Science of the Total Environment 901 (2023) 165854

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Agricultural burning in Imperial Valley, California and respiratory symptoms in children: A cross-sectional, repeated measures analysis

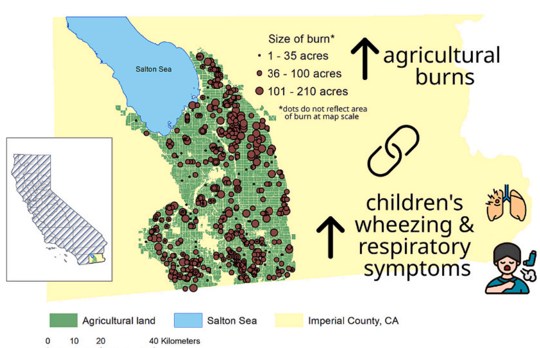
Elizabeth M. Kamai [a,*], Brandyn C. Ruiz [a], Yoshira Ornelas Van Horne [a,b], Dayane Duenas Barahona [a], Esther Bejarano [c], Luis Olmedo [c], Sandrah P. Eckel [a], Jill E. Johnston [a], Shohreh F. Farzan [a]

[a] Department of Population and Public Health Sciences, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA
[b] Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, NY, USA
[c] Comite Civico del Valle, Brawley, CA, USA

HIGHLIGHTS

- Agricultural burning produces toxins that can harm children's respiratory health.
- There were 906 permitted agricultural burns in Imperial Valley in 2016–2019.
- Living near agricultural burning is linked to more wheezing and bronchitic symptoms.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Katarzyna Kordas

Keywords:
Air pollution
Wheeze
Bronchitic symptoms
AIRE

ABSTRACT

Burning of agricultural fields is an understudied source of air pollution in rural communities in the United States. Smoke from agricultural burning contains air toxics that adversely impact respiratory health. Imperial County in southeastern California is a highly productive agricultural valley that heavily employs agricultural burning to clear post-harvest crop remnants. We related individual-level exposure to agricultural burns to parent-reported respiratory symptoms in children.

We leveraged the Children's Assessing Imperial Valley Respiratory Health and the Environment (AIRE) cohort of 735 predominantly Hispanic low-income elementary school students in Imperial County. Parents reported children's respiratory health symptoms and family demographic characteristics in questionnaires collected at enrollment and in annual follow-up assessments from 2017 to 2019. Permitted agricultural burns in Imperial County from 2016 to 2019 were spatially linked to children's geocoded residential addresses. We used generalized estimating equations to evaluate prevalence differences (PDs) in respiratory symptoms with increasing exposure to agricultural burning within 3 km in the 12 months prior to each assessment.

* Corresponding author.
E-mail address: Kamai@usc.edu (E.M. Kamai).

https://doi.org/10.1016/j.scitotenv.2023.165854
Received 17 March 2023; Received in revised form 7 July 2023; Accepted 26 July 2023
Available online 28 July 2023

Nearly half of children (346, 49 %) lived within 3 km of at least one agricultural burn in the year prior to study enrollment. In adjusted models, each additional day of agricultural burning in the prior year was associated with a one percentage point higher prevalence of wheezing (PD 1.1 %; 95 % CI 0.2 %, 2.0 %) and higher bronchitic symptoms (PD 1.0 %; 95 % CI -0.2 %, 2.1 %). Children exposed to four or more days of burning had an absolute increased prevalence of wheezing and bronchitic symptoms of 5.9 % (95 % CI -0.3 %, 12 %) and 5.6 % (95 % CI -1.8 %, 13 %), respectively, compared to no burn exposure. Associations with wheezing were stronger among children with asthma (PD 14 %; 95 % CI -1.4 %, 29 %).

To our knowledge, this is the first U.S. study of agricultural burning and children's respiratory health. This work suggests that reducing agricultural burning could improve children's respiratory health.

1. Introduction

Open burning of agricultural fields to remove crop residue left after harvesting remains a common agricultural practice and an underappreciated source of air pollution exposure worldwide (Jenkins et al., 1992). Globally, agricultural burning is widespread and accounts for nearly half as much biomass burned as wildfires (Rangel and Vogl, 2018). Across the continental United States (US), agricultural burning amounts to an estimated ~3 to 5.8 million acres burned annually (McCarty et al., 2009; Pouliot et al., 2017). Approximately 15.5 million people within the US are affected by crop burning and related smoke exposures (McCarty, 2011). While prior research has identified adverse health impacts from wildfire events (Holstius et al., 2012) and domestic biomass burning (Naeher et al., 2007), there is a paucity of research on the specific impact of agricultural burning on health in US populations, despite evidence that it is a widespread practice associated with release of toxic air pollutants (Rangel and Vogl, 2018).

California (CA) burns the largest acreage of crop residue of any state, approximately 205,000 acres per year, producing an estimated six tons per day of fine particulate matter ($PM_{2.5}$) in 2017 (Pouliot et al., 2017; California Air Resources Board (CARB), 2021a). These burns are concentrated in three agricultural regions: San Joaquin Valley in Central CA, Butte County near Sacramento, and Imperial Valley in southeastern CA (California Air Resources Board (CARB), 2021a). The majority of the estimated 17 % of the population of CA that lives near agricultural burning (McCarty, 2011) are people of color and living below the poverty line (Assessment OoEHH, 2015), making this exposure an environmental justice concern.

Residents of the rural border region of the Imperial Valley are >80 % Latino with a 20 % unemployment rate, and >1 in 3 children live in poverty (Bureau USC, 2014). These communities contend with poor air quality and elevated particulate matter (PM) levels, with concentrations reaching 10 times the federal limits (Johnston et al., 2019). In 2022, the American Lung Association ranked El Centro, the largest city in the region, among the 10 most polluted metropolitan areas in the country for year round particle pollution (American Lung Association, 2022). Further, residents of this region experience elevated rates of asthma morbidity. One in 5 children is diagnosed with asthma and the rate of asthma-related pediatric emergency room visits and hospitalizations is double the CA state average (Lipsett et al., 2009; Farzan et al., 2019).

Compared to other sources of air pollution, agricultural burning is an underrecognized source of air toxic exposures in CA. Although smoke from agricultural burning generally has been considered as more of a nuisance than a public health hazard, due to the relatively short, episodic exposure periods (Wu et al., 2006), smoke from agricultural burning contains chemical compounds – including PM, nitrogen dioxide, and polyaromatic hydrocarbons (Holder et al., 2017) – which can have detrimental impacts on human health as a result of both acute and chronic exposures (Jimenez et al., 2006). Researchers have measured significantly higher coarse (PM_{10}) and fine ($PM_{2.5}$) PM levels within 2 miles of agricultural burns in Imperial Valley (Wagner et al., 2012). Moreover, components of PM that are produced by the burning of biomass (e.g. potassium, organic carbon, and elemental carbon) (Yoon et al., 2018; Sarnat et al., 2008) are more strongly associated with emergency department visits for respiratory disease, as compared to other sources of $PM_{2.5}$ (Sarnat et al., 2008; Krall et al., 2017a). While the literature assessing health endpoints is limited, existing evidence suggests that open burning of agricultural fields has adverse health consequences for nearby populations (Long et al., 1998; Van Horne et al., 2022).

