# Farming in the Lone Star State: Agricultural Equipment Survey for Texas

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**ABSTRACT**

The Texas Commission on Environmental Quality (TCEQ) recognizes nonroad sources as potentially important contributors to Texas air quality concerns, and is considering emission reduction strategies for these sources. Preparing both temporally and spatially representative nonroad sector inventories will support TCEQ analyses to accurately characterize the emission reductions needed to achieve and maintain compliance with air quality standards. One of TCEQ's goals is to improve current criteria pollutant emission estimates from agricultural equipment such as tractors, combines, mowers, and sprayers. Under contract to the TCEQ, E.H. Pechan & Associates, Inc. (Pechan) and its subcontractor (Ewald & Wasserman Research Consultants, LLC) conducted a telephone survey of agricultural equipment owners in Texas. The collected data will be used to refine equipment populations, annual hours of use, and seasonal, weekly and diurnal activity profiles for these equipment types. These activity inputs will replace the default data in the Texas NONROAD model (TexN) for preparing base year and select forecast year inventories.

For the first phase of this project, we requested the necessary data from agricultural equipment owners in Texas through a telephone survey conducted during July/August of 2008. The second phase of the project involves statistical analysis of the survey data and development of updated model inputs. This paper describes the survey effort, and a preliminary analysis of the resulting data, including comparisons with model default values. The paper concludes with a discussion of insights that may assist other researchers in developing agricultural equipment emission inventories.

## APPROACH

Sampling design and stratification was developed based on an analysis of fuel data by farming sector available from the U.S. Census of Agriculture. As summarized in Table 1, State-level agricultural gasoline, fuels, and oil expenditure and tractor population data for Texas were compiled from the U.S. Department of Agriculture (USDA)'s *2002 Census of Agriculture*. These data indicate that more than one-third of Texas expenditures on agricultural sector fuels/oils, and over one half of total agricultural tractor populations are in North American Industrial Classification System (NAICS) code 112111 − Beef Cattle Ranching and Farming. Other major contributing sectors to total agricultural sector fuel/oil expenditures are the crop farming NAICS codes 1111, 11192-11194, and 11199, defined in Table 1. Because there are a number of different crops associated with NAICS codes 1111 and 11193, 11194, and 11199, Pechan also developed estimates of the volume of diesel and gasoline fuel consumption in Texas by individual crop. These estimates, which were computed by multiplying USDA 2005 estimates of the planted acreage by crop type in Texas by diesel/gasoline fuel consumption estimates per planted acre by crop type, are displayed in Table 2. This table indicates that cotton, forage, sorghum, wheat, and corn account for a large proportion of total crop production-related diesel/gasoline consumption in Texas.

Based on this analysis, the sampling plan initially included six quota cells, based on NAICS-code defined farming operations, and included: 1) cotton farming, 2) hay farming; 3) wheat farming; 4) beef cattle ranching; 5) all other farming activities including cattle feed lots; and 6) all support activities for agricultural operations. During survey implementation, it was established that few respondents in the sixth quota group identified themselves as a farming support entity. As such, support activities for agricultural operations were eliminated from the final sample frame.

A questionnaire was developed to ask for information concerning the types of agricultural equipment operated, and the operating schedules of the equipment. In general, the survey requested the following information:

1) Farm production acreage (and head of cattle for beef farmers)
2) County location
3) Equipment type/fuel type
4) Equipment count
5) Volume of fuel used
6) Annual hours of use and percentage of use by season
7) Weekday versus weekend day use
8) Hourly (i.e., diurnal) use

The list of equipment types included in the study, along with a description, is provided in Table 3. These equipment types are consistent with EPA's NONROAD and TCEQ's TexN models, which is important since the survey-based data may replace equipment-specific defaults in TexN. NONROAD reports emission estimates for diesel and gasoline-fueled engines for all of these equipment types, and provides estimates for compressed natural gas (CNG) and liquefied petroleum gas (LPG) engines for select equipment. CNG and LPG fueled engines are typically used in a limited number of farming applications, including irrigation sets.

Altogether, 2,309 farming operation surveys were completed with a total of 1,576 unique respondents. If a respondent engaged in multiple farming operations, as was the case in almost

50 percent of the completed interviews, the telephone survey system randomly selected up to two farming operations for the actual telephone survey. Table 4 shows the distribution of completed surveys among the five quota groups, as well as the statistical representativeness of the respective quota data. It should be noted that the initial sample frame calculations were based on quota groups as defined by farm NAICS classification by Dun & Bradstreet. During the course of data collection it became apparent that the quota definition based on the initial sample frame had very little correlation to the responses of survey participants regarding their farming operations. Therefore, the sample frame and number of completed surveys needed for each farming quota was recalculated to reflect the number of farming operations based on Census of Agriculture data, presumed to be a more accurate reflection of number of farming operations, rather than the Dun & Bradstreet counts of farming records.

