Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower

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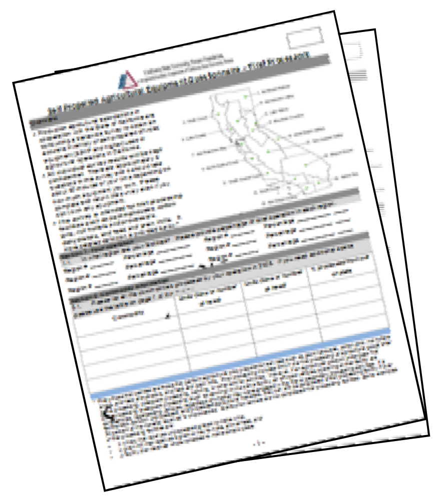
1. Introduction

The California Air Resources Board (CARB) developed a self-propelled agricultural diesel emissions inventory for equipment over 25 horsepower in 2011, created from a 2008 survey that collected significantly detailed data on farm size, equipment, and commodity, with support from the agricultural community. This multi-year effort involved numerous agricultural stakeholders, farmers, producers, and equipment operators throughout California. The survey culminated in the largest data set and subsequent analysis of its kind on agricultural equipment, and has allowed for a detailed study of fuel use by farm size, commodity, and equipment horsepower.

2. Farm Equipment Survey



CARB's current inventory for off-road diesel vehicles used in agriculture (primarily tractors) is based on a 2008 survey of California farms, custom operators, first processors, and equipment rental facilities. The survey gathered a representative sample and used acreage data provided by the 2007 USDA Census of Agriculture[1], which was scaled up to represent statewide farms. Given the great variety of farms, both by region, crops, and size (including regional diversity amongst basic farming practices), the survey required significant participation from the agricultural industries in California. With over 1,700 survey participants, the survey was a success, largely due to the efforts of agricultural stakeholders distributing and reaching the agricultural industries, gaining the participation of so many individual farmers and members of the agricultural industry.

Table 2.1 outlines the type of information requested in the survey. The level of detail requested by the survey provided a strong basis for the new inventory, both in specificity and sheer number of farms represented.

[1] USDA 2007 Census, https://www.agcensus.usda.gov/Publications/2007/

Table 2.1 Type of Requested Information

Farm	Equipment
Commodities Grown or Harvested	Vehicle Type
Acres (per commodity)	Model Year
Double Cropping Practices[2]	Horsepower
Custom Operator Activity on Farm	Fuel Type and Annual Consumption
Region of the State	Annual Use in Hours
	Manufacturer and Make

Most producers reported multiple commodities grown and multiple pieces of equipment. Similar data were requested from custom operators and first processors, focusing on the type and amount of custom work performed or the amount of goods processed, respectively. Over 10,000 applicable pieces of equipment were reported, the majority being tractors of various sizes. The agricultural stakeholders identified equipment type choices, which was included in the survey. In most cases, the respondents included one of the 15 equipment types shown in Table 2.2. If the equipment type varied, then the written entry was matched to one in table.

Table 2.2 Number of Self-Propelled Diesel Vehicles Reported in Survey

Equipment Type	Number in Survey
Agricultural Tractors	7,022
Crawler/Backhoe/Loader/Dozer/Grader	699
Other	627
Nut Harvester	556
Forklifts	271
Other Harvesters	258
Combine Harvesters	233
Swathers/Windrowers/Hay Conditioners	135
Sprayers/Spray rigs	117
Cotton Pickers	112
ATVs	55
Balers (Self-Propelled)	47
Bale Wagons (Self-Propelled)	45
Hay Squeeze/Stack retriever	38
Forage & Silage Harvesters	16
Total	**10,231**

[2] Double cropping is the practice of growing multiple crop cycles per annum such as growing two separate crops on the same land. One example would be growing and harvesting grain crops on 15 acres of land in spring and summer and following that by growing silage corn on that same land and harvesting in autumn. USDA acreage reports would count that as two separate 15-acre farms. For the purposes of scaling up to USDA California totals, it is important that the survey accurately represent double cropping.

Of the information collected, almost all respondents reported equipment type, vehicle horsepower, and annual activity in hours. Of these responses, 2,583 reported annual fuel consumption in pounds or gallons of diesel fuel, which was significant in determining load and estimating fuel use from the agriculture sector.

