Identifying Populations Potentially Exposed to Agricultural Pesticides Using Remote Sensing and a Geographic Information System

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Pesticides used in agriculture may cause adverse health effects among the population living near agricultural areas. However, identifying the populations most likely to be exposed is difficult. We conducted a feasibility study to determine whether satellite imagery could be used to reconstruct historical crop patterns. We used historical Farm Service Agency records as a source of ground reference data to classify a late summer 1984 satellite image into crop species in a three-county area in south central Nebraska. Residences from a population-based epidemiologic study of non-Hodgkin lymphoma were located on the crop maps using a geographic information system (GIS). Corn, soybeans, sorghum, and alfalfa were the major crops grown in the study area. Eighty-five percent of residences could be located, and of these 22% had one of the four major crops within 500 m of the residence, an intermediate distance for the range of drift effects from pesticides applied in agriculture. We determined the proximity of residences to specific crop species and calculated crop-specific probabilities of pesticide use based on available data. This feasibility study demonstrated that remote sensing data and historical records on crop location can be used to create historical crop maps. The crop pesticides that were likely to have been applied can be estimated when information about crop-specific pesticide use is available. Using a GIS, zones of potential exposure to agricultural pesticides and proximity measures can be determined for residences in a study. *Key words*: agriculture, epidemiology, exposure assessment, geographic information systems, pesticides, remote sensing. *Environ Health Perspect* 108:5–12 (2000). [Online 22 November 1999]
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Exposure to pesticides has been associated with increased risks of certain cancers, adverse reproductive outcomes, and neurotoxicity among farmers and other pesticide applicators (*1–3*). Some of the same adverse health effects have also been observed among farmers' families and the general population living in agricultural areas (*1,2,4–7*), although specific exposures were not evaluated in most studies.

Farm families and rural residents may be exposed to agricultural pesticides because their residences are adjacent to agricultural land and this type of indirect exposure to pesticides may be significant. Among farmers who applied pesticides in Iowa and North Carolina, between 40 and 50% of farmers' homes were within 100 yards of crop fields where pesticides were applied (*8*). Many rural residents live in small towns that are bordered by agricultural areas. Pesticide-spraying applications can result in drift occurring at distances up to 1,000 yards (*9–11*). Higher levels of pesticides in house dust (*12*) and higher levels of pesticide metabolites in children (*13*) were found in homes of agricultural workers as compared to reference homes. The proximity of the homes to crop fields sprayed with pesticides was associated with higher exposure levels.

Questionnaire methods have been used to assess agricultural pesticide exposures among farmers and pesticide applicators (*14–16*). However, other methods are needed to identify agricultural pesticide exposures in the general population; those in the general population are not likely to know the types of pesticides used in the vicinity of their residences. Biologic monitoring methods for the active ingredients and metabolites of pesticides are available (*17*); however, for many pesticides with short half-lives biologic levels are only indicative of recent exposure.

Pesticide levels in house dust have been measured in several epidemiologic studies of cancer because pesticides can persist in the indoor environment for months or years and they may be a good indicator of historical exposures (*18–20*). The use of carpet dust pesticide levels as an exposure measure in health studies is complicated by the fact that the persistence of the pesticides depends on the chemical characteristics of the compounds. To aid in the interpretation of carpet dust pesticide data, most studies have included detailed questions about home, garden, and occupational use of pesticides. However, questionnaires are not useful to ascertain proximity to crops because most respondents would be unaware of the changes in crop patterns and pesticide use over time in the vicinity of their residence. If residences can be located in a study, historical crop maps and data on agricultural pesticide use can be used to ascertain this information.

Remote sensing data and geographic information systems (GIS) have been used to study associations between landscape characteristics and the incidence of disease, primarily vectorborne diseases (*21,22*). Satellite image data have been used to classify agricultural land by crop type (*23*). Land cover types (e.g., vegetation, bare soil, water, urban areas) differ in their reflectance and spectral characteristics (termed spectral signature); therefore, a satellite image may be classified into land cover types based on their distinct spectral signatures. However, validation data are required to accurately classify land cover by individual crop species. For example, a study by Xiang et al. (*24*) classified a Landsat image using field validation of the crop classification to investigate the relationship between proximity of maternal residences to crop fields as a risk factor for low birth weight. To create historical crop maps, historical sources of validation data are required.

We conducted a feasibility study to assess whether satellite image data could be used to create historical crop maps using Farm Service Agency records for validation. Because pesticide use varies by type of crop (*25*), crop type can be used to identify source areas for potential exposure to agricultural pesticides. We conducted the study in three counties in Nebraska that were part of a population-based case–control study of non-Hodgkin lymphoma (NHL) designed to evaluate the use of specific pesticides by farmers as a risk factor for NHL (*14*). We located the study participants' residences on the crop map and determined the proportion

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of the study population that lived within the range of potential pesticide drift from crop fields. We identified the pesticides used and classified them according to their probability of use.

Methods

Our method consisted of the following steps. First, we created a historical land cover map by classifying a 1984 satellite image according to the location of the different land cover types including specific crop species. Second, we calculate probabilities of pesticide use by crop type from Nebraska data on pesticide use. Third, we mapped pesticide use in the study area by combining the information from steps one and two. Fourth, we located the study participants' residences on the land cover map and determined the proportion with crop fields within 500 m of the residences (an intermediate distance for the range of drift from pesticide applications). Fifth, for residences with crops within 500 m, we calculated the area of the crop fields within the 500-m buffer and the distance to the crop fields.

Project GIS. We developed a GIS for the feasibility study counties. The GIS is an integrated system incorporating both GIS and image processing functionality, constructed using Arc/Info and ArcView GIS software (Environmental Systems Research Institute, Redlands, CA) and the ERDAS IMAGINE image processing system (ERDAS, Inc., Atlanta, GA). We list some of the GIS coverages (data containing geographic features and associated descriptive information) and the sources of the data in Table 1.