The target number of completed surveys represents the number of surveys needed to achieve a pre-established precision level. The confidence interval at a confidence level of 95 percent ranges from 3.48 to 6.73 among the five quota groups. The smaller the confidence interval, the more precise the data. Note that the data collected for the hay farming and beef cattle farming respondents exceeded our targeted confidence interval of 5 percent.

## RESULTS

Questions concerning hourly and weekday/weekend day operations were asked in relation to the operation of all equipment used by the respondent, and not specific to a certain equipment type. Questions on annual and seasonal usage, and number of pieces of equipment, and fuel-type distributions were asked for each of 10 types of equipment owned (operated) by the respondent. For all temporal activity variables, responses were weighted by two factors. First, the values were weighted by the number of pieces of equipment for which respondents provided information (i.e., equipment counts per respondent as a fraction of total equipment for all respondents). This step generated a weighted average per equipment type per quota group. Second, the values were weighted by the fraction of the surveyed respondents quota-specific farming activity (e.g., acres of cotton harvested) to the State-level total activity data for their quota group. This second step produces a weighted average for each equipment type across all quota groups.

Discussions of the preliminary results for weekly and hourly temporal profiles, as well as annual and seasonal use are presented in the following sections. For these variables, final survey results are compared to existing default data, either from EPA modeling protocols or NONROAD2005 model defaults. Note that TexN and NONROAD model default data are equivalent for the inputs addressed in this paper. In addition, procedures for estimating equipment populations and fuel consumption from the survey data are discussed.

### Weekly and Hourly Temporal Profiles

The survey requested information on the operation of equipment during eight 3-hour time periods during a typical day. Percentage of farm operations occurring during each time period were weighted by the associated number of equipment owned by the respondent, to give more weight to those respondents operating more pieces of equipment. The typical diurnal profile developed from the survey results is shown in Figure 1, and compared to EPA's diurnal profile for diesel agricultural equipment, as listed in EPA's Emission Modeling Clearinghouse.[1] EPA's default profile reflects variations within each 3-hour period, but were aggregated for the same time periods as the survey. Note that for the 24-hour period, the survey data shows higher relative activity from 6AM to 6PM, and considerably less from 6PM to 6AM. EPA's default hourly profile shows comparatively higher levels of activity than the survey data starting at 6PM and through the night up to 6AM. Although NONROAD and TexN models do not have the ability to calculate hourly emissions, TCEQ may use the survey-based diurnal profile for their own modeling efforts.

The survey also asked for respondents to provide the percent of weekly use occurring on a weekday versus a weekend day. Based on these percentages, it was estimated that operators were 1.4 times as likely to operate equipment on an average weekday than an average weekend day. Table 5 shows the default NONROAD model weekly profile, which assumes that agricultural equipment is 2 times as likely to be operated during an average weekday than an average weekend day.[2] It should be noted that the weekly inputs for NONROAD are not based on survey data, but were developed based on EPA's assessment of typical usage patterns and comparability with California Air Resources Board (ARB's) use profiles in their OFFROAD model.

## Annual Hours of Use and Seasonal Activity

Survey respondents were asked to provide estimates of the hours of operation per week and the weeks of operation per year for each specific equipment type. We then estimated annual hours of use by multiplying hours of operation per week by weeks of operation per year. Figure 2 shows a comparison of the annual use values derived from the survey and those included in NONROAD/TexN for diesel equipment types.[3] Table 6 provides a tabular comparison of the annual use values for both diesel and gasoline equipment reported by the survey. In addition, the count of equipment forming the basis of use values is listed in the last column of Table 6. The average use values for diesel equipment were based on responses for at least 200 pieces of equipment (for irrigation sets) and up to over 4,000 pieces (for agricultural tractors). With the exception of agricultural mowers, preliminary hours per year estimates are much higher than NONROAD default values. This could be due to regional differences, e.g., equipment in Texas is operated more than the national average due to climatic and farming activity differences. Alternatively, it is possible that forthcoming estimates of Texas equipment populations will be lower than NONROAD defaults, offsetting the higher use profile indicated by the survey. Given these significant differences, we plan to further evaluate these results to determine if the data are sufficiently robust to replace defaults.