2.1 Survey Representation

Agricultural stakeholders aided in categorizing the commodity survey responses into 12 general groups. Table 2.3 organizes survey responses by commodity groups, reporting the number of responses and the corresponding statewide representation. For livestock categories such as beef and milk cows, USDA typically groups farms by head of livestock. The survey results collected a sufficient number of responses to create separate bins for livestock, so USDA livestock groupings by farm size were not necessary.

Table 2.3 Survey Representation by Commodity Group

Commodity	Number of Surveys	Percent of Statewide Commodity Acres in the Survey
Nut Crops	506	13%
Hay, Forage, Pasture, Grains	474	15%
Grapes	413	9%
Tree Fruit	226	6%
Citrus	166	23%
Row Crops	136	16%
Vegetables, hand-picked	87	15%
Vegetables, machine-picked	29	8%
Beef Cows[3]	71	N/A*
Nursery, Greenhouse, Floriculture	37	N/A*
Milk Cows	12	N/A*

3. AGRICULTURAL EQUIPMENT FUEL USE PER FARM AND ACRE

Similar to the metric miles per gallon for on-road vehicles, fuel use per acre is a metric of efficiency and productivity for off-road diesel vehicles, especially those used in agriculture. The availability of fuel use data at a detailed level, collected from the surveys, provided vastly improved metrics for fuel use based on farms and acreage.

Table 3.1 lists the farm size grouping according to acreage. The USDA Census of Agriculture helped determine the acreage groupings, which were necessary in calculating the inventory's scaling factors.

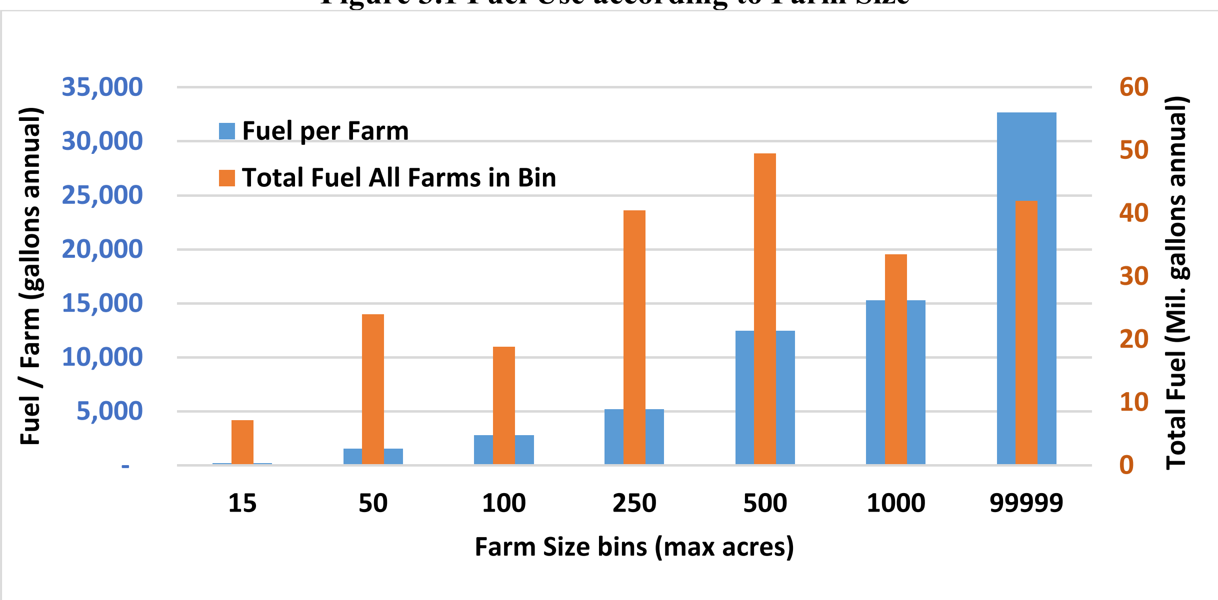
[3] Percent of statewide data shown is percent of head of beef cows or milk cows.
* Acreage data does not apply to these commodities.

