Forecasting California Pesticide Demand using PUR Dataset

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Abstract

Pesticide use related to agriculture and non-agricultural uses has increased six-fold during the last three decades. California has been collecting pesticide use since 1990, and that is recognized as the most comprehensive pesticide reporting program in the world. The program includes the information for 1003 active ingredients and 309 end use commodities. This study aims to develop a relationship between end uses and chemicals to determine the possible impact of end-uses for pesticide demand. In this study, we develop a comprehensive relationship between the pesticide end-uses and active ingredients and analyze pesticide demand using the historical data available from the PUR dataset and agricultural production data using stochastic simulation methods.

Keywords: Pesticide use, PUR dataset, stochastic simulation

1. Introduction

Pesticides are divided into many classes including insecticides (bug control), herbicides (weed control), and fungicides (fungus control), rodenticides and antimicrobials etc. The largest share of expenditures on pesticides is associated with agricultural production. The Environmental Protection Agency (EPA) reported that in 2007, $8 billion of the $12.5 billion in total pesticide expenditures were purchases intended for use in agriculture (EPA, 2014). In other areas significant portions of pesticide expenditures are attributable to water treatment, household cleaners, disinfectants and swimming pool maintenance, etc. Based on the information available on the California Department of Pesticide Regulation webpage, this study aims to create a forecasting method for future pesticide demand. Thus, we develop a comprehensive relationship between the pesticide end-uses and active ingredients.

The demand for pesticides use in agricultural production has long been of great interest for researchers. Researchers suggested various methods to find the relationship between agricultural pesticide use and factors impacting pesticide use. Previous studies of this relationship have been based primarily on survey or aggregated agricultural production data (Burrows, 1983; Antle, 1984; Lichtenberg and Zilberman, 1986; Fernandez-Cornejo, 1998; Zilberman, Undated). For example, Burrows (1983) analyzed the effects on pesticide demand of Integrated Pest Management (IPM) in cotton production utilizing survey data of cotton farmers in the San Joaquin Valley. In his study, Burrows developed a regression model where the variables influencing pesticide use were pesticide price, crop price, pest control service, expected yield, farm size, IPM, irrigation, and weather. He concluded that the IPM adoption caused a sizable reduction in pesticide expenditures by the cotton farmers who participated in the study. The paper argued that the model could be improved by accounting for possible simultaneous equation bias in the regression model and the use of limited variables to define IPM adoption.

Lichtenberg and Zilberman (1986) suggested that unlike standard inputs such as land, labor and capital, modelling pesticide use is fundamentally different. The difference comes from the nature of pesticide, which does not enhance productivity directly but controls the damage caused by environmental conditions. Lichtenberg and Zilberman (1986) proposed four specifications to model pesticide use aiming to decrease error from its traditional specification. This study makes us realize the importance of model specification when pesticide use is of concern. Some empirical studies also investigate both the rational and mathematical relationship between agricultural pesticide use and other variables in agricultural production. For instance, Antle (1984) found that in the United States, pesticide use increases when the average crop price increases. His results also indicate that pesticide use decreases when the agricultural labor expense, machinery cost and land prices increase. Although Antle's results are rational in terms of impact of other variables on pesticide use, the mathematical relationship utilized would not be applicable for analyzing individual crops or chemicals because the study results are based on national averages of crop and pesticide prices.

Additional research points to the difficulty in estimating pesticide use. For example, Fernandez-Cornejo et al. (1998) summarized several perspectives on pesticide productivity and relative yield effects of pesticide use. The simulated results in this study show that pesticide use estimations tend to be highly variable depending on the model specification, regression model, variable selection, data availability, and experts' opinions. Zilberman (undated) applied one of the specifications developed by Lichtenberg and Zilberman (1986) to data obtained from cotton production in the San Joaquin Valley of California. He reported the available data: output amount; input values for labor, fertilizer and machinery; pesticide amount; education and experience of farmers; output price, pesticide price; IPM enrollment of the farmers. Then, he tested several estimation methods to increase the validity of his results. His results indicated that pesticide use significantly decreases the damage in cotton production and IPM increases the effectiveness of pesticide use. This method does allow one to replicate it for each chemical on a single crop. However, when dealing with larger populations such as our 25 main crops, 25 highly used pesticides, and 10 variables for each crop-chemical match up, it requires 625 crop-chemical combinations and around 6250 historical data sets. This makes this method almost unreasonable to assess pesticide use in a larger area than a simple crop-chemical assessment.