Based on responses to questions concerning operation during the four seasons of the year, we estimated the average seasonal percentages for each equipment type. The NONROAD model includes a single seasonal allocation for all agricultural equipment, regardless of engine or application.[4] For comparison, the Texas survey data were evaluated across all equipment types. A comparison of the survey-based and NONROAD/TexN profiles is shown in Figure 3. The survey data shows more activity than NONROAD during the winter and summer seasons, but significantly less activity during the fall. Because the seasonal data were collected by equipment type, we also plan to analyze the data to identify potential use profiles for individual equipment types.

## Equipment Populations and Fuel Consumption

To estimate equipment populations for the entire region, scaling factors will be developed by quota group and equipment type, i.e., source classification code (SCC). These factors will be calculated by:

1) Adding up the number of pieces of equipment and the acres harvested for each equipment type within each quota group.

2) Calculating the scaling factor by dividing the number of pieces of owned equipment by the number of acres harvested. An example calculation for agricultural tractors used in cotton farming in Carson County follows as an example.

Equation (1) $SF = Eq_{SCC,\ Quota} \div Acres_{Quota}$

where

| | | |
|---|---|---|
| $SF_{SCC,\ QUOTA}$ | = | Scaling factor, for SCC/QUOTA combination |
| $Eq_{SCC,\ QUOTA}$ | = | Agricultural tractors for all surveyed cotton farmers; 679 |
| $Acres_{QUOTA}$ | = | Acres harvested by surveyed cotton farmers; 256,321 |

Resulting in:
Equation (2) $SF_{SCC,\ QUOTA} = 679 \div 256{,}321 = 0.002649$

3) County-level acres of cotton harvested for Texas (compiled from USDA) will then be multiplied by this scaling factor to yield an estimate of county, SCC-level populations:

Equation (3) $Eq_{SCC,\ CTY} = SF_{SCC,\ QUOTA} * Acres_{CTY}$

where

| | | |
|---|---|---|
| $Eq_{SCC,\ CTY}$ | = | County equipment count, by SCC |
| $SF_{SCC,\ QUOTA}$ | = | Scaling factor for agricultural tractors used in cotton farming; 0.002649 |
| $Acres_{CTY}$ | = | Total acres cotton harvested in county; 25,000 |

Resulting in:
Equation (4) $Eq_{SCC,CTY} = 0.002649 * 25{,}000 = 66$ agricultural tractors

To estimate total equipment in use, populations derived from scaling the surveyed equipment populations to counties for all five quota farming groups will be added together. We plan to review the survey responses to determine whether there are records which should be removed (because they are identified as outliers). For example, where respondents indicated that no equipment of a specific type was used, state agricultural experts will be contacted to establish if this makes logical sense for the given crop type. In cases where it does make sense, we will include the acreage in our equipment population calculations.

Procedures for estimating fuel consumption will be similar to the equipment population extrapolation. From the respondent data for annual amount of fuel used, we will develop fuel use profiles relating gallons of fuel consumed by quota group to acres harvested or head of cattle. Then we will apply the scaling factors to county-level surrogate data for the State of Texas. As with the population analysis, we will determine if the data are robust for all fuel types. CNG and LPG estimates in particular would need to be based on relatively few data points.

Final estimates for population and fuel consumption, as well as all temporal activity data will be evaluated and compared to the NONROAD/TexN defaults. The data will be assessed considering the number of data points forming the basis of the values, as well as the reasonableness of the responses. Recommendations will then be made as to which data should replace existing model defaults. As a final phase for this project, TexN model runs using the revised inputs developed from this study will be performed. We will compare the updated model results with county and State emission estimates using default TexN inputs.

## CONCLUSIONS

According to USDA estimates, this survey collected information on agricultural equipment fleets from farming operations contributing to the majority of reported agricultural fuel and equipment use. A sample frame was initially developed based on NAICS codes as reported in Dun & Bradstreet records. In performing the survey, it was established that the quota definition based on the sample disposition had very little association with the responses of survey participants regarding their farming operations. Sample-defined quotas for hay and wheat were particularly incongruent, since only 6.1 percent of all completed interviews with hay farmers actually resulted from a hay farming sample point. Correspondingly, most surveys of wheat farmers (29.1 percent) were completed with sample points defined as "other farming." In performing surveys of farming operations, one should keep in mind the potential for misclassification based on NAICS code assignment. It is important to confirm from the respondents what operation they are engaged in. Similar to this study, sample quotas may need to redefined based on alternate data (e.g., the number of farms per Census data).