To our knowledge, there is no study in the U.S. that has examined the association between children's health and agricultural burning, nor is much known about the implications of agricultural burning for children's respiratory health in general. The purpose of this study was to assess the respiratory health impacts of agricultural burning in a rural, diverse population of school aged children in Imperial Valley, CA.

2. Methods

2.1. Study population

Community concerns about air pollutants and children's respiratory health led to the initiation of the Children's Assessing Imperial Valley Respiratory Health and the Environment (AIRE) Study, a community-academic partnership with the Comité Civico del Valle (CCV), an Imperial Valley-based community organization. This partnership facilitated connections with school administrators (superintendents and principals) throughout the Imperial Valley who agreed to support study activities. To reflect the variability of the communities and environmental exposures, we ultimately selected one elementary school from five of the eight towns in the region for participation. Children were enrolled in 2017–2019 while in 1st and 2nd grade. All children were eligible to participate. Teachers distributed consent forms and questionnaires in both English and Spanish for children to bring home to their parents. Parents of 735 children consented to their child's participation in the AIRE Study, and 708 (96 %) completed and returned the accompanying baseline questionnaire.

2.2. Outcome assessment

AIRE adapted survey instruments from the validated International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire and the Children's Health Study developed to assess the prevalence of respiratory symptoms (Mallol et al., 2013a; Peters et al., 1999). Parents and guardians were asked to complete this questionnaire upon enrollment and as part of the annual follow-up assessments conducted in 2017–2019. The survey included a series of questions about their child's health history and during the prior 12 months, including asthma, respiratory symptoms (i.e. persistent cough, wheezing, shortness of breath), respiratory infections, medication use, outdoor/physical activity, allergies/atopic conditions, and eye disease/irritation (Mallol et al., 2013b).

The primary outcomes of interest for this study were the 12-month period prevalences of wheezing, sneezing, and bronchitic symptoms. Bronchitic symptoms were defined as having any one of the following symptoms in the prior 12 months: *a*) a cough first thing in the morning or *b*) cough at other times of day that lasted for as much as 3 months in a row during the previous 12 months; *c*) congestion or phlegm not accompanied by a cold; or *d*) a report of bronchitis during the previous 12 months (McConnell et al., 2006; McConnell et al., 2003).

2.3. Exposure to agricultural burning

In California, agricultural burns are regulated by the California Air Resources Board (CARB), which requires reporting to the local air quality management district as of 2003 (Title 17 §80,100). In Imperial Valley, the Air Pollution Control District (APCD) maintains records of permitted burns that include burn date, acres burned, crop type, and the nearest Imperial Irrigation District (IID) canal gate to the burn as a spatial reference. Burn activity, by regulations, occurs during school hours (typically lasting from morning though mid-afternoon). We acquired all of the permitted burns in Imperial Valley in 2016–2019 and geocoded them using the location of the nearest IID canal gate as reported in each permit. We spatially linked these points to the locations of children's residential addresses at the time each study questionnaire was completed using ArcMap (ESRI). One child's home address could not be geocoded; they were assigned the location of their school.

We calculated the number of days of burning that had occurred within 3 km of a child's residence in the 12 months prior to each questionnaire. We assessed exposure both continuously and categorically. We divided the exposed population into three equal groups to create a total of four categories: "no exposure," "low (1 day)," "medium (2-3 days)," and "high (4 or more days)" exposure levels.

2.4. Covariates

Parents reported children's health history and child and family demographic characteristics in questionnaires collected at enrollment and in annual follow-up assessments from 2017 to 2019. These included children's characteristics such as age, sex, race/ethnicity, history of asthma diagnosis and medication use, as well as parent/caregiver information including educational attainment, insurance coverage, maternal history of asthma, and tobacco usage. Child exposure to secondhand smoke at home was defined as living with a current smoker or the presence of any regular visitors who smoke inside the home, regardless of whether the child is also present. Maternal smoking during pregnancy was dichotomized as any or none.

The California Natural Resources Agency (CNRA) Department of Water Resources (DWR) collects, compiles, and publishes publicly available maps of land use data in California, including a statewide "crop map." We spatially linked children's residential addresses to the fields/land identified as agriculture using this map and estimated home proximity to the nearest agricultural field for each child. Since proximity to agricultural fields may indicate additional exposure to pesticides or diesel equipment, and current California regulations prohibit agricultural pesticide applications within ¼ mile (~402 m) of schools (C.C.R. 6690, 2018), we dichotomized distance to agricultural fields at 400 m.

2.5. Statistical analysis

We estimated differences in the prevalence of respiratory symptoms over 12 months associated with exposure to agricultural burning within 3 km using generalized estimating equations with an exchangeable covariance matrix and the robust sandwich estimator of the variance to account for repeated observations from some participants. We specified the identity link and Gaussian distribution to obtain estimates of prevalence differences (rather than odds ratios) (Naimi and Whitcomb, 2020).

Based on prior literature, directed acyclic graphs, and model fit (using quasilikelihood under the independence model criterion [QIC], a

