethyl, parathion and lung cancer that have not been previously observed in the AHS and deserve further evaluation.

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**Table 1. Selected Baseline Characteristics of Lung Cancer Cases and non-Cases, Agricultural Health Study (1993-1997)**

Characteristic*	Lung cancer cases <i>n</i> =546 (%)	Cohort Members (Non-cases) <i>n</i> =49,266 (%)
<b>Age</b>		
<55	170 (31.1)	36,434 (74.0)
55-59	114 (20.9)	4,693 (9.5)
60-64	108 (19.8)	3,754 (7.6)
65-69	78 (14.3)	2,465 (5.0)
70-74	57 (10.4)	1,307 (2.7)
≥75	19 (3.5)	613 (1.2)
<b>Smoking status (pack-years)**</b>		
Never smoked	57 (10.4)	26,803 (54.4)
Former <3.75	15 (2.8)	4,552 (9.2)
Former 3.75-15	27 (5.0)	4,128 (8.4)
Former > 15	176 (32.2)	5,405 (11.0)
Current < 11.25	26 (4.8)	1,522 (3.1)
Current 11.25-28.5	49 (9.0)	2,623 (5.3)
Current >28.5	196 (35.9)	4,233 (8.6)
<b>Gender</b>		
Male	535 (98.0)	48,005 (97.4)
Female	11 (2.0)	1,261 (2.6)
<b>Race**</b>		
White	519 (95.1)	48,060 (97.8)
Black/other	27 (4.9)	1,103 (2.2)
<b>State of Residence</b>		
Iowa	231 (42.3)	32,895 (66.8)
North Carolina	315 (57.7)	16,371 (33.2)
<b>Education**</b>		
<12	128 (24.1)	4,124 (8.5)
12	268 (50.5)	22,797 (47.2)
>12	135 (25.4)	21,363 (44.2)
<b>Other chronic lung disease (bronchitis and emphysema)**</b>		
No	455 (89.7)	45,165 (96.4)
Yes	52 (10.3)	1,683 (3.6)

**Table 1 (Continued). Selected Baseline Characteristics of Lung Cancer Cases and non-Cases, Agricultural Health Study (1993-1997)**

Characteristic	Lung Cancer Cases	No. of cohort members (noncases)
Family history of lung cancer**		
No	442 (90.4)	43,549 (93.7)
Yes	47 (9.6)	2,927 (6.3)
Vegetable Intake (servings/week)**		
≤4	173 (35.2)	15,228 (32.8)
5-7	188 (38.3)	16,913 (36.5)
>7	130 (26.5)	14,223 (30.7)
Fruit Intake (servings/week)**		
≤2	204 (40.0)	15,313 (32.5)
3-6	189 (37.1)	18,627 (39.6)
≥7	117 (22.9)	13,128 (27.9)
Alcohol intake (servings/time period)**		
Never	227 (44.3)	14,843 (31.4)
≤3/month	121 (23.6)	12,928 (27.4)
>4/ week	165 (32.2)	19,439 (41.2)

\*Using response categories from the AHS enrollment questionnaire.

\*\*Numbers do not sum to total due to missing data.

**Table 2. Hazard Ratios and 95% Confidence Limits for Lung Cancer by Lifetime Days Pesticide Exposure and Intensity-weighted Lifetime Days, Agricultural health Study**

