Collection of Agriculture Equipment Activity Study

Technical Seminar

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Presented By:

Thomas Durbin, Chas Frederickson, George Scora, Alexander Vu, and Kent Johnson
University of California, Riverside
Bourns College of Engineering
Center for Environmental Research and Technology

And

A. Alexandrou and Matthew Crowder
Chair, Department of Industrial Technology,
Jordan College of Agricultural Sciences and Technology
California State University at Fresno

UNIVERSITY OF CALIFORNIA, RIVERSIDE

Background

- Agriculture is one of the most critical economic sectors in California.
  - Estimated $50-$144 billion in annual sales/value added
  - Representing 400,000 to 1.57 million jobs
- Diesel engines commonly used in agriculture applications
  - Over 50% of states agriculture equipment is in the San Joaquin Valley (SJV), which is classified as an extreme ozone nonattainment area and a serious nonattainment area for PM2.5
  - 22% of NOx in SJV from farm equipment in 2020

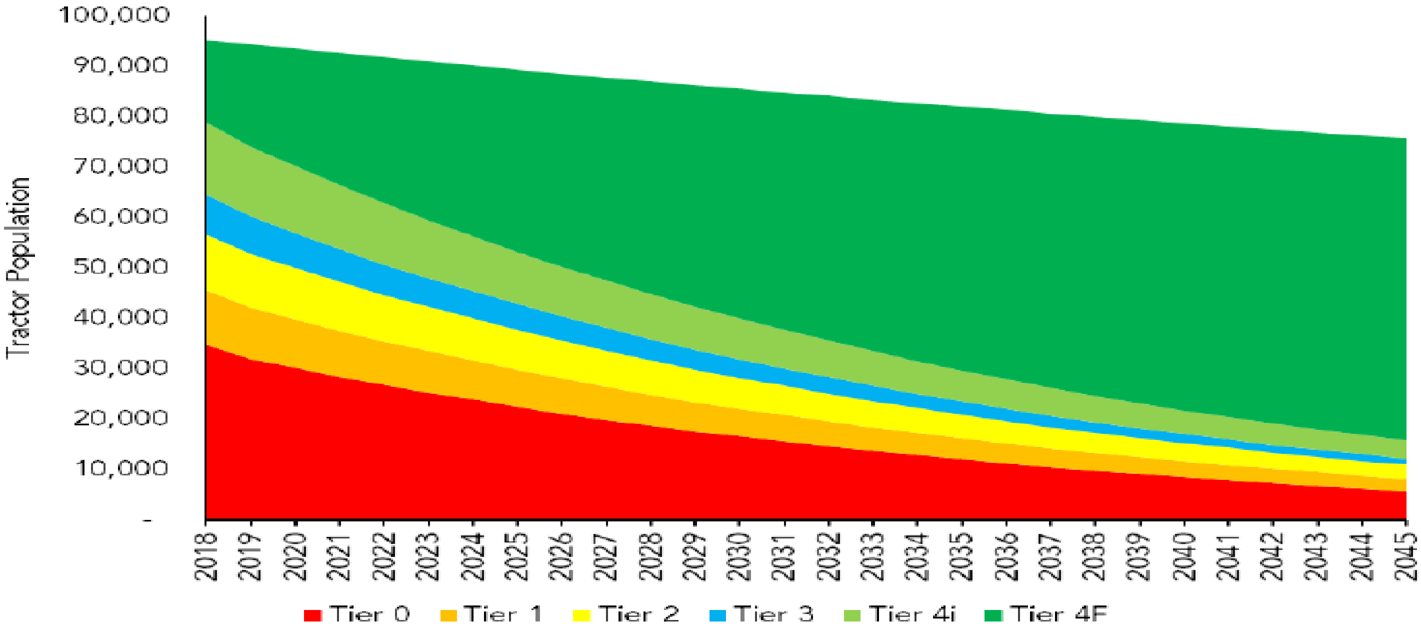
Background II

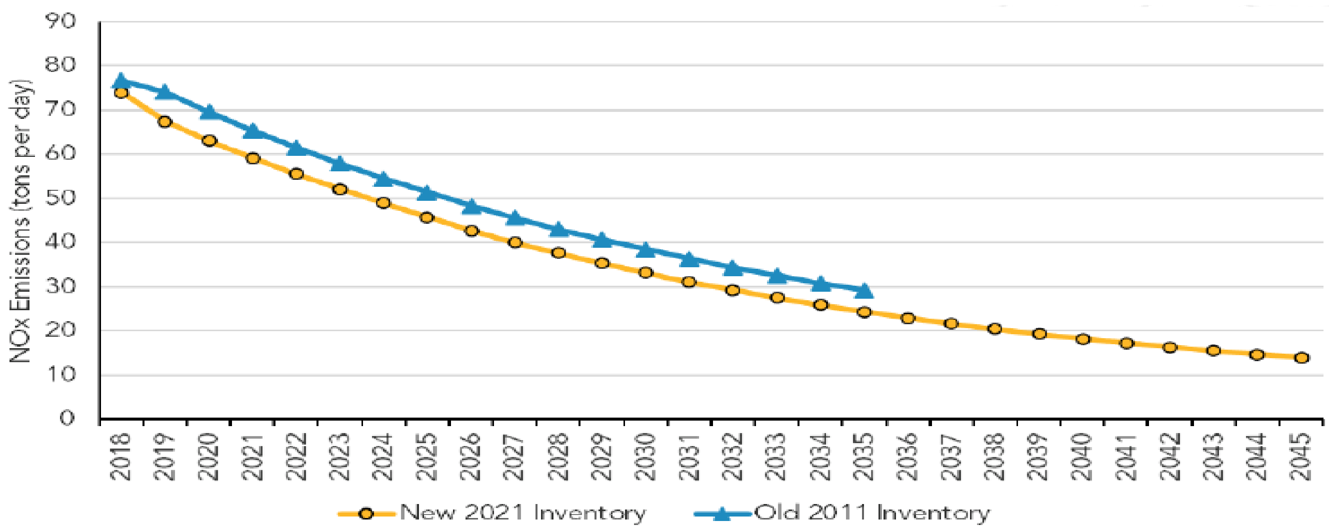
- Accurate data on agriculture equipment is critical to improve emissions inventories.
  - To improve air quality
  - Develop effective incentive strategies for the SJV
- CARB conducted agriculture equipment populations surveys in 2008 and 2018.
- More information is needed on in-use activity patterns, and to understand how ag equipment differs from other off-road equipment.

Objective

- To collect real-world data from agricultural equipment to improve the emission inventory and to inform air quality programs and policies and incentive programs in California.
- Characterize how agricultural engines in the SJV operate under actual working conditions.
- Measure activity parameters (e.g., fuel use, engine load, hours of use, engine speed, and torque)
- Funding from CARB, U.S. EPA, and SJV Air Pollution Control District (SJV APCD), San Joaquin Valleywide Air Pollution Study Agency (Study Agency).

2021 Emissions Inventory Baseline





- The top graph is for the statewide population of tractors, which represents a majority of the agricultural equipment population.
- Bottom graph is statewide NOx emissions inventory in tons per day

Calculating Emissions Inventories

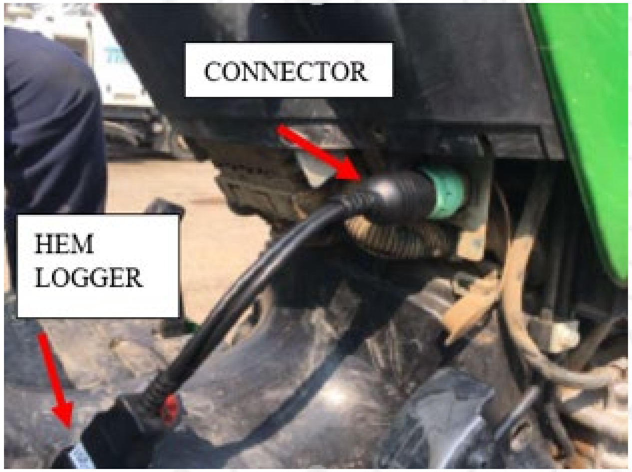
$$\text{Emissions} = \text{Horsepower} * \text{Activity} * \text{Load Factor} * (\text{Emissions Factor}_{\text{Zero Hour}} + \text{Deterioration Rate} * \text{Accumulated Hours}) * \text{Fuel Correction Factor}$$

$$\frac{\text{grams}}{\text{year}} = \text{hp} * \frac{\text{hr}}{\text{year}} * (\text{unitless}) * \left(\frac{\text{grams}}{\text{hp}-\text{hr}} + \frac{\text{grams}}{\text{hp}-\text{hr}^2} * \text{hr}\right) * (\text{unitless})$$

$$\text{Work} = \text{Horsepower} * \text{Activity} * \text{Load Factor}$$

Data Collection Campaign

- Monitoring of 208 pieces equipment over 22 farms
  - Data collection attempts on 240 tractors, including 127 tractors for HEM
  - 185 monitored > 10 months, 23 less than 10 months
  - Data logging with HEM loggers on 103 tractors
    - 91 tractors > 10 months, 12 tractors < 10 months
- Data obtained from 2 rental agencies
  - One with 35 tractor records over 3 years and one with 12 tractors during harvest season for 2 months



Tractor Test Matrix

Engine HP Rating	Group 1: Tree/Orchard/Nut				Group 2: Field and Row Crops			
	Tier 0,1,2		Tier 3 and 4		Tier 0,1,2		Tier 3 and 4	
	Total	HEM Logged	Total	HEM Logged	Total	HEM Logged	Total	HEM Logged
hp < 50	3	0	7	0	1	0	1	1
50 ≤ hp < 175	25	1	69	18	8	2	32	22
175 ≤ hp < 300	1	0	7	7	2	1	19	19
300 ≤ hp < 600	0	0	8	8	0	0	25	24
Total	29	1	91	33	11	3	77	66