Table 1. Selected coverages contained in the project GIS.

Coverage theme	Source
Public land survey system boundaries of township, section, and range	University of Nebraska Conservation and Survey Division (Lincoln, NE)
TIGER files (census bureau line files containing streets and address ranges by county)	U.S. Bureau of the Census (Washington, DC)
Soils data from two sources	Nebraska Natural Resources Commission; University of Nebraska Conservation and Survey Division, (Lincoln, NE)
Places (boundary files showing limits of census-designated places)	Consortium for International Earth Science Network (University Center, MI)
Residence locations (point file showing locations of study participants' residences)	Generated from address matching results obtained from Geographic Data Technology (Lebanon, NH) as well as ancillary sources
Land cover including crop types	Derived from Landsat satellite image classification
500-m buffers around residences	Generated using the GIS

Abbreviations: GIS, geographic information system; TIGER, topologically integrated geographic encoding and referencing.

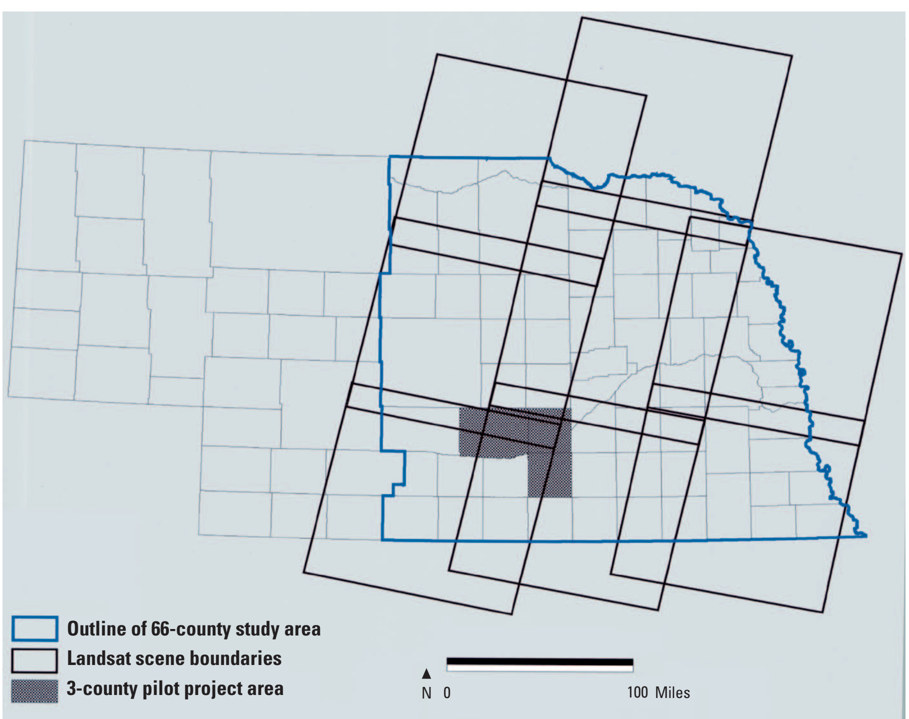

Figure 1. Nebraska county boundaries with study area counties highlighted and outlines of Landsat imagery scene extents.

Study area and population. Figure 1 shows the location of the three counties in our feasibility study and the eight Landsat images that cover most of the 66 counties in the original population-based case–control study of NHL (*14*). Three counties in south-central Nebraska (Adams, Buffalo, and Hall) were chosen for the feasibility study on the basis of their high agricultural production, their proximity to each other, and the location of most of the land area within the boundaries of one Landsat satellite image. Eligibility for the feasibility study was limited to participants who were residents of one of the three counties at the time of the interviews, and who had lived at their interview residence for 10 or more years (n = 126; median duration of residence = 30 years). We excluded shorter duration residents (n = 40, 24%) because we were interested in identifying potential exposures among the study population that was residentially stable. We located the study participants' residences at the time of the interviews (1986–1987) based on the street address; we were not able to locate previous residences because complete address information was not available.

Satellite image data. We obtained a Landsat Multispectral Scanner image (Path 29, Row 32) for late summer (29 August 1984) from the U.S. Geological Survey EROS Data Center (EDC, Sioux Falls, SD). All of Hall and Adams Counties fell within the extent of the image, whereas the western third of Buffalo County was not included in the image. Therefore, the land cover classification for Buffalo County included only the part of the county in the image.

A portion of the unclassified satellite image for an area of Buffalo county is shown in Figure 2. The unclassified image is a color infrared display of the image bands 4, 2, and 1, which contain wavelengths in the near infrared and red and green visible light regions. These wavelengths are useful for discriminating different land cover and vegetation types. In the unclassified image, green vegetation is shades of red, whereas senescent vegetation and bare soil are shades of blue.

The image was georeferenced to a map base processed to correct for geometric distortion, then resampled to a 60-m × 60-m pixel resolution by EDC. A pixel is the grid cell picture element that represents a certain portion of the landscape. A late summer image date was selected because the predominant crops in the study area (corn, sorghum, soybeans) are at maximum maturity at this time of the year, which makes the crops most distinguishable from bare soil and from each other.

Farm service agency data. We obtained historical records on the types of land cover at specific locations from the Nebraska Farm Service Agencies (FSAs) in Hall and Adams Counties. We used these records as our ground reference data both to classify the satellite image and to test accuracy of the classification. The records provided by the Hall and Adams County FSAs were 1984 aerial photographs, with annotations as to what crops were grown in a specific field. FSA records for 1984 were not available for Buffalo; therefore, the land cover map for eastern Buffalo County was classified based on data from Hall and Adams Counties.

