Development of Agricultural Dust Emission Inventories for the Central States Regional Air Planning Association

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ABSTRACT

In support of the Central States Regional Air Planning Association's (CENRAP) need to develop a regional haze plan, Sonoma Technology, Inc. (STI) developed a 2002 emission inventory of particulate matter (PM) emissions from agricultural dust sources for the nine-state CENRAP region, which includes Texas, Oklahoma, Louisiana, Arkansas, Kansas, Missouri, Nebraska, Iowa, and Minnesota. Emissions from agricultural tilling operations were estimated by applying emission factors to county-specific activity data for tilling practices and county-specific silt contents. Activity data were gathered through surveys of agricultural extension offices and geographic information system (GIS) databases of soil characteristics were used to prepare county-specific soil silt contents. Emissions from confined animal feeding operations (CAFOs) were estimated by applying the best available emission factors to facility-specific animal population data recorded in the National Pollutant Discharge Elimination System (NPDES) permit files of each CENRAP state. Total $PM_{2.5}$ emissions from agricultural dust in the CENRAP region were estimated to be 295,000 tons per year, a figure that is approximately 20% lower than the estimates included in the 2002 preliminary National Emission Inventory (NEI). In addition, the spatial distributions of emissions differed significantly from those included in the 2002 preliminary NEI.

INTRODUCTION

The Central States Regional Air Planning Association (CENRAP) is developing a regional haze plan in response to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas. To develop an effective regional haze plan, the CENRAP ultimately must develop a conceptual model of the phenomena that lead to episodes of low visibility in the CENRAP region. Thus, the CENRAP is researching visibility-related issues for its region, which includes Texas, Oklahoma, Louisiana, Arkansas, Kansas, Missouri, Nebraska, Iowa, and Minnesota. Both primary particulate matter (which is emitted directly to the atmosphere in particulate form) and the formation of secondary particulate matter (which is generated from chemical transformations in the atmosphere of gaseous precursor species such as ammonia, nitrogen oxides, sulfur oxides, and volatile organic compounds) contribute to regional haze in the CENRAP region. In recognition of these issues, the CENRAP sponsored the development of improved emission inventories for sources of agricultural dust. Agricultural operations, such as crop tilling, crop harvesting, or confined animal feeding operations (CAFOs), release emissions of geologic fugitive dust. This paper describes the information sources and methods STI used to calculate county-level emissions of agricultural fugitive dust for the CENRAP region for calendar year 2002 on the basis of bottom-up data and the best available emission factors and guidance.

Agricultural tilling and CAFO's were prioritized because they have previously been considered important in other inventories. According to the 1999 NEI and the Western Regional Air Partnership (WRAP) 2002 agricultural particulate matter (PM) emissions inventory agricultural tilling and CAFOs were the largest contributors to agricultural fugitive dust, encompassing more than 90% of the PM emissions from agricultural sources (E.H. Pechan and Associates, 2004). Other sources contributing to the agricultural PM emissions included cotton ginning, cropping burning, and crop transport, however these sources are minuscule in comparison to the combined affect of agricultural tilling and CAFOs. Therefore, agricultural tilling and CAFOs were selected for bottom-up treatment. Emissions of PM_{10} and $PM_{2.5}$ for these source categories were estimated by acquiring bottom-up activity data and applying emission factors from EPA guidance or other literature. Activity data for agricultural tilling operations were gathered through a survey of county agricultural extension offices (Reid et al., 2004a). CAFO locations and livestock populations were gathered from a variety of national, state, and local departments and agencies.

TECHNICAL APPROACH

Agricultural Tilling Operations

EPA's guidance for estimating PM emissions from agricultural crop tilling involves combining a constant emission factor with county-level activity data, including the silt content of surface soils, the number of tillings performed in a year for each crop type, and the acres of each crop type (U.S. Environmental Protection Agency, 2001, 2004b). For conservational tillage practices, such as no till, mulch-till, and ridge-till, the number of tillings performed per year is reduced proportionally according to information provided by the Conservation Information Technology Center (CTIC) (U.S. Environmental Protection Agency, 2004b; Conservation Technology Information Center, 2004). Emissions from agricultural crop tilling are calculated according to the equation below.

$$E = c \times k \times s^{0.6} \times p \times a$$

E represents the PM emissions in units of pounds per year, and *c* equals the constant emission factor of 4.8 lbs/acre-tilling. A dimensionless particle size multiplier, *k*, is applied to calculate either PM_{10} (k=0.21) or $PM_{2.5}$ (k=0.042). The silt content of the soil, *s*, is defined as the mass fraction of particles smaller than 0.75 µm diameter found in soil to a depth of 10 cm, expressed as a percent. The other activity data include *p*, which represents the number of tillings or passes that are performed in a year for each crop type, and *a*, which represents the acres of land tilled for each crop type. In summary, the methodology requires the following activity data, at county level:

- Acres of land planted by crop type.
- Tillings per year by crop.
- Conservational tilling practice type.
- Silt content of soils.

