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Agricultural Injury Surveillance Using a Regional Trauma Registry

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ABSTRACT

Background: The burden of traumatic injury among workers in agriculture is substantial. Surveillance can inform injury prevention efforts to reduce farmworkers' risk. We posited that the regional trauma registry can provide surveillance for agricultural injury requiring trauma-center care.

Methods: The Northeast Texas regional trauma registry was queried for patients injured in agricultural settings during 2016-2019 occurring in the 23,580 square mile study area subdivided into 219 US Census Zip Code Tract Area (ZCTA). Population at risk was estimated from the 2017 Census of Agriculture. Kuldorff's SaTScan identified case hot spots. A multivariable, geographically weighted regression model was fit for cases/1000 workers.

Results: In total, 273 cases occurred, (mean 68 cases per year [95% confidence interval 55.1-80.9]) among 96 ZCTA. The mean injury rate was 3.9 (95% confidence interval 3.4-4.3) cases per 1000 farmworkers. Animals and farm machinery were the most common injury mechanisms, 52.0% and 20.9%, respectively. Trauma ZCTA demonstrated more farms (median 170 *versus* 95.5, $P < 0.001$), greater farm acreage (53,900 acres *versus* 32,800, $P = 0.004$), and higher median total product sales ($6.5 million *versus* $3.9 million, $P < 0.001$). Six hot spots were identified with relative risks from 2.85 to 5.31. The multivariable model of cases/1000 workers demonstrated significant associations with workers per ZCTA (a mean β-coefficient of 0.004 with P values <0.05 in 145 of 219 [66.5%] ZCTA) and percent rural population ($\beta = -6.62$, P values <0.05 in 76.1% of ZCTA).

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Conclusions: Regional trauma registry data, combined with census data and spatial analyses, can identify actionable geographic areas of high agriculture-related injury risk.

Background

Agriculture-related occupational injury is a serious public health matter. According to the US Bureau of Labor Statistics (BLS), the incidence of serious nonfatal agricultural injuries totaled 3.2 and 3.6 cases per 100 full-time workers for crop and animal production, respectively.[1] In addition, 360 fatal injuries occurred in 2013.[1,2] By 2018, there were 3.4 and 4.3 nonfatal cases per 100 full-time crop and animal production workers, respectively, and 411 fatalities nationwide.[3,4]

Injury surveillance can monitor fatal and nonfatal injuries experienced by workers in agriculture. Despite the heavy burden of illness and injury in this workgroup, there is no formal national agricultural injury surveillance program.[5,6] Both the RAND Corporation and the National Occupational Research Agenda (NORA) have advocated using existing data sources for injury surveillance in agriculture.[7,8] One valuable data source for this purpose is regional trauma registries. Trauma centers verified by the American College of Surgeons Committee on Trauma are mandated to maintain current registries of all injured patients arriving for treatment.[9] The required data elements describe the mechanism and setting of the injury, all patient injuries, hospital care provided, and patient outcomes.[9] In addition to the required data elements, registries often collect other data points including the geographic location of injury. This information allows for future prospective injury risk reduction interventions.[10] The availability of the US Postal Services Zip Code for the location of the injury event combined with Geographic Information System mapping and analysis can be used to identify agricultural trauma hot spots in any trauma center service area. Geospatial analytic techniques have been applied in epidemiological studies of disease and injuries, as well as environmental aspects of farm and ranch management.[11-14] In addition, Ranapurwala *et al.*[15] applied geospatial techniques to analyze roadway characteristics in farm vehicle crashes. However, a paucity of studies utilize geospatial analysis to study agricultural injuries.

This project responds to the NORA for Agriculture, Forestry, and Fishing Objective AG-03: Improve reporting and surveillance of injury and illness in the agriculture sector.[7] We use the Northeast Texas Regional Trauma Registry (NTRTR) as a surveillance tool for agricultural injuries requiring trauma center evaluation and treatment by applying geospatial analysis to reveal spatial associations with trauma incidents.

Materials and Methods

Patient data

This study was approved by the Institutional Review Board of UT Health East Texas (case number 2020-025) after expedited review. As per the Code of Federal Regulations, a waiver of informed consent was granted for this study. We tabulated patients' records from the Texas Regional Advisory Council Trauma Service Area G (TSA-G) trauma registry (NTRTR) who presented with agricultural injuries that occurred between 2016 and 2019. The Trauma Service Area system is the means by which the Texas State Department of Health Services organizes, coordinates, and monitors emergency medical services (EMSs) at a local level across the state. There are 22 such areas in Texas.[16] Cases were initially seen among 31 hospitals with definitive care provided among 12 hospitals across the study area, as well as patients who were transferred from smaller nontrauma centers to the level I and II centers. Cases were identified as per the International Classification of Diseases, 10th Revision, Clinical Modification (ICD-10-CM) external causes of morbidity codes, including the supplementary factors related to causes of morbidity classified elsewhere (Y90-Y99) describing agricultural settings (e.g., farm, land under cultivation, outbuildings, Y92.79). In addition, free text fields in the registry augmented case identification related to agricultural activities where the agriculture-related activity or setting was not specified in the ICD-10-CM code. As such, patients were included if they were treated by the trauma centers in the region and their record included the Zip Code of where their injury occurred. The case variables include sex, race and ethnicity, age, comorbid chronic diseases, mechanism of injury, all injuries coded in the Abbreviated Injury Scale and ICD-10-CM lexicons, mode of transport to the caring facility, insurance type, date of injury, hospital charges, and hospital discharge condition. Injury severity was computed for each patient with the Injury Severity Score (ISS) based on the Abbreviated Injury Scale lexicon.[17] Mechanisms of injury were categorized as per the Matrix of E-code Groupings from the Centers for Disease Control and Prevention.[18] Then, mechanisms were further categorized as farm machinery-related or animal-related as per the narrative description in the records. For example, a patient's hand was crushed by hydraulic hay lifting equipment *versus* being kicked in the face while feeding horses. Patients were excluded from analysis if their injury incidents occurred in counties not contiguous to TSA-G ($n = 11$). The study protocol, including patient exclusion and data analysis, is displayed in Figure 1.