The survey collected data from respondents conducting farming operations in 242 of the 255 total counties in Texas. However, it is important to consider that the data collected from this survey represent average use profiles for all counties in the State. Though equipment populations will be generated by county, these will not reflect differences in equipment use that may occur based on the county of operation. Farmers engaged in the same crop farming activity may utilize different practices and equipment (e.g., tilling versus no tilling) in different parts of the State, which would impact the equipment use profiles. If reflecting county or regional differences is required, one would need to collect a representative sample based on strata defined by these smaller geographic areas. One should also establish that the year of the survey was not extremely atypical in terms of weather conditions which may impact the intensity of farming operations.

Preliminary estimates of activity based on the survey data show differences from NONROAD/TexN model defaults. In some cases these differences are significant, e.g., for annual hours of use estimates by equipment type. Since nonroad activity is dependent on several variables, including equipment populations, it will be important to assess all activity parameters before making conclusions on how overall activity based on the survey compares to current assumptions.

## REFERENCES


1. U.S. Environmental Protection Agency, *Temporal Profile and Cross Reference File for CAIR Platform, dated February 2005*, Emission Modeling Clearinghouse (EMCH), web address http://www.epa.gov/ttn/chief/emch/temporal/, accessed March 2009.

2. U.S. Environmental Protection Agency, *Weekday and Weekend Day Temporal Allocation of Activity in the draft NONROAD2004 Model*, Office of Transportation and Air Quality, Ann Arbor, MI, EPA420-P-04-015, Revised April 2004.

3. U.S. Environmental Protection Agency, *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling*, Office of Transportation and Air Quality, Ann Arbor, MI, EPA420-P-04-005, Revised April 2004.

4. U.S. Environmental Protection Agency, *Seasonal and Monthly Activity Allocation Fractions for Nonroad Engine Emissions Modeling*, http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2005/420r05017.pdf Office of Transportation and Air Quality, Ann Arbor, MI, EPA420-R-05-017, December 2005.

**Table 1. 2002 Census of Agriculture data for Texas.**

| Agricultural Sector (NAICS code) | Gasoline, Fuels, & Oils ($1,000s) | Number of Agricultural Tractors |
|---|---|---|
| Beef cattle ranching and farming (112111) | 172,674 | 212,705 |
| Oilseed and grain farming (1111) | 88,506 | 26,558 |
| Cotton farming (11192) | 81,550 | 18,340 |
| Sugarcane, hay, & all other crop farming (11193, 11194, 11199) | 58,755 | 51,550 |
| Cattle feedlots (112112) | 26,341 | 7,793 |
| Animal aquaculture and other animal production (1125,1129) | 24,672 | 31,112 |
| Poultry and egg production (1123) | 21,914 | 5,219 |
| Greenhouse, nursery, and floriculture production (1114) | 20,053 | 4,642 |
| Vegetable and melon farming (1112) | 12,985 | 4,455 |
| Dairy cattle and milk production (11212) | 9,425 | 3,621 |
| Sheep and goat farming (1124) | 7,917 | 12,255 |
| Fruit and tree nut farming (1113) | 4,934 | 9,292 |
| Hog and pig farming (1122) | 3,594 | 2,439 |
| *Total* | 533,321 | 389,981 |

**Table 2. 2005 Texas diesel and gasoline consumption estimates by crop type.**

| Crop Type | Estimated 2005 Gallons | |
|---|---|---|
| | Diesel | Gasoline |
| Cotton, all | 115,911,120 | 25,691,640 |
| Forage-land used for all hay & haylage, grass silage, & greenchop | 66,443,398 | Not available |
| Wheat for grain, all | 28,050,000 | 3,850,000 |
| Sorghum for grain | 21,320,000 | 6,150,000 |
| Corn for grain | 18,245,000 | 2,255,000 |

| | | |
|---|---|---|
| Rice | 8,423,400 | 404,000 |
| Peanuts for nuts | 8,321,000 | 641,300 |
| Oats for grain | 3,519,000 | 483,000 |
| Soybeans for beans | 1,066,000 | 338,000 |
| *Subtotal* | 271,298,918 | 39,812,940 |