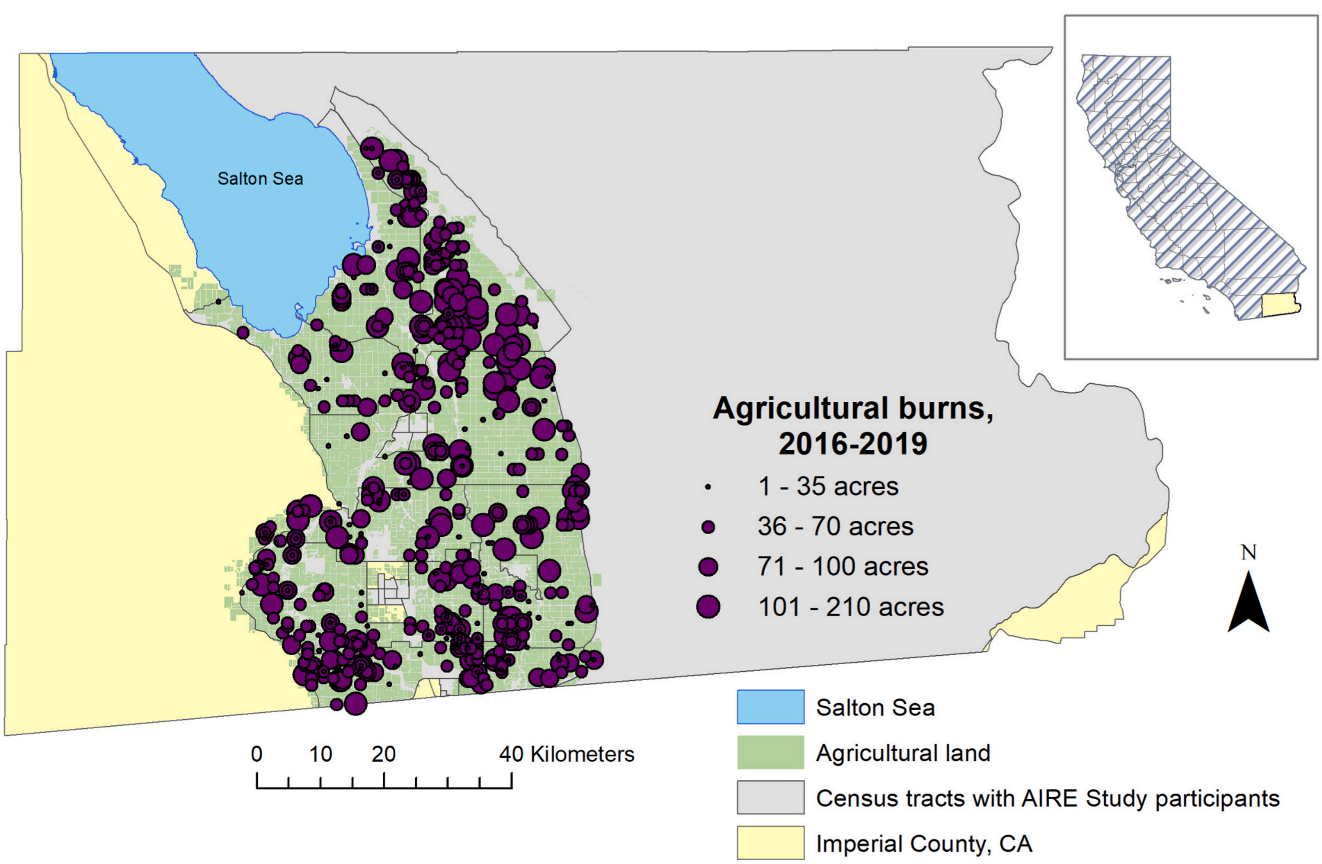


Fig. 1. Location of permitted agricultural burns in Imperial Valley, 2016–2019. Note: dots do not reflect area of burn at map scale.

Table 1
Demographic characteristics of study participants at first survey.

	Total population at first survey	Agricultural burning within 3 km	No agricultural burning within 3 km
Total	708 (100 %)	346 (49 %)	362 (51 %)
Child age in years[a, b]	8 (7, 8)	8 (7, 8)	8 (8, 9)
Missing	*1*	*0*	*1*
Child sex			
Female	381 (54 %)	186 (54 %)	195 (54 %)
Male	327 (46 %)	160 (46 %)	167 (46 %)
Language of survey			
English	471 (67 %)	223 (64 %)	248 (69 %)
Spanish	237 (33 %)	123 (36 %)	114 (31 %)
Hispanic ethnicity			
Yes	638 (94 %)	312 (93 %)	326 (94 %)
No	44 (6 %)	23 (7 %)	21 (6 %)
Missing	*26*	*11*	*15*
Child history of asthma at first survey			
Yes	166 (24 %)	85 (25 %)	81 (23 %)
No	539 (76 %)	260 (75 %)	279 (78 %)
Missing	*3*	*1*	*2*
Highest household education at first survey			
Less than 12th	137 (20 %)	82 (24 %)	55 (16 %)
Completed high school	197 (29 %)	96 (28 %)	101 (30 %)
Some college	236 (35 %)	109 (32 %)	127 (37 %)
Completed 4 years college	60 (9 %)	30 (9 %)	30 (9 %)
Graduate or professional	50 (7 %)	22 (6 %)	28 (8 %)
Missing	*28*	*7*	*21*
Two adults in household			
No	256 (38 %)	133 (39 %)	123 (36 %)
Yes	423 (62 %)	205 (61 %)	218 (64 %)
Missing	*2*	*8*	*21*
Health insurance			
Private	134 (20 %)	57 (17 %)	77 (23 %)
Public	494 (74 %)	256 (76 %)	238 (71 %)
None	43 (6 %)	22 (7 %)	21 (6 %)
Missing	*37*	*11*	*26*
Secondhand smoke exposure			
Yes	47 (8 %)	25 (8 %)	22 (7 %)
No	566 (91 %)	284 (92 %)	282 (93 %)
Missing	*95*	*37*	*58*
Maternal history of asthma			
Yes	122 (18 %)	64 (19 %)	58 (17 %)
No	558 (82 %)	274 (81 %)	284 (83 %)
Missing	*28*	*8*	*20*
Maternal smoking during pregnancy			
Yes	54 (8 %)	29 (9 %)	25 (7 %)
No	625 (92 %)	310 (91 %)	315 (93 %)
Don't know	*29*	*7*	*22*
Missing			
Proximity to agricultural field[c]			
<400 m	397 (56 %)	181 (52 %)	216 (60 %)
400+ m	311 (44 %)	165 (48 %)	146 (40 %)

[a] Median, IQR.
[b] p for independent sample *t*-test <0.05.
[c] p for between groups chi-square test <0.05.

modification of the Akaike's information criterion [AIC]), we adjusted models for child sex, highest education among child's caretakers at baseline (dichotomized at < high school), distance to agriculture at survey (dichotomized at 400 m), language of survey, and biological mother's history of asthma. We chose a priori to additionally evaluate models stratified by doctor-diagnosed asthma.

Table 2
Prevalence difference (PD) in respiratory health symptoms per one additional day of agricultural burning within 3 km in the past year.

	Total population (n = 808[a])		Asthmatics (n = 206[a])	Non-asthmatics (n = 601[a])
	Crude PD	Adjusted PD[b]	Adjusted PD[c]	Adjusted PD[c]
Wheeze (n = 154[a])	0.99 % (0.10 %, 1.88 %)	1.11 % (0.18 %, 2.03 %)	2.34 % (0.73 %, 3.96 %)	0.41 % (−0.48 %, 1.30 %)
Bronchitic symptoms (n = 178[a])	0.83 % (−0.25 %, 1.91 %)	0.97 % (−0.19 %, 2.12 %)	0.97 % (−1.20 %, 3.13 %)	0.81 % (−0.52 %, 2.13 %)
Sneeze (n = 280[a])	0.52 % (−0.71 %, 1.75 %)	0.61 % (−0.68 %, 1.89 %)	1.96 % (0.08 %, 3.84 %)	−0.08 % (−1.68 %, 1.52 %)

[a] Number of observations with non-missing covariates.
[b] Adjusted for: child sex, language of survey, insurance type (public, private, none), highest education of adult guardian (</> high school) at survey, agriculture within 400 m, and biological mother's history of asthma.
[c] Adjusted for: child sex, language of survey, insurance type (public, private, none), highest education of adult guardian (</> high school) at survey, agriculture within 400 m, and biological mother's history of asthma.