Geographic data modeling

The geographic region of interest was a contiguous 32-county area of Northeast Texas, covering 23,581 square miles. This region envelops TSA-G which consists of 19 contiguous counties. The rationale for adding 13 additional contiguous counties was to include patients treated by the trauma centers in our region whose injuries occurred in adjacent service areas without trauma centers in reasonable proximity. The single level I and single level II trauma centers in the study region are the only tertiary trauma facilities in a greater than 30,000

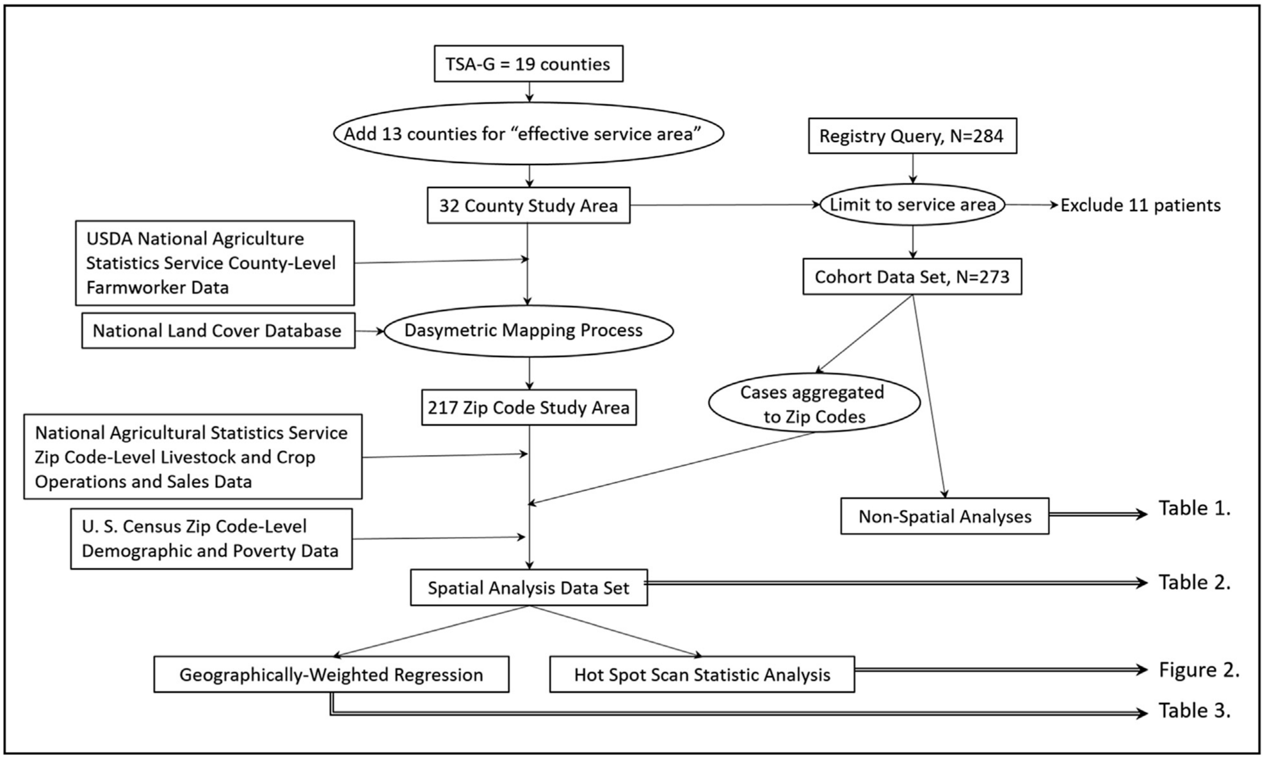


Fig. 1 — Schematic representation of study protocol.

square mile area of Texas. In addition to the level I and II centers, there were four level III, 17 level IV, and eight non-trauma center hospitals in the study area. The NTRTR data included the Zip Code for the location of injury and were geocoded to the corresponding US Census Bureau Zip Code Tabulation Area (ZCTA) within the study region. The ZCTA is an areal geographic representation of the US Postal Service Zip Codes associated with mailing addresses. ZCTA are created by assigning the majority Zip Code of the mailing addresses within a census block to the entire census block, and then, all census blocks with similar Zip Codes are combined into a single ZCTA.[19] We chose to conduct the analyses at the ZCTA level to produce the most granular targets for injury prevention efforts.

The study region consisted of 32 counties in Northeast Texas. According to the US Department of Agriculture (USDA) 2017 Census of Agriculture, this region is home to 44,583 farms, covering over 7.5 million acres of farmland.[20] The farm operations are primarily livestock production oriented.[20] Descriptive data from the USDA Statistics Service Quick Stats were obtained for agricultural economic characteristics which included numbers of and annual sales of crop and animal production operations (farms or ranches), cumulative farm acreage, and population at risk, defined as farmworkers.[21] Although the farmworker data are enumerated by counties, the locations of farm operations and workers are not homogeneously distributed across the county footprint. Therefore, we used dasymetric mapping as a technique for disaggregating spatial data from the county level and redistributing to ZCTAs following the method described by Holloway *et al.*[22] as outlined by Duh.[23] We applied the National Land Cover Database as the ancillary data source.[24] The National Land Cover Database is a raster data set at 30 square meter (~323 square foot) resolution with each raster cell classified as one of 16 land cover categories. The classes include open water, developed open space, developed low intensity, developed medium intensity, developed high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands. The types of land cover used for the dasymetric mapping process were determined by means of a geographically weighted regression (GWR) model (an extension to a standard linear regression model to spatially weight observations). The GWR model used worker density (workers per raster cell per county) as the dependent variable and the percentage of each land cover type's raster cells per county as the independent variables. The significantly associated land cover types were used in the dasymetric mapping disaggregation process to redistribute worker locations to smaller ZCTA. The land types identified as significant by the GWR model included herbaceous (weight = 8%), deciduous forest (13%), developed open space (14%), mixed forest (15%), evergreen forest (18%), and hay/pasture (32%). The relative density weights for the dasymetric process were based on the GWR regression coefficients.