Classification of land cover. The first step in crop classification was the sampling of 95 locations on the portion of the satellite image containing Adams and Hall Counties. These sites were between 70 and 140 acres, and represented the major spectral signature types in the image. The 95 locations were screen digitized in the GIS and linked to the ground reference information from the FSA. Odd-numbered sites (n = 47) were used as classification training sites (calibration) and even-numbered sites (n = 48) were used as test sites to determine the accuracy of the classification (validation).

We classified the six dominant agricultural land cover types in the study area: corn, sorghum, soybeans, alfalfa, rangeland, and bare soil. Corn, sorghum, soybeans, and alfalfa combined accounted for 93% of the crop acres harvested in the three counties in 1984. Alfalfa has multiple harvest dates throughout the growing season; therefore, we only classified alfalfa fields at full cover. Winter wheat was the other major crop (7% of acres harvested) but because it is harvested by July, it could not be differentiated from bare soil on a late summer image. We used a standard smoothing technique (a 3 × 3 pixel-smoothing filter) to remove scattered pixels in the image that were likely to be misclassified. We created a new coverage in the GIS that identified the location of the clusters of pixels classified as a single crop type (termed crop polygons).

We evaluated the overall classification performance as well as that of the individual land cover types. The overall classification accuracy was calculated by dividing the number of correctly classified pixels by the total number of pixels in the FSA test sites used for validation. The individual class performance was calculated by dividing the number of correctly classified pixels for a specific cover type by the total number of pixels of that land cover type in the test data sites.

Pesticide use. We obtained pesticide use data from several sources. The Agricultural Extension Service at the University of Nebraska (Lincoln, NE) conducted several surveys of farmers' pesticide use on major crops in Nebraska from the late 1970s through the 1990s. The mail surveys result in statewide estimates of acres treated (includes multiple applications) and application rates for specific herbicides and insecticides for the major crop species. From the 1982 survey (*25*), the survey year closest to 1984, we obtained information about the acres of each major crop that were treated with a specific pesticide or pesticide combination and the total acres planted. Agricultural pesticide use changed only moderately between 1982 and the next survey year (1987); therefore, use estimates from 1982 are likely to reflect use over several years.

The 1982 Nebraska survey and other data sources for 1984 did not contain information on the usual number of applications of each pesticide. We obtained this information for Nebraska for 1987 (the first year available) from the U.S. Environmental Protection Agency Biological and Economic Analysis Division of the Office of Pesticide Programs, which has a computerized database from a private market survey of pesticide use among farmers (*26*).

We calculated probabilities of use for the pesticides that together accounted for the top 85% or more of use (by weight of active ingredient) on corn, soybeans, and sorghum (*25*). Probabilities could not be calculated for the other major crops (alfalfa, wheat) and pasture and rangeland because of the lack of information on the acres treated with specific pesticides. However, the percentage of acres treated with pesticides was low (alfalfa 5%; wheat 11%; pasture and rangeland 5%). The low acreage for these crops and low pesticide use meant that they were minor contributors to pesticide use in Nebraska.

Crop-specific probabilities of pesticide use were calculated by first dividing the crop acres treated with a specific pesticide (which included multiple applications to the same acreage) by the average number of applications per season to give an estimate of the acres treated one or more times with the pesticide. The average number of applications ranged from 1.0 to 1.04 for the major crop herbicides and from 1.0 to 1.25 for the major crop insecticides. The estimate was then divided by the total acres planted in the crop to give the estimated probability that a crop type was ever treated with the pesticide. We linked the probabilities to the crop map in the GIS, creating a new coverage of probability of chemical use for each crop polygon in the study area.

Information on pesticide application rates was obtained from the Nebraska pesticide use survey (*25*). Pesticides were applied at slightly different rates depending on the formulation. Therefore, we calculated an average application rate by weighting the application rates for each pesticide formulation by the number of acres to which it was applied.

Address geocoding. Addresses of the study participants were sent to a geocoding firm (Geographic Data Technology, Lebanon, NH), which generated latitude and longitude coordinates from the street addresses using enhanced U.S. Bureau of the Census topologically integrated geographic encoding and referencing (TIGER) line files (U.S. Bureau of the Census, Washington, DC). TIGER files contain the geographic location of streets and street address ranges for all U.S. counties. Rural route addresses in our study were not included in these files. We obtained street addresses for the rural route addresses from the county agencies responsible for 911 address assignment or from the postal service. To map rural addresses, we manually compared county road maps with updated 911 street names to the digital TIGER line files and estimated the residence locations by interpolating within the address range for the street segment.

Classification of residences. Studies have demonstrated that drift from aerial pesticide applications can extend from 500 to 1000 m (*9,10*). Drift from boom-type sprayers has been demonstrated at distances of 300 to 800 m from the application area (*9,11*). We used a 500-m buffer around residences to define the zone of potential exposure to crop pesticides because this was an intermediate distance for the range of drift effects from crop pesticides.

First, we determined which residences were located within a town boundary (community residences) and which were outside of towns (rural residences). The town boundaries were the U.S. Bureau of the Census place designations, which we obtained from the Consortium for International Earth Science Information Network (University Center, MI). Second, we created a new coverage in the GIS that mapped a circular buffer with a 500-m radius around each residence.

A residence was defined as potentially exposed to crop pesticides if it had one or more of the major crop types (corn, sorghum, soybeans, alfalfa) within the buffer. For each residence we determined the total area (in hectares) of each crop type within the 500-m buffer. We also determined the distances (in meters) from the residence to the centroid of each part of the crop fields that fell within the buffer and calculated an average distance for each residence. We would have preferred to determine the distance between a residence and the nearest edge of each crop field. However, there was not a straightforward procedure for calculating this in the GIS; therefore, we used the software's standard function for determining the distance to the centroid of a polygon from a defined point.