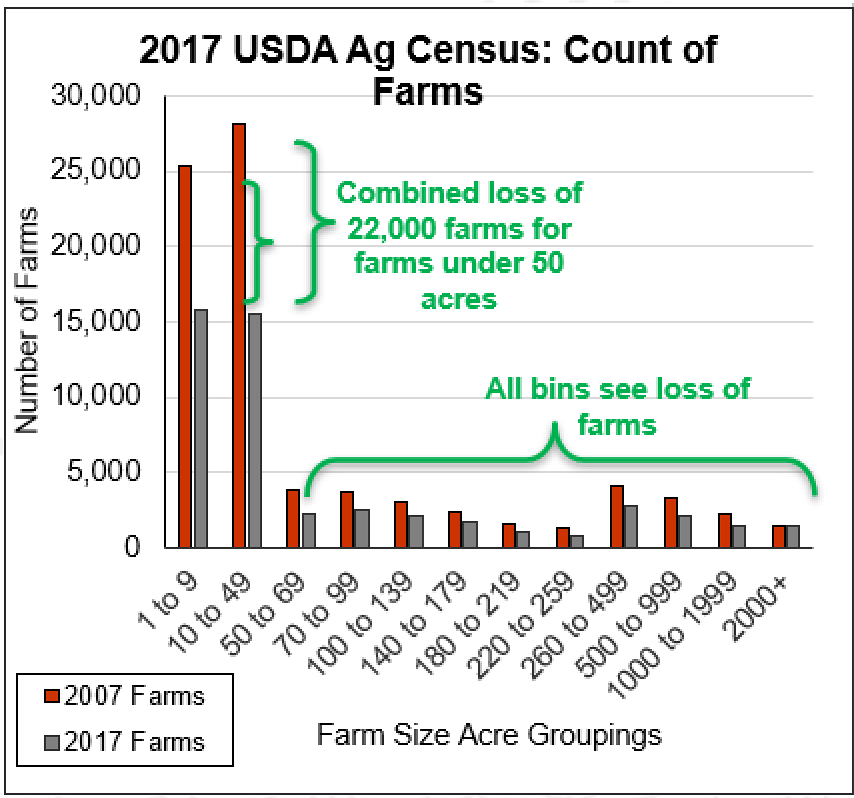
Total Equipment Monitored: 208 Total Equipment HEM Logged: 103

Note that two of the HEM data loggers acquired less than 5 minutes or less, so they were not included in the main data analysis

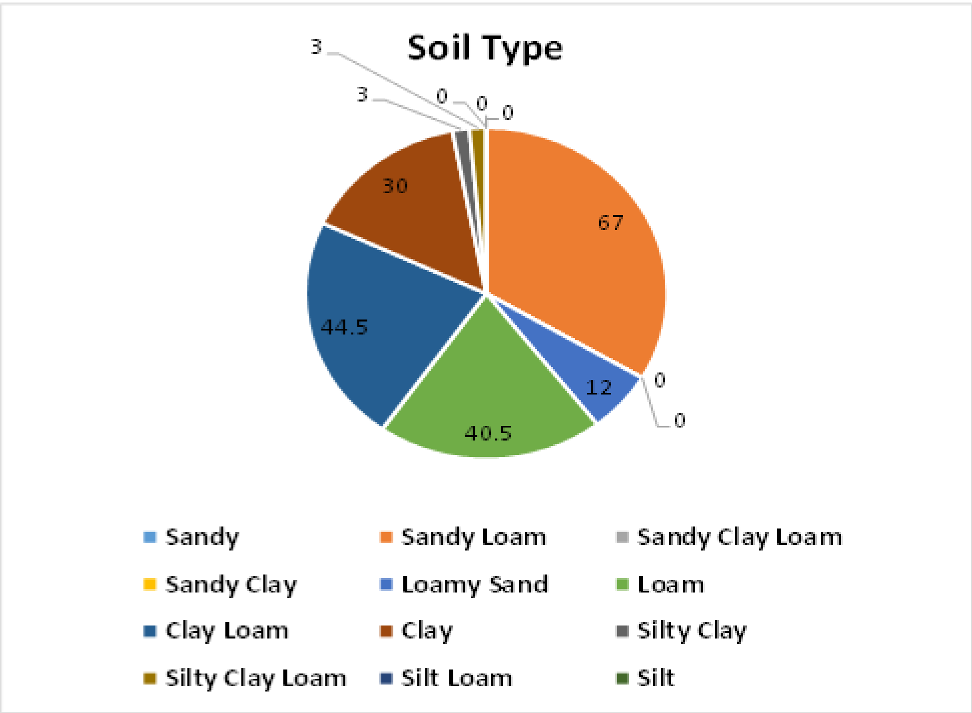
Farm Distribution

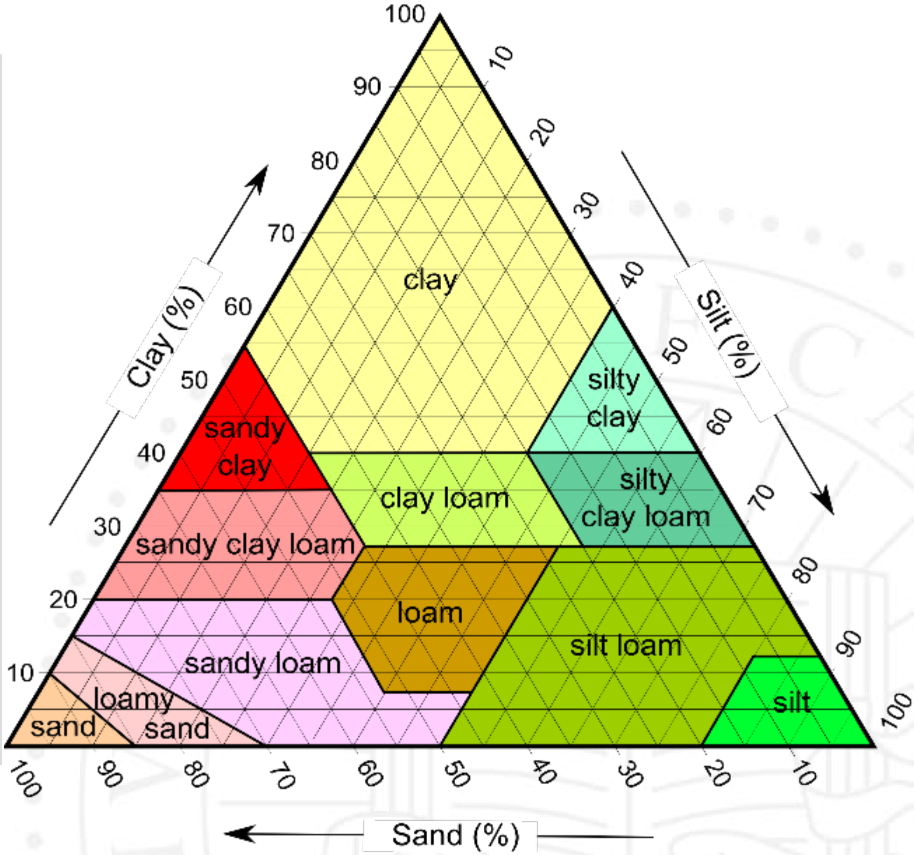
- Number of farms by size in acres

	# of Farms	# of Tractors
<250	- 3	- 6
250-999	- 6	- 48
1,000-1,999	- 2	- 13
2,000-9,999	- 7	- 92
10,000 – 20,000	- 3	- 40
Custom farm	- 1	- 9