In sensitivity analyses, we additionally adjusted for maternal smoking during pregnancy and children's exposure to secondhand smoke, and we stratified models by the reported use of asthma control medications. We also evaluated alternative measures of exposure to agricultural burning (number of burns, acres burned), as well as agricultural burning occurring within 5 km of children's addresses.

3. Results

There were 906 permitted agricultural burns in Imperial Valley in 2016–2019 (Fig. 1). The most frequently listed crop burned was Bermuda (n = 467, 52 %), followed by wheat (n = 191, 21 %), sudan (n = 79, 9 %), and klein (n = 66, 7 %), all of which are types of grasses typically used as animal feed. Burning varied by season and crop, with 43 % burns occurring in January or February and another third in June through August (Supplemental Figs. S1, S2).

Between 2017 and 2019, 708 children in the AIRE Study contributed 932 observations, 880 of which were not missing outcomes or key covariate information (child sex, family education, or asthma diagnosis). Children lived between 0.27 and 14 km from an agricultural burn in the 12 months prior to the date of their parent's questionnaire, with a median of 3 km. Nearly three quarters of children lived within 5 km of at least one agricultural burn (Supplemental Table S1). Measures of exposure to agricultural burning were highly correlated (Supplemental Table S2).

Children who lived within 3 km of a permitted agricultural burn in the 12 months prior to enrollment were generally similar to those who lived further from agricultural burning (Table 1), except for their proximity to agricultural land. Counterintuitively, the children living closest to agricultural land were less likely to also be exposed to agricultural burning than those living >400 m from agriculture. At enrollment, 130 (20 %), 231 (35 %), and 158 (23 %) children reported wheezing, sneezing or bronchitic symptoms, respectively in the prior 12 months.

In unadjusted models, each additional day of agricultural burning in the prior 12 months was associated with a 1 percentage point increase in prevalence of wheezing (95 % CI 0.10 %, 1.88 %), and 0.83 percentage point increase in prevalence of bronchitic symptoms (95 % CI -0.25 %, 1.91 %) (Table 2). Adjustment for covariates did not materially change estimates. In adjusted models restricted to children with doctor-diagnosed asthma, each additional day of agricultural burning in the prior 12 months was associated with a 2.34 percentage point increase in

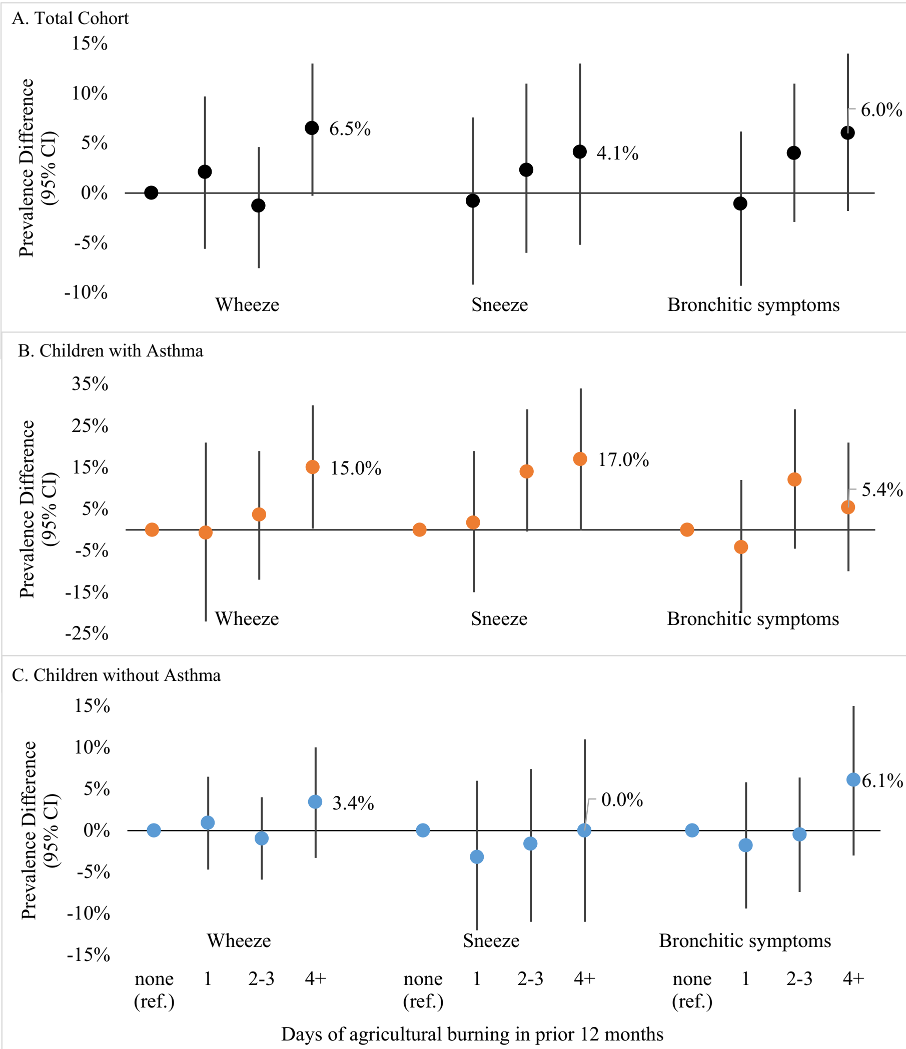


Fig. 2. Prevalence difference (PD) in respiratory health symptoms at in the past year in (A) the total cohort, (B) among children with asthma, (C) among children without asthma, at increasing days of agricultural burns within 3 km, compared to no burn days. All models adjusted for child's sex, highest education among child's caretakers at baseline (dichotomized at < high school), distance to agriculture at survey (dichotomized at 400 m), and biological mother's history of asthma. Estimates presented are for highest category of days of burning vs. the referent of zero days of burning.

the prevalence of wheezing (95 % CI 0.73 %, 3.96 %) and a 1.96 percentage point increase in the prevalence of sneezing (95 % CI 0.08 %, 3.84 %).