Results

Crop classification. The results of the accuracy assessment of the crop classification are shown in Table 2. The overall classification accuracy for all land cover types, including rangeland, bare soil, and crops, was 78%. The accuracy for rangeland and for bare soil were 68 and 96%, respectively. Errors in the classification of rangeland resulted from misclassification as bare soil. The overall accuracy for the four major crops was 80%. The highest classification accuracy was 90% for corn, followed by 77% for alfalfa, and 75% for both sorghum and soybeans. Sorghum was misclassified as corn for 24% of the pixels tested. Misclassification of soybeans was mainly due to classification as alfalfa and visa versa. The number of test sites used to determine the classification accuracy varied by crop type from four for sorghum to twelve for corn. Figure 2 shows a comparison of the original Landsat satellite image and the land cover map resulting from the classification for a region of Buffalo County near Shelton, Nebraska.

Pesticide use. Statewide estimates of pesticide use probabilities (prob) and average application rates are shown in Table 3 for corn, sorghum, and soybeans. The probabilities could sum to > 1 because the same acreage could be treated with multiple pesticides. Probabilities of herbicide and insecticide use on alfalfa and insecticide use on soybeans were not calculated because the numbers of acres treated were not reported (*25*) due to the low percentage of acres treated. Atrazine was the major herbicide used on corn (prob = 0.54) and sorghum (prob = 0.72), whereas trifluralin was the major herbicide used on soybeans (prob = 0.49). The number of herbicides used on these crops was limited. Three herbicides accounted for > 85% of the applications to corn (atrazine, alachlor, butylate) and soybeans (trifluralin, metribuzin, alachlor), whereas two herbicides accounted for > 85% of applications to sorghum (atrazine, propachlor). There was some overlap in use of the major herbicides across crops. Atrazine was used on both corn and sorghum and alachlor was used on both corn and soybeans.

Application rates varied by the type of herbicide and by the crop treated. The highest average application rate was 3.54 lb active ingredient per acre for butylate on corn; the lowest rate was 0.33 lb active ingredient per acre for metribuzin on soybeans. The application rates for atrazine and alachlor depended on which crop was treated. Corn had higher application rates than both sorghum for atrazine and soybeans for alachlor.

The probabilities of use for individual insecticides were much lower than for the herbicides (Table 3). Fonofos was the insecticide with the highest probability of use on corn (prob = 0.19). Parathion was the insecticide most likely to be used on sorghum (prob = 0.13). The number of insecticides accounting for 85% or more of applications was five for corn (fonofos, terbufos, carbofuran, phorate, chlorpyrifos) and two for sorghum (parathion, carbofuran). Application rates for insecticides on corn were similar. Carbofuran was used on both corn and sorghum at similar application rates.

The land area with probable use of the herbicide atrazine is illustrated in Figure 3. In this example, the potential source area for atrazine was the land area classified as corn and sorghum because it was used on both crops. The colored areas on the map are the aggregates of the 60-m^2 pixels classified as these crops. Although the majority of the land area of the three counties was a potential source area for atrazine, the presence of urban areas, other crop types, rangeland, and the riparian areas along the Platte River (the southern border of Buffalo County and southeast half of Hall County) resulted in variability in the areal distribution.

Address geocoding. The geocoding firm matched 84 of the 126 addresses (67%) exactly to a longitude and latitude. The remaining

Table 2. Land cover classification accuracy results for Adams, Buffalo, and Hall Counties, Nebraska, 1984.

Class	Land cover class	Test sites (*n*)	Pixels in test site images (*n*)	Correct (%)	Pixels classified into the land cover class (*n*) Ra	Bs	Co	Gs	Sb	Al
Ra	Rangeland/pasture/ harvested crops	8	800	68	546	254	0	0	0	0
Bs	Bare soil/roads/ nonvegetated	5	231	96	9	222	0	0	0	0
Co	Corn	12	750	90	4	0	671	19	56	0
Gs	Grain sorghum	4	609	75	8	0	145	456	0	0
Sb	Soybeans	12	1,149	75	3	0	0	4	866	276
Al	Alfalfa, full cover	7	538	77	37	0	0	30	58	413
Total		48	4,077							
Overall accuracy				78						