Distribution of Soil Type





Four main soil types were Sandy Loam, Clay Loam, Loam, and Clay

Information being acquired

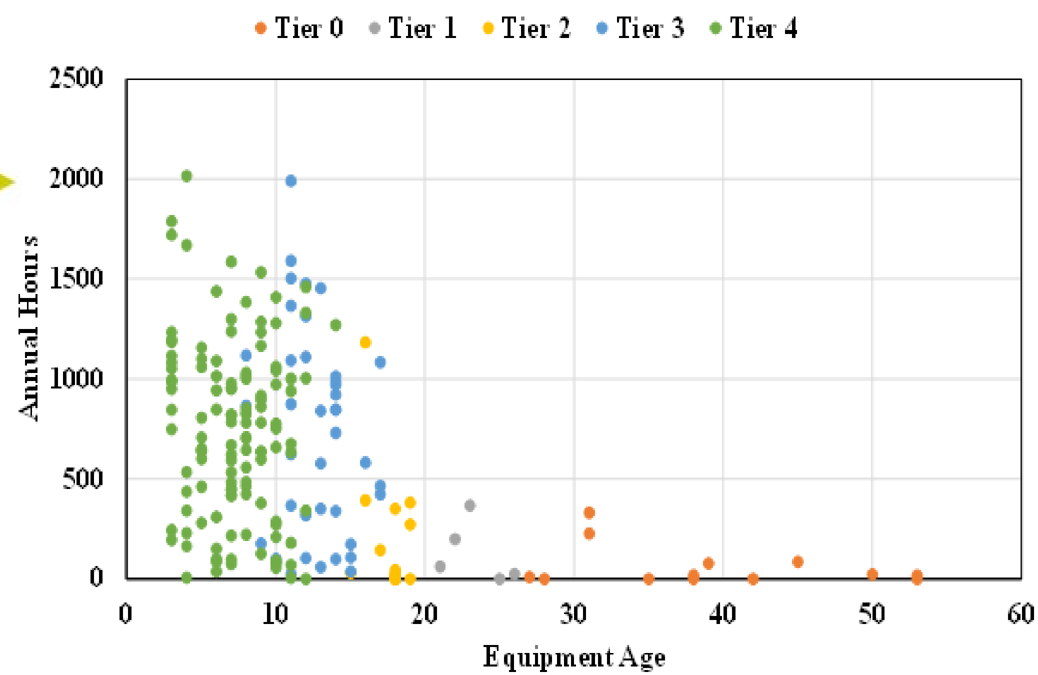
Work =

Horsepower * Activity * Load Factor

Table 4.16 Tractor Load Factor by Horsepower Bin

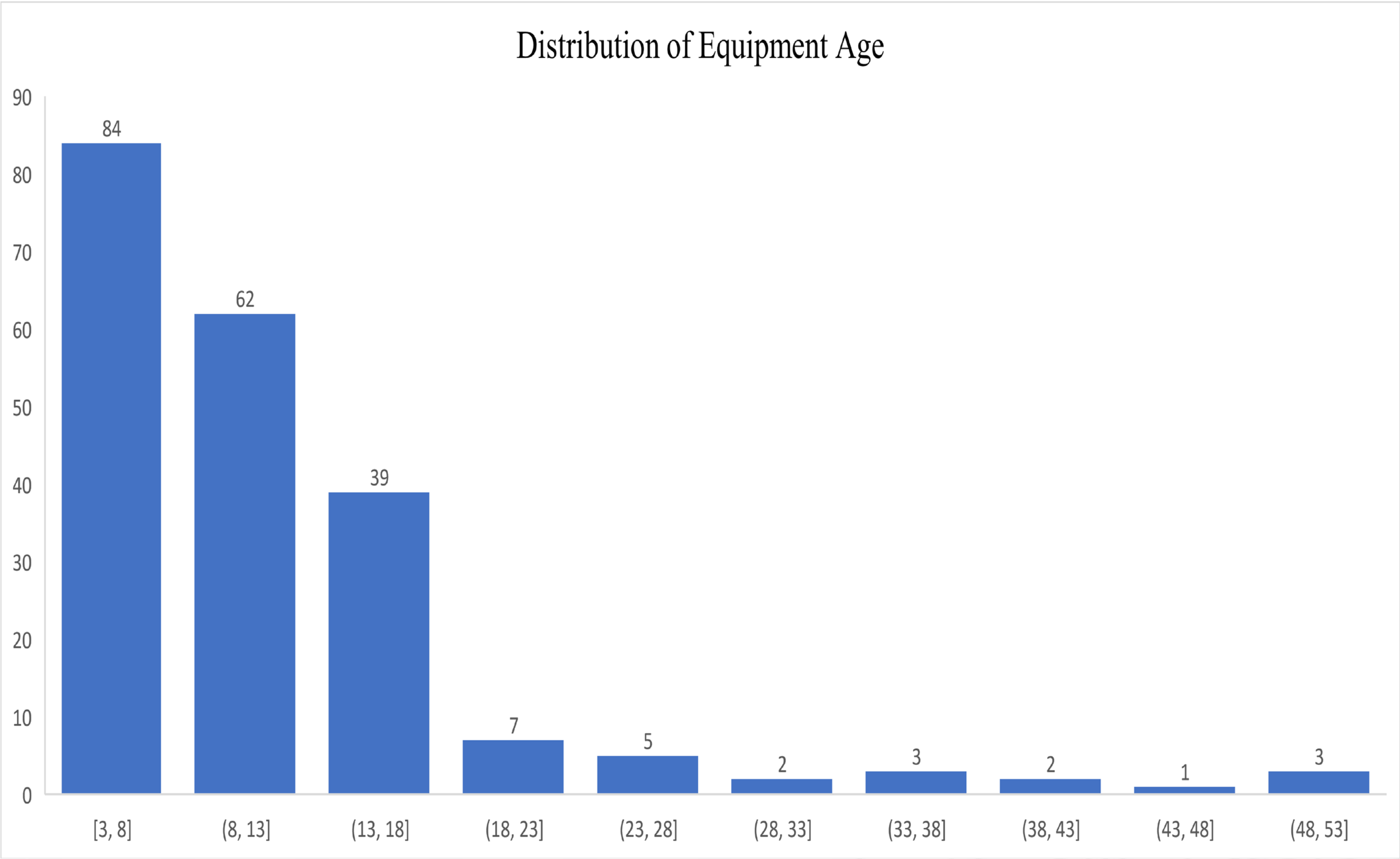
Horsepower Bin	Load Factor
25-50	43.6%
51-75	45.2%
76-100	47.3%
101-175	50.9%
176-300	44.4%
301-600	34.0%
All Bins	**48.2%**
Standard Deviation	**21.8%**