### Table 3. Equipment types included in survey.

| Equipment Type | Description |
|---|---|
| 2- Wheel Tractors | Walk-behind 2-wheeled tractors for use in edible produce or other intensive farming |
| Agricultural Tractors | Large and small agricultural tractors (most prevalent farm equipment type) |
| Combines | Self-propelled combined harvesting and cleaning equipment |
| Balers | Equipment that bales from loose or windrowed hay or other forage mowed crop |
| Agricultural Mowers | Equipment for mowing not intended for later baling or harvesting |
| Sprayers | Small (backpack) and large (self-propelled) powered equipment designed specifically for spraying |
| Tillers > 6 HP | Primarily small tillers similar to those used in lawn and garden applications intended to be used in edible produce or other intensive farming |
| Swathers | Equipment designed to cut crops for later baling or harvesting including windrowers |
| Irrigation Sets | Agricultural pumps and pivot wheel irrigation equipment to distribute water to fields or livestock. |
| Other Agricultural Equipment | Other various cultivation equipment types and include harvesters or other special cultivating equipment |

### Table 4. Completed surveys and associated confidence interval.

| Quota Group | NAICS | Respondent Group | Number of Farms (Census 2000) | Target Number of Completed Surveys | Completed Surveys | Confidence interval at 95% confidence level |
|---|---|---|---|---|---|---|
| 1 | 111920 | Cotton farming | 6,321 | 362 | 205 | 6.73 |
| 2 | 111940 | Hay farming | 31,173 | 379 | 622 | 3.89 |
| 3 | 111140 | Wheat farming | 9,031 | 369 | 320 | 5.38 |
| 4 | 112111 | Beef cattle farming | 127,974 | 383 | 788 | 3.48 |
| 5 | 111+112 | All other farming | 54,427 | 376 | 374 | 5.05 |
| | | **Total** | **228,926** | **1,869** | **2,309** | **2.03** |

### Table 5. Comparison of weekly profiles.

| Time Period | NONROAD | Survey |
|---|---|---|
| Average Weekday | 0.167 | 0.154 |
| Average Weekend Day | 0.083 | 0.113 |
| Weekday/Weekend Fraction | 2 | 1.4 |
| Weekday Total (x5) | 0.833 | 0.771 |
| Weekend Total (x2) | 0.167 | 0.226 |

**Table 6. Comparison of annual hours of use values.**

| Equipment Description | NONROAD/TexN | TCEQ Survey | Ratio, Survey/ NONROAD | Count of Equipment |
|---|---|---|---|---|
| Gasoline 2-Wheel Tractors | 286 | 425 | 1.5 | 44 |
| Gasoline Agricultural Tractors | 550 | 676 | 1.2 | 204 |
| Gasoline Combines | 125 | 83 | 0.7 | 16 |
| Gasoline Balers | 68 | 176 | 2.6 | 19 |
| Gasoline Agricultural Mowers | 175 | 171 | 1.0 | 138 |
| Gasoline Sprayers | 80 | 125 | 1.6 | 93 |
| Gasoline Tillers > 6 HP | 43 | 78 | 1.8 | 26 |
| Gasoline Swathers | 95 | 92 | 1.0 | 6 |
| Gasoline Other Agricultural Equipment | 124 | 544 | 4.4 | 422 |
| Gasoline Irrigation Sets | 716 | 2,766 | 3.9 | 42 |
| Diesel 2-Wheel Tractors | 544 | 999 | 1.8 | 439 |
| Diesel Agricultural Tractors | 475 | 1,080 | 2.3 | 4,532 |
| Diesel Combines | 150 | 440 | 2.9 | 384 |
| Diesel Balers | 95 | 300 | 3.2 | 401 |
| Diesel Agricultural Mowers | 363 | 362 | 1.0 | 581 |
| Diesel Sprayers | 90 | 344 | 3.8 | 522 |
| Diesel Tillers > 6 HP | 172 | 453 | 2.6 | 211 |
| Diesel Swathers | 110 | 383 | 3.5 | 147 |
| Diesel Other Agricultural Equipment | 381 | 760 | 2.0 | 491 |
| Diesel Irrigation Sets | 749 | 1,601 | 2.1 | 204 |