County-level acreages of grown crops were prepared previously on the basis of 2002 US Department of Agriculture National Agricultural Statistics Service (NASS) data (Reid et al., 2004a). The EPA's Emissions Inventory Improvement Program suggests that local data for the number of tillings per year for each crop type and the temporal distribution of tilling activities are desirable (U.S. Environmental Protection Agency, 2004b). A survey of tilling practices was conducted by contacting county agricultural extension offices throughout the CENRAP region (Reid et al., 2004a). Questionnaires were designed to elicit information about the tilling practices for each crop type grown in each respondent's county. The survey results were analyzed and extrapolated for each of the CENRAP states to estimate the number of tillings per year by crop type, the temporal distributions of temporal tilling activities, and the rate of occurance of conservational tilling practices.

The EPA National Air Pollutant Emission Trends Procedures Document provides a cross-reference table with silt contents for various soil types (U.S. Environmental Protection Agency, 1998). The State Soil Survey Geographic Database (STATSGO) produced by the Natural Resources

Conservation Service of the United States Department of Agriculture was used to determine soil types at the county level (National Resources Conservation Service, 1994). County-level silt contents were determined by using the EPA Procedures Document to cross-reference silt contents with STATSGO soil types.

Livestock Operations

EPA guidance specifies an emission factor equal to 17 tons of PM_{10} per thousand head of feeding cattle per year (or 93 lbs PM_{10} per thousand head per day), and an assumption that 15% of PM_{10} is emitted as $PM_{2.5}$ (U.S. Environmental Protection Agency, 2004a). However, our literature review indicated that the EPA's guidance results in greatly overestimated emission inventories (Flocchini and James, 2001; Goodrich et al., 2002). Two recent studies performed by the University of California at Davis and Texas A&M University yielded emission factors of 28.9 lbs PM_{10} per thousand head per day (Flocchini and James, 2001) and 19 lbs PM_{10} per thousand head per day (Goodrich et al., 2002) for beef cattle at feedlots. The midpoint—24 lbs PM_{10} per thousand head per day—was selected by STI and used to estimate emissions of PM_{10} for beef cattle feedlots in the CENRAP region for this study. In addition, STI selected an emission factor of 4.4 lbs PM_{10} per thousand head per day was selected for use in estimating emissions for dairies. This emission factor was based on sampling conducted at a single central Texas dairy during the summer of 2002 (Goodrich et al., 2002), and is therefore highly uncertain. However, it was the best available emission rate that could be identified at the time of this study.

Facility-specific population estimates for beef cattle feedlots and dairies were prepared by using NASS population data and National Pollutant Discharge Elimination System (NPDES) records (Coe and Reid, 2003). Each January and July, NASS surveys a sample group of livestock producers, which are statistically representative of all livestock operations in each state. These surveys are used to produce estimated livestock populations by county. However, the NASS data do not contain any information on CAFO locations . Feedlots service thousands of animals in fairly confined spaces, such that emissions from these facilities are better treated as point sources. To address this limitation, agricultural and environmental agencies or departments in each state were contacted to request information about CAFO locations. In addition, each state was contacted to acquire facility-specific data from the NPDES. Facility-specific livestock populations were subtracted from county-wide populations and allocated to specific CAFO locations.

No information was identified that could be used to develop temporal patterns for this source category. However, emissions are likely to vary with seasonal and diurnal changes in climate conditions and animal husbandry practices.

RESULTS

Agricultural Tilling Operations

Total PM_{10} emissions from agricultural tilling operations in the CENRAP region are estimated at over 1.3 million tons per year, with $PM_{2.5}$ emissions contributing about 270,000 tons to this total (see Figure 1). High $PM_{2.5}$ emissions are being generated in Iowa, Kansas and Minnesota. Multiple crop types (i.e. corn, wheat, rice and soybeans) dominate a large land area within these states, causing increased tillings per year and $PM_{2.5}$ emissions. A geographic distribution of county-level $PM_{2.5}$ emissions appears in Figure 2. Temporal variations in $PM_{2.5}$ emissions by month, day-of-week, and hour-of-day appear in Figures 3 through 5.