Table 3.1 Farm Size bins (in Acres)

Farm Size Groupings
0 to 15 Acres
15 to 50 Acres
50 to 100 Acres
100 to 250 Acres
250 to 500 Acres
500 to 1,000 Acres
Over 1,000 Acres

Figure 3.1 displays both the total fuel use (orange bars) and fuel used per individual farm (blue bars) by farm size bins. Unsurprisingly, the largest farms (those operating over 1,000 acres) used the most fuel per farm by a large margin. However, the most fuel used in total was by farms between 250 to 500 acres due to the larger number of farms in that bin.

Figure 3.1 Fuel Use according to Farm Size



While the largest farms use the most fuel per farm, they are the most efficient in terms of fuel used per acre. Figure 3.2 shows a decreasing trend in fuel per acre as farm size increases.

Figure 3.2 Fuel Use per Acre, by Farm Size bins

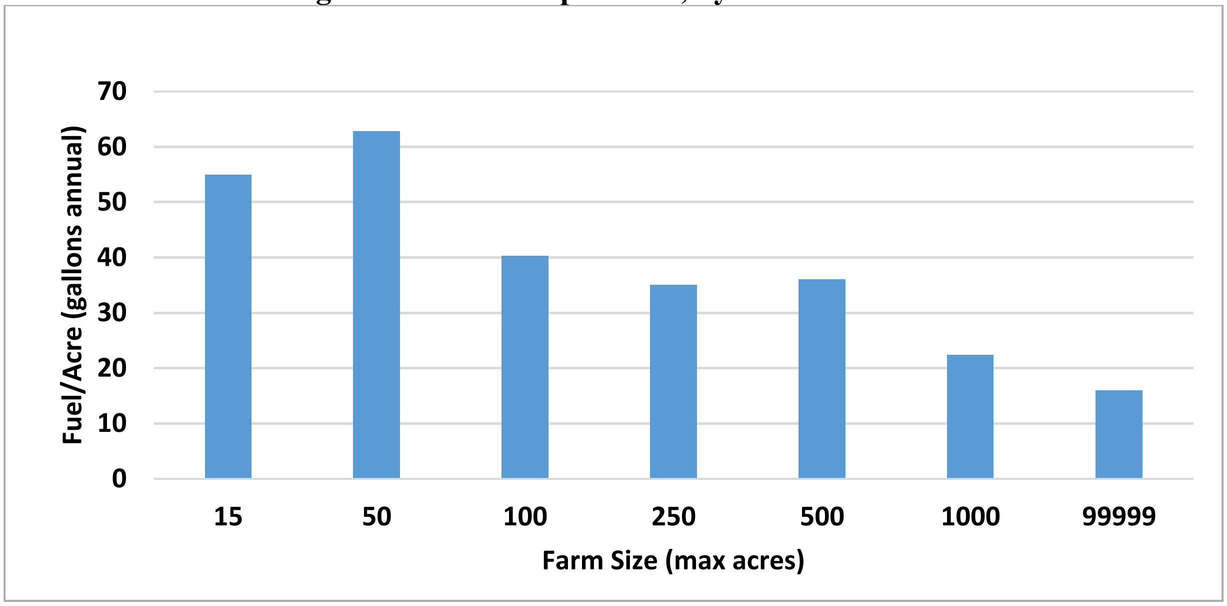
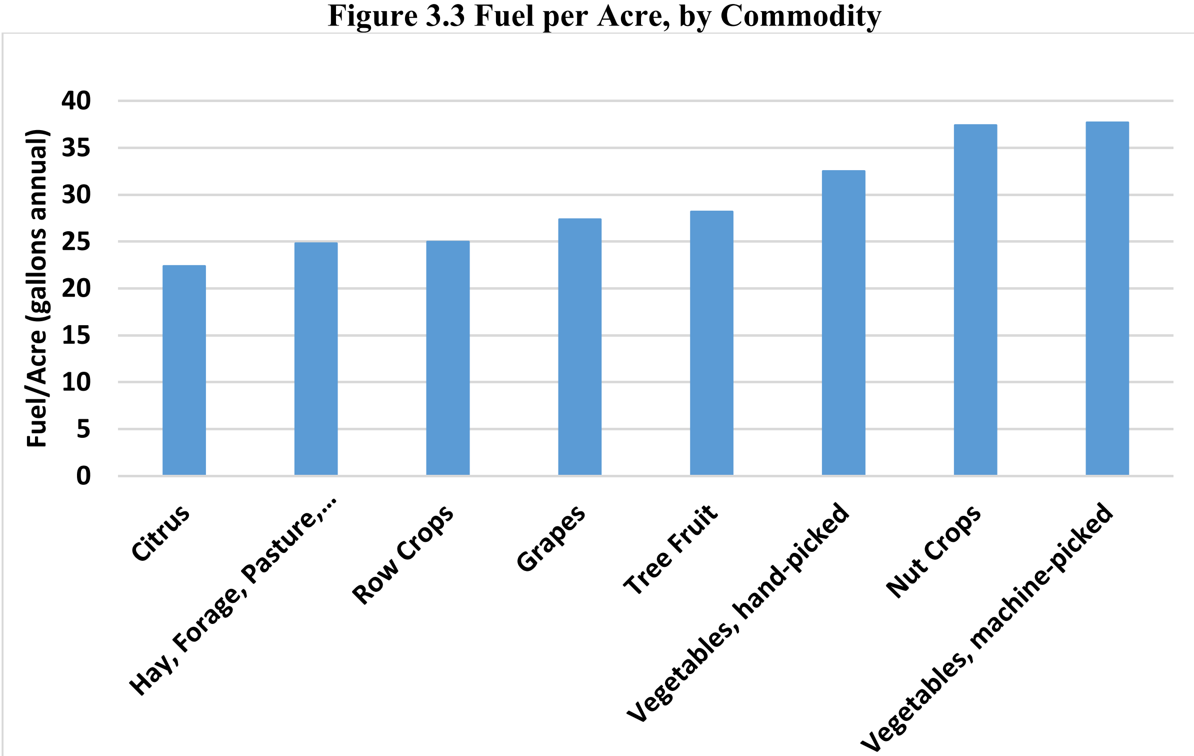