When exposure to days of agricultural burning was categorized into quartiles, children with the highest level of exposure (4–13 days in the prior 12 months) within 3 km of their residence had a prevalence of wheezing that was 6.49 (95 % CI: −0.27 %, 13.25 %) percentage points higher than the prevalence of wheezing in children with no exposure after adjusting for child sex, caretaker education, distance to agricultural land, and maternal history of asthma (Fig. 2, Supplemental Table S3).

Associations between agricultural burning and respiratory symptoms appear to be driven by children with asthma; those with the highest exposure had a prevalence of wheezing and sneezing that were 15.08 (95 % CI 0.29 %, 29.87 %) and 16.94 (95 % CI -0.10 %, 33.99 %) percentage points higher than that among children with asthma unexposed to agricultural burning within 3 km of their residence (Fig. 2, Supplemental Table S3).

In sensitivity analyses that used the total number of agricultural burns (rather than days of burning) in the prior 12 months to define exposure to agricultural burning, estimates of association were similar (Supplemental Tables S4-S7). When we evaluated exposure to agricultural burning within 5 km of a child's residence, we found similar associations; however, the number and days of burning within 5 km was also positively associated with the prevalence of bronchitic symptoms among children *without* asthma (Supplemental Tables S6, S8). Models stratified by the reported use of asthma control medication were similar to those stratified by doctor-diagnosed asthma (Supplemental Tables S7, S9). There was limited evidence of positive associations between the acres of land burned within 5 km and prevalence of children's respiratory outcomes. Additional adjustment for maternal smoking during pregnancy and children's secondhand smoke exposure did not materially alter results (data not shown).

4. Discussion

In this novel study of children's respiratory health, we found that children living near agricultural burning in Imperial Valley, California had a higher prevalence of wheezing, sneezing, and bronchitic symptoms than children living further from permitted burns. To our knowledge, this is the first U.S. study to document associations between children's respiratory health symptoms and agricultural burning, and our results both provide a strong basis for future investigation into links between episodic outdoor smoke exposure and children's health outcomes in rural communities and also identify areas for future research. Notably, we identified a clear, statistically significant signal in this community that is already disproportionately burdened by both air pollution and asthma hospitalizations.

Children are highly susceptible to the impacts of air pollutants, as their lungs and immune systems are still developing. Exposure to air pollutants has been linked to acute adverse respiratory effects, such as asthma exacerbations and respiratory distress, while early life insults to the lung may elevate the risk of long-term disease (Stocks et al., 2013; Micklin, 1998). Children may be at greatest risk of long-term effects of air pollutant exposures, such as deficits in lung growth, airway inflammation and new onset asthma (Stocks and Sonnappa, 2013). Over 6 million children in the US are living with asthma (Akinbami et al., 2016), making it the most commonly diagnosed chronic childhood disorder. As the prevalence of pediatric asthma continues to rise, trends suggest widening racial, ethnic and economic disparities (Akinbami et al., 2016; Bhan et al., 2015).

It is estimated that 15.5 million people within the contiguous US are affected by crop burning (McCarty, 2011). However, there is a paucity of data on agricultural burnings in the scientific literature and limited or inconsistent reporting of burn activities on the national scale (Lin et al., 2012). One study suggested that over 12,000 km^2 were burned annually in the contiguous United States (US), which is equivalent to ~43 % of the annual average area of wildland fires (McCarty et al., 2009). It is anticipated that the contribution of agricultural burning as a source of global air toxics, PM emissions, and greenhouse gases will continue to rise as more agricultural land uses burning to clear crop residue (Korontzi et al., 2006).

Smoke from agricultural burning contains various chemical compounds, including PM, nitrogen dioxide, carbon monoxide, black and brown carbon and polyaromatic hydrocarbons (PAHs) (Holder et al., 2017). Across the continental US, it is estimated that ~50,000 tons of $PM_{2.5}$ are attributable to crop burning each year (Pouliot et al., 2017). Among counties with burning in eastern Washington, crop burning was found to be the second largest source of $PM_{2.5}$ (~35 %), after airborne soil (Jimenez et al., 2006). Real-time short-term field measurements in 2012 in Imperial Valley, CA found that PM_{10}, $PM_{2.5}$ and naphthalene (a PAH) were significantly elevated downwind of crop burning when compared to upwind samples (Harnly et al., 2012). In general, however, studies have relied on a few field measures or on estimates derived from satellite data because the limited monitoring network in most rural areas results in inadequate data to fully characterize changes in air quality due to burning episodes under varying meteorological conditions (Jimenez et al., 2006). Additionally, agricultural burning pollutants are likely as toxic as other sources of air pollutants; in one toxicological study, a single low dose of ambient particles of agricultural burning-derived particles induced significant alterations in pulmonary mechanics and lung histology in mice, similar to the effects of traffic-derived particles (Mazzoli-Rocha et al., 2008). Therefore, air pollutants generated by agricultural burning may be as detrimental to respiratory health as other well characterized sources.

The health effects of agricultural field burning smoke exposure have been less extensively studied when compared to other anthropogenic air pollutants such as fossil fuel combustion, likely due to the combination of relatively brief and intermittent burning activities and the setting of rural communities with lower population density and sparser air quality monitoring infrastructure (Wu et al., 2006). While previous studies have supported an association between agricultural burning and respiratory health, most have focused on emergency department (ED)/hospitalization data among adults and lack detailed individual-level assessment of respiratory health symptoms. In a multicity US-based study that examined primary source-specific $PM_{2.5}$, researchers found evidence that $PM_{2.5}$ from biomass burning was positively associated with respiratory disease ED visits (Krall et al., 2017b). Positive and statistically significant associations have been observed between increases in $PM_{2.5}$, elemental carbon, and organic carbon, a marker of vegetative burning, and respiratory-related hospital admissions (Peng et al., 2009). Researchers have measured a decrease in lung function during the burning season, as compared to non-burning seasons, in adults (Agarwal et al., 2010) and in children (Awasthi et al., 2010). In Hawaii, the ratio of ED visits for respiratory illness in exposed versus unexposed populations was higher on burn days compared to non-burn days, although this difference was not statistically significant after controlling for temporal confounders and wind direction (Mnatzaganian et al., 2015). A similar study in Louisiana also found a positive, but not significant, association between asthmatic hospitalization rates during sugar cane burning periods (Boopathy et al., 2002). An ecological time-series study in Brazil found that hospital admissions for asthma were significantly higher during burn periods compared to non-burn periods (Arbex et al., 2007).

Epidemiological studies on health effects of non-fossil fuel PM exposures in vulnerable communities is limited (De Sario et al., 2013). Previous research suggests that people of lower socioeconomic status and racial/ethnic minorities are more vulnerable to the adverse health effects of pollution. For example, epidemiological studies have found higher mortality effects of air pollution among the less educated (Vega et al., 1999) and among racial/ethnic minorities (Ito and Thurston, 1995). Furthermore, in the US, the distributions and types of rural pollution are typically not well characterized, nor are the population-level health effects of such types of pollution (Michael et al., 2010). Rural low-income and people of color often lack the financial and social resources to mitigate their exposures, such as moving to less polluted areas, using air conditioners instead of opening windows, or influencing local and state government to reduce pollution exposures (M. TK., 2001).