Figure 1. Particulate matter emissions from agricultural tilling operations by state.

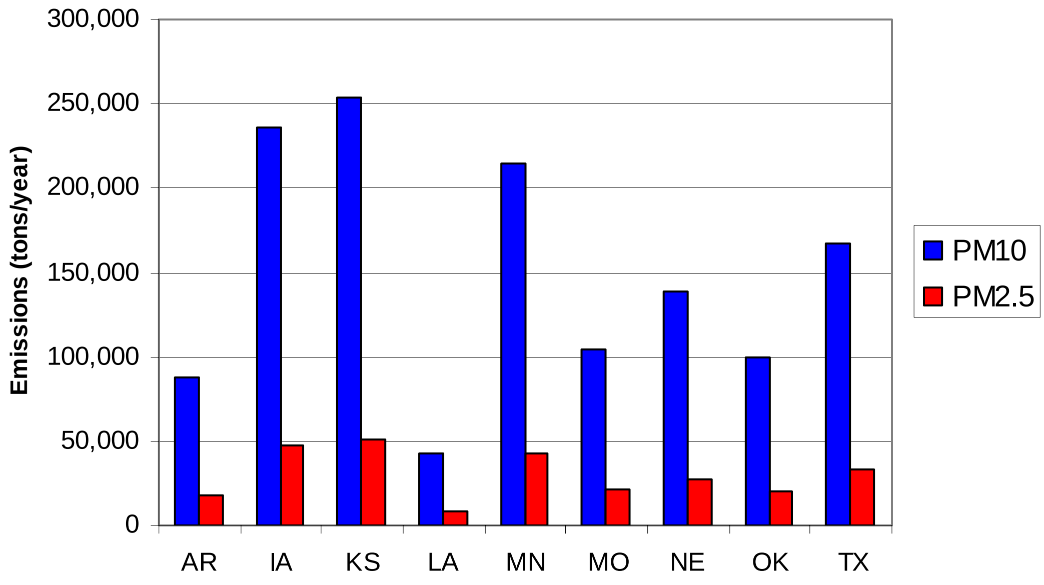


Figure 2. County-level $PM_{2.5}$ emission estimates for agricultural tilling operations.

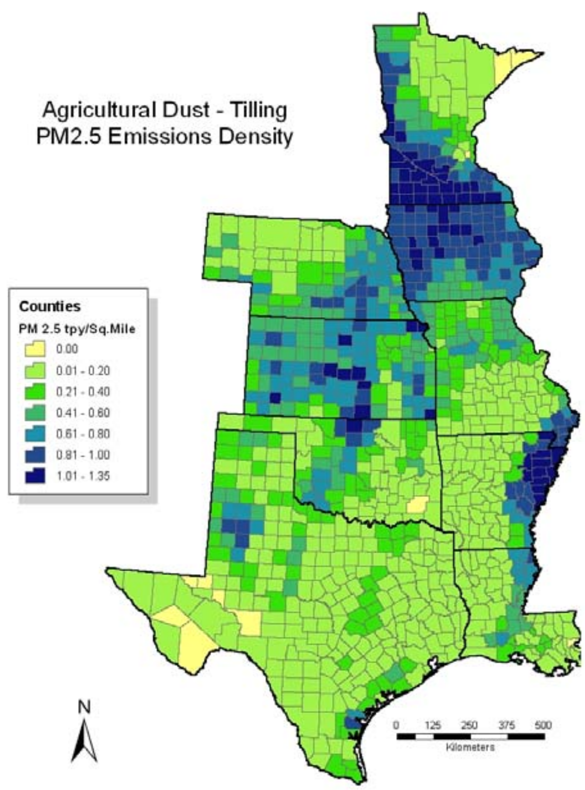


Figure 3. Monthly variability in agricultural tilling emissions by state.