Figure 3.3 shows fuel use per acre by commodity, thus demonstrating that all commodities consume, on average, between 22 and 38 gallons per acre annually.

Figure 3.3 Fuel per Acre, by Commodity



3.1 Relationship of Fuel Use to Equipment Size

There is a wide range of fuel use per acre, reflecting many different farming practices, equipment, farming efficiencies, and even operator preferences. Detailed fuel data allows a close look at which factors may influence fuel use, and in particular, the significance of equipment horsepower on fuel use per acre.

Figure 3.4 displays average fuel use per acre based on the horsepower of equipment used on that acreage. In general, fuel use is consistent for equipment between 40 and 120 horsepower. Then, fuel use per acre decreases as the equipment's horsepower increases. It is assumed this is the result of large horsepower equipment being used on large farms, which are more efficient per acre.

Figure 3.4 Average Fuel Use per Acre, by Horsepower Bin

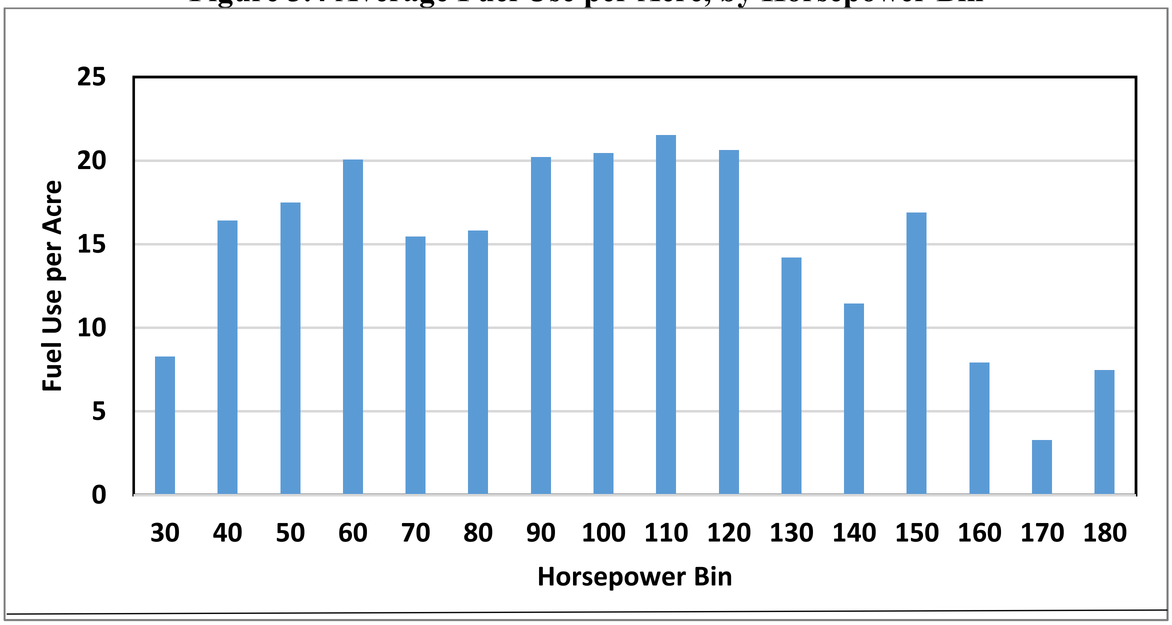
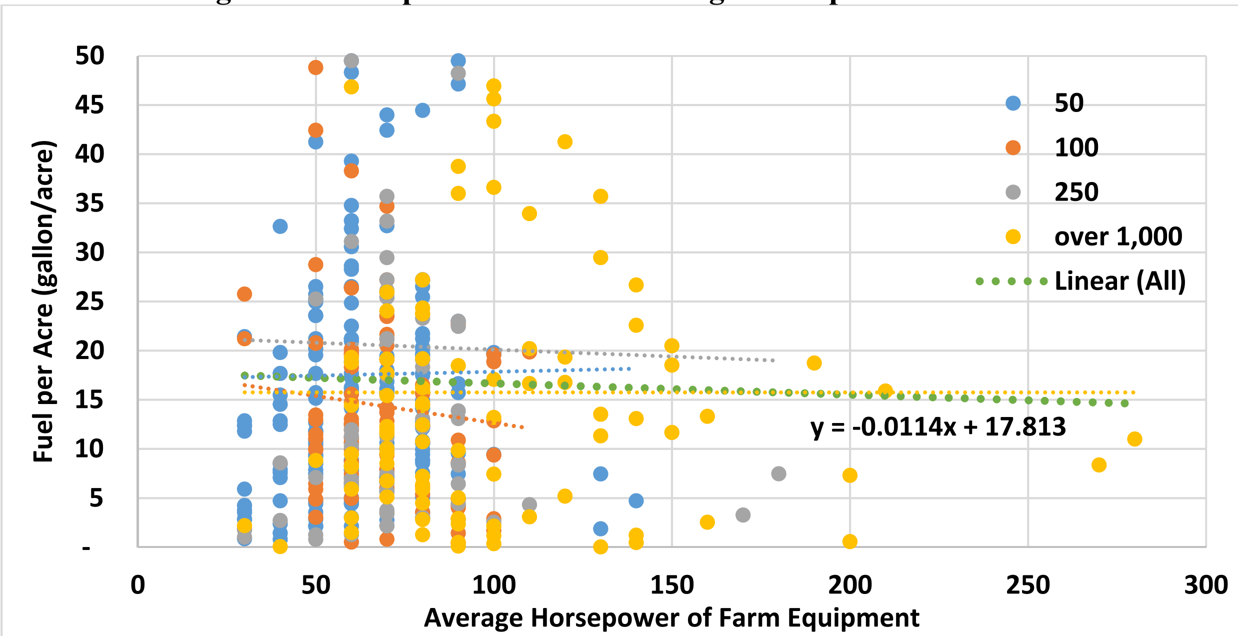


Figure 3.5 presents results when farm size is controlled while using data from farm size bins of 50, 100, 250, and over 1,000 acres, as depicted in the figure's legend. The data exhibits two important trends. First, when farm size is controlled, there is a very wide range of data, creating a data cloud. Second, there is a decreasing trend in fuel per acre as horsepower increases. This means fuel use per acre decreases as equipment horsepower increases. This is likely due to efficiencies gained with larger horsepower equipment.