Pesticide	Lifetime Days				Intensity-weighted Lifetime Days			
	Cases (n)	Hazard* Ratio	95% Confidence Interval	P for trend	Cases (n)	Hazard* Ratio	95% Confidence Interval	P for trend
Chlorimuron-ethyl (herbicide; pyrimidinylsulfonylurea) <sup>S</sup>								
Non-exposed	180	1.0	Ref.		180	1.0	Ref.	
Q1	14	1.10	0.64-1.90		21	1.09	0.69-1.72	
Q2	37	0.96	0.67-1.38		21	0.97	0.62-1.51	
Q3	11	1.17	0.64-2.16		20	1.04	0.65-1.68	
Q4	16	1.74	1.02-2.96	0.180	16	1.69	1.00-2.83	0.294
Dicamba (herbicide; benzoic acid)								
Non-exposed	293	1.0	Ref.		293	1.0	Ref.	
Q1	38	0.64	0.44-0.92		39	0.57	0.40-0.82	
Q2	45	0.57	0.40-0.83		44	0.66	0.47-0.95	
Q3	45	0.75	0.55-1.04		36	0.73	0.48-1.10	
Q4	36	0.86	0.60-1.24	0.007	44	0.81	0.59-1.13	0.001
Pendimethalin (herbicide; dinitroaniline) <sup>S</sup>								
Non-exposed	160	1.0	Ref.		160	1.0	Ref.	
Q1	21	1.00	0.61-1.62		25	0.81	0.52-1.26	
Q2	33	0.85	0.58-1.24		32	0.81	0.50-1.31	
Q3	29	0.91	0.58-1.42		27	1.26	0.82-1.92	
Q4	28	1.50	0.98-2.31	0.283	26	1.47	0.93-2.31	0.551
Carbaryl (insecticide; carbamate) <sup>S</sup>								
Non-exposed	112	1.0	Ref.		112	1.0	Ref.	
Q1	58	0.93	0.66-1.30		47	0.94	0.65-1.36	
Q2	38	0.99	0.66-1.49		35	0.99	0.67-1.46	
Q3	33	1.15	0.76-1.74		41	1.16	0.79-1.40	
Q4	28	1.17	0.76-1.79	0.436	34	1.04	0.70-1.54	0.757
Carbofuran (insecticide; chlorinated organic)								
Non-exposed	336	1.0	Ref.		336	1.0	Ref.	
Q1	40	0.76	0.55-1.05		32	0.81	0.56-1.16	
Q2	29	0.80	0.54-1.19		31	0.80	0.55-1.16	
Q3	23	1.08	0.62-1.89		29	0.87	0.59-1.29	
Q4	28	0.99	0.67-1.47	0.299	28	0.88	0.59-1.30	0.133
Chlordane (insecticide; chlorinated organic) <sup>S</sup>								
Non-exposed	169	1.0	Ref.		169	1.0	Ref.	
Q1	22	1.57	1.01-2.46		17	1.64	0.99-2.70	
Q2	26	1.13	0.75-1.71		17	1.34	0.81-2.21	
Q3	12	0.95	0.53-1.70		21	0.88	0.56-1.39	
Q4	13	1.13	0.64-2.01	0.426	18	1.27	0.78-2.08	0.403
Chlorpyrifos (insecticide; phosphorothioate)								
Non-exposed	339	1.0	Ref.		339	1.0	Ref.	
Q1	54	0.84	0.63-1.13		44	0.91	0.66-1.25	
Q2	52	1.08	0.79-1.48		41	0.74	0.53-1.03	
Q3	41	0.86	0.61-1.21		40	1.03	0.74-1.44	
Q4	46	0.98	0.71-1.35	0.497	38	0.88	0.62-1.25	0.210

**Table 2 (continued). Hazard Ratios and 95% Confidence Limits for Lung Cancer by Lifetime Days Pesticide Exposure & Intensity-weighted Lifetime Days, Agricultural Health Study**

Pesticide	Lifetime Days				Intensity-weighted Lifetime Days			
	Cases (n)	Hazard* Ratio	95% Confidence Interval	P for trend	Cases (n)	Hazard* Ratio	95% Confidence Interval	P for trend
DDT (insecticide; chlorinated organic) <sup>§</sup>								
Non-exposed	140	1.0	Ref.		140	1.0	Ref.	
Q1	20	1.45	0.92-2.38		29	1.01	0.68-1.52	
Q2	42	0.86	0.61-1.22		27	0.96	0.63-1.45	
Q3	22	1.09	0.69-1.72		25	0.99	0.64-1.53	
Q4	23	1.33	0.84-2.10	0.695	26	1.46	0.95-2.25	0.506
Dieldrin (insecticide; chlorinated organic) <sup>§</sup>								
Non-exposed	230	1.0			230	1.0	Ref.	
T1	6	0.58	0.26-1.31		5	1.01	0.42-2.47	
T2	6	1.49	0.66-3.37		4	0.50	0.18-1.34	
T3	4	1.93	0.70-5.30	0.472	7	2.06	0.95-4.43	0.880
Heptachlor (insecticide; chlorinated organic) <sup>§</sup>								
Non-exposed	216	1.0	Ref.		216	1.0	Ref.	
Q1	6	1.19	0.53-2.68		7	1.13	0.53-2.39	
Q2	11	0.65	0.35-1.19		6	0.56	0.25-1.26	
Q3	10	0.89	0.47-1.68		10	0.77	0.41-1.46	
Q4	5	0.66	0.27-1.62	0.228	9	0.82	0.42-1.60	0.193
Parathion (insecticide; phosphorothioate) <sup>§</sup>								
Non-exposed	211	1.0	Ref.		211	1.0	Ref.	
Q1	5	1.60	0.66-3.89		11	1.58	0.86-2.91	
Q2	17	1.48	0.90-2.43		9	1.37	0.70-2.69	
Q3	7	1.65	0.78-3.52		7	1.82	0.86-3.89	
Q4	6	1.17	0.51-2.68	0.073	8	1.20	0.58-2.47	0.049
Malathion (insecticide; phosphorothioate) <sup>§</sup>								
Non-exposed	78	1.0	Ref.		78	1.0	Ref.	
Q1	28	0.98	0.54-1.78		40	0.99	0.61-1.61	
Q2	76	1.11	0.80-1.52		57	1.02	0.72-1.43	
Q3	35	1.00	0.67-1.50		44	1.18	0.81-1.72	
Q4	45	1.35	0.93-1.97	0.168	43	1.37	0.94-2.00	0.197
Maneb/Mancozeb (fungicide; dithiocarbamate) <sup>§</sup>								
Non-Exposed	214	1.0	Ref.		214	1.0	Ref.	
Q1	7	3.27	1.54-6.97		11	3.21	1.74-5.91	
Q2	11	1.39	0.76-2.57		6	0.91	0.40-2.06	
Q3	10	1.34	0.71-2.53		9	1.44	0.74-2.81	
Q4	5	0.72	0.30-1.76	0.939	7	0.86	0.40-1.83	0.436