In our study we quantify pesticide use by focusing on the historical relationship of main variables, especially correlations, distributions and deviations associated with those variables influencing pesticide use. We then incorporate randomness to these variables by using simulation to forecast future use. Researchers develop such models along with simulation methods to allow the researcher to estimate chemical use more accurately using available data without encountering model specification issues. In this study, we use such models and Monte Carlo simulation methods, which are very well suitable for large datasets, to forecast pesticide demand.

1.1. Pesticide Use Reporting Program in California

Pesticide use is positively correlated with agricultural production. According to the National Agricultural Statistics Service of the U.S. Department of Agriculture (USDA-NASS, 2011), California produces about half of the nation's vegetables and melons and over half of the fruits and nuts in the United States. According to the DPR, California became the first state to require full reporting of agricultural pesticide use in response to demands for more realistic and comprehensive pesticide use data in 1990 (DPR, 2014). In this context, the DPR launched the Pesticide Use Reporting (PUR) program, recognized as the most comprehensive in the world (DPR, 2014).

The PUR program requires that all agricultural pesticide use must be reported monthly to county agricultural commissioners, who in turn, report the data to DPR. The DPR focuses on product compliance to protect consumers from side effects by registering active ingredients (AIs) for sale and use in California. The PUR dataset, is published and available to the public on the

DPR website. It includes information for 1003 active ingredients and 309 end uses from 1991 to 2012 (PUR, 2014). The PUR dataset is a great source for marketplace surveillance and use in forecasting future pesticide demand in California.

2. Data summary

PUR dataset covers the period from 1991 to 2012. The data are collected from the DPR webpage and includes chemical quantity (Q_{PUR}) applied for each specific end-use. The PUR dataset provides information about the end-use, location, application date, acres treated and pesticide applied. A total of 1003 chemicals and 309 end-uses are reported for this period. In 2012, there were 629 chemicals and 238 end-uses included in the PUR dataset. An input-output matrix was developed for end-use relative to each AI for 2012.

These end-uses are grouped into 33 end-use categories; the first 31 end-uses include 25 agricultural crops and 6 non-agricultural end-use. These are the larger end use shares and are forecasted individually. The rest of the end use representing only a minor share of the total are aggregated into two groups: other agricultural end use and other non-agricultural end use.

Figures 1 and 2 show shares of major chemicals assigned to the end-use commodities. The application of (Z,Z)-11,13-Hexadecadienal dominates end use for agricultural commodities which is followed by chloropicrin. For non-agricultural end-use, Fipronil and 1,3-dichloropropene are the most important chemicals.