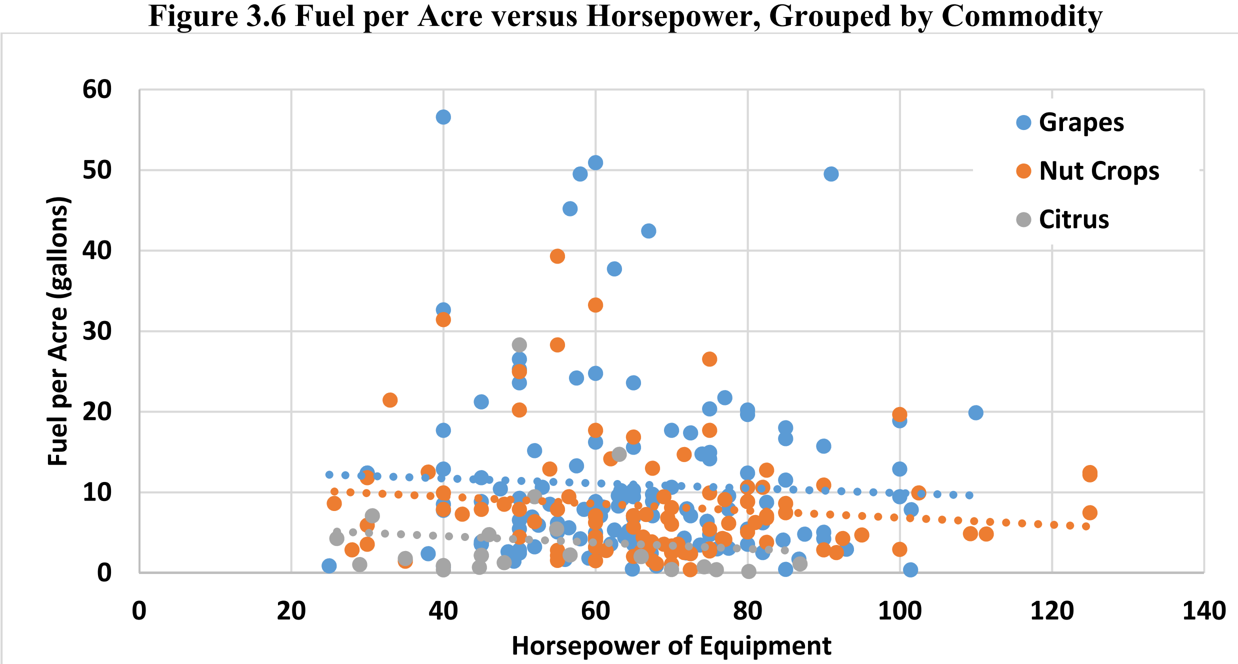
Furthermore, farms under 50 acre (blue circles) report a slight increase in fuel use as horsepower increases. Trend lines from the 100, 250, and over 1,000 acre farms (circles colored orange, grey, and yellow respectively) have a declining slope. However, the overall trend representing all acreage groups (green line) demonstrates a minor decline in fuel use per acre as horsepower increases.

Figure 3.5 Fuel per Acre versus Average Horsepower on a Farm



Next, Figure 3.6 groups data by commodity, where blue represents grapes, orange for nut crops, and grey for citrus. Data is limited to these three commodities because they had the largest quantity of fuel reports that included only one major commodity. A downward trend is visible according to commodity type and fuel use per acre. It is also evident by the data cloud that a strong relationship between the variables is lacking.

Figure 3.6 Fuel per Acre versus Horsepower, Grouped by Commodity



Overall, the data shows there likely is no strong relationship between fuel use per acre and the equipment's horsepower. **A consistent downward trend can be observed in the data cloud with approximately 0.06% fuel decrease per horsepower increased. However, a reasonable, conservative conclusion suggests fuel per acre does not change as an equipment's horsepower changes. Fuel use per acre is independent of horsepower of equipment used on that acreage.**

4. LOAD FACTOR

A load factor represents the proportion of maximum horsepower an engine produces on average under a particular use. For example, if a 300 horsepower tractor uses 240 horsepower when pulling a plow, it runs at an 80 percent load factor for that use (240 divided by 300). When pulling a heavy water tank, the same engine might use 150 horsepower, therefore running at 50 percent load (150 divided by 300). When the tractor is moving across the farm without pulling anything, it may use 60 horsepower, or a 20 percent load (60 divided by 300).