Based on the known associations between community socioeconomic, population demographic features and traumatic injury, we included variables for total population, percentage of population living in poverty, percentage rural population, age, and race obtained from the 2017 American Community Survey 5-year estimates.[25] Rurality was defined as per the 2010 US Census classification schema, based on population density within urban areas (urban population) *versus* the population not included in an urban area (rural population).[26] ZCTA population density was defined as total population per acre in each ZCTA.

Spatial analysis

Hot spot analysis for high rates of injury events among farmworkers in the study area was performed using Kulldorff's spatial scan statistic for a discrete Poisson probability model via the SaTScan application, version 9.6.[27] We specified a maximum cluster size of 50% of a population within a 20 km moving scan radius. Hot spots were defined as a local relative risk ratio of 2 or greater. We conducted the hot spot analysis on the data in aggregate as well as each of the 4 years in the period studied.

A multivariable spatial regression model of trauma events per 1000 farmworkers per ZCTA was fit using the multiscale GWR (MGWR) method developed by Fotheringham *et al.*[28] The MGWR method was chosen to represent nonstationary associations or associations between the predictors and the outcome which can vary across the study region. The MGWR results were tabulated for each predictor to summarize the model β-coefficients, *P* value, and number (%) of the observation points where the associated *P* value is less than 0.05.

Nonspatial characteristics of the ZCTA were compared as per whether a trauma event occurred within their boundaries and whether a ZCTA was identified as part of a hot spot. Nonspatial data manipulation and analyses were conducted using Stata 17.1 (Stata Inc, College Station, TX). Tests of significance for nonspatial data included the rank sum test for nonparametric continuous data, the chi-square test for categorical descriptors and outcomes, and the Kruskal–Wallis equality-of-population rank test for nonparametric continuous descriptors and dichotomous outcomes. Spatial data manipulation, mapping, and exploratory spatial data analysis were performed using ArcMap 10.8 (ESRI, Redlands, CA). Significance was conditioned on $P < 0.05$.

Results

Nonspatial analyses

The registry query yielded 284 patients. After exclusion of 11 patients, 273 patients remained for analysis. The population at risk was estimated to be 70,880 farmworkers.[29] Thus, the overall injury rate was 3.9 per 1000 farmworkers. Most patients were male (200, 73.5%) and white (218, 79.9%). The mean age was 47.5 years (standard deviation [SD] 21.9). Patient ages ranged from 2 years old to 90 years old, and those who are aged 75 years and older represented nearly 10% of the cases. Most injury events involved work with animals (52.0%). Farm machinery and falls accounted for 20.9% and 13.9% of injury events, respectively. Blunt mechanisms were responsible for the vast majority of injuries (97.1%), whereas penetrating injuries accounted for the remainder (2.9%). There were 885 total injuries among the 273 patients studied. Injuries to the lower extremities were most common, affecting 125 patients (45.8%). The median ISS was 6 (range, 1-75; interquartile range [IQR], 7). Admission to the intensive care unit was required by 89 (32.6%) patients where the median stay was 3 days. The median hospital stay was also 3 days. Most patients were transported by the EMS ground ambulance (56.8%), and nearly one-fifth of patients in the group were transported by air EMS (19.4%). The remainder (62 [22.7%]) presented to the emergency department (ED) via a private vehicle. Interhospital transfer to higher levels of care was necessary for 46.5% of the patients. Although most patients had commercial insurance, 26% had no insurance to cover their costs of care. The median hospital charge was nearly \$50,000, including one patient who accrued over \$940,000 in medical care charges. The cumulative hospital and EMS charges for agriculture-related injuries in Northeast Texas totaled more than \$21 million. The majority (94.5%) were discharged alive with full recovery. However, six (2.2%) were left with disability, and two required long-term acute care for their ongoing medical problems. Six patients died at the hospital (2.2%). The six fatalities included four incidents involving vehicles, three tractors and one all-terrain vehicle (ATV). The remaining two deaths involved animals, one horse and one cow. See Table 1.

ZCTA, where injury events occurred, were compared with those in the study area where no events occurred. The median number of farm operations was greater in ZCTA with events than that in those without, 170 *versus* 95.5 respectively, $P < 0.001$. In addition, the median farm acreage was also greater among the event-related ZCTA, 53.9 acres (IQR 67.5) *versus* 32.8 (47.0). The values of annual livestock (57%) and crop production (82%) were higher among the event-associated ZCTA, $P < 0.001$ for each. Event ZCTA also had higher median counts of total farmworkers (effect size = 154.3, $P < 0.001$) and 40% more workers per acre, $P < 0.05$. The median population of event ZCTA were more than two times higher than those of ZCTA, where no events took place ($P < 0.001$), but had an 8% lower percentage of rural population ($P < 0.01$). There were slight but statistically significant differences between event and nonevent ZCTA for median percentages of American Indians and Asians.