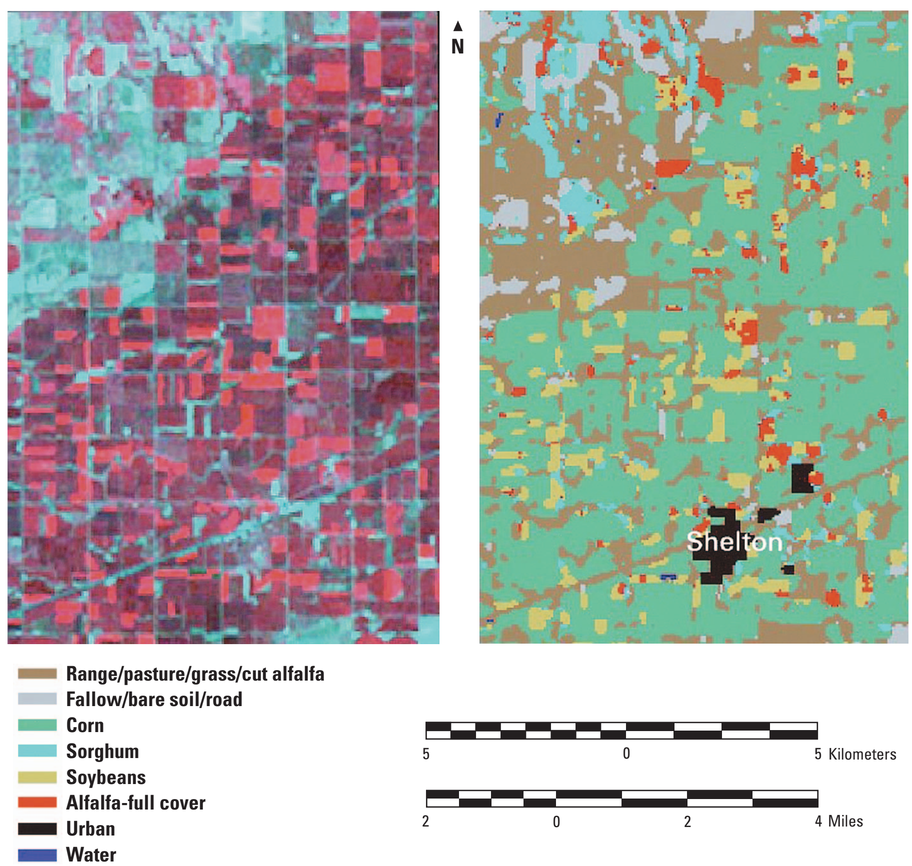

Figure 2. Original Landsat image (left) and the land cover map (right) for a region of Buffalo County including Shelton, Nebraska.

42 addresses were matched either to the centroid of a zip code plus the 4-digit extension (n = 4, 3%), the zip code plus the first 2 digits of the extension (n = 5, 4%) or to the 5-digit zip code (n = 33, 26%). Eighteen of the 42 addresses (43%) that could only be matched to a zip code were rural route addresses. We were able to find a street address for all but a few of the rural route addresses by contacting either the county agency responsible for 911 addresses or the postal service. Most of the other street addresses that were not matched by the geocoding firm had incomplete address information (e.g., no street number) or had slight differences in street names, which prevented an exact match. For example, our database had a Fourth Street address and the TIGER database address was E. 4th Street. Most of these addresses were subsequently located using city maps, postal service databases, and Internet map databases. After these efforts, a total of 107 residents were located (85%), leaving 19 addresses (15%) that could only be matched to a 5-digit zip code (e.g., if the address consisted of only a town, or town and box number), a zip plus 2, or a zip plus 4. The 19 residences that could not be located were excluded from further analyses.

Table 3. Pesticide use probabilities and application characteristics for the major crops in Nebraska, 1982.

Crop	Acres treated (%)	Pesticide[a]	Class	Prob[b]	Appl[c] rate	Appl timing
Herbicides						
Corn	91.5[d]	Atrazine	Triazine	0.54	1.42	March–June
		Alachlor	Acetanilide	0.30	1.76	April–June
		Butylate	Carbamate	0.20	3.54	March–May
Sorghum	90.3	Atrazine	Triazine	0.72	0.89	March–June
		Propachlor	Anilide	0.54	1.72	May–June
Soybeans	91.0	Trifluralin	Dinitroaniline	0.49	0.84	April–June
		Metribuzin	Triazine	0.35	0.33	March–April
		Alachlor	Acetanilide	0.32	1.33	April–June
Insecticides						
Corn	62.2[e]	Fonofos	Organophosphate	0.19	1.1	May–October
		Terbufos	Organophosphate	0.13	1.25	April–June
		Carbofuran	Carbamate	0.07	1.09	April–November
		Phorate	Organophosphate	0.05	1.12	May–November
		Chlorpyrifos	Organophosphate	0.05	1.12	April–August
Sorghum	21.1	Parathion	Organophosphate	0.13	0.64	March–November
		Carbofuran	Carbamate	0.05	1.06	April–November
Soybeans	1.5	Parathion	Organophosphate	NA[f]	NA	March–November
		Carbofuran	Carbamate	NA	NA	April–November

Abbreiviations: Appl, application; Prob, probability.
[a]Pesticides listed accounted for the top 85% of use (pounds of active ingredient). [b]Calculated from acres treated, average number of applications per season, and acres of crop planted. [c]In pounds per acre. Weighted average of individual chemical and chemical combination application rates; weights were acres treated. [d]Percent of all acres treated with herbicides (all types). [e]Percent of all acres treated with insecticides (all types). [f]No data available on the quantities used or the application rates from the 1982 Nebraska pesticide survey.