103 Monitored with HEM Data Logger (4 Tier 0 – 2)

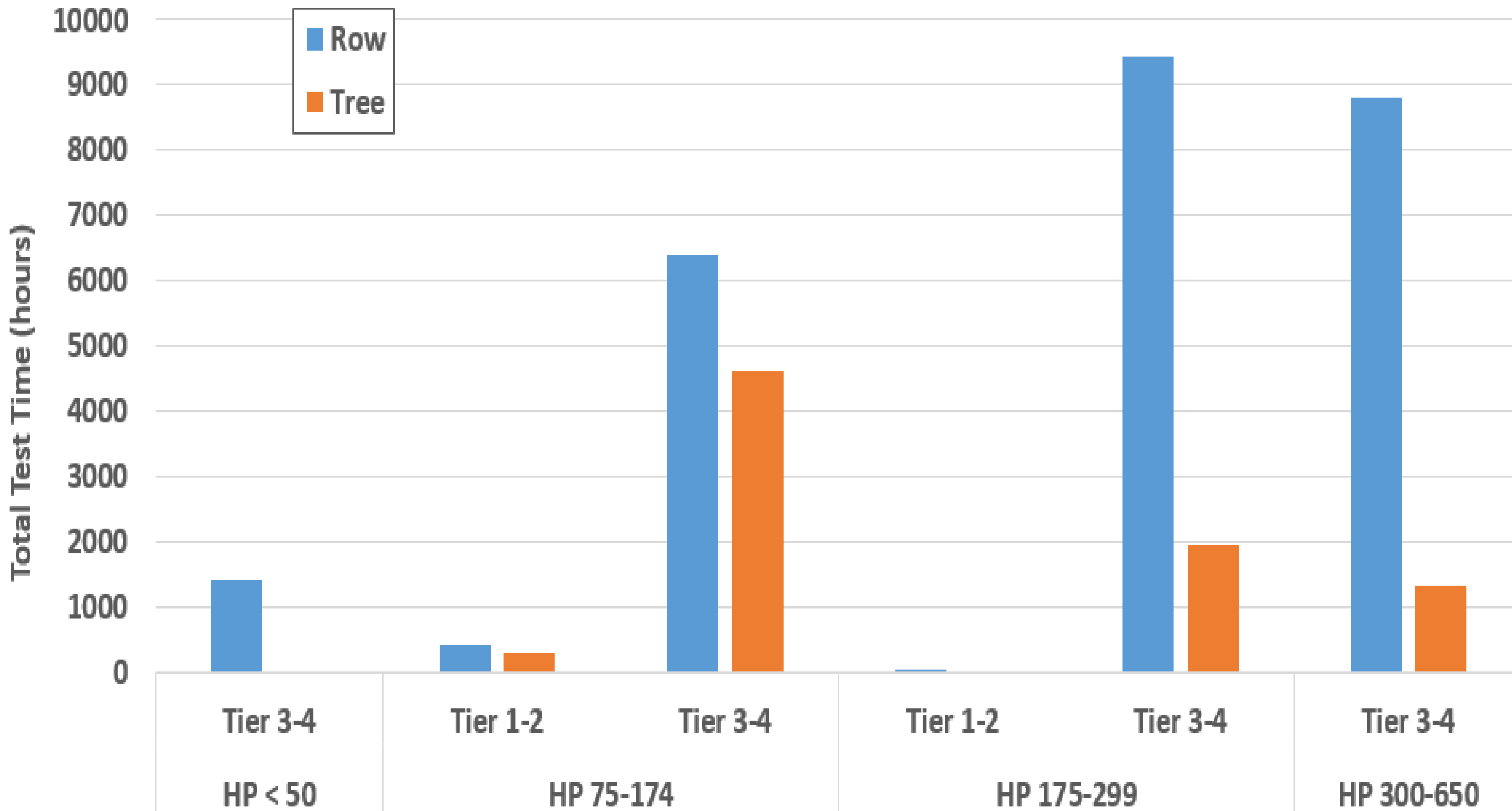


208 Monitored with Engine Hours (40 Tier 0 – 2)

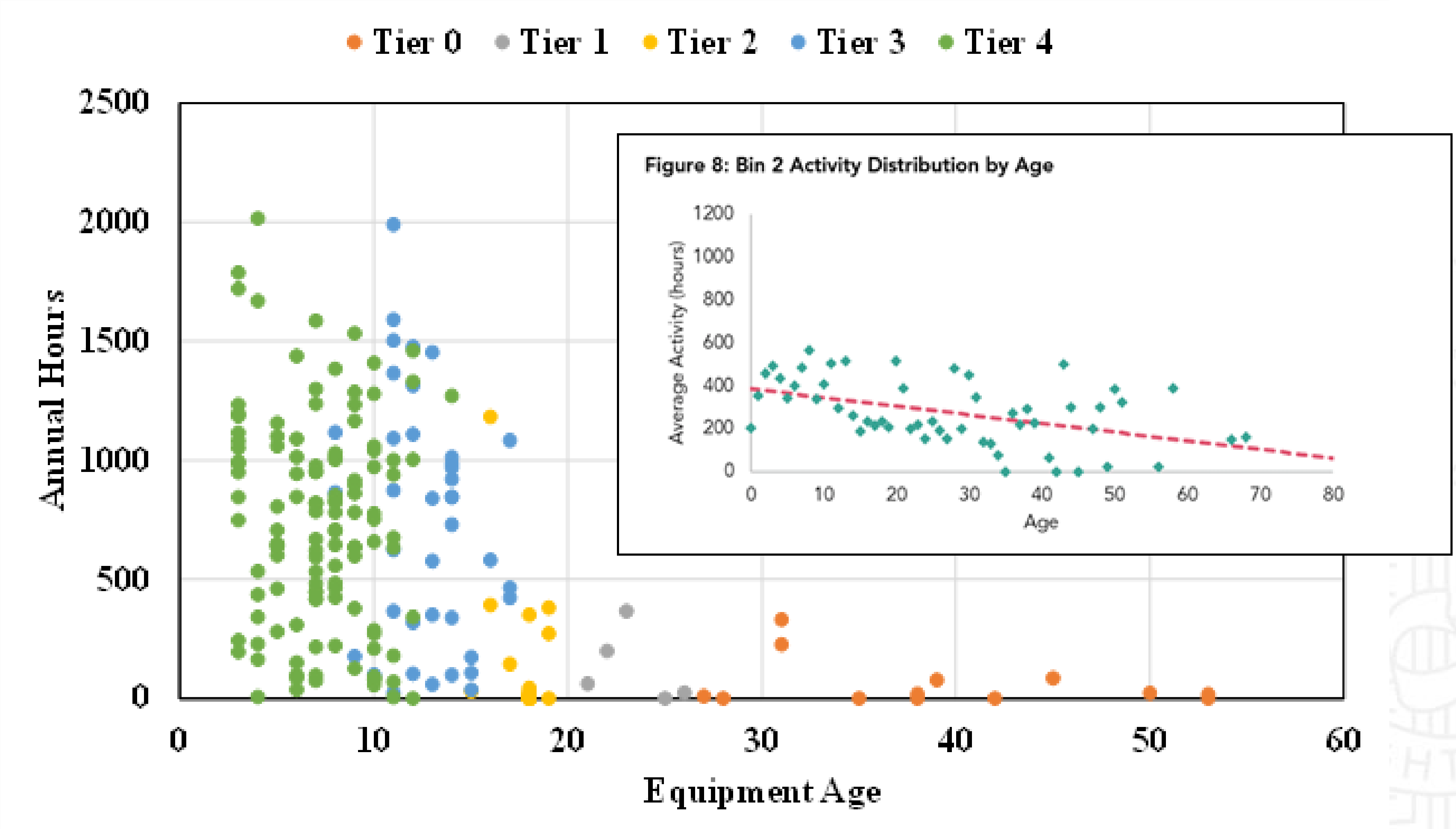
Equipment Age Distribution



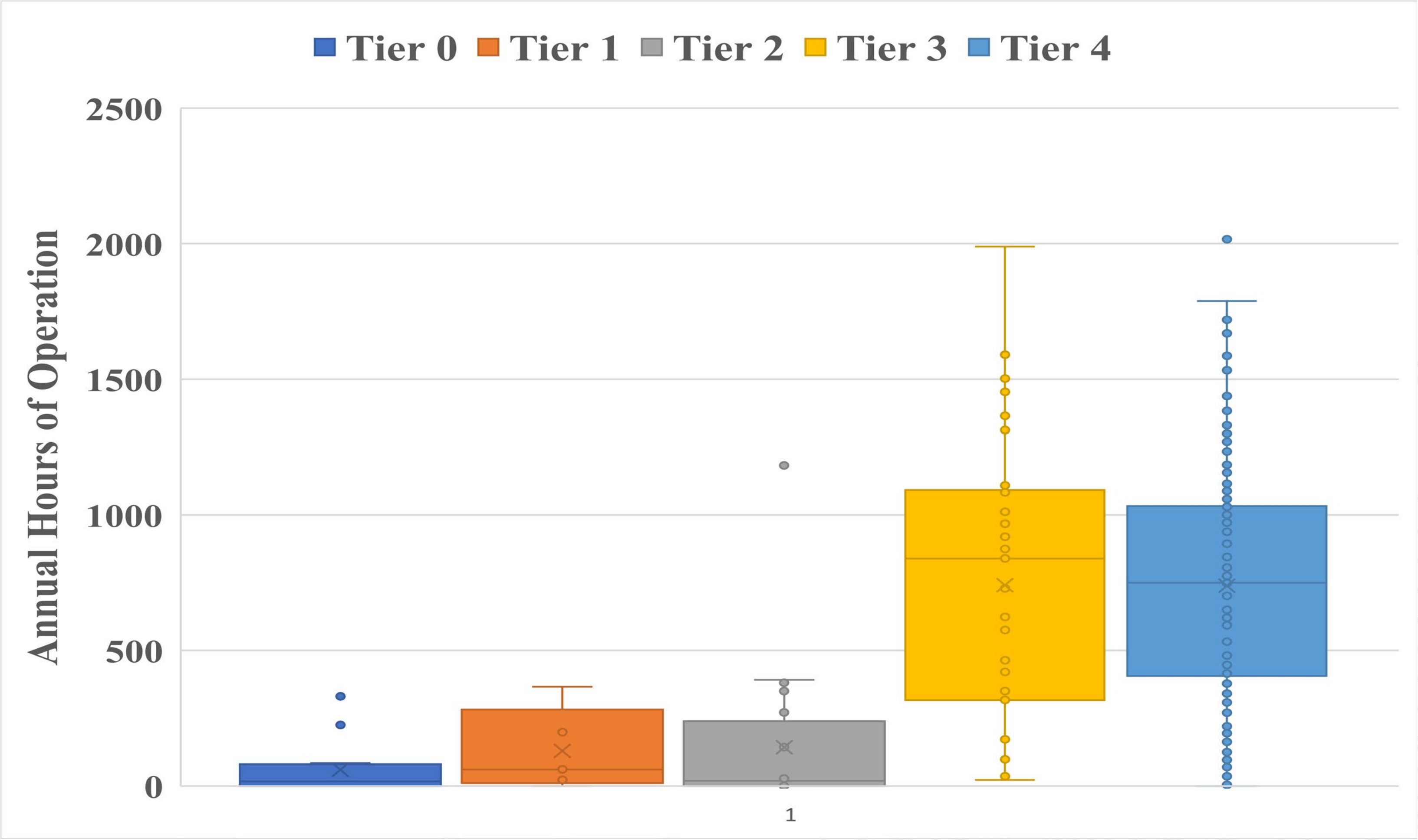
Total Activity Collection



Annual Hours by Tier Level vs Equipment Age Distribution

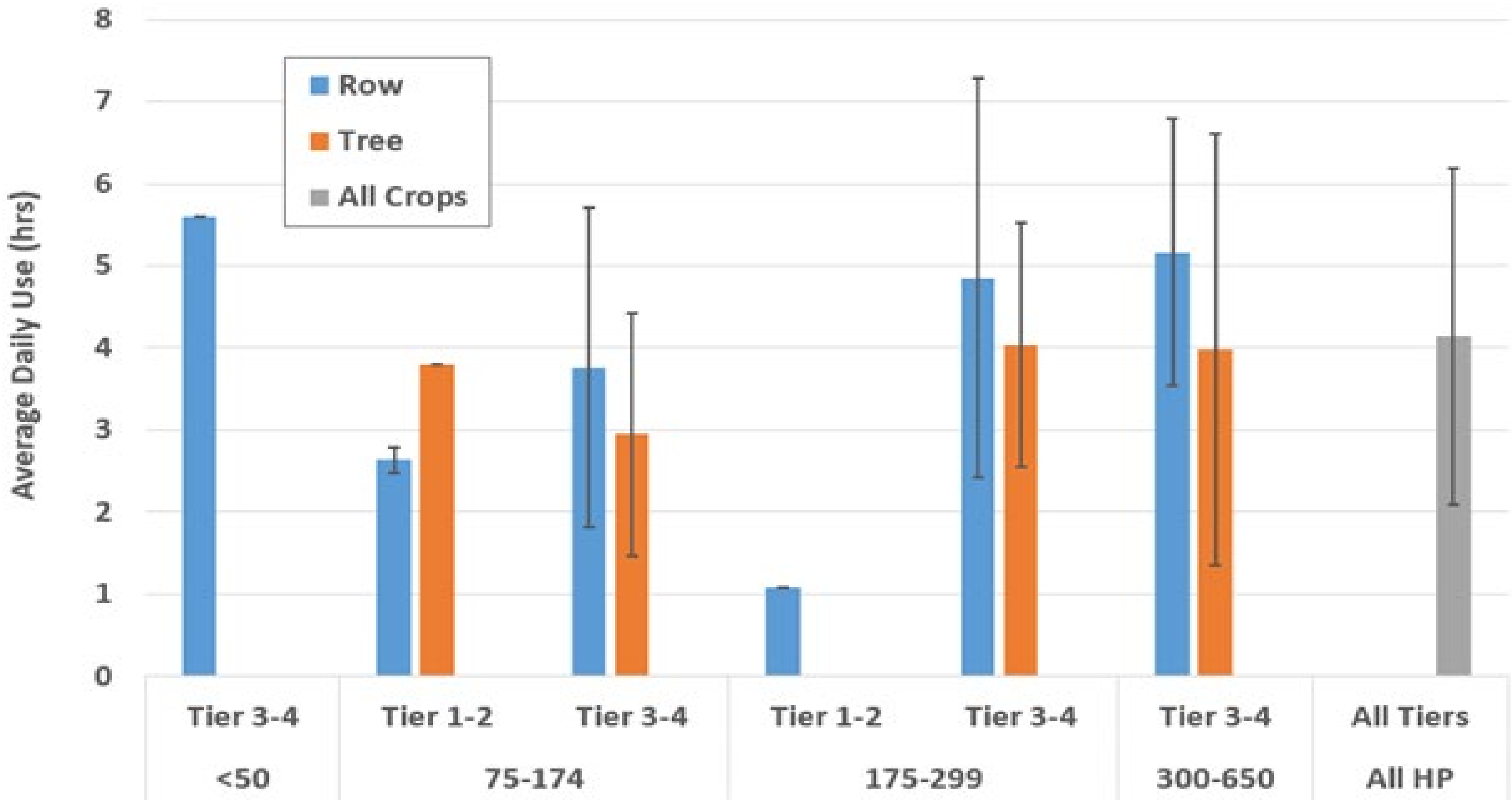


Annual Hours of Use Data



- Average annual hours of use varied from 60 to 741 hours year

Hours of Use per Day Data



- Average hours of use per day mostly varied from 2.6 to 5.6 hours per day, with an average of 4.1 hours per day