Fewer characteristics distinguished hot spot ZCTA than non–hot spot ZCTA. Hot spot ZCTA had a slightly lower percentage of livestock operations by comparison, 62.3 (IQR 9.7) *versus* 65.7 (IQR 8.5), respectively. Median crop sales were 77% greater among ZCTA in hot spots ($P < 0.05$). The median number of farm workers per acre in the hot spots was 50% greater than that in non–hot spot ZCTA, 0.009 *versus* 0.006, $P < 0.001$. The populations of ZCTA associated with hot spots tended to be greater in number and have lower median percentages of rurality and persons living in poverty. See Table 2.

Spatial analyses

During the study period, 123 ZCTA had no trauma events requiring trauma center treatment. Among the event-associated ZCTA, the rate varied from 0.7 to 200 events per 1000 workers, where the high outlier of 200 events per 1000 workers represented a single event in a ZCTA with 5

Table 1 – Description of 273 patients injured in agricultural settings during 2016-2019.

Sex, *n* (%)	N (%)
Male	200 (73.5)
Female	72 (26.5)
Race/ethnicity, *n* (%)	
White	218 (79.9)
Hispanic/Latino, any race	29 (10.6)
Black	20 (7.3)
Asian	1 (0.4)
Other/unknown	5 (1.8)
Age, years, mean (SD)	47.5 (21.9)
Min, max	2, 90
<5	9 (3.3)
5-14	11 (4.0)
15-19	20 (7.4)
20-34	42 (15.4)
35-59	98 (36.0)
60-74	65 (23.9)
≥75	27 (9.9)
Mechanism of injury, *n* (%)	
Animal related	142 (52.0)
Farm machinery related	57 (20.9)
Fall	38 (13.9)
Motor vehicle crash, Incl ATV	17 (6.2)
Struck by or struck against	15 (5.5)
Other mechanism	4 (1.5)
Blunt mechanisms	265 (97.1)
Penetrating mechanisms	8 (2.9)
Body regions of injury, *n* (%)*	
Head	49 (17.9)
Face	56 (20.5)
Neck	5 (1.8)
Thorax	64 (23.4)
Abdomen	39 (14.3)
Spine	46 (16.8)
Upper extremity	113 (41.4)
Lower extremity	125 (45.8)
External/superficial	3 (1.1)
Injury severity score	6 (7)
Transport mode, *n* (%)	
Ground EMS	155 (56.8)
Air EMS	53 (19.4)
Private vehicle	62 (22.7)
Unknown	3 (1.1)
Interhospital transfer, *n* (%)	127 (46.5)
Insurance status, *n* (%)	
Private/commercial	102 (37.4)
Medicaid/Medicare/government	92 (33.7)
Uninsured	71 (26.0)
Other/unknown	8 (2.9)
Total hospital days	3 (3)
Intensive care unit days, (*n* = 89 [32.6%])	3 (3)
Mechanical ventilator days, (*n* = 13 [4.8%])	3 (6)
Hospital charge, median (IQR)	$49,895 (74,151)
Discharge condition, *n* (%)	
Alive, full recovery	258 (94.5)
Moderate disability	4 (1.5)
Severe disability	2 (0.7)
Transferred to long-term care	2 (0.7)
Died	6 (2.2)
Year of injury, *n* (%)	
2016	65 (23.9)
2017	65 (23.9)
2018	62 (22.8)
2019	80 (29.4)

*Percentages reflect the proportion of 923 total injuries in the cohort.

farmworkers. The rates of farmworker trauma are mapped with six hot spots superimposed in Figure 2. The hot spots represented 95 cases (34.8%) among 8284 farmworkers or 11.5 cases per 1000 over a combined area of 2101 square miles (8.9% of the study area). The cases that took place in hot spots were not significantly different from non–hot spots in terms of the proportions of injury mechanisms (animal-related = 55.7%, machinery = 22.1%, falls = 11.6%, ATV = 5.3%, struck by/against = 3.2%, and other mechanism = 2.1%, $P = 0.7$). See Figure 2.

When the hot spot analysis was repeated for each year studied, no hot spots were identified for 2016. However, the years 2017, 2018, and 2019 each demonstrated one or more hot spots. These are in the same general vicinity as the areas identified in the analysis with all years combined. The results of this analysis are shown in Figure 3 with the density of farmworkers per 10,000 acres, the locations of hospitals and trauma centers in the study area, and major roadways shown for reference. Of note, the level I and level II trauma centers are within 50 miles of the outer boundaries of the hot spots when analyzed by year.

The MGWR model demonstrated nine ZCTA characteristics associated with trauma events per 1000 farmworkers. The number of farmworkers per ZCTA bore a significant, positive association with trauma events per 1000 farmworkers in 66.5% of the ZCTA in the study area (mean β-coefficient = 0.004, [SD = 0.001]), or for every additional 1000 farmworkers in a ZCTA, four more trauma events would occur. Similarly, the proportion of whites in the population was positively associated with the outcome in 44.5% of ZCTA, although the effect size was 10-fold higher (0.04 [0.02]). Conversely, the population density was negatively associated with agricultural trauma events, a mean β-coefficient of −64.2 (SD 31.2). The proportion of rural population was also negatively associated (a mean β-coefficient of −3.04, [SD 1.52]). The remaining five predictors in the model demonstrated positive associations in some ZCTA and negative associations in others. For example, the proportion of population living in poverty was positively associated with the outcome in 15 ZCTA and negatively associated in 35 ZCTA with β-coefficients ranging from -0.10 to 0.06 (mean = 0.03, [SD = 0.06]). Elder patients (65

Table 2 – Comparison of 219 Zip Code Tabulation Areas by trauma event status.