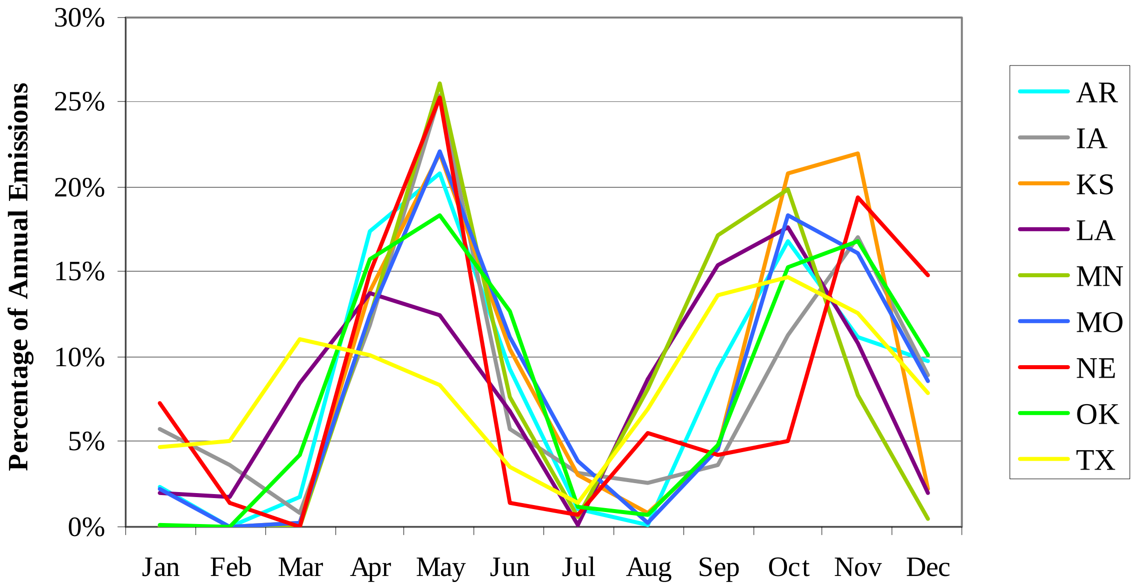


Figure 4. Day-of-week variability in agricultural tilling emissions by state.