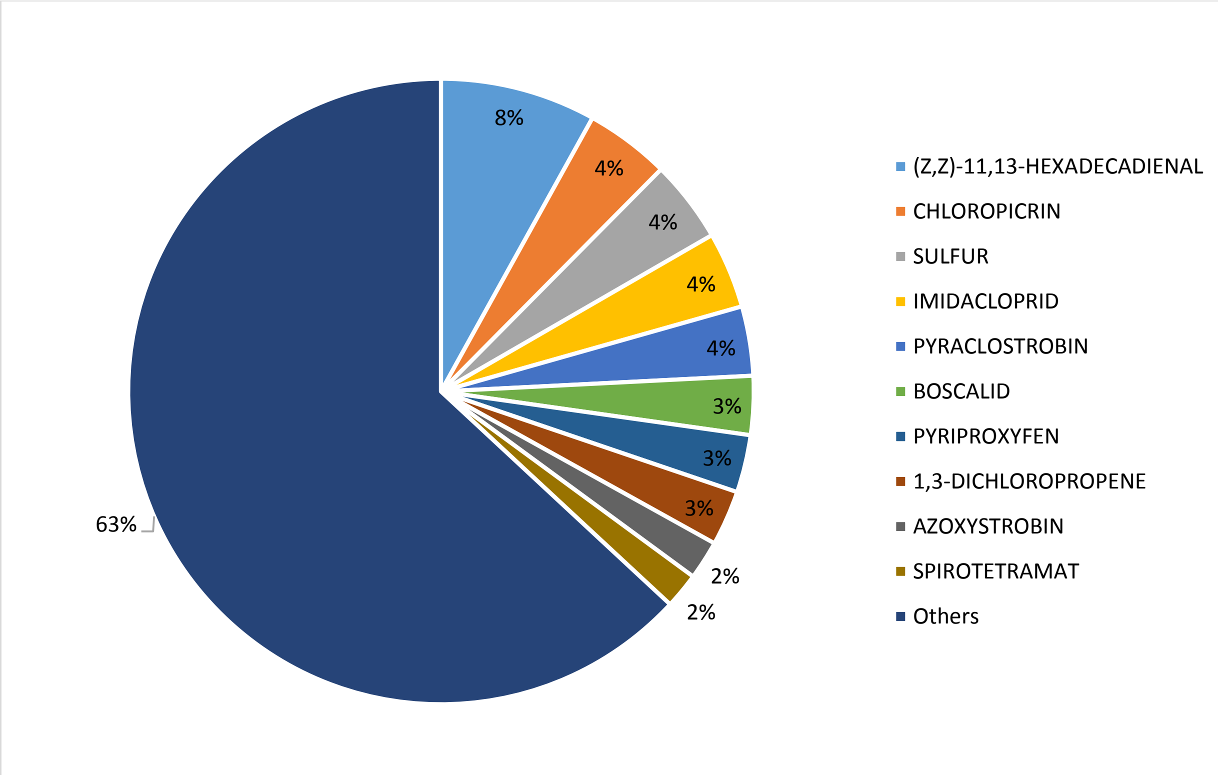

Figure 1. Major pesticide use by 25 selected agricultural commodities in 2012 (% of total pounds applied)

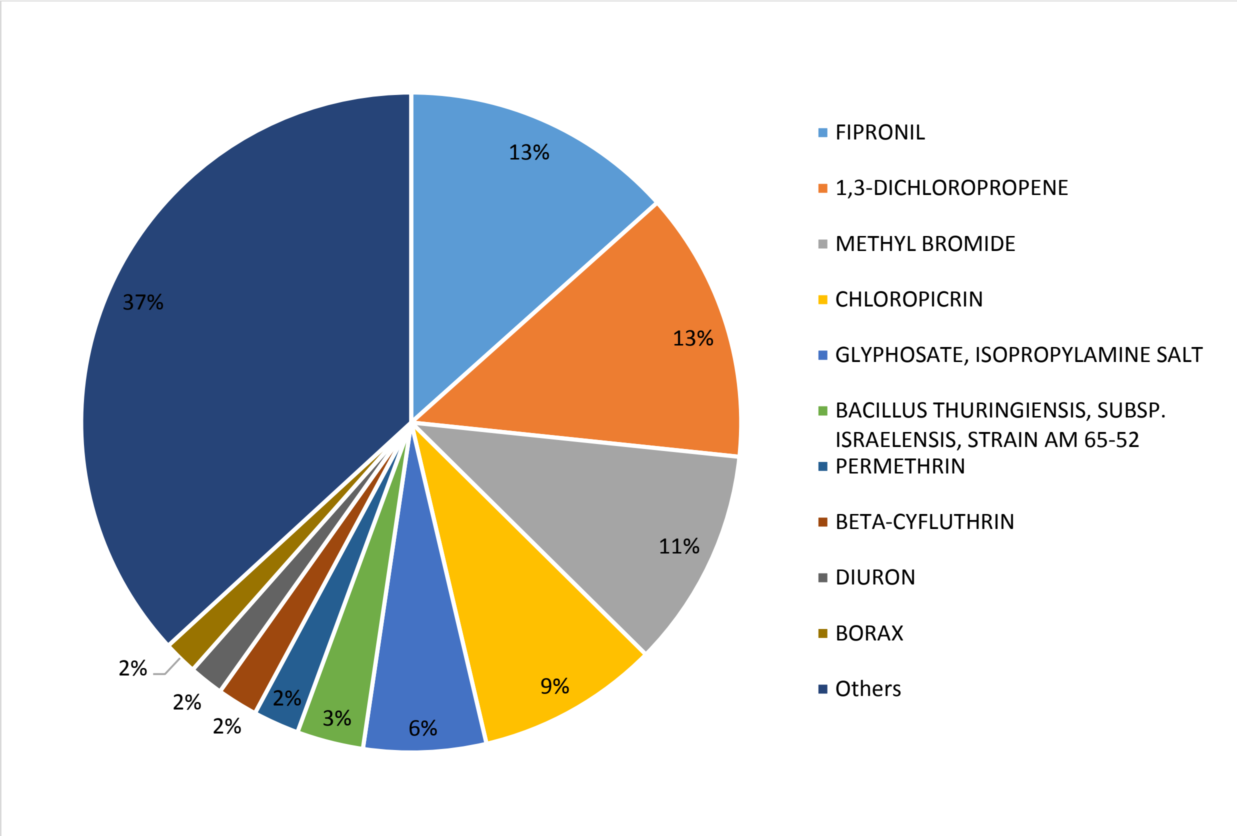

Figure 2. Major pesticide use by six non-agricultural end uses in 2012 (% of total pounds applied)

In total For example, is the largest recorded use chemical accounting for 28 percent of total end-use.