	All ZCTA	Events	No events	(+) Hot spot[††]	(−) Hot spot
Number of ZCTA[*]	217	96 (43.8)	123 (56.2)	22 (10.1)	197 (89.9)
Number of farms[†]	131.5 (203)	170 (206.5)	95.5 (164)[**]	180.5 (168)	126.5 (184.5)
Percent livestock operations	65.4 (8.8)	64.6 (7.0)	65.9 (10.6)	62.3 (9.7)	65.7 (8.5)[¶]
Cumulative farm acreage[†, ‡]	42.8 (52.6)	53.9 (67.5)	32.8 (47.0)[**]	35.9 (945.3)	42.7 (53.1)
Production sales[†,§]					
Livestock	3.5 (5.7)	4.4 (5.8)	2.8 (5.0)[**]	3.3 (5.0)	3.6 (5.7)
Crop	1.4 (2.1)	2.0 (2.2)	1.1 (1.9)[**]	2.3 (1.1)	1.3 (2.1)[¶]
Total	5.2 (7.2)	6.5 (8.2)	3.9 (7.1)[**]	5.7 (5.3)	5.1 (7.2)
Total farm labor workers[†]	250.1 (344.4)	338.7 (405.0)	184.4 (248.8)[**]	384.8 (365.3)	245.8 (300.8)
Workers per acre	0.006 (0.004)	0.007 (0.004)	0.005 (0.004)[¶]	0.009 (0.003)	0.006 (0.004)[**]
Total population[†,‖]	3.8 (8.4)	6.6 (9.9)	2.7 (5.7)[**]	8.9 (9.1)	3.4 (7.2)[**]
Percent rural population[†]	100 (42.6)	91.7 (49.2)	100 (12.8)[#]	56.8 (50.9)	100 (36.6)[**]
Percent population in poverty[†]	16.8 (8.2)	16.3 (7.3)	17.2 (8.9)	12.5 (3.6)	17.3 (8.3)[¶]
Population age groups, years[†]					
% less than 5	25.8 (7.0)	25.4 (5.7)	26.4 (8.2)	5.9 (3.2)	5.9 (3.4)
% 5-14	5.8 (3.2)	6.1 (2.3)	5.7 (4.1)	12.6 (4.1)	13.0 (4.9)
% 15-19	6.6 (2.6)	6.6 (2.0)	6.7 (3.0)	6.6 (1.5)	6.6 (2.7)
% 20-34	16.1 (5.6)	16.1 (5.3)	16.4 (6.1)	18.2 (6.9)	16.0 (5.6)
% 35-59	31.8 (6.2)	31.4 (4.9)	32.3 (6.9)	31.8 (5.7)	31.8 (6.2)
% 60-74	17.3 (7.2)	17.4 (6.5)	17.3 (8.6)	15.2 (7.7)	17.6 (6.7)
% ≥ 75	7.6 (4.4)	8.0 (4.0)	7.0 (4.5)	6.7 (4.9)	7.7 (4.3)
Race/ethnicity[†]					
% white	84.5 (15.3)	83.2 (14.9)	85.4 (16.2)	88.9 (18.6)	84.0 (14.6)
% black	9.3 (14.4)	12.0 (13.7)	7.9 (14.7)	6.3 (18.9)	9.5 (14.1)
% American Indian	0.2 (0.7)	0.3 (0.8)	0.1 (0.6)[¶]	0.4 (0.9)	0.2 (0.7)
% Asian	0.1 (0.6)	0.2 (0.9)	0 (0.4)[#]	0.5 (0.9)	0 (0.6)[¶]
% other race	1.0 (3.1)	1.1 (2.1)	0.9 (3.9)	0.9 (1.5)	1.0 (3.2)
% Hispanic/Latino	10.3 (13.6)	12.0 (10.9)	9.3 (15.9)	11.4 (12.6)	10.2 (13.7)

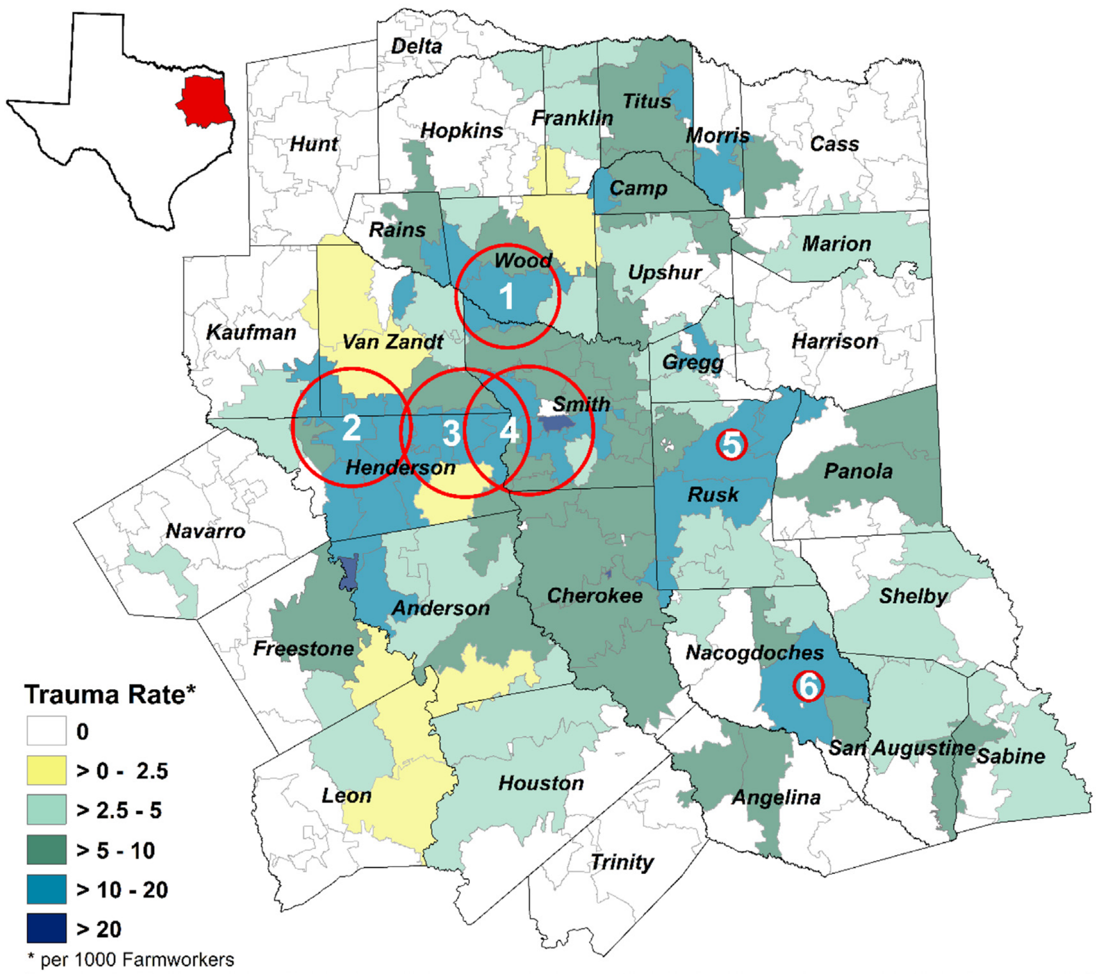
[*] *n* (%).
[†] Median (IQR).
[‡] 1,000 Acres.
[§] In $1 million units.
[‖] ×1000 population.
[¶] $P < 0.05$.
[#] $P < 0.01$.
[**] $P < 0.001$.
[††] Hot spot analysis for all years combined.