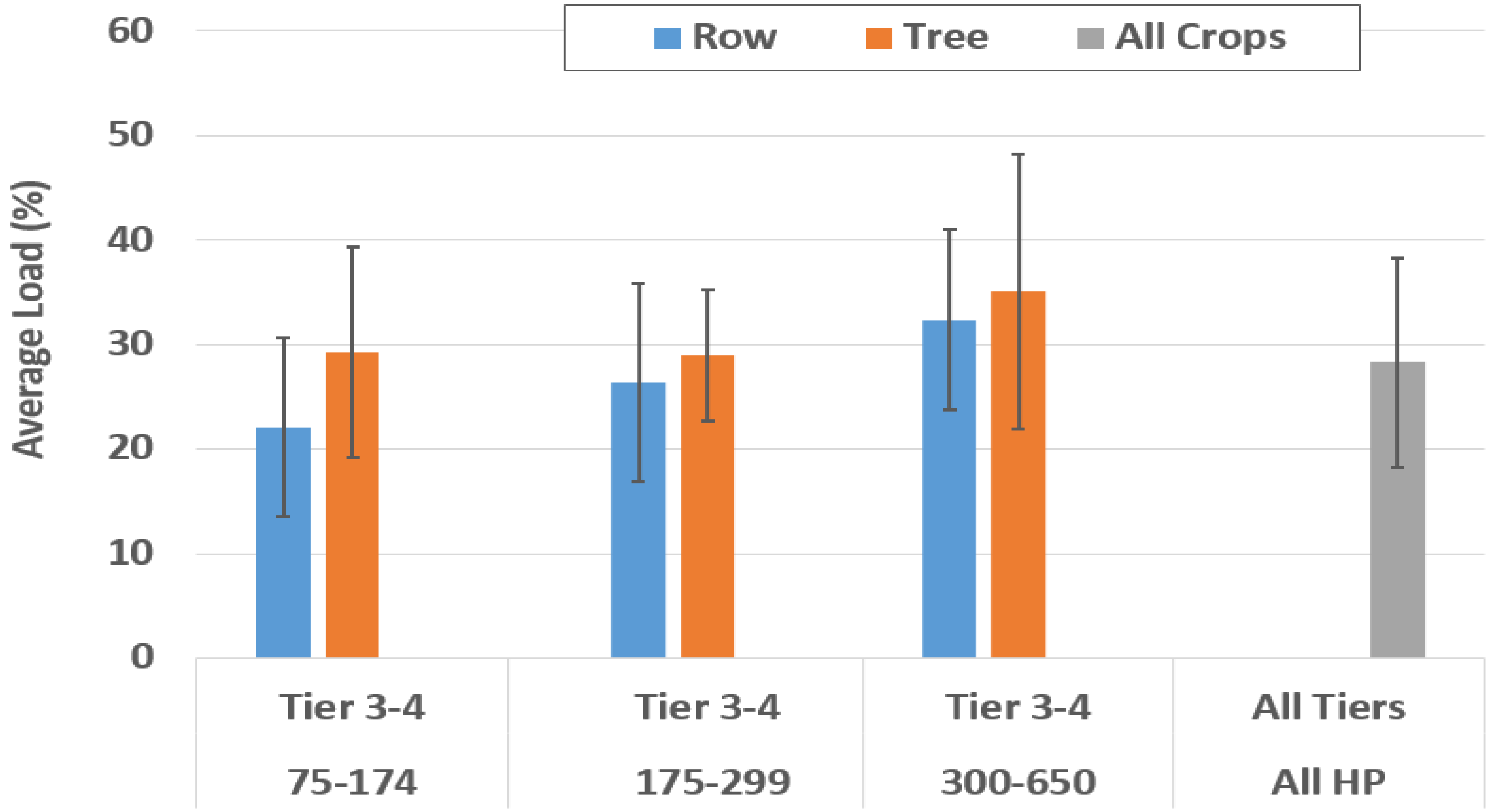
Rental Agency #1

Manufacturer	Model	Start Date	End Date	Rental Duration (Days)	Hours Logged	Hours/day	Hours/Month
John Deere	5085M	11/20/2019	2/26/2020	98	262	3.7	81.3
John Deere	6125M	2/21/2020	3/6/2020	14	31	3.1	67.3
John Deere	6115M	5/1/2020	5/5/2020	4	15	5.3	114.0
John Deere	5115ML	2/27/2020	5/26/2020	89	150	2.4	51.2
John Deere	5115ML	2/27/2020	6/8/2020	102	308	4.2	91.8
John Deere	5100ML	8/6/2020	10/1/2020	56	92	2.3	49.9
John Deere	5115ML	8/10/2020	10/1/2020	52	84	2.3	49.1
John Deere	4044M	9/23/2020	10/6/2020	13	19	2.0	44.4
John Deere	4044M	9/23/2020	10/6/2020	13	23	2.5	53.8
John Deere	5100ML	10/7/2020	10/22/2020	15	55	5.1	111.5
John Deere	5085M	8/3/2020	10/22/2020	80	115	2.0	43.7
John Deere	5115ML	8/3/2020	10/30/2020	88	261	4.2	90.2
John Deere	5100ML	8/3/2020	10/30/2020	88	380	6.0	131.3
John Deere	5075GL	8/20/2020	11/5/2020	77	203	3.7	80.1
John Deere	5115ML	11/3/2020	11/10/2020	7	33	6.6	143.3
John Deere	5115ML	8/3/2020	11/11/2020	100	411	5.8	124.9
John Deere	5115ML	8/3/2020	11/11/2020	100	397	5.6	120.7
John Deere	6125M	8/12/2020	11/13/2020	93	424	6.4	138.6
Kubota	M8560	8/12/2020	11/13/2020	93	317	4.8	103.6
John Deere	5100ML	11/10/2020	12/23/2020	43	107	3.5	75.6
			Average	61.3	184	4.1	88.3
Kubota	M9960	3/15/2021	4/29/2021	45	73	2.3	49.3
Kubota	M9960	3/15/2021	4/29/2021	45	55	1.7	37.2
John Deere	5075GL	3/24/2021	4/30/2021	37	88	3.3	72.3
John Deere	5100GN	8/12/2021	9/9/2021	28	246	12.3	267.1
John Deere	4044M	9/24/2021	10/6/2021	12	31	3.6	78.5
John Deere	4052M	9/24/2021	10/6/2021	12	42	4.9	106.4
John Deere	6125M	9/12/2021	12/9/2021	88	168	2.7	58.0
			Average	38.1	100	4.4	95.5
John Deere	5125ML	8/1/2022	9/26/2022	56	143	3.6	77.6
John Deere	3043D	9/16/2022	10/4/2022	18	27	2.1	45.6
John Deere	3043D	9/16/2022	10/4/2022	18	40	3.1	67.6
John Deere	5055E	8/10/2022	10/7/2022	58	108	2.6	56.6
John Deere	5115ML	8/10/2022	10/7/2022	58	64	1.5	33.5
John Deere	5115ML	6/12/2022	11/4/2022	145	34	0.3	7.1
John Deere	5115ML	8/1/2022	12/9/2022	130	492	5.3	115.1
John Deere	5125ML	8/24/2022	1/25/2023	154	463	4.2	91.4
			Average	79.6	171	2.8	61.8

Rental Agency #2

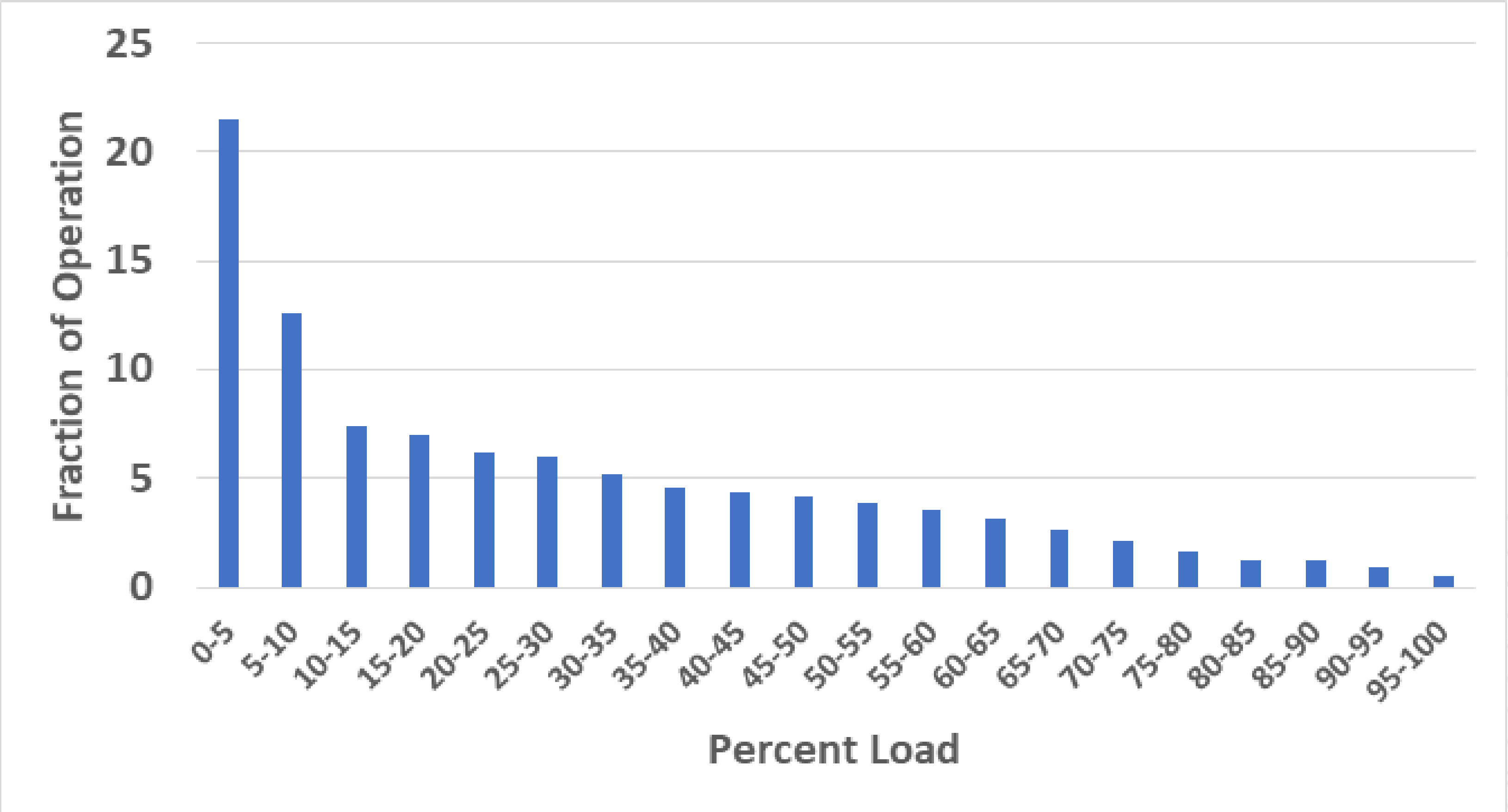
Model Number	Manufacturer	Start Date	End Date	Rental Duration (Days)	Hours Logged	Hours/day	Hours/Month
5045E	John Deere/2021	09/01/2021	10/27/2021	56	184	4.6	99.9
5075E	John Deere/2021	09/01/2021	10/27/2021	56	342	8.6	185.7
5075E	John Deere/2021	09/01/2021	10/27/2021	56	278	7.0	150.9
5055E	John Deere/2021	09/01/2021	10/27/2021	56	165	4.1	89.6
5075E	John Deere/2022	09/01/2022	10/14/2022	43	317	10.3	224.1
5065E	John Deere/2022	09/01/2022	10/14/2022	43	246	8.0	173.9
5065E	John Deere/2022	09/01/2022	10/14/2022	43	471	15.3	333.0
5055E	John Deere/2022	09/01/2022	10/14/2022	43	275	9.0	194.4
5045E	John Deere/2022	09/01/2022	10/14/2022	43	430	14.0	304.0
5075E	John Deere/2022	09/01/2022	10/14/2022	43	458	14.9	323.8
5075E	John Deere/2022	09/01/2022	10/14/2022	43	348	11.3	246.0
5075E	John Deere/2022	09/01/2022	10/14/2022	43	279	9.1	197.2
			Average	47.3	316.1	9.7	210.2