This study evaluated associations between residential proximity to agricultural burning and children's respiratory health using individual exposure assessment and detailed respiratory symptom ascertainment. Due to the cross-sectional nature of this study, we cannot determine whether agricultural burning is causing the observed associations with respiratory health symptoms. There may be residual confounding due to unmeasured risk factors for children's respiratory health that varied with the distribution of exposure to agricultural burning over the course of 12 months. The outcomes of this study were the 12-month period prevalences of parent-reported symptoms of respiratory health using a modified ISAAC questionnaire (Mallol et al., 2013a). This assessment is well-validated and has been used extensively to evaluate associations between air pollution and children's respiratory health (McConnell et al., 2003; McConnell et al., 1999; Andersson et al., 2011) However, this measure may be subject to recall bias if parents of children with more extreme or more recent symptoms were more likely to report them. Parent questionnaires did not reference any air pollution/emission events, but it is possible that respiratory symptoms that occurred during days of agricultural burning may have been more memorable. The direction of any potential bias is uncertain, however, because agricultural burning may have occurred in either close or distant temporal proximity to the time of the questionnaires. There are several important environmental factors linked to children's respiratory health that we were unable to account for in this study. We did not adjust for ambient ozone, as there was only one active EPA ozone monitor in Imperial Valley during the study period, nor did we adjust for temperature or relative humidity, as these factors are similar across the Valley, with limited variation expected between individuals over a 12 month period for any of these measures. Further, we were unable to account for any potential differences in indoor air quality between participants over the course of the study. We chose not to adjust for ambient particulate matter, as agricultural burning is a key source of PM levels in Imperial Valley (Harnly et al., 2012; Kelly et al., 2010; Watson and Chow, 2001). Future research is warranted to investigate the co-occurrence of other environmental exposures in the region known to be related to respiratory symptoms, such as traffic-related pollution or industrial emissions, and to evaluate symptoms over shorter time periods or to examine associations with clinical measures of respiratory health.

We relied on permits from the Air Pollution Control District to assign exposure to agricultural burning. There may be some misclassification due to discrepancies between information reported on permits and the actual burns that occurred. Moreover, we did not account for the wind speed and direction during the burns, which could affect which residents are potentially affected by the burns. Further investigation comparing agricultural permits to satellite imagery or smoke plumes, local air monitoring data, or other quantitative metrics of potential exposure from agricultural burns could clarify the extent to which the permits reflect true smoke exposure among the surrounding communities. However, because agricultural burning is regulated via the permitting process, permits are a highly policy-relevant marker of this exposure. Understanding the relationship between metrics that can be identified – and potentially regulated – by the permitting process, such as the number or size of permitted burns, is useful to developing policy solutions to protect children's health. Further, although correlated with number of burns and burn days, we do not see statistically significant associations between acres of crops burned and children's respiratory health. Rather, our findings provide an important foundation for future prospective analyses of agricultural burning and children's respiratory health.

Participation in our study was open to all children enrolled in in 2nd-3rd grades in 2017–2018 at five schools from different towns across Imperial Valley. Because we did not enroll children from every elementary school in the area, the generalizability of our results may be limited. However, this population of low income, predominantly Hispanic/Latino families is reflective of both the demographic characteristics of much of the Imperial Valley as well as that of communities disproportionately exposed to prescribed burning to prevent wildfires (Kondo et al., 2022), another potential source of periodic smoke exposure in much of the Western United States, Australia, and elsewhere where wildfire management tools are required. Like agricultural burning, prescribed burns can emit localized high levels of PM and other respiratory irritants from the combustion of biomass (Jaffe et al., 2020; Haikerwal et al., 2015). Although to our knowledge there is no existing research of the impacts of prescribed burns specifically on children's respiratory health, our results support literature linking even modest levels of wildfire smoke exposure to pediatric asthma exacerbations and respiratory emergency admissions (Aguilera et al., 2021; Moore et al., 2023).

Agricultural burning persists as a widespread practice in California, the United States, and globally. It is a fast, inexpensive method that requires minimal resources to remove excess biomass and transition between crops when fields are replanted multiple times in a growing season (California Air Resources Board (CARB), n.d.). It can also be an effective method to control crop pests and diseases. Alternatives, such as soil tillage, chipping and mulching, and whole orchard recycling, can improve both soil health and broader environmental health outcomes (Ni et al., 2016; California Air Resources Board (CARB), 2021b; Wallander, 2020), but can be costly and out of reach for small farmers (Klein, 2022). Elsewhere in California, regulators aim to phase out the practice of agricultural burning by 2025 – in part by providing financial incentives for choosing more sustainable alternatives – with the goals of improving air quality and public health outcomes (California Air Resources Board (CARB), 2021a; California Air Resources Board (CARB), 2021b). To our knowledge, no such financial incentive programs yet exist in Imperial Valley.

5. Conclusion

Agricultural burning is an important and underappreciated source of air pollution in rural California. Our results indicate a link between this exposure and the prevalence of respiratory symptoms among vulnerable school-aged children in Imperial Valley. Reducing agricultural burning would require substantial investment from state and local regulators and policymakers. Further research should explore whether and how such investments in Imperial Valley would improve the respiratory health of vulnerable children in these communities.

Funding

This work was supported by R01ES029598 and 3R01ES029598-04S1 from the National Institute of Environmental Health Sciences.

CRediT authorship contribution statement

EMK: Methodology, Formal Analysis, Visualization, Writing – original draft preparation; BCR: Software, Data Curation, Formal Analysis; YOVH: Investigation, Software, Data Curation, Formal Analysis, Writing – reviewing and editing; DDB: Project administration, Investigation, Data Curation; EB: Resources, Supervision; LO: Resources, Supervision; SPE: Methodology, Writing – reviewing and editing; JEJ: Conceptualization, Methodology, Funding Acquisition, Investigation, Writing – reviewing and editing; SFF: Conceptualization, Methodology, Funding Acquisition, Investigation, Writing – reviewing and editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgements

We are grateful for all of the children and families in the AIRE cohort for their enthusiasm and participation in this study. This study could not have been completed without the support and guidance of our community partners at Comite Civico del Valle.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2023.165854.