\*Adjusted for age, smoking status and pack-years, gender, and total lifetime pesticide use.

<sup>§</sup>Lifetime-days of use were obtained from the take home questionnaire.

**Table 3. Hazard Ratios and 95% Confidence Limits for Lung Cancer by 5 and 15 year Lagged Lifetime Days Pesticide Exposure, Agricultural Health Study**

Pesticide	5 Years Lag				15 year Lag			
	Cases (n)	Hazard* Ratio	95% Confidence Interval	P for Trend	Cases (n)	Hazard* Ratio	95% Confidence Interval**	P for Trend
Chlorimuron-ethyl (herbicide; pyrimidinylsulfonylurea) <sup>S</sup>								
Non-exposed	181	1.0	Ref.		206	1.0	Ref.	
Q1	16	1.24	0.75-2.06		16	0.87	0.52-1.44	
Q2	35	0.90	0.62-1.31		15	0.46	0.27-0.78	
Q3	10	1.15	0.60-2.20		5	0.65	0.27-1.59	
Q4	16	1.61	0.96-2.71	0.295	13	1.36	0.77-2.40	0.222
Dicamba (herbicide; benzoic acid)								
Non-exposed	299	1.0	Ref.		329	1.0	Ref.	
Q1	38	0.62	0.44-0.88		35	0.52	0.37-0.74	
Q2	43	0.54	0.38-0.77		34	0.47	0.33-0.67	
Q3	45	0.73	0.53-1.00		37	0.61	0.43-0.86	
Q4	33	0.79	0.55-1.14	0.001	21	0.59	0.38-0.93	<0.001
Pendimethalin (herbicide; dinitroaniline) <sup>S</sup>								
Non-exposed	161	1.0	Ref.		201	1.0	Ref.	
Q1	24	1.18	0.76-1.85		12	0.49	0.26-0.90	
Q2	30	0.78	0.52-1.18		13	0.39	0.22-0.69	
Q3	26	0.88	0.55-1.41		8	0.33	0.16-0.68	
Q4	25	1.31	0.84-2.05	0.602	19	1.11	0.68-1.82	0.003
Carbaryl (insecticide; carbamate) <sup>S</sup>								
Non-exposed	112	1.0	Ref.		131	1.0	1.0	
Q1	55	0.87	0.51-1.22		36	0.66	0.46-0.95	
Q2	35	0.92	0.61-1.338		31	1.00	0.67-1.48	
Q3	29	1.20	0.79-1.82		32	1.29	0.87-1.90	
Q4	30	1.05	0.70-1.59	0.787	16	0.61	0.36-1.04	0.399
Carbofuran (insecticide; carbamate)								
Non-exposed	336	1.0	Ref.		354	1.0	Ref.	
Q1	40	0.76	0.54-1.05		36	0.67	0.47-0.94	
Q2	29	0.81	0.55-1.20		23	0.67	0.44-1.02	
Q3	24	1.11	0.64-1.91		25	1.38	0.78-2.43	
Q4	27	0.95	0.64-1.43	0.261	18	0.63	0.39-1.02	0.006
Chlordane (insecticide; chlorinated organic) <sup>S</sup>								
Non-exposed	169	1.0	Ref.		172	1.0	Ref.	
Q1	0	-	-		1	8.72	1.19-64.22	
Q2	48	1.30	0.94-1.79		45	1.21	0.87-1.69	
Q3	12	0.95	0.53-1.70		11	0.89	0.48-1.63	
Q4	13	1.13	0.64-2.01	0.424	13	1.13	0.64-2.00	0.605
Chlorpyrifos (insecticide; phosphorothioate)								
Non-exposed	344	1.0	Ref.		401	1.0	Ref.	
Q1	55	0.85	0.63-1.13		44	0.63	0.46-0.86	
Q2	49	0.98	0.71-1.35		39	0.77	0.56-1.07	
Q3	43	0.91	0.66-1.26		20	0.43	0.28-0.68	
Q4	41	0.86	0.61-1.20	0.188	27	0.57	0.38-0.85	<0.001