Equation 4.1 calculates how engine load and activity affect maximum annual fuel usage. For example, a 100 horsepower tractor operating for 100 hours per year at full load (i.e. where the engine is running at maximum horsepower for the entire time that the engine is used, also referred to as 100% load factor). The equation relies on the US EPA[4] constant fuel consumption rate of 0.408 lb per horsepower-hour. Thus, the engine has the potential to consume 582 gallons per year.

Equation 4.1 Annual Fuel Usage

$$horsepower * annual\ activity * fuel\ consumption\ rate * fuel\ conversion\ rate = Max\ Annual\ Fuel\ Usage$$

$$100\ hp * \frac{100\ hr}{yr} * \frac{0.408\ lbs}{hp\text{-}hr} * \frac{1\ gal}{7.1\ lbs} = \frac{582\ gal}{yr}$$

Based on the calculation above, if a tractor's owner reported a tractor used 233 gallons of fuel that year, the average load factor would be 40% (or 233 divided by 582) using Equation 4.2.

Equation 4.2 Load Factor calculation

$$Load\ Factor = \frac{Reported\ Fuel\ Usage}{Max\ Annual\ Fuel\ Usage}$$

$$Load\ Factor = \frac{233\ gal/yr}{582\ gal/yr} = 40\%$$

[4] Exhaust Emission Factors for Nonroad Engine Modeling--Compression-Ignition, Report No. NR-009A, February 13, 1998.

4.1 Load Factors for All Equipment Types

The following information is necessary for updating load factors and was provided by survey respondents: fuel consumption, annual activity, and horsepower for 1,549 vehicles (70% were tractors). Data on equipment types were combined in the following groups: (1) tractors, (2) balers and bale wagons, (3) construction, forklifts, ATVs and others, (4) harvesters of all types, (5) hay squeeze and (6) spray rigs. Since hay squeezes lacked sufficient data, they were combined with tractors, the largest category, and share their load factor. Table 4.1 expresses load factor by equipment type. Based on all the responses, tractors have an average load factor of 0.48, with the other equipment types coming in between 0.4 to 0.5.

Table 4.1 Load Factor by Equipment Type

Agricultural Tractors	0.48
Combine Harvesters	0.44
Forage & Silage Harvesters	0.44
Cotton Pickers	0.44
Nut Harvester	0.44
Other Harvesters	0.44
Balers (Self-Propelled)	0.50
Bale Wagons (Self-Propelled)	0.50
Swathers/Windrowers/Hay Conditioners	0.48
Hay Squeeze/Stack Retriever	0.42
Sprayers/Spray Rigs	0.42
Agricultural Loader and Backhoes	0.40
Agricultural Forklifts	0.40
Agricultural ATVs	0.40
Other Agricultural Equipment	0.40

4.2 Load Factor Example and Standard Deviation

Tractors are a large portion of the inventory. Responses provided sufficient data to study load factor by horsepower group, which demonstrates the greatest impact on vehicle activity and age distributions. Table 4.2 lists tractor load factor by horsepower group, the average load factor for all tractors, and the standard deviation of load factor for all tractors.

Table 4.2 Tractor Load Factor by Horsepower Bin

Horsepower Bin	Load Factor
25-50	43.6%
51-75	45.2%
76-100	47.3%
101-175	50.9%
176-300	44.4%

301-600	34.0%
All Bins	**48.2%**
Standard Deviation	**21.8%**

The 21.8% standard deviation signifies that most tractors have a load factor between 30% and 70%. Although this is a wide range, it does not indicate inconsistencies in the data, but is more likely due to the large variation in tractor duty cycles and usage.