References

Agarwal, R., Awasthi, A., Mittal, S., Singh, N., Gupta, P.K., 2010. Effects of air pollution on respiratory parameters during the wheat-residue burning in Patiala. J. Med. Eng. Technol. 34 (1), 23–28.
Aguilera, R., Corringham, T., Gershunov, A., Leibel, S., Benmarhnia, T., 2021. Fine particles in wildfire smoke and pediatric respiratory health in California. Pediatrics 147 (4).
Akinbami, L.J., Simon, A.E., Rossen, L.M., 2016. Changing trends in asthma prevalence among children. Pediatrics 137 (1), 1–7.
American Lung Association, 2022. Most Polluted Cities. State of the Air. https://www.lung.org/research/sota/city-rankings/most-polluted-cities. Accessed 13 March 2023.
Andersson, M., Modig, L., Hedman, L., Forsberg, B., Ronmark, E., 2011. Heavy vehicle traffic is related to wheeze among schoolchildren: a population-based study in an area with low traffic flows. Environ. Health 10, 91.
Arbex, M.A., Martins, L.C., de Oliveira, R.C., et al., 2007. Air pollution from biomass burning and asthma hospital admissions in a sugar cane plantation area in Brazil. J. Epidemiol. Community Health 61 (5), 395–400.
Assessment OoEHH, 2015. California Communities Environmental Health Screening Tool, Version 2.0 (CalEnviroScreen 2.0). Sacramento, CA.
Awasthi, A., Singh, N., Mittal, S., Gupta, P.K., Agarwal, R., 2010. Effects of agriculture crop residue burning on children and young on PFTs in North West India. Sci. Total Environ. 408 (20), 4440–4445.
Bhan, N., Kawachi, I., Glymour, M.M., Subramanian, S.V., 2015. Time trends in racial and ethnic disparities in asthma prevalence in the United States from the Behavioral Risk Factor Surveillance System (BRFSS) study (1999–2011). Am. J. Public Health 105 (6), 1269–1275.
Boopathy, R., Asrabadi, B., Ferguson, T., 2002. Sugar cane (Saccharum officinarum L) burning and asthma in Southeast Louisiana, USA. Bull. Environ. Contam. Toxicol. 68 (2), 173–179.
Bureau USC, 2014. 2010 Census, Vol 2014.
C.C.R. 6690, 2018. Pesticide use near schoolsites. In: Regulations CCo (Ed.), Title 3. Food and Agriculture.
California Air Resources Board (CARB), 2021a. San Joaquin Valley Agricultural Burning Assessment Resolution 21-4.
California Air Resources Board (CARB), 2021b. Staff Recommendations. San Joaquin Valley Agricultural Burning Assessment.