**Table 3 (continued). Hazard Ratios and 95% Confidence Limits for Lung Cancer by 5 and 15 year Lagged Lifetime Days Pesticide Exposure, Agricultural Health Study**

Pesticide	5 Years Lag				15 year Lag			
	Cases (n)	Hazard* Ratio	95% Confidence Interval	P for Trend	Cases (n)	Hazard* Ratio	95% Confidence Interval**	P for Trend
DDT (insecticide; chlorinated organic) <sup>§</sup>								
Non-exposed	140	1.0	Ref.		140	1.0	Ref.	
Q1	20	1.48	0.92-2.38		20	1.44	0.90-2.31	
Q2	42	0.86	1.61-1.22		42	0.87	0.61-1.23	
Q3	22	1.09	0.69-1.72		22	1.09	0.69-1.71	
Q4	23	1.33	0.84-2.10	0.695	23	1.35	0.85-2.13	0.709
Dieldrin (insecticide; chlorinated organic) <sup>§</sup>								
Non-exposed	230	1.0	Ref.		230	1.0	Ref.	
Tertile 1	6	0.58	0.26-1.31		6	0.59	0.26-1.32	
Tertile 2	6	1.49	0.66-3.37		6	1.44	0.64-3.26	
Tertile 3	4	1.93	0.70-5.30	0.471	4	2.09	0.76-5.75	0.468
Heptachlor (insecticide; chlorinated organic) <sup>§</sup>								
Non-exposed	216	1.0	Ref.		216	1.0	Ref.	
Q1	6	1.19	0.53-2.68		6	1.16	0.51-2.61	
Q2	11	0.65	0.35-1.19		11	0.65	0.36-1.20	
Q3	10	0.89	0.47-1.68		10	0.90	0.47-1.69	
Q4	5	0.66	0.27-1.62	0.228	5	0.67	0.28-1.64	0.239
Parathion (insecticide; phosphorothioate) <sup>§</sup>								
Non-exposed	212	1.0	Ref.		214	1.0	Ref.	
Q1	4	1.22	0.54-3.28		4	1.09	0.40-2.94	
Q2	17	1.49	0.90-2.44		15	1.44	0.85-2.43	
Q3	7	1.63	0.76-3.47		9	1.96	1.00-3.82	
Q4	6	1.17	0.51-2.69	0.083	4	0.81	0.30-2.24	0.168
Malathion (insecticide; phosphorothioate) <sup>§</sup>								
Non-exposed	82	1.0	Ref.		110	1.0	Ref.	
Q1	26	0.93	0.53-1.62		15	0.59	0.34-1.02	
Q2	71	1.01	0.73-1.39		53	0.69	0.50-0.96	
Q3	35	0.67	0.65-1.45		35	0.87	0.59-1.28	
Q4	44	1.29	0.89-1.88	0.303	32	0.85	0.57-1.28	0.378
Maneb/Mancozeb (fungicide; dithiocarbamate) <sup>§</sup>								
Non-Exposed	216	1.0	Ref.		221	1.0	Ref.	
Q1	6	2.88	1.27-6.54		6	3.20	1.41-7.20	
Q2	9	1.14	0.58-2.23		6	0.81	0.36-1.83	
Q3	11	1.45	0.79-2.66		10	1.40	0.74-2.64	
Q4	5	0.71	0.29-1.74	0.993	4	0.58	0.22-1.58	0.566

\*Adjusted for age, smoking status and pack-years, gender, and total lifetime pesticide use.

<sup>§</sup>Lifetime-days of use were obtained from the take home questionnaire.