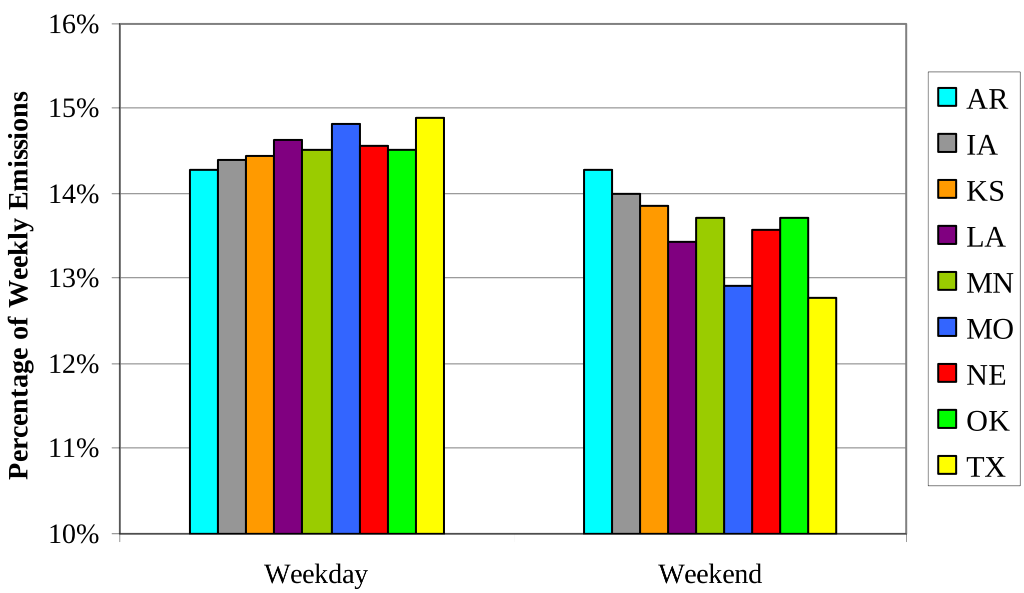
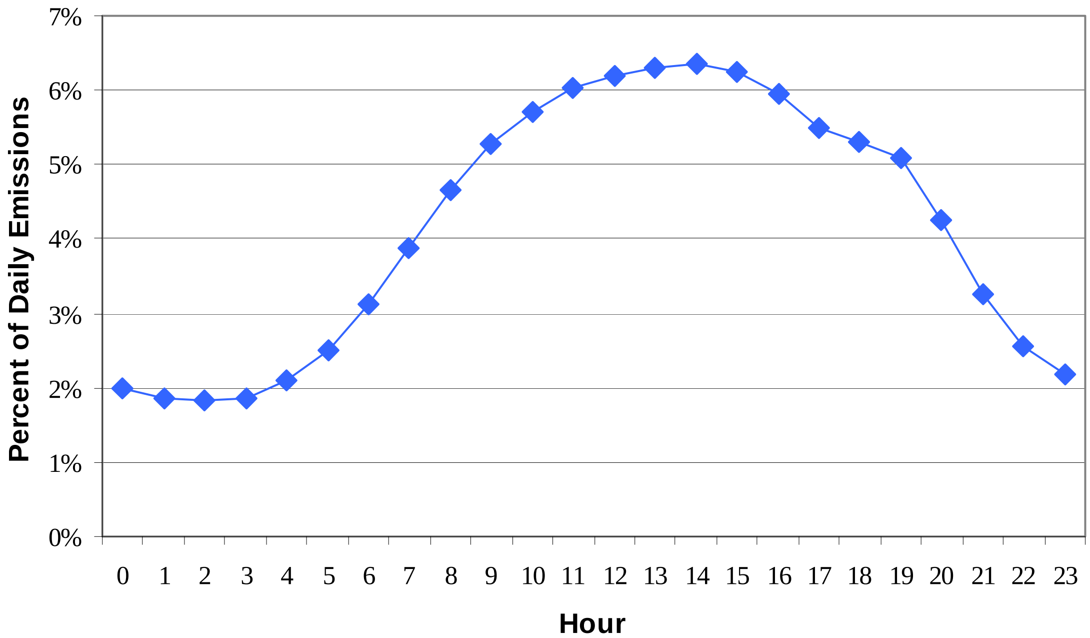
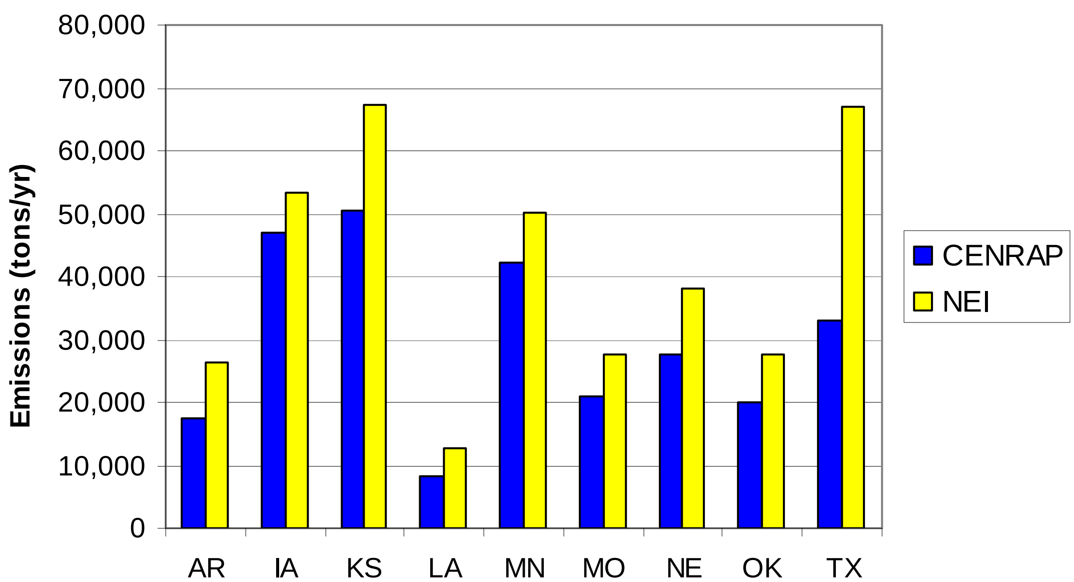


Figure 5. Diurnal variability in agricultural tilling emissions (same for all states).



The use of locally representative activity information in the development of emission inventories for agricultural tilling operations permitted a significant improvement over the inventory compiled for the preliminary 2002 NEI. The most significant sources of improvements included county-level soil silt contents and locally reported tilling practices (reported as the number of tilling passes completed for each crop type). Emission estimates in the CENRAP 2002 inventory are generally 25% to 30% lower than corresponding estimates from the preliminary 2002 NEI, although the discrepancy varies from state-to-state (see Figure 6). These differences seem primarily due to the incorporation of local information on tilling practices because the reported number of tilling passes by crop type was often less than indicated by EPA guidance. A likely explanation is that conservational tilling practices have become more prevalent in recent years, particularly in Texas, where the most dramatic differences between the preliminary 2002 NEI and the CENRAP inventory are apparent.