**Figure 1. Comparison of diurnal profiles.**

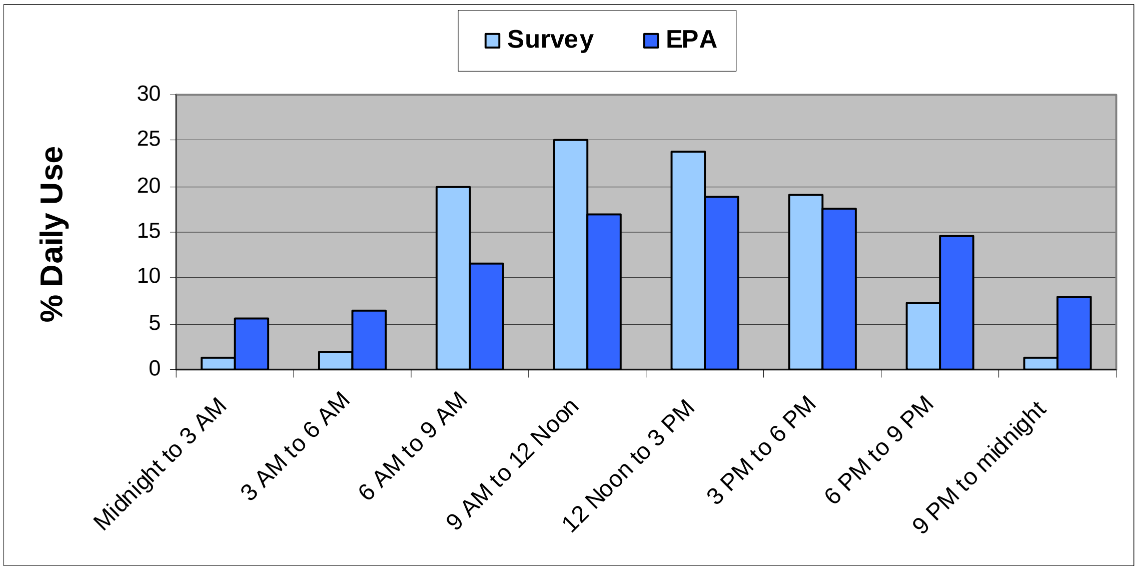


**Figure 2. Comparison of annual hours of use values for diesel equipment.**

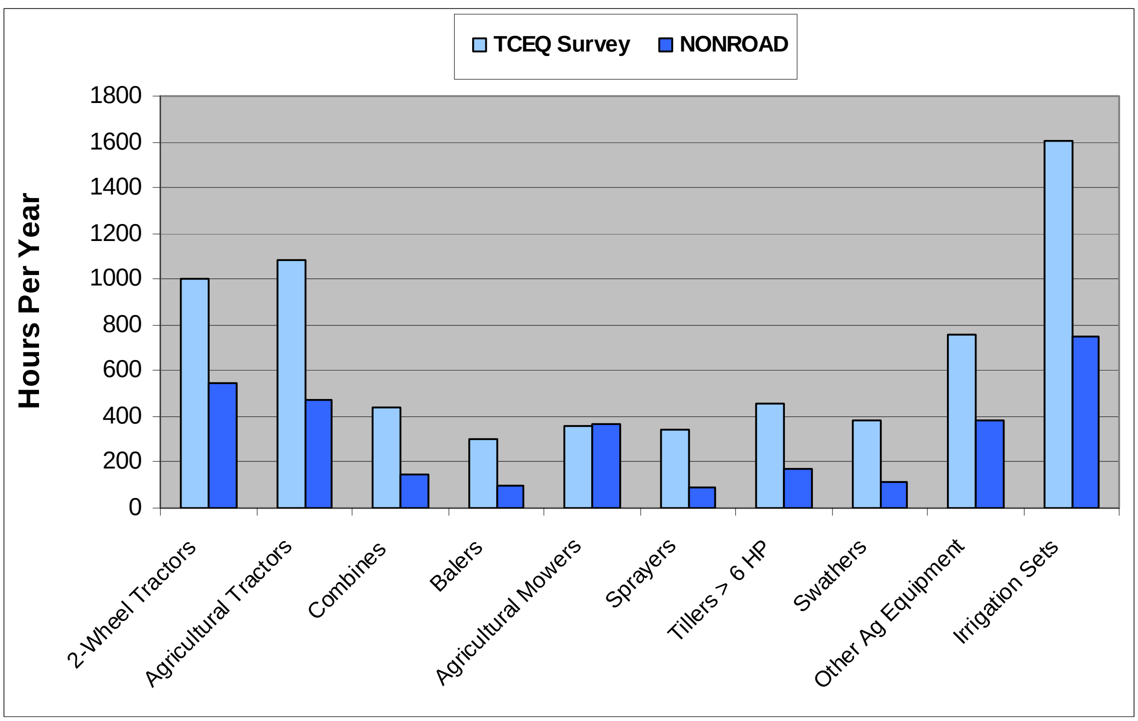

**Figure 3. Comparison of seasonal use profiles.**