Engine Load Percentage Data



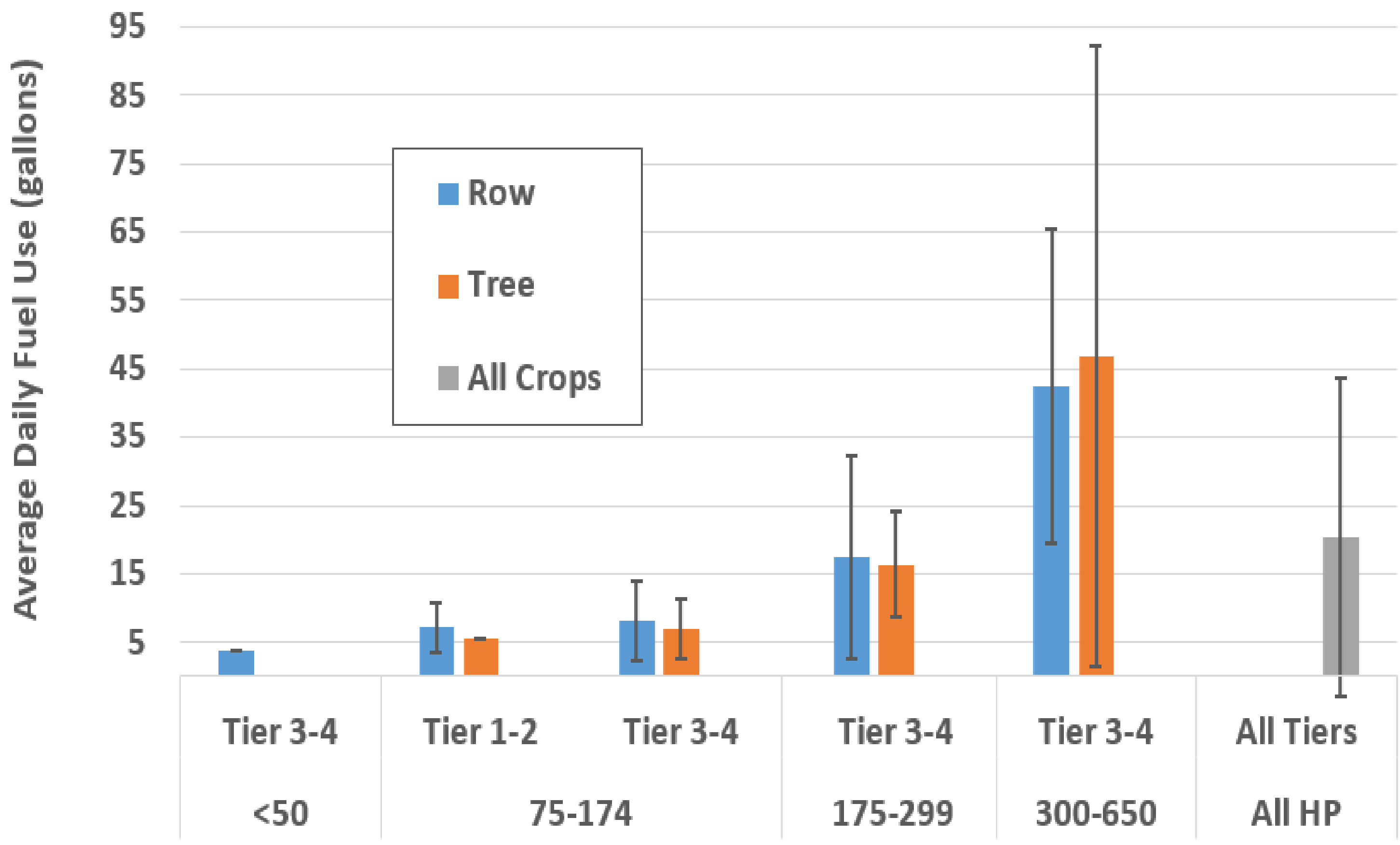
- Average engine load percent varied from 22% to 35% for different categories, with an overall average load of 28%

Engine Load Percentage Data



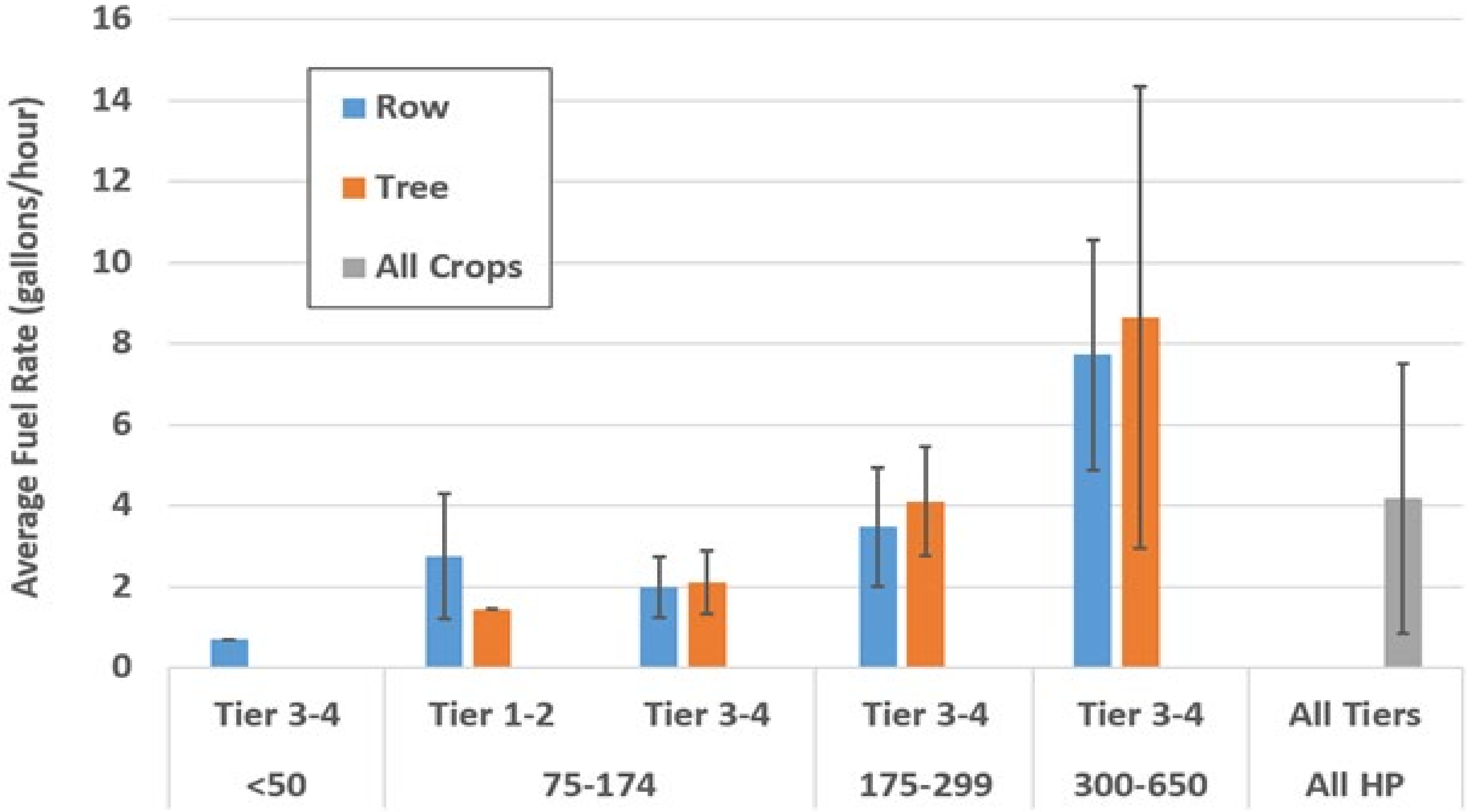
- Average engine load percent showed a high fraction of load percentage from 0-10%, with a gradual tapering off with increasing load above that

Daily Fuel Use Data



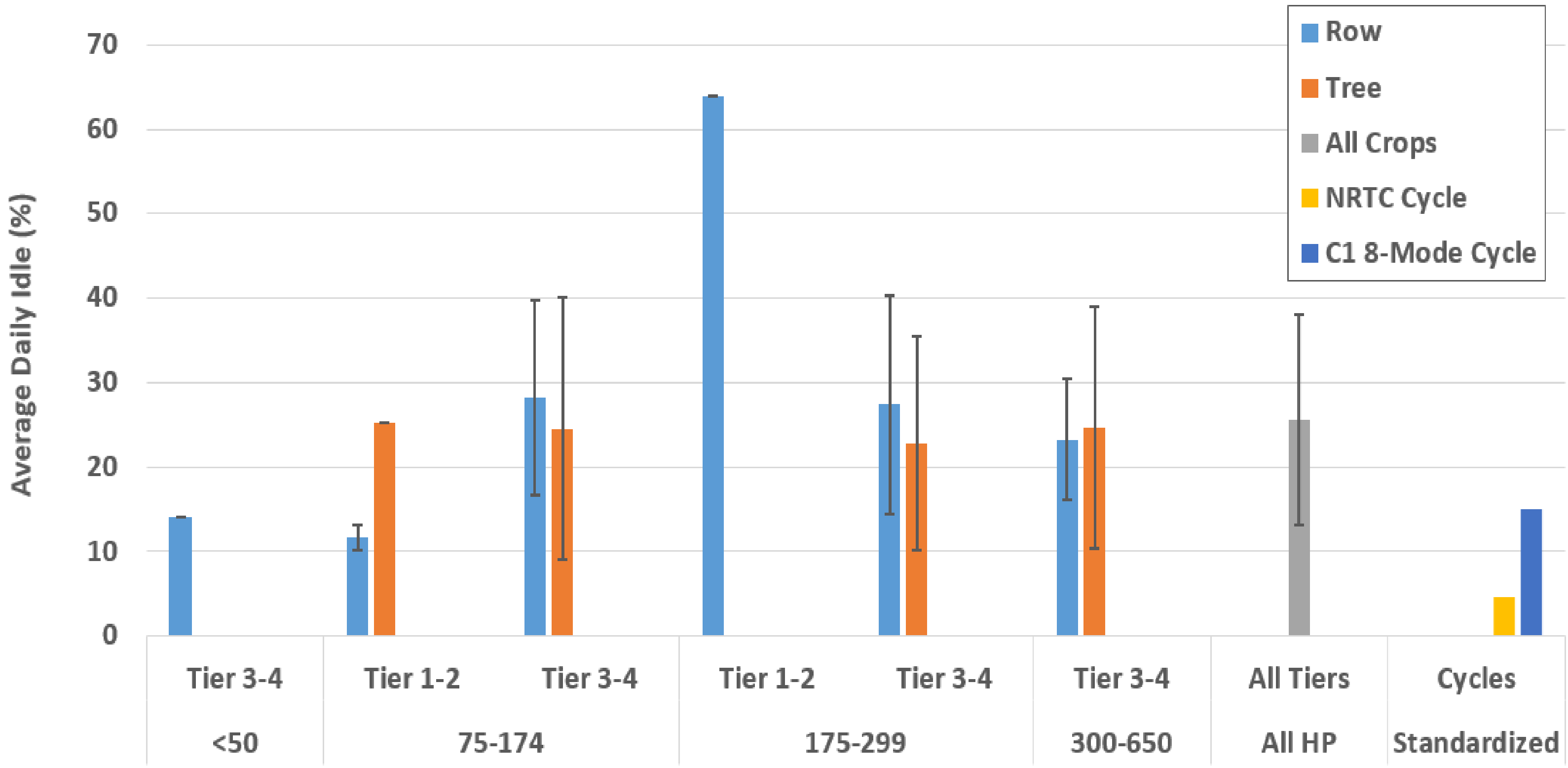
- Daily fuel use showed an as expected increasing trend with engine horsepower size, with average fuel use of 20.4 gallons per day