Figure 6. State-by-state comparison of $PM_{2.5}$ emissions from agricultural tilling operations.



Livestock Operations

Total PM_{10} emissions from livestock operations in the CENRAP region were estimated to be 51,000 tons per year, with $PM_{2.5}$ emissions contributing about 7,700 tons to this total (Figure 7). A geographic distribution of county-level PM_{10} emissions appears in Figure 8. As shown in Figure 7, Kansas and Texas beef cattle feedlots and dairies produce the highest amount of PM_{10} emissions in the CENRAP region. These high emissions are due to high population CAFO facilities located in Northern Texas and Western Kansas, which is depicted in the county-level PM_{10} emission estimates maps in Figure 8 and the facility locations map in Figure 9. Another important artifact from the county-level PM_{10} emission estimates maps is the discontinuity of county level emissions estimates across state borders, in particular Missouri. Based on the local CAFO data collected from the sources listed above, Missouri is home to over 520 CAFOs, however the majority of populations in these facilities consist of pigs/hogs and turkeys and emission factors were only available for beef cattle feed lots and dairies.

Figure 7. PM_{10} emissions from livestock operations by state and facility type.

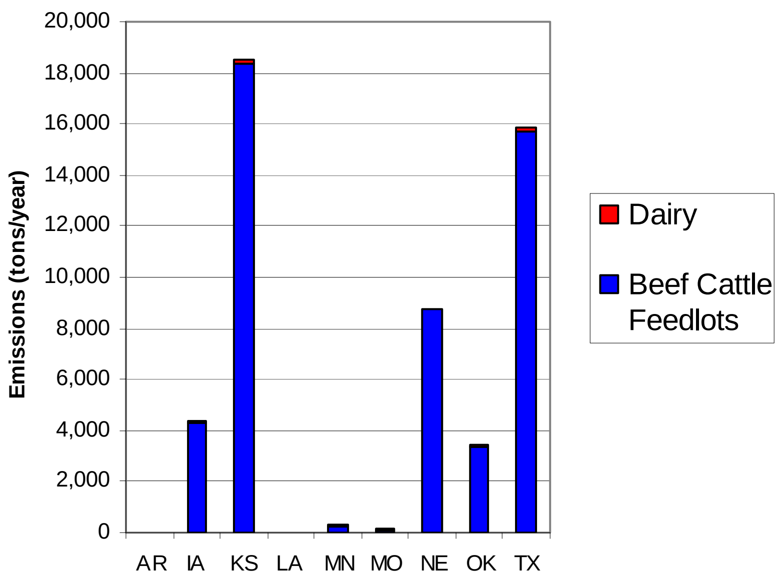
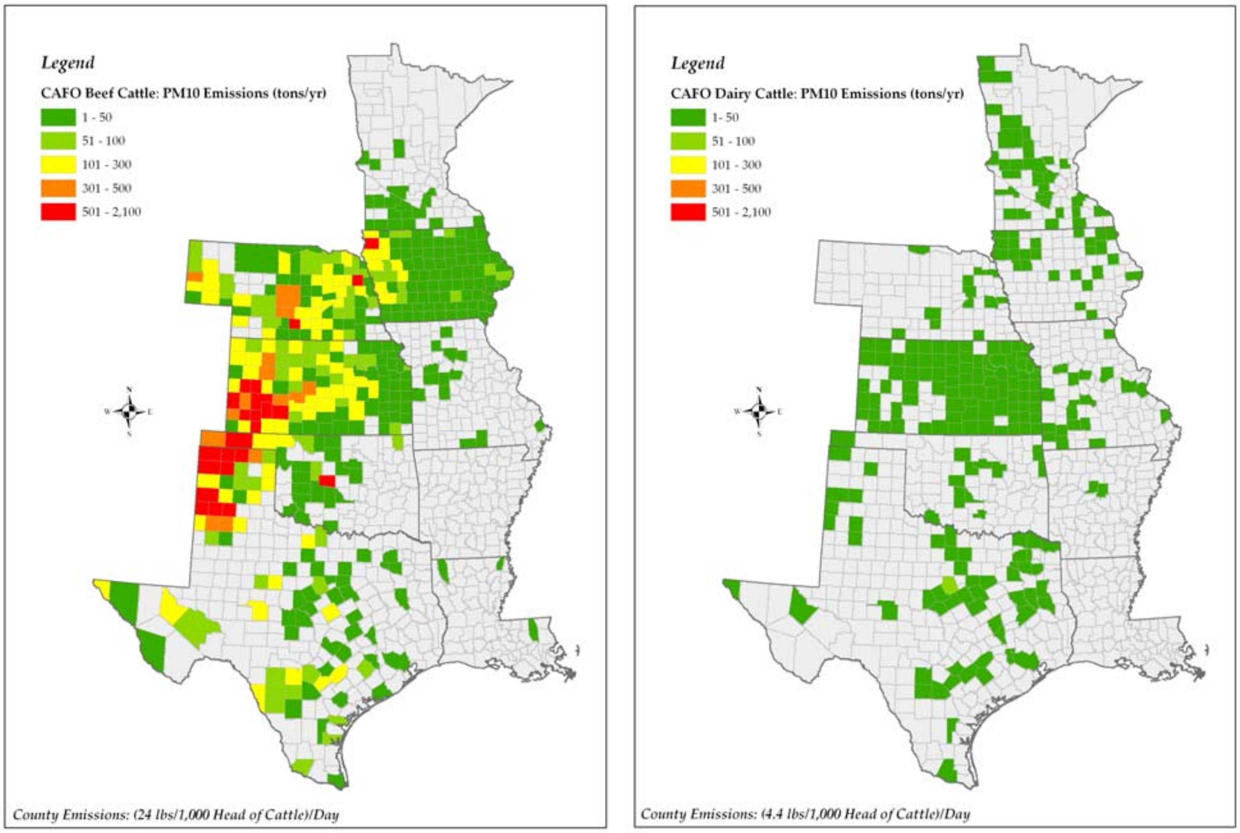