years old and older) comprised 26.4% of the cohort. The proportion of the population who are aged 65 years and older also demonstrated mixed effects in the study area where the association was positive in 42 ZCTA and negative in 24. β-Coefficients ranged from −0.12 to 0.12 (mean = 0.03 [SD 0.09]). The remaining parameters which included the proportion of Hispanic/Latino ethnicity in the population, the numbers of farm and ranch operations, and the numbers of livestock operations each had mixed associations with the outcome. See Table 3.

Discussion

This study demonstrates the utility of a regional trauma registry combined with geospatial analysis to identify areas of heightened trauma risk in the agricultural industry of Northeast Texas. By analyzing the data at the ZCTA level, the hot spots identified more than a third of the injury locations in a collective area occupying one-tenth of the region. These are the areas of greatest need for injury prevention efforts across a 32-county region. As such, the NTRTR is an effective means for surveillance of traumatic injury events requiring trauma center care among farmworkers and, thereby, addresses the NORA Objective AG-03 with an existing data source. More importantly, the analysis identifies areal characteristics associated with injury events.

The patients in this study included patients across a wide age range. This age range is not unique to the present study. Forst *et al.*[30] studied trauma registry data from the Ohio Department of Public Safety and found persons injured in the agricultural industry aged from 1 year old to 102 years old. The



	1	2	3	4	5	6
N Cases	20	13	18	25	9	10
Mechanism						
Animal-Related	9 (45.0)	8 (61.5)	15 (83.3)	11 (44.0)	6 (66.7)	4 (40.0)
Farm Machinery	5 (25.0)	4 (30.8)	1 (5.6)	6 (24.0)	3 (33.3)	2 (20.0)
ATV/MVC	1 (5.0)	0	0	4 (16.0)	0	0
Fall	4 (20.0)	1 (7.7)	0	3 (12.0)	0	3 (30.0)
Struck By or Against	1 (6.7)	0	0	1 (4.0)	0	1 (10.0
Other Mechanism	2 (1.12	0	2 (11.1)	0	0	0
Farmworkers, N	1,881	1233	2156	1992	452	572
Traumas/1,000 Farmworkers	10.6	10.5	8.3	12.6	19.9	17.5
N ZCTAs	3	3	4	10	1	1
Square Miles	460.7	238.9	459.8	477.8	180.0	283.9
Relative Risk	2.90	2.85	2.93	3.49	5.31	4.67

Fig. 2 — Trauma rates per 1000 farmworkers and hot spots of agriculture worker traumatic injury events.

Idaho Trauma Registry query by Shaver *et al.*[31] identified a cohort of patients injured in agricultural settings which had similar age range to our study, 3-82 years old. The National Agricultural Workers Survey for 2013-2014 reported the average age of farmworkers was 38 years old.[32]

In our cohort, there were 20 patients younger than 15 years old, including a 2-year-old who died as a result of a horse falling on him. Despite agriculture being one of the most dangerous industries in the United States, it is the only industry where children can be present in work areas, regardless of age.[33] In an effort to mitigate this hazard to children, the National Farm Medicine Center and the National Children's Center for Rural and Agricultural Health and Safety have published guidelines for children in the agricultural workplace.[34] Injuries to older farm workers are also worthy of note. As a whole, more workers older than the age of 55 years are employed in agriculture than any other industry in the United States.[35] In the present study, over one-third of the