Fuel Use per Hour Data



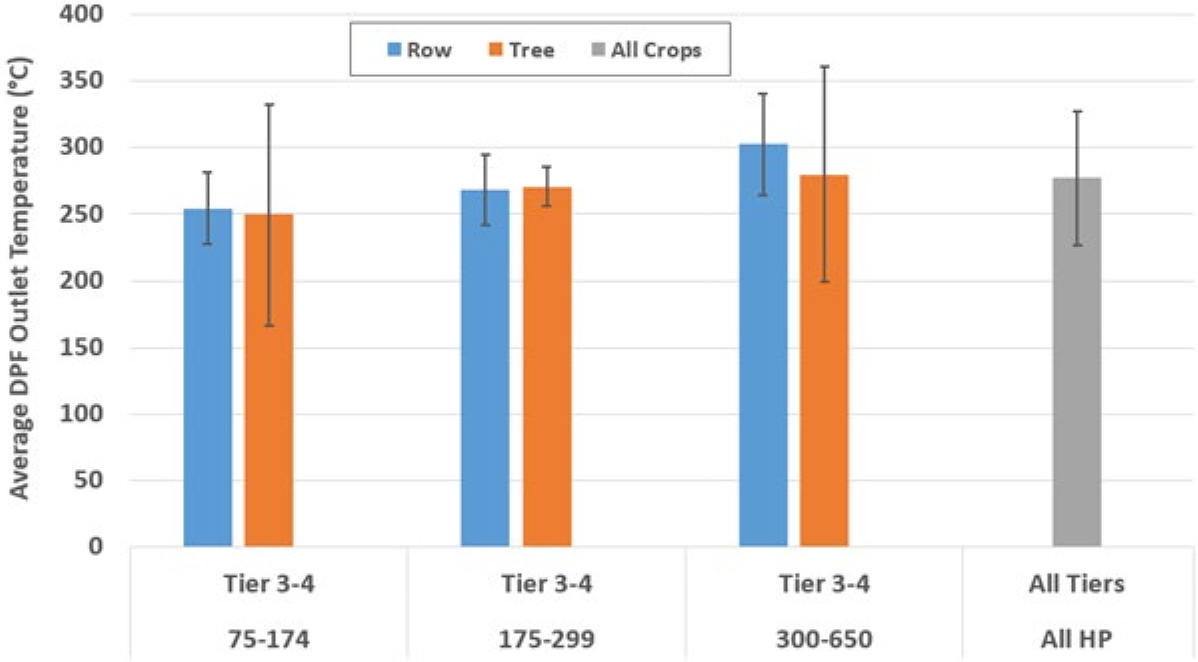
- Fuel Use per hour showed an as expected increasing trend with engine horsepower size, with average fuel use of 4.2 gallons per hour
- For higher hp – 7.7 to 8.6 gals/hour   For lower hp - ~ 2 gals/hour

Idling Data



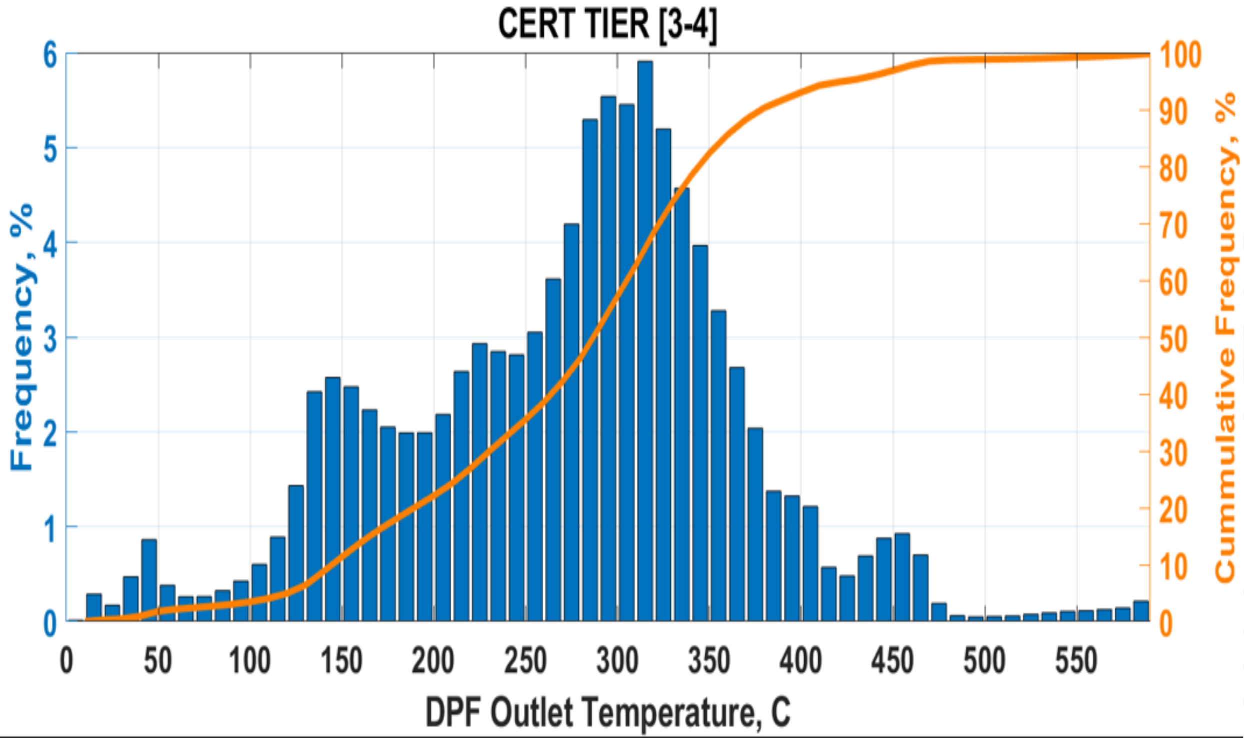
- Average idle fractions for most categories varies from 23 to 28% with a good deal of variability within categories, and an overall average of 27%.
- Average idle fractions for the C1 and NRTC cycles are 4% and 15%, respectively, is lower than the in-use measurements.

DPF Outlet Temperature



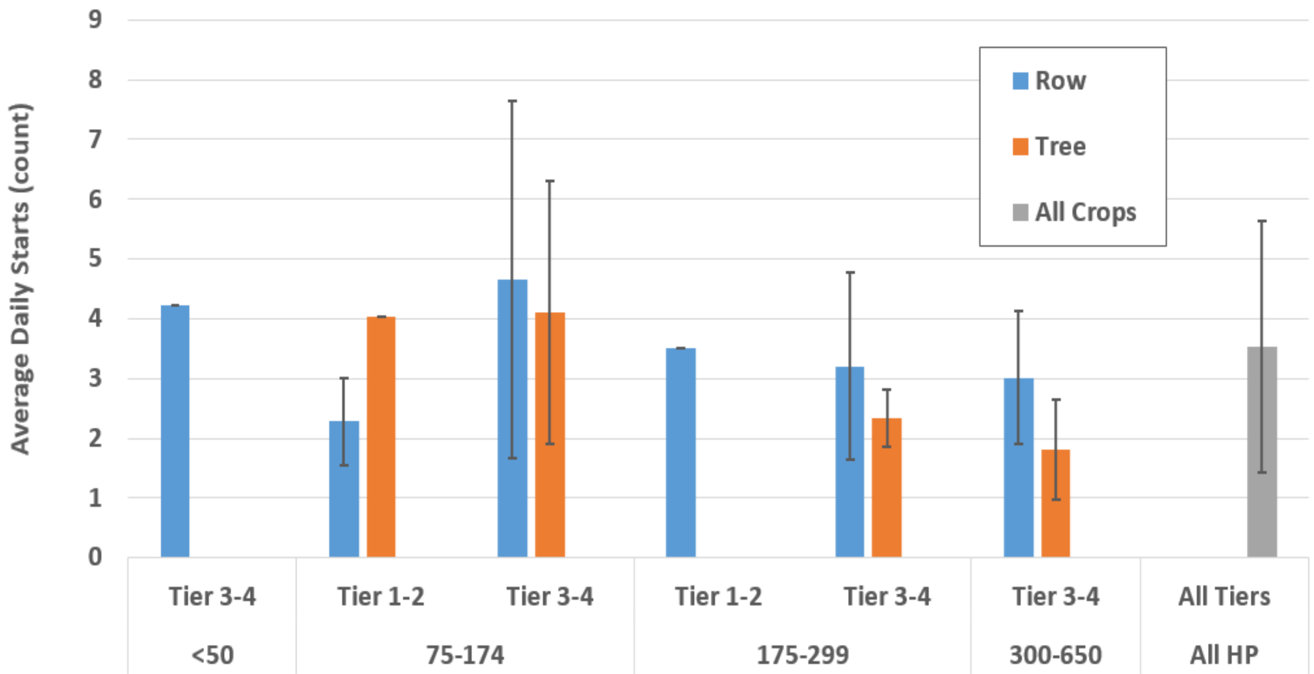
- Average DPF outlet temperatures were at or above 250 °C category for both the tree and row crops, for all of the different hp categories, and for the different farm sizes.