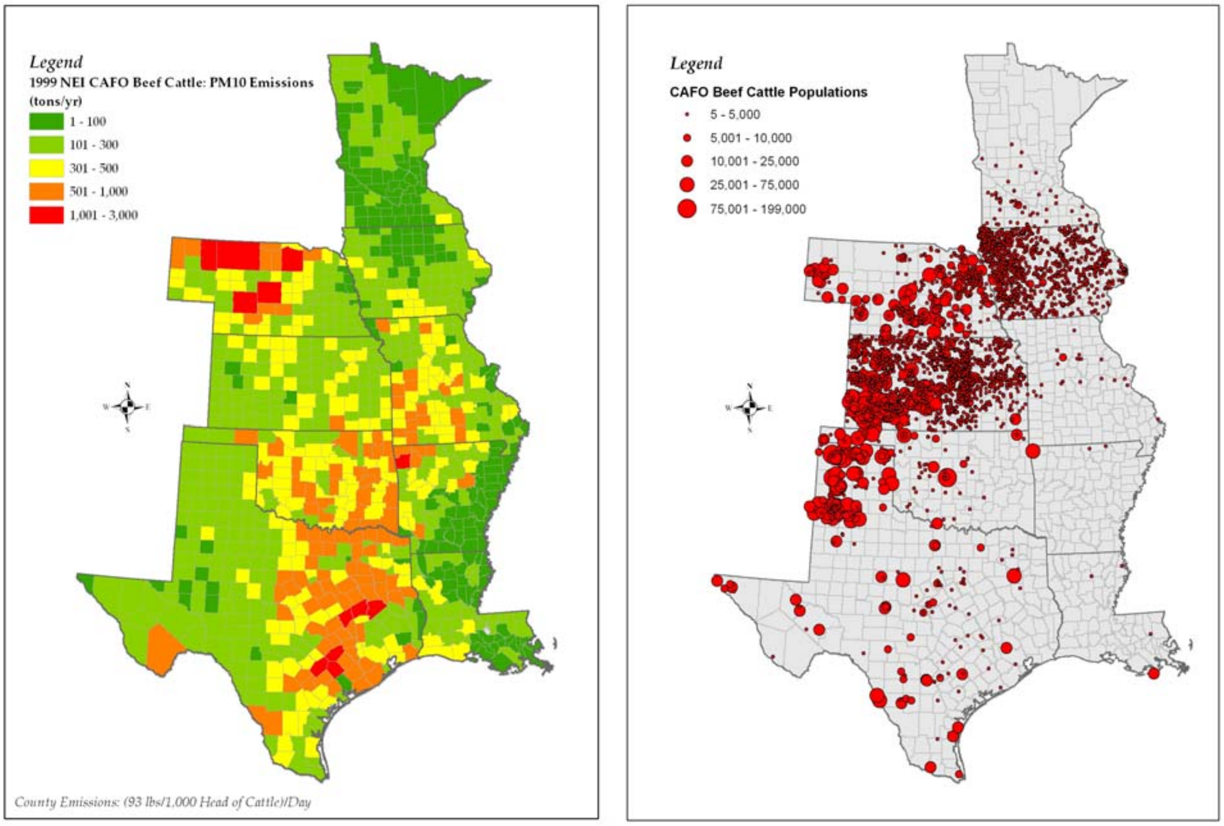
Figure 8. County-level PM_{10} emission estimates for beef cattle feedlots (left) and dairies (right).