California Air Resources Board (CARB). Agricultural Burning. https://ww2.arb.ca.gov/our-work/programs/agricultural-burning#:~:text=Agricultural%20burning%20is%20the%20intentional,such%20as%20hay%20and%20rice. Accessed 13 March 2023.
De Sario, M., Katsouyanni, K., Michelozzi, P., 2013. Climate change, extreme weather events, air pollution and respiratory health in Europe. Eur. Respir. J. 42 (3), 826–843.
Farzan, S.F., Razafy, M., Eckel, S.P., Olmedo, L., Bejarano, E., Johnston, J.E., 2019. Assessment of respiratory health symptoms and asthma in children near a drying saline Lake. Int. J. Environ. Res. Public Health 16 (20).
Haikerwal, A., Reisen, F., Sim, M.R., et al., 2015. Impact of smoke from prescribed burning: is it a public health concern? J. Air Waste Manage. Assoc. 65 (5), 592–598.
Harnly, M., Naik-Patel, K., Wall, S., Quintana, P.J.E., Pon, D., Wagner, J., 2012. Agricultural burning monitored for air pollutants in Imperial County; exposure reduction recommendations developed. Calif. Agric. 66 (3), 85–90.
Holder, A., Gullett, B., Urbanski, S., et al., 2017. Emissions from prescribed burning of agricultural fields in the Pacific Northwest. Atmos. Environ. 166, 22–33.
Holstius, D.M., Reid, C.E., Jesdale, B.M., Morello-Frosch, R., 2012. Birth weight following pregnancy during the 2003 Southern California wildfires. Environ. Health Perspect. 120 (9), 1340.
Ito, K., Thurston, G.D., 1995. Daily PM10/mortality associations: an investigations of at-risk subpopulations. J. Expo. Anal. Environ. Epidemiol. 6 (1), 79–95.
Jaffe, D.A., O'Neill, S.M., Larkin, N.K., et al., 2020. Wildfire and prescribed burning impacts on air quality in the United States. J. Air Waste Manage. Assoc. 70 (6), 583–615.
Jenkins, B., Turn, S., Williams, R., 1992. Atmospheric emissions from agricultural burning in California: determination of burn fractions, distribution factors, and crop-specific contributions. Agric. Ecosyst. Environ. 38 (4), 313–330.
Jimenez, J., Wu, C.-F., Claiborn, C., et al., 2006. Agricultural burning smoke in eastern Washington—part I: atmospheric characterization. Atmos. Environ. 40 (4), 639–650.
Johnston, J.E., Razafy, M., Lugo, H., Olmedo, L., Farzan, S.F., 2019. The disappearing Salton Sea: a critical reflection on the emerging environmental threat of disappearing saline lakes and potential impacts on children's health. Sci. Total Environ. 663, 804–817.
Kelly, K.E., Jaramillo, I.C., Quintero-Nunez, M., et al., 2010. Low-wind/high particulate matter episodes in the Calexico/Mexicali region. J. Air Waste Manage. Assoc. 60 (12), 1476–1486.
Klein, K.V., 2022. Monica. 'What am I going to do?' Small growers especially apprehensive of a future without burning. KVPR. https://www.kvpr.org/environment/2022-09-06/what-am-i-going-to-do-small-growers-especially-apprehensive-of-a-future-without-burning. (Accessed 10 February 2023).
Kondo, M.C., Reid, C.E., Mockrin, M.H., Heilman, W.E., Long, D., 2022. Socio-demographic and health vulnerability in prescribed-burn exposed versus unexposed counties near the National Forest System. Sci. Total Environ. 806 (Pt 2), 150564.
Korontzi, S., McCarty, J., Loboda, T., Kumar, S., Justice, C., 2006. Global distribution of agricultural fires in croplands from 3 years of Moderate Resolution Imaging Spectroradiometer (MODIS) data. Glob. Biogeochem. Cycles 20 (2).
Krall, J.R., Mulholland, J.A., Russell, A.G., et al., 2017a. Associations between source-specific fine particulate matter and emergency department visits for respiratory disease in four U.S, cities. Environ. Health Perspect. 125 (1), 97–103.
Krall, J.R., Mulholland, J.A., Russell, A.G., et al., 2017b. Associations between source-specific fine particulate matter and emergency department visits for respiratory disease in four U.S. cities. Environ. Health Perspect. 125 (1), 97–103.
Lin, H.W., Jin, Y., Giglio, L., Foley, J.A., Randerson, J.T., 2012. Evaluating greenhouse gas emissions inventories for agricultural burning using satellite observations of active fires. Ecol Appl. 22 (4), 1345–1364.
Lipsett, M., Smorodinsky, S., English, P., Copan, L., 2009. BASTA Border Asthma & Allergies Study: Final Report. Richmond, CA.
Long, W., Tate, R.B., Neuman, M., Manfreda, J., Becker, A.B., Anthonisen, N.R., 1998. Respiratory symptoms in a susceptible population due to burning of agricultural residue. Chest 113 (2), 351–357.
M. TK., 2001. Agriculture, the environment, and sources of state ideology and power. Cult. Agric. 23 (1), 1–7.
Mallol, J., Crane, J., von Mutius, E., et al., 2013a. The international study of asthma and allergies in childhood (ISAAC) phase three: a global synthesis. Allergol Immunopathol (Madr) 41 (2), 73–85.
Mallol, J., Crane, J., von Mutius, E., Odhiambo, J., Keil, U., Stewart, A., 2013b. The international study of asthma and allergies in childhood (ISAAC) phase three: a global synthesis. Allergol. Immunopathol. 41 (2), 73–85.
Mazzoli-Rocha, F., Bichara Magalhães, C., Malm, O., Hilário Nascimento Saldiva, P., Araujo Zin, W., Faffe, D.S., 2008. Comparative respiratory toxicity of particles produced by traffic and sugar cane burning. Environ. Res. 108 (1), 35–41.
McCarty, J.L., 2011. Remote sensing-based estimates of annual and seasonal emissions from crop residue burning in the contiguous United States. J. Air Waste Manage. Assoc. 61 (1), 22–34.
McCarty, J.L., Korontzi, S., Justice, C.O., Loboda, T., 2009. The spatial and temporal distribution of crop residue burning in the contiguous United States. Sci. Total Environ. 407 (21), 5701–5712.
McConnell, R., Berhane, K., Gilliland, F., et al., 1999. Air pollution and bronchitic symptoms in Southern California children with asthma. Environ. Health Perspect. 107 (9), 757–760.
McConnell, R., Berhane, K., Gilliland, F., et al., 2003. Prospective study of air pollution and bronchitic symptoms in children with asthma. Am. J. Respir. Crit. Care Med. 168 (7), 790–797.
McConnell, R., Berhane, K., Molitor, J., et al., 2006. Dog ownership enhances symptomatic responses to air pollution in children with asthma. Environ. Health Perspect. 114 (12), 1910–1915.
Michael, H., Evan, F., Joel, H., 2010. Pollution sources and mortality rates across rural-urban areas in the United States. J. Rural. Health 26 (4), 383–391.
Micklin, P., 1998. International and regional responses to the Aral crisis: an overview of efforts and accomplishments. Post-Soviet Geography and Economics 39 (7), 399–416.
Mnatzaganian, C.L., Pellegrin, K.L., Miyamura, J., Valencia, D., Pang, L., 2015. Association between sugar cane burning and acute respiratory illness on the island of Maui. Environ. Health 14 (1), 81.
Moore, L.E., Oliveira, A., Zhang, R., Behjat, L., Hicks, A., 2023. Impacts of wildfire smoke and air pollution on a pediatric population with asthma: a population-based study. Int. J. Environ. Res. Public Health 20 (3).
Naeher, L.P., Brauer, M., Lipsett, M., et al., 2007. Woodsmoke health effects: a review. Inhal. Toxicol. 19 (1), 67–106.
Naimi, A.I., Whitcomb, B.W., 2020. Estimating risk ratios and risk differences using regression. Am. J. Epidemiol. 189 (6), 508–510.
Ni, X., Song, W., Zhang, H., Yang, X., Wang, L., 2016. Effects of mulching on soil properties and growth of tea olive (Osmanthus fragrans). PLoS One 11 (8), e0158228.
Peng, R.D., Bell, M.L., Geyh, A.S., et al., 2009. Emergency admissions for cardiovascular and respiratory diseases and the chemical composition of fine particle air pollution. Environ. Health Perspect. 117 (6), 957–963.
Peters, J.M., Avol, E., Navidi, W., et al., 1999. A study of twelve Southern California communities with differing levels and types of air pollution. I. Prevalence of respiratory morbidity. Am. J. Respir. Crit. Care Med. 159 (3), 760–767.
Pouliot, G., Rao, V., McCarty, J.L., Soja, A., 2017. Development of the crop residue and rangeland burning in the 2014 National Emissions Inventory using information from multiple sources. J. Air Waste Manage. Assoc. 67 (5), 613–622.
Rangel MA, Vogl TS. Agricultural fires and health at birth. Rev. Econ. Stat. 2018(0).
Sarnat, J.A., Marmur, A., Klein, M., et al., 2008. Fine particle sources and cardiorespiratory morbidity: an application of chemical mass balance and factor analytical source-apportionment methods. Environ. Health Perspect. 116 (4), 459–466.
Stocks, J., Sonnappa, S., 2013. Early life influences on the development of chronic obstructive pulmonary disease. Ther. Adv. Respir. Dis. 7 (3), 161–173.
Stocks, J., Hislop, A., Sonnappa, S., 2013. Early lung development: lifelong effect on respiratory health and disease. Lancet Respir. Med. 1 (9), 728–742.
Van Horne, Y.O., Farzan, S.F., Razafy, M., Johnston, J.E., 2022. Respiratory and allergic health effects in children living near agriculture: a review. Sci. Total Environ. 832, 155009.
Vega, J., Cifuentes, L., Lave, L., 1999. Daily mortality by cause and socio-economic status in Santiago, Chile 1988-1996. Epidemiology 10 (4).
Wagner, J., Naik-Patel, K., Wall, S., Harnly, M., 2012. Measurement of ambient particulate matter concentrations and particle types near agricultural burns using electron microscopy and passive samplers. Atmos. Environ. 54, 260–271.
Wallander S. Soil Tillage and Crop Rotation. Farm Practices & Management 2020. Accessed 13 March 2023.
Watson, J.G., Chow, J.C., 2001. Source characterization of major emission sources in the imperial and Mexicali Valleys along the US/Mexico border. Sci. Total Environ. 276 (1–3), 33–47.
Wu, C.-F., Jimenez, J., Claiborn, C., et al., 2006. Agricultural burning smoke in Eastern Washington: part II. Exposure assessment. Atmos. Environ. 40 (28), 5379–5392.
Yoon, S., Fairley, D., Barrett, T.E., Sheesley, R.J., 2018. Biomass and fossil fuel combustion contributions to elemental carbon across the San Francisco Bay Area. Atmos. Environ. 195, 229–242.