DPF Outlet Temperature



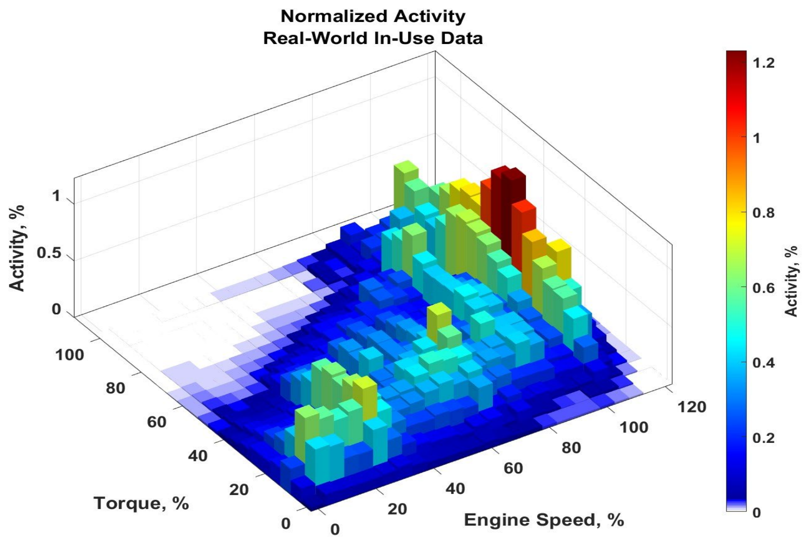
- DPF outlet temperature is above 200°C for 78.5% of operating time.
- So, for 21.5% of the operating time, the DPF outlet temperature would be below 200°C, which would likely not be high enough to allow for the injection of urea into the SCR
  - 17.2% of below 200°C operation is at loads below 10%.

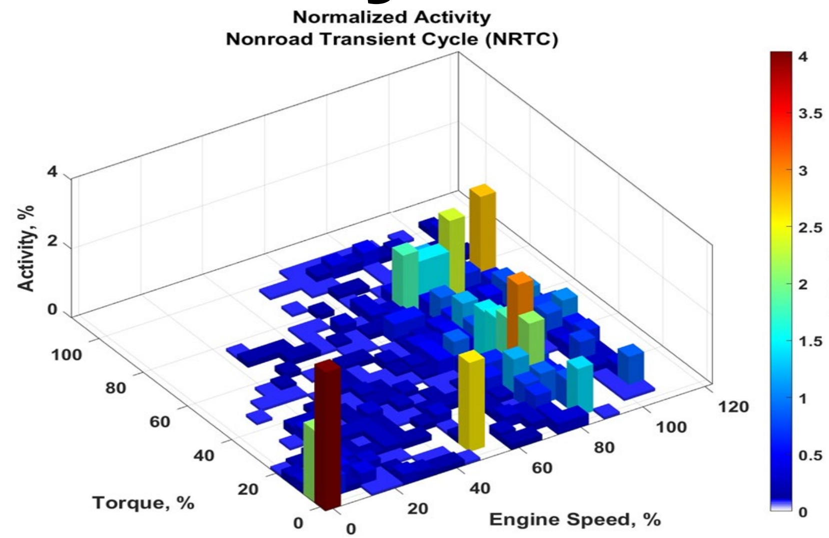
Engine Starts



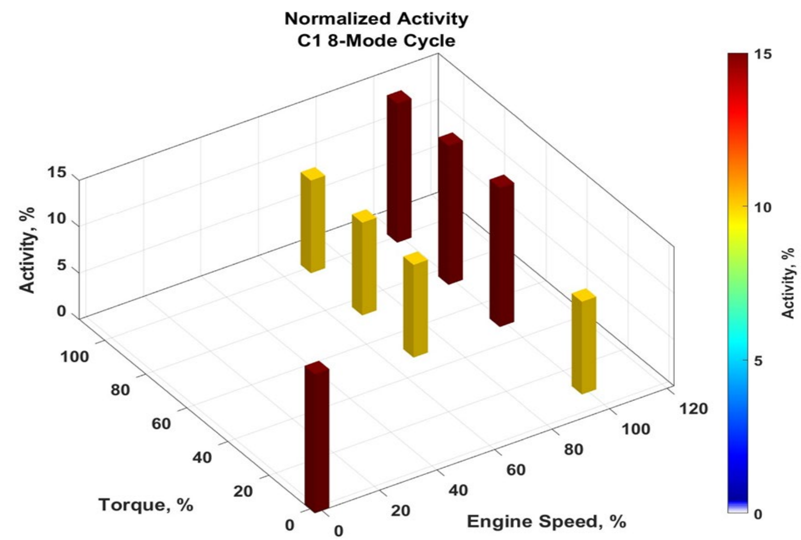
- Average number of starts per day was ~3.5 starts, with a range for most categories from 2.5 and slightly more than 4 starts per day.
- 2.2 average hot starts - soaks with durations ≥ 30 seconds and ≤ 60 minutes
- 0.4 average intermediate starts - ≥ 60 minutes and ≤ 720 minutes

In-Use data vs. Test Cycles

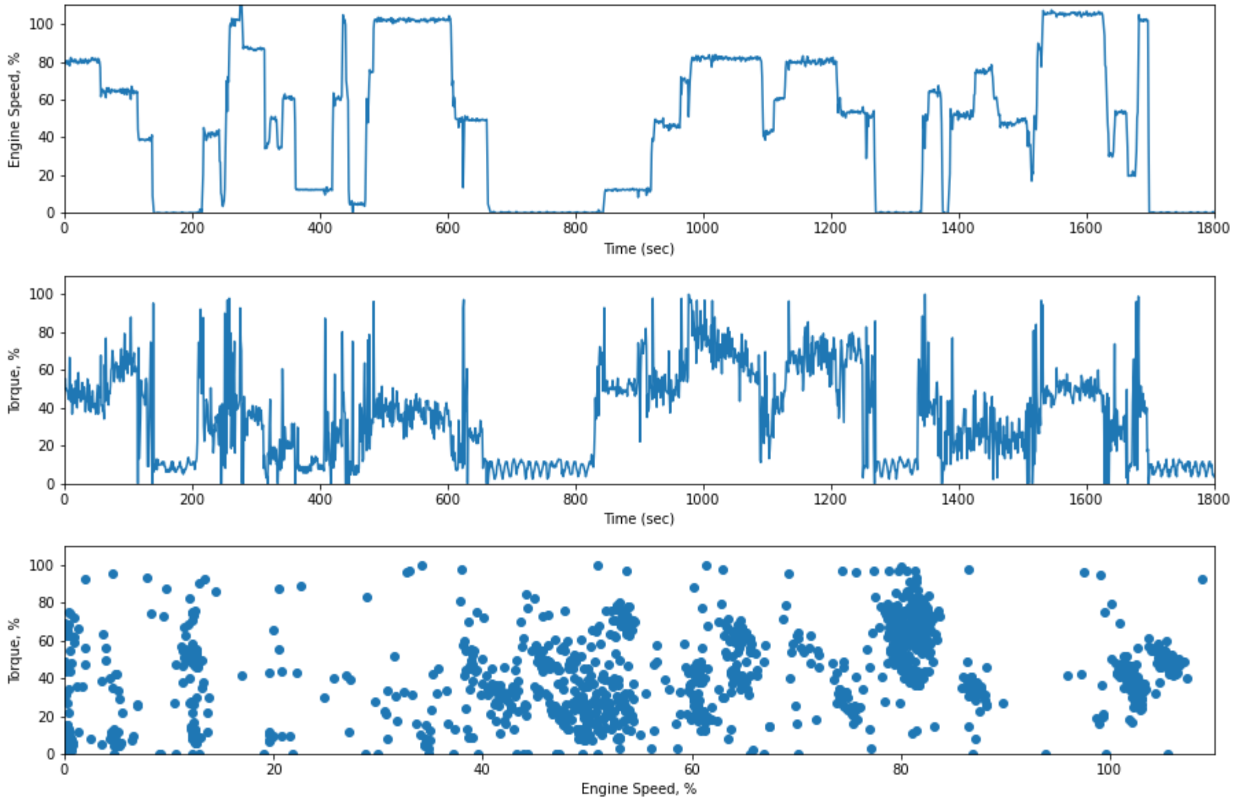




- The in-use activity data covers a much broader range of operating conditions than are found in the certification cycles.
- In general, the distributions for the in-use data show that there could be a more significant contribution at low load conditions than is captured in the certification cycles.



Engine Speed - Torque Profiles



- Engine test cycles developed based on snippets of real-world, in-use data.
- Test cycles for overall tractor profiles, plus different crop types/ horsepowers.
- Most representative engine speed and torque profile for the engine dynamometer test cycle determined by snippet showing most similar breakdown in power bins compared to the whole population file, based a mean square error.

Summary and Conclusions

- Hours of operation
  - Hours/day averaged 4.1 hr/day, with a range from 2.6 to 5.6 hr/day
  - Average annual hours of usage declined as a function of engine age/older engine technology. The average annual hours were 60 hours - Tier 0, 130 hours - Tier 1, 143 hours - Tier 2, 741 hours - Tier 3, and 739 hours - Tier 4.
- Average engine load - ranged between 22% and 33% for different categories, with an overall average load percentage of 28%
  - About 32% of the operation was below 10%
- Average Idle fractions - for most categories varies from 23 to 28% with a good deal of variability within categories, and an overall average of 27%
- Fuel Use per hour increased with increasing horsepower size
  - Average 4.2 gallons/hour Higher hp – 7.7 to 8.6 gals/hour Lower hp - ~ 2 gals/hour
- In-use activity data covers broader range of operation than certification cycles
  - And includes more operation at low loads
- Engine test cycles developed based on snippets of real-world, in-use data

Recommendations

- This extensive study, with 208 tractors and real-time activity, provides a strong foundation upon which CARB and other air quality agencies can construct updates to their emissions inventories and inform incentive and other air quality programs
- Air quality agencies should consider these findings with other datasets to update emissions inventories and to support air quality programs, such as the Funding Agriculture Replacement Measures for Emission Reductions (FARMER).
- Such agencies should consider longitudinal assessments using this study design to assess long-term trends of the in-use agricultural fleet.
  - Follow-up studies could assess how engine load distributions and idling times measured today change for the in-use fleet of agricultural equipment in the 2030 timeframe.
- Near-term, CARB should consider supplementing the results of this study using a broader survey collecting information on the distribution of engine population by tier and annual activity levels of such equipment.

Acknowledgements

- We acknowledge assistance from stakeholders in the agriculture industry, including Roger Isom, California Cotton Ginners and Growers Association (CCGGA)/Western Agriculture Processors Association (WAPA), Manuel Cunha, Nisei Farmers League, Chris McGlothlin, CCGGA/WAPA, Kevin Abernathy, Milk Producers Council, and others, for support in identifying participating farms and leasing companies, technical support in the development of the program, and valuable comments in stakeholder meetings.
- We acknowledge funding from the California Air Resources Board under contract 19RD002. We knowledge additional funding from the San Joaquin Valley Air Pollution Control District (SJV APCD) and the San Joaquin Valleywide Air Pollution Study Agency and from the United States Environmental Protection Agency (U.S. EPA) under Contract No. 68HE0C18C0001 with Eastern Research Group. CARB and the U.S. EPA also provided data loggers in-kind for use for the project.

APPENDIX