The methods STI used to develop emission inventories for livestock operations represent a significant improvement over existing inventories, both in terms of the total annual emissions calculated and the geographic distribution of those emissions. The 1999 NEI included an estimated 270,000 tons per year of PM_{10} emissions from CAFOs in the CENRAP region—a figure more than five times higher than that estimated for the CENRAP inventory. A literature search indicated that the emission factor of 17 tons per 1000 animals per year, which was used during development of the 1999 NEI, was too high for this source category. Ultimately, an emission factor of 4.4 tons per 1000 animals per year was selected for beef cattle and an emission factor of 0.8 tons per 1000 animals per year was used for dairy cows.

In addition, the use of facility coordinates greatly enhanced the spatial distribution of emissions. For the 1999 NEI, an assumption was used that the number of cattle housed at CAFOs is approximately 10% of the total number of beef cattle in each county, regardless of feedlot locations or local animal husbandry practices. As a result, emissions were assigned to many counties in which no feedlots operate, as illustrated by Figure 9, which contrasts the geographic distribution of emissions in the 1999 NEI with known feedlot locations and populations. Side-by-side comparison of these figures shows that the 1999 NEI registers high emissions densities in eastern Texas, Oklahoma, western Missouri, and northwestern Nebraska—areas where very few CAFOs exist. In reality, most CAFOs in the CENRAP region accumulate in a band that reaches from the Texas panhandle, across Kansas and southeastern Nebraska, and across the state of Iowa.

Figure 9. NEI county-level PM_{10} emissions for beef cattle feedlots vs. actual beef cattle feedlot locations and populations.



CONCLUSIONS

The emission inventories prepared by STI for agricultural tilling and confined animal feeding operations in the nine-state CENRAP region represent significant improvements over existing inventories due to the use of local activity data gathered through surveys and other methods. Emission estimates from the CENRAP agricultural tilling inventory are generally about 25% to 30% lower than corresponding estimates from the preliminary 2002 NEI. These reductions seem primarily due to the incorporation of local information on tilling practices because the reported number of tilling passes for each crop type was often less than indicated by EPA guidance. The methods used to develop emission inventories for livestock operations represent a significant improvement over existing inventories, both in terms of the total annual emissions calculated and the geographic distribution of those emissions. PM_{10} emission estimates from the CENRAP beef and dairy CAFO inventory was one-fifth of the estimated for the 1999 NEI inventory.

RECOMMINDATIONS FOR FURTHER RESEARCH

The limited body of research into emission factors and emission processes represents the most significant weakness in the agricultural fugitive dust emission inventories. Investment in the development of emissions measurement programs and process-based approaches that account for soil moisture, meteorological conditions, and agricultural practices would produce substantial improvements in the accuracy and certainty of fugitive dust emission inventories. They would also allow development of seasonal and diurnal patterns.

A survey of agricultural extension offices and the use of bottom-up animal population data produced significantly altered spatial allocations and emissions estimates for sources of agricultural fugitive dust. State-level emissions estimates were revised by 25% to 50% and CAFO emissions were displaced to entirely different geographic areas of the CENRAP. Further modest improvements could be made by gathering bottom-up activity data for the next-largest sources of agricultural fugitive dust, including cotton ginning operations and/or crop transport. However, emissions from these types of sources are likely to be dwarfed by emissions from agricultural tilling dust and are likely to be of significance in only a few areas of the CENRAP where cotton ginning occurs.

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KEY WORDS

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Nebraska
Oklahoma
Texas