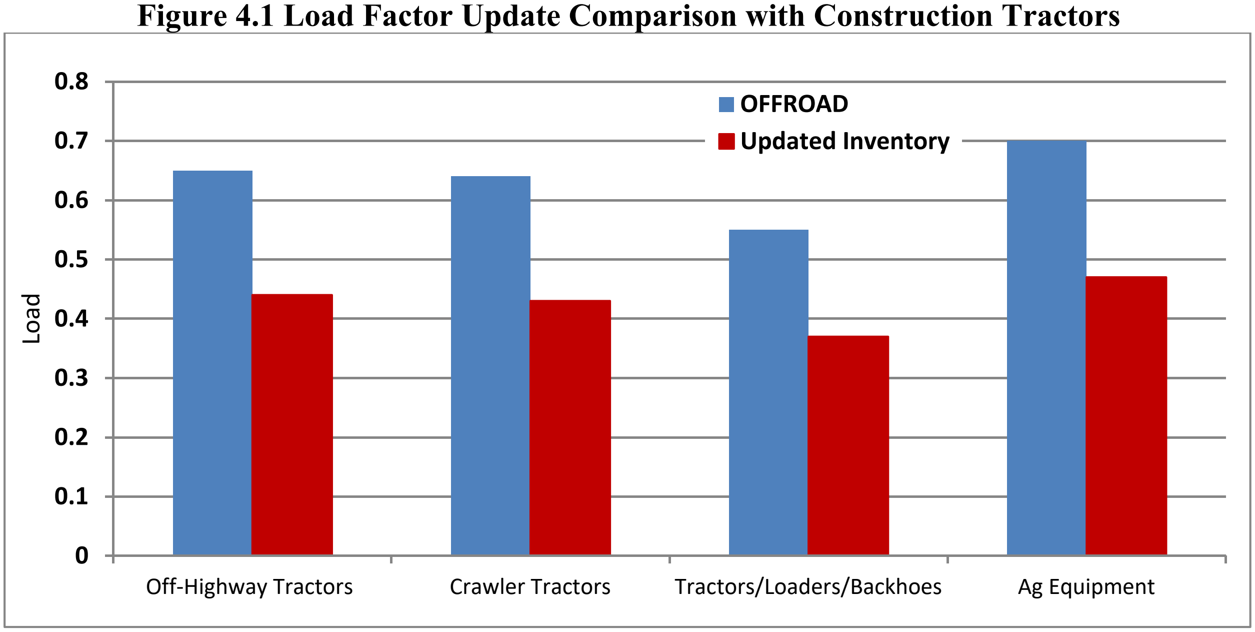
The data for non-tractor equipment was not sufficient to study adequately by horsepower bin, as most bins would consistent of under 20 reports. However, the total number of responses for non-tractors with 1,166 fuel reports have a standard deviation similar to tractors, at 20.8% or 0.208.

Non-tractor equipment includes combine harvesters, forage & silage harvesters, cotton pickers, nut harvester, other harvesters, balers (self-propelled), bale wagons (self-propelled), swathers/windrowers/hay conditioners, hay squeeze/stack retriever, sprayers/spray rigs, agricultural loaders and backhoes, agricultural forklifts, agricultural ATVs, and other agricultural equipment (a catch-all category for equipment that does not fit any other definition within agriculture).

4.3 Load Factor Comparison

There is little research on agricultural equipment load factors. Notably, when the construction portion of the OFFROAD2007 model was updated, the relatively high load factor of 0.65 for tractor categories was reduced to 0.44. Figure 4.1 compares the old load factors (colored blue) to the updated load factors (colored red). The first three sets of columns compare construction data. The last column displays load factor for agricultural tractors, which follows the same decreasing trend.

Figure 4.1 Load Factor Update Comparison with Construction Tractors



5. CONCLUSION

The collected California agricultural survey data represents the largest data set of its kind. It includes detailed agricultural information pertaining to farm size, equipment type, equipment horsepower, and commodity, which was analyzed to study equipment efficiency and load factor. The metric used in this report, associated with agricultural equipment efficiency, is fuel use per acre.

This analysis evaluated fuel use by farms of different acreage and by different size horsepower engines. The data suggest fuel use per acre and equipment horsepower are independent. However, as horsepower increases, fuel use per acre presents a slight decreasing trend. This suggests that fuel use per acres slightly decreases as equipment horsepower increases, which can be attributed to efficiency gains of larger horsepower equipment.

The large dataset also allowed for in-depth analysis on agricultural equipment load factors, a topic with little research. Tractors, specifically, represent the inventory's largest population, provided significant data to analyze load factor by horsepower group according to vehicle activity and age. The average load factor for tractor across all horsepower groups is 0.48, with a standard deviation of 0.218. The load factors for all non-tractor agricultural equipment varies from 0.4 to 0.5, with a standard deviation of 0.208.