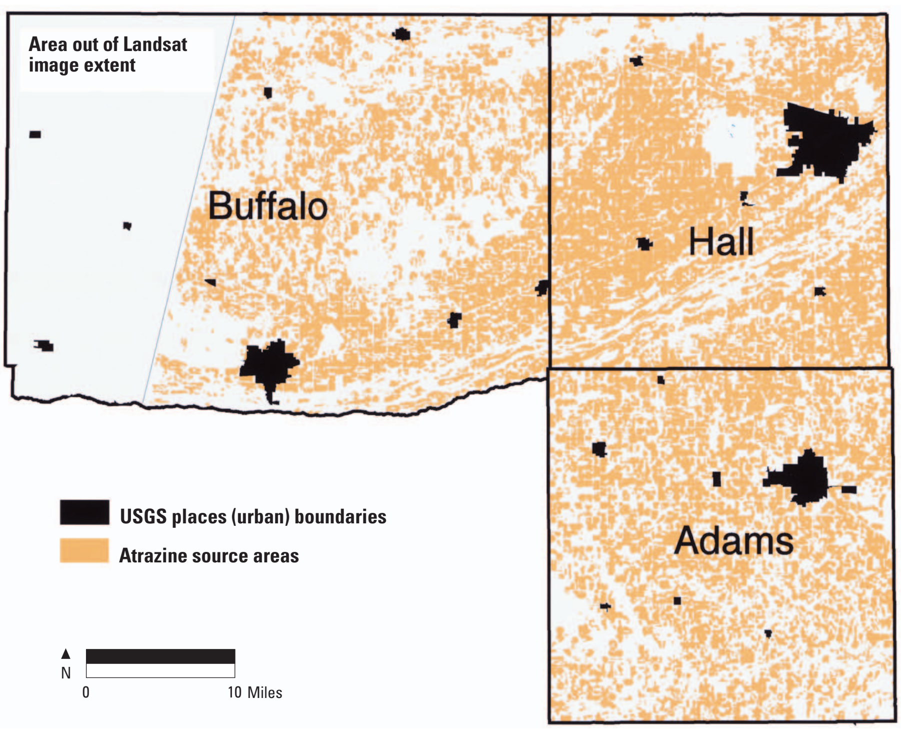

Figure 3. Map of the three-county area with source areas for atrazine highlighted. USGS, U.S. Geological Survey.

Classification of residences. A total of 97 (91%) of the 107 residences were classified as community residences because they were located within a town boundary and the remaining 10 (9%) residences outside of towns were classified as rural. Among all residences, 22% had at least one of the four major crops (corn, sorghum, soybeans, alfalfa) within 500 m of the residence. Of the community residences, 14 (15%) had crop fields within the 500-m buffer around the residence, whereas all 10 rural residences (100%) had crops within the buffer. Corn and sorghum occurred most frequently for both community residences (corn 86%, sorghum 71%) and rural residences (corn 90%, sorghum 80%). Soybeans and alfalfa were each located within buffers for 21% of the community and 50% of the rural residences with crops within the buffers.

The crop area and average distance to the centroid of crop fields that were within the 500-m buffers are shown in Table 4. The area of each buffer was 78.2 hectares. The median area of crop cover was 7.1 hectares (9.1% of buffer) for the community residences and 31.3 hectares (40% of buffer) for the rural residences. Corn was the predominant crop, accounting for a median area of 4.3 hectares for the community residences and 29.3 hectares for the rural residences. Median areas for the other crops were < 1.0 hectare for the community residences and < 4.0 hectares for the rural residences. The median of the average distance to the center of the crop fields within the buffers was 378 m for rural residences and 419 m for community residences.

Within the GIS, we had the capability to zoom in on specific residences, to create visual displays of the local landscape, and to conduct spatial queries. An example of a visual display is illustrated in Figure 4, which shows two residences (one community and one rural), their 500-m buffers, and the areas of potential exposure to pesticides applied to corn and to sorghum.

Discussion

This feasibility study demonstrated that historical crop maps can be created from remote sensing data using FSA records as a source of ground truth information. Using a GIS, the distance to and area of crop fields within the range of pesticide drift can be quantified for residences in a study. Crop-specific pesticide use survey data allow for the identification of the major crop pesticides and their probabilities of use.

Our results indicated that a substantial proportion of the population in agricultural areas may have exposure to crop pesticides through the proximity of their residences to crop fields. In the three-county study area in eastern Nebraska, 22% of the study population had crops within 500 m of their residence. Fifteen percent of community residences had crop fields within 500 m of the residence, indicating that residence in a town may not preclude exposure to crop pesticides. Corn and sorghum were the most frequent crop types near residences, reflecting the predominance of these crops in the three counties. The likelihood of exposure to herbicides was high because of the high percentage of crop acres treated with herbicides (> 90%). Insecticides were used less frequently. A few herbicides and insecticides accounted for the majority of crop pesticides used. The proportion of the study population with occupational exposure to the major crop pesticides, as determined by interviews (*14*), was much lower than 22%. For example, the prevalence of exposure to any of the major corn and sorghum herbicides was 6% for corn and 5% for sorghum.

Table 4. Crop area, average distance to crops, and proximity metric for community and rural residents.

Exposure category	Major crops within buffer (hectares),[a] median (IQR)[b]	Average distance to centroid of crop field (meters), median (IQR)[b]
Community residences[c] (n = 14)	7.1 (3.0–9.9)	419.9 (390.4–457.1)
Rural residences[d] (n = 10)	31.3 (29.4–47.8)	378.3 (347.8–384.4)

IQR, interquartile range.
[a]Total area of buffer = 78.2 hectares. [b]25th–75th percentiles. [c]Community residences (within a town boundary) with crops within 500 m of residence. [d]Residences outside of a town boundary with crops within 500 m of residence.