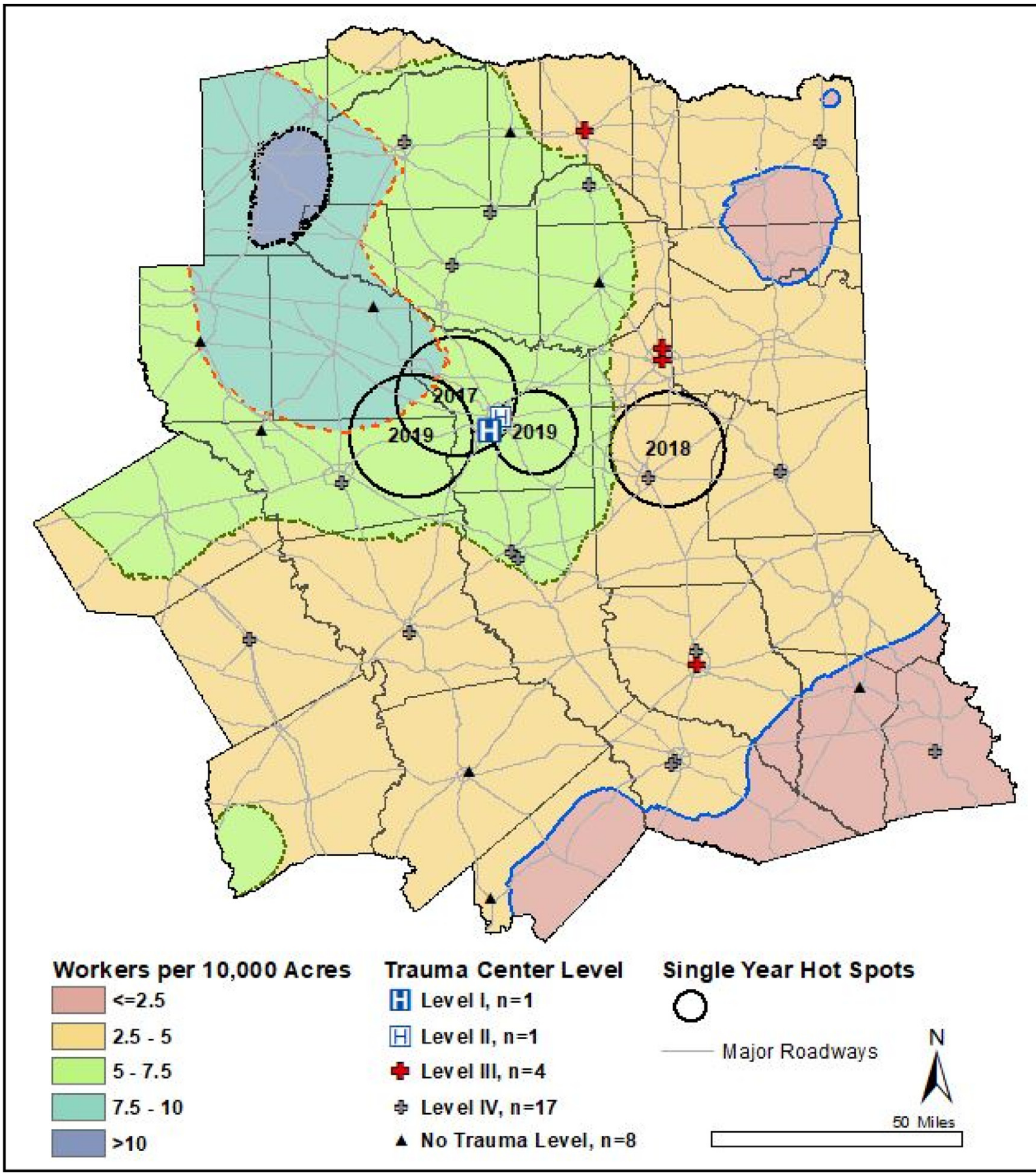


Fig. 3 — Workers per 10,000 acres, trauma centers, and hot spots for 2017, 2018, and 2019.

patients were 60 years and older, including 27 patients aged 75 years or older (9.9%). As per the USDA 2017 Census of Agriculture for Texas, 24.1% of ranchers and farmers were 65-74 years old and 13.8% were 75 years and older.[29] Gelberg *et al.* compared agricultural injuries between young (18-59 years old) and elderly (age greater than 59 years) in New York and Kentucky. They found elderly farmworkers sustained more severe injuries and more fatal injuries than the younger group.[36] Voaklander *et al.* reviewed the available literature and found medication use and chronic disease conditions such as arthritis and hearing problems as risk factors for agricultural injuries.[37] They posited that these factors may contribute to the increased risk of such trauma among older farmers.[37] In the present study, there was no difference in injury severity when patients aged 65 years and older were compared with the younger members of the cohort (data not shown). We did find a mixed association of the proportion of population aged 65 years and older and the outcome illustrating the complex relationship between the age profile of the population and the rate of agricultural trauma.

The severity of injury in this cohort spanned the range of the ISS, 1 to 75, although most patients sustained injuries of only modest severity with a median ISS of six. Other investigators of agricultural trauma have observed similar results. For example, in a report by Nogalski *et al.*, 95.7% of their cohort of farmers treated in a single facility in Poland had an ISS less than 9 and 77.6% had less than 3.[38] Similarly, an article published by Murphy *et al.* included 47 patients treated at a

Table 3 – The MGWR model for traumas per 1000 farmworkers in 219 Zip Code Tabulation Areas.

Parameters	$P < 0.05$, n (%)*	β-min†	β-max†	β-mean†
Farmworkers per ZCTA	145 (66.5)	0.002	0.007	0.004
ZCTA population density	62 (28.4)	−126.33	−10.57	−64.20
Proportion living in poverty	50 (22.9)	−0.10	0.06	−0.03
Proportion rural population	166 (76.1)	−6.62	−0.97	−3.04
Proportion aged 65 years and older	66 (30.3)	−0.12	0.12	0.03
Proportion white race	97 (44.5)	0.01	0.07	0.04
Proportion Hispanic/Latino ethnicity	75 (34.4)	−0.07	0.07	0.01
Number of operations per ZCTA	50 (22.9)	−0.03	0.02	−0.02
Livestock operations per ZCTA	43 (19.7)	−0.04	0.04	0.01

MGWR: R^2 (overall) 0.59.
* Percent of all ZCTA.
† In all ZCTA where the parameter's $P < 0.05$.

single institution for cattle-related injuries in Ireland with a mean ISS of 6.9.[39] Damroth *et al*. analyzed data from the National Trauma Data Bank and identified 5631 patients injured in farming activities, 42% of whom had ISS values less than 9. Of note, in these studies, animal-related mechanisms of injury represented all or most of the patients under study. In contrast, Shaver *et al*. analyzed data from the Idaho Trauma Registry with 44% of the cohort injured by machinery, ATVs, or tractors with a mean ISS of 13.[31] As such, the findings of the present study are concordant with those from other investigators in diverse settings, showing animal-related mechanisms of injury tend to produce less severe injuries than machinery and vehicles.