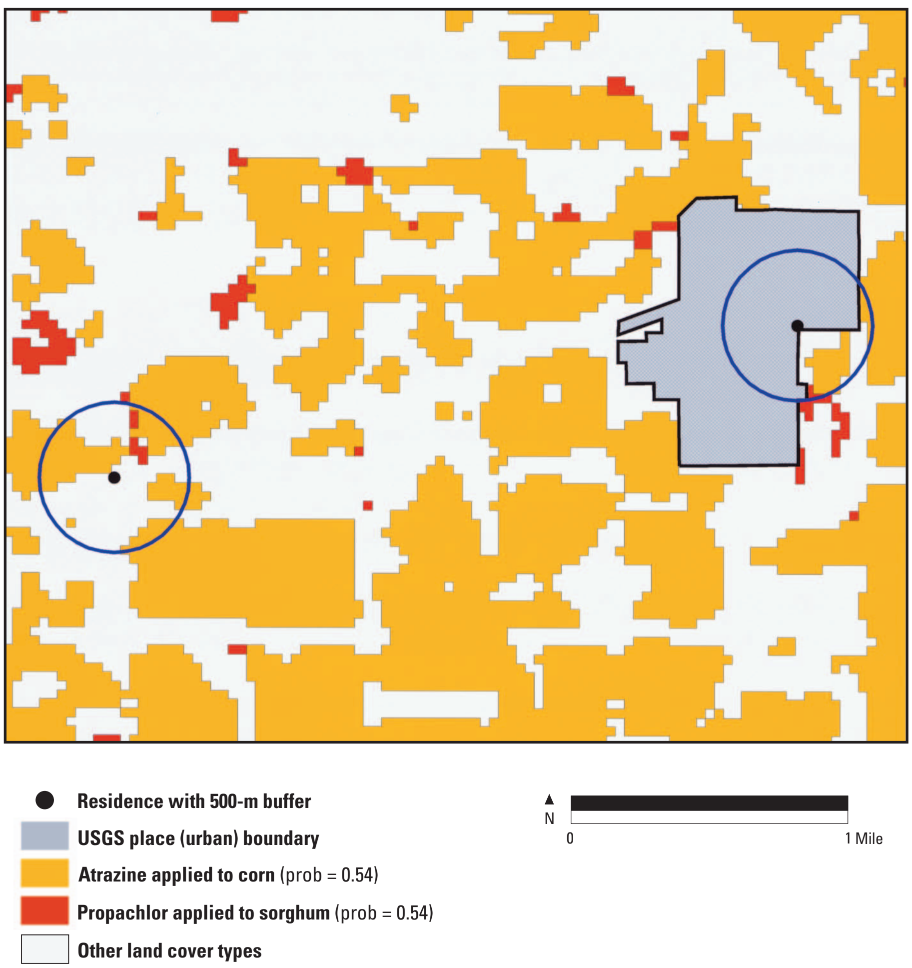

Figure 4. Example of two residences and their 500-m circular buffers overlaid on the crop map of corn and sorghum fields. USGS, U.S. Geological Survey. Probabilities (prob) of atrazine use on corn and propachlor use on sorghum are noted.

Our estimate of 22% of residences exposed may be conservative for eastern Nebraska because the three counties in our feasibility study contain three of the seven largest towns (population > 20,000) in the 66 counties of eastern Nebraska. The proportion of the population near the edges of towns would be expected to vary by the towns' population size because a higher proportion of residences are near the perimeter in small towns as compared to large towns. Additionally, sprayed pesticides drift further than the 500-m distance we used to classify the population as potentially exposed. Secondary drift due to volatilization of pesticides and wind erosion of pesticide-laden soil may further increase the geographic area affected (*27–29*).

The characterization of crop fields in proximity to residences may be a useful method for classifying individuals with respect to their potential for indirect exposure to crop pesticides. However, the relationship between proximity to crop fields and residential exposure needs further evaluation. The assumptions are that the proximity and area of crop fields near residences are correlated with crop pesticide levels in the homes and that exposure at the residence results in exposure to the individual. Although these assumptions have not been specifically evaluated for the crops and geographic area of our study, there are various studies that indicate that these assumptions are likely to be valid. Pesticide drift from spraying operations occurs at distances up to 1,000 m for aerial spraying and up to 800 m for ground boom applications (*9–11*). Dermal exposures to agricultural pesticides in the home have been correlated with pesticide levels in the outdoor environment, indoor air, house dust, and surface loading in the home (*30*). Two studies evaluated the proximity of residences to crops and found that residences closer to crop fields sprayed with pesticides had higher pesticide levels in homes (*12*) and higher exposure levels in children (*13*). These studies used the study participants' estimates of the distance from the residence to the nearest crop field; the crop area near the residence was not estimated. Our method quantifies crop area and distance, which would be useful for future studies of the relationship between these factors and residential levels of agricultural pesticides. Further, the evaluation of changes in crop patterns and pesticide use over time in relation to pesticide levels in carpet dust should aid in the understanding of the temporal aspects of this exposure measure in epidemiologic studies.

Although studies to date indicate that residential proximity to crop fields is a determinant of residential exposure, the same studies indicate that the presence of an agricultural worker in the home is a major contributor to higher exposure levels (*12,13,18*). The relative contribution of carry-home exposures in households with agricultural workers should also be considered in future studies.

Our method for creating historical crop maps and identifying potential crop pesticide exposures is dependent on the availability of satellite imagery, historical records on crop locations, and pesticide use information. Satellite image data are available from the early 1970s. However, historical ground reference information generally was not available in Nebraska until the early 1980s. Approximately 80% of the FSAs in the 66-county study area had records starting in 1981 because the agencies were told in the early 1980s to maintain their records indefinitely for the purposes of the federal crop insurance program. Previously, the agencies kept records for approximately 5 years (*31*).

Our land cover classification results indicate that corn could be distinguished from sorghum, soybeans, and full-cover alfalfa using a late summer satellite image. Soybeans and full-cover alfalfa would be difficult to separate at this time of the growing season because of their similar spectral characteristics. Further, alfalfa fields are difficult to identify because of the multiple harvest dates throughout the growing season; therefore, we only attempted to classify alfalfa fields at full cover. Winter wheat was harvested by July, so it could not be determined. Using an early spring image may make it possible to identify alfalfa and winter wheat fields because it would be prior to the first harvest. However, wheat and alfalfa have relatively little pesticide use and accounted for a small percent of the crop area in the study area, so these crops would not contribute substantially to the population's potential exposure.

We did not distinguish between irrigated and nonirrigated crops in this study, although we did find evidence to suggest that the spectral response of a particular crop is dependent on irrigation practices (*32*). Further research to separate crops into irrigated and nonirrigated classes should improve the crop classification accuracy. Furthermore, pesticide use on specific crops is greater if the crop is irrigated (*25*). Pesticide use information in Nebraska was obtained for irrigated and nonirrigated crops separately; therefore, information on whether a crop type was irrigated would allow a more accurate estimation of the probabilities of pesticide use.

The crop classification method we used requires a substantial amount of ground reference data to train the classification algorithm and to test the classification results. If several years of imagery were classified over large regions, it would require significant resources to collect and process the data. Information on the prevalence of crop rotations would be necessary to determine how often land cover would need to be reconstructed for these maps to be used as a basis for identifying changes in pesticide use. We recently evaluated the feasibility of using county agricultural statistics as an alternative to ground reference data and found that it was possible to create crop maps for corn, the dominant crop type in the study area (*32*). If this proves successful for other crop types, the effort involved in reconstructing land cover over large geographic regions could be substantially reduced.

We found that a limiting factor for our approach of using crop maps to identify populations potentially exposed to agricultural pesticides was the availability of detailed data on pesticide use. Pesticide use data are important because pesticide use patterns change over time as certain pesticides are restricted or as new formulations are marketed. Calculating the probability that a specific pesticide was used on a crop field each season requires annual estimates of the acres treated with each pesticide. This information can be obtained from surveys of farmers, such as those conducted by the U.S. Department of Agriculture (USDA), or from a pesticide use reporting system, such as that used by the state of California, where agricultural pesticide use is reported for each public land survey section (approximately 1 square mile). The earliest pesticide use survey in Nebraska was conducted by the University of Nebraska Cooperative Extension Service for the 1978 growing season. Surveys were also conducted for the 1982 and 1987 growing seasons. In 1986, the USDA began annual surveys of the major field crops in the major producing states. The number of states included varied slightly by crop and by year but the major crop-producing states were included most years and Nebraska was included every year (*33*). The crops included corn, soybeans, winter wheat, and others. Sorghum was included in 1991 for Nebraska but not for later years.

One objective of the feasibility study was to determine the completeness and accuracy of residence location, which is an important component of many environmental epidemiology studies. In our study, the geocoding was initially done by Geographic Data Technology, a company that used U.S. Census Bureau TIGER file street address ranges and assigned location to a street address by interpolation between address ranges assuming an equal spacing of houses along the street. All houses were assigned a latitude and longitude 5 ft from the edge of the street. Address matching resulted in exact location information for only 67% of residences. One problem with relying on TIGER files for address location is that rural route addresses are often not included. We were able to determine the new street addresses for most rural route addresses by contacting the county agencies responsible for rural route address assignments (for 911 emergency purposes); however, this was labor intensive.

Another potential problem with accurately locating rural residences is that they are usually located on large land areas and the home is likely to be substantially removed from the road. In Adams County, the highway department which assigned street addresses in rural areas estimated that the houses were usually between 90 and 200 feet from the road and that the distance varied widely (*34*). If this is typical of other rural areas, rural house locations as determined by this mapping procedure are likely to be less precise than urban or suburban locations. This uncertainty in residence location can be overcome by the use of a global positioning system to determine longitude and latitude readings at the residence.

One limitation of this approach to identify residences with higher potential exposure to crop pesticides is that some of the necessary data resources for this method did not exist before the 1980s. A further limitation is that the use of buffers and proximity as an exposure metric can result in considerable misclassification (*35,36*) because exposure does not occur solely within the buffer and because proximity is only one factor that affects exposure. Our use of a buffer approach to define exposure is an improvement over most previous studies because the crop maps allowed us to define the specific areas within the buffer that were sources for the crop pesticides. Furthermore, the 500-m distance used in our study was not chosen arbitrarily, but was based on the pesticide drift literature.

To further refine the appropriate buffer distance, information on the recommended application methods for each major pesticide can be obtained from the Nebraska Cooperative Extension Service guideline reports (*37*). This information was also collected in the 1982 pesticide use survey by crop and by pesticide applied (*25*). The specific time periods when pesticides were likely to have been applied could be estimated using annual information on planting and crop development dates (*38*) together with Extension Service data on application timing (e.g., preplant, preemergent, etc.).

Pesticide levels in residences may correlate well with the crop area within a specified distance from the home (*12,13*); however, further studies are required to determine the utility of this method for classifying a population with respect to their residential exposure levels. Furthermore, other factors that affect the geographic extent and persistence of pesticides in the environment should be considered. We are currently integrating our GIS with computer-based models incorporating the pesticide application rate and wind direction and speed for predicting the geographic area affected by primary drift at the time of application (*39*). However, the method also lends itself to prediction of pesticide transport by other mechanisms. For example, after identifying locations where pesticides are applied or deposited by drift, information on soil type, geophysical factors, and the chemical characteristics of the compounds can be used to predict pesticide transport into groundwater and soil erosion by wind or water (*40,41*).

In summary, the use of historical crop maps for classifying a study population with respect to their potential for past exposure to crop pesticides may be a useful addition to future health studies. This method will allow the identification of populations with potentially higher exposures to crop pesticides and would be useful in the design of future studies to evaluate the health effects of exposures to agricultural pesticides. This method will also allow the evaluation of changes in crop patterns and crop-specific pesticide use over time in relation to pesticide levels in the home. Such an evaluation should lead to a clearer interpretation of pesticide levels in house dust as an exposure measure in epidemiologic studies (*18,19*).

Our results indicate that the potential for indirect exposure to agricultural pesticides through residential proximity to crop fields may be significant for residents of highly agricultural areas. We found that 22% of the study participants had crops within 500 m of their residence. The likelihood that herbicides were used on these crops was high and was limited to a few specific chemicals. Insecticide use was less frequent but also consisted of a few major insecticides. Further research should refine this approach by estimating pesticide drift and transport in the environment. The validity of this method for classifying a study population with respect to the level of crop pesticides in their homes should be determined by household measurements.

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