The mechanisms associated with the trauma events leading to trauma center treatment in the present study differed in many respects from published literature. Goldcamp studied data from the 2001 and 2004 Occupational Injury Surveillance of Production Agriculture Surveys and showed animal-related injury incidents and falls accounted for 16% and 25%, respectively, of all injuries in 2004.[40] In our study, 52% of traumas were animal-related and falls accounted for another 13.9%. The proportion of animal-related trauma events may be a reflection of the proportion of Texas agricultural commodities accounted for by cattle production, approximately 50%.[41] An important difference between the present study and that by Goldcamp is the method by which the data were obtained. Their study was a survey and defined injury events as having resulted in restricted work activity or caused the individual to seek medical care,[40] whereas the data for the present study are from the NTRTR. As such, the cohort in the present study required trauma center treatment, which was not required for the survey.

Nonspatial analyses of the data demonstrated that the ZCTA where traumatic injury events took place had, on average, fewer but larger farm operations producing higher agriculture product sales with more total workers and higher median worker counts per farm acre. These findings are consistent with those of other investigators. A meta-analysis of 38 studies by Jadhav *et al*. revealed increased farm size, livestock production, higher gross sales, and more workers on the farm were associated with higher odds of injury.[42] In an analysis of survey data by Browning *et al*., the size of the cattle heard was found to increase the odds of injury on cattle farms in Kentucky.[43] Although the sizes of cattle herds and crop operations are not available in our data, the sales of crops and livestock were greater in the ZCTA where injury events took place. In the multivariable MGWR model, total sales of neither crops nor livestock were significant predictors. However, numbers of all agricultural operations and the numbers of livestock operations per ZCTA were significant in the model, although the associations were mixed in terms of positive and negative effects regarding the outcome.

In the MGWR model, the proportion of the rural population was negatively associated with events per 1000 farmworkers and was significant in the greatest number of ZCTA in the area. Population density also had a negative association with the outcome and the largest effect size of the predictors in the model. Thus, areas with lower population density, lower rurality, or greater urbanity are associated with a greater likelihood of agricultural trauma events. These two characteristics, rurality and urbanity, may seem contradictory; however, large lot development defined as one or more acres per house, in rural areas, is one of two pathways of land development in the United States.[44] Harland *et al*. observed that agricultural equipment crashes in urban [ZCTA] represented 30% of all farm equipment crashes in nine Midwestern states.[45] As such, the encroachment of land development into less populated rural areas may increase the risk of injury events and warrants further study.

The hot spot analysis revealed areas where injury prevention resources might be applied to greatest effect. Interventions aimed at improving safety in the agricultural setting exist for farming machinery and tractor-related hazards, as well as the hazards associated with animal handling. These include retrofitted roll-over protective structures for tractors manufactured before 1985, when such structures became standard equipment. Several states have successfully implemented rebate programs in an attempt to mitigate rollover hazards.[46] On the job, task-related training by coworkers has been shown to be protective from injuries from livestock handling and machinery.[47] As most of the events in the hot spots were animal related, initiatives toward educating animal handlers may prove beneficial.

The inferences presented in this study must be considered in light of certain limitations. First, the injury incidence rates we report differ by an order of magnitude less than the rate published by the USBLS. The factors likely contributing to this difference include the case definition of injury, in that the USBLS defines serious injury as involving days away from work, job transfer, or restriction. The USBLS cases also included illnesses caused by insecticide exposure,[1] whereas the data we analyzed originated at the point of contact with tertiary care trauma centers and do not include minor injuries not evaluated in an ED nor deaths at the scene of injury. Next, this study is not population-based, and the geospatial aspect of the analysis may limit its generalizability of the model predictors and coefficients beyond our region. Finally, because of the necessary modeling of the geospatial data to redistribute worker locations, there may be impacts from the modifiable areal unit problem. The modifiable areal unit problem describes the circumstance where changing the level of data aggregation may result in different spatial patterns of the phenomena of interest.[48] The strengths of the study include the combining of registry-based clinical data and geospatial features of the places where the injuries occurred. This may be the first such study of agricultural injuries and has implications for future targeted prevention strategies.

Conclusion

Trauma registry data can provide valuable information for the surveillance of agricultural injuries in Northeast Texas, particularly when combined with geospatial analysis. Based on these results, injury prevention initiatives should address risks associated with livestock and farm machinery and focus on the hot spots identified. Continued monitoring for agricultural injury hot spots can allow for refinement and validation of surveillance methods.

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Authors' Contributions

A.C. contributed to literature search, study design, data analysis, data interpretation, writing, and manuscript revision. R.F. contributed to study design, data analysis, data interpretation, and writing. Y.D. contributed to study design, data interpretation, and writing. R.S. contributed to literature search, data analysis, data interpretation, writing, and manuscript revision. J.B. contributed to literature search, data interpretation, writing, and manuscript revision. C.W. contributed to literature search, data interpretation, writing, and manuscript revision. V.C. contributed to literature search, study design, data interpretation, and writing. M.C. contributed to study design, data interpretation, and writing. S.N. contributed to study design, data analysis, data interpretation, and writing.

Disclosure

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