Table 1. Share of chemicals in 2012 (in pounds)

Chemical Code	Chemical Name	Chemical Use Amount	Share of chemicals
5314	(Z,Z)-11,13-Hexadecadienal	10,574,757.72	6.16%
136	Chloropicrin	7,926,399.19	4.62%
573	1,3-Dichloropropene	6,447,887.64	3.75%
3849	Imidacloprid	6,181,687.73	3.60%
560	Sulfur	5,739,920.64	3.34%
5759	Pyraclostrobin	5,120,539.21	2.98%
4019	Pyriproxyfen	4,744,735.13	2.76%
5790	Boscalid	4,176,921.80	2.43%
385	Methyl Bromide	3,511,314.12	2.04%
4037	Azoxystrobin	2,983,585.06	1.74%
5955	Spirotetramat	2,790,550.68	1.62%
1855	Glyphosate, Isopropylamine Salt	2,661,388.57	1.55%
2254	Abamectin	2,382,755.65	1.39%
5964	Chlorantraniliprole	2,353,794.53	1.37%
970	Potassium N-Methyldithiocarbamate	2,343,212.02	1.36%
616	Metam-Sodium	2,315,220.11	1.35%
5946	Spinetoram	2,300,051.04	1.34%
4000	Cyprodinil	2,174,733.31	1.27%
3995	Fipronil	2,035,870.70	1.19%
	Other Chemicals	92,984,149.26	54.14%

Table 2. Share of chemicals by end-use commodity in 2012 (in pounds)

Commodity Code	Commodity Name	End Use Chemical Amount	Share
29143	Grapes, Wine	25,704,944.11	14.97%
3001	Almond	20,630,727.71	12.01%
29141	Grapes	14,743,783.26	8.58%
1016	Strawberry (All Or Unspec)	13,603,819.46	7.92%
29136	Tomatoes, For Processing/Canning	13,280,626.89	7.73%
29111	Carrots, General	7,185,732.28	4.18%
2006	Orange (All Or Unspec)	5,238,234.95	3.05%
40008	Soil Application, Preplant-Outdoor (Seedbeds,Etc.)	4,829,446.60	2.81%
28072	Rice (All Or Unspec)	4,535,819.91	2.64%
3009	Walnut (English Walnut, Persian Walnut)	3,667,180.05	2.14%
10	Structural Pest Control	3,459,304.22	2.01%
3011	Pistachio (Pistache Nut)	3,368,078.59	1.96%
40	Rights Of Way	2,954,015.20	1.72%
29121	Cotton, General	2,905,211.84	1.69%
23001	Alfalfa (Forage - Fodder) (Alfalfa Hay)	2,845,683.72	1.66%
5004	Peach	2,731,199.24	1.59%
14011	Onion (Dry, Spanish, White, Yellow, Red, Etc.)	1,811,020.66	1.05%
11003	Peppers (Fruiting Vegetable), (Bell,Chili, Etc.)	1,775,218.39	1.03%
30	Landscape Maintenance	1,516,319.64	0.88%
66000	Uncultivated Agricultural Areas (All Or Unspec)	1,481,664.78	0.86%
5002	Cherry	1,165,051.20	0.68%
5003	Nectarine	1,159,239.49	0.67%
50	Public Health Pest Control	946,061.00	0.55%
2008	Tangerine (Mandarin, Satsuma, Murcott, Etc.)	918,770.82	0.53%
22005	Corn (Forage - Fodder)	906,993.10	0.53%
13045	Lettuce, Head (All Or Unspec)	906,127.17	0.53%
13031	Lettuce, Leaf (All Or Unspec)	899,181.20	0.52%
10008	Watermelons	451,864.07	0.26%
13024	Spinach	354,572.35	0.21%
13005	Broccoli	296,507.99	0.17%
29119	Corn, Human Consumption	242,289.15	0.14%
A	Other Ag Com	17,465,847.27	10.17%
N	Other Nonag Com	7,768,937.77	4.52%

Trends of top 15 end-use values for 1990 to 2012 are shown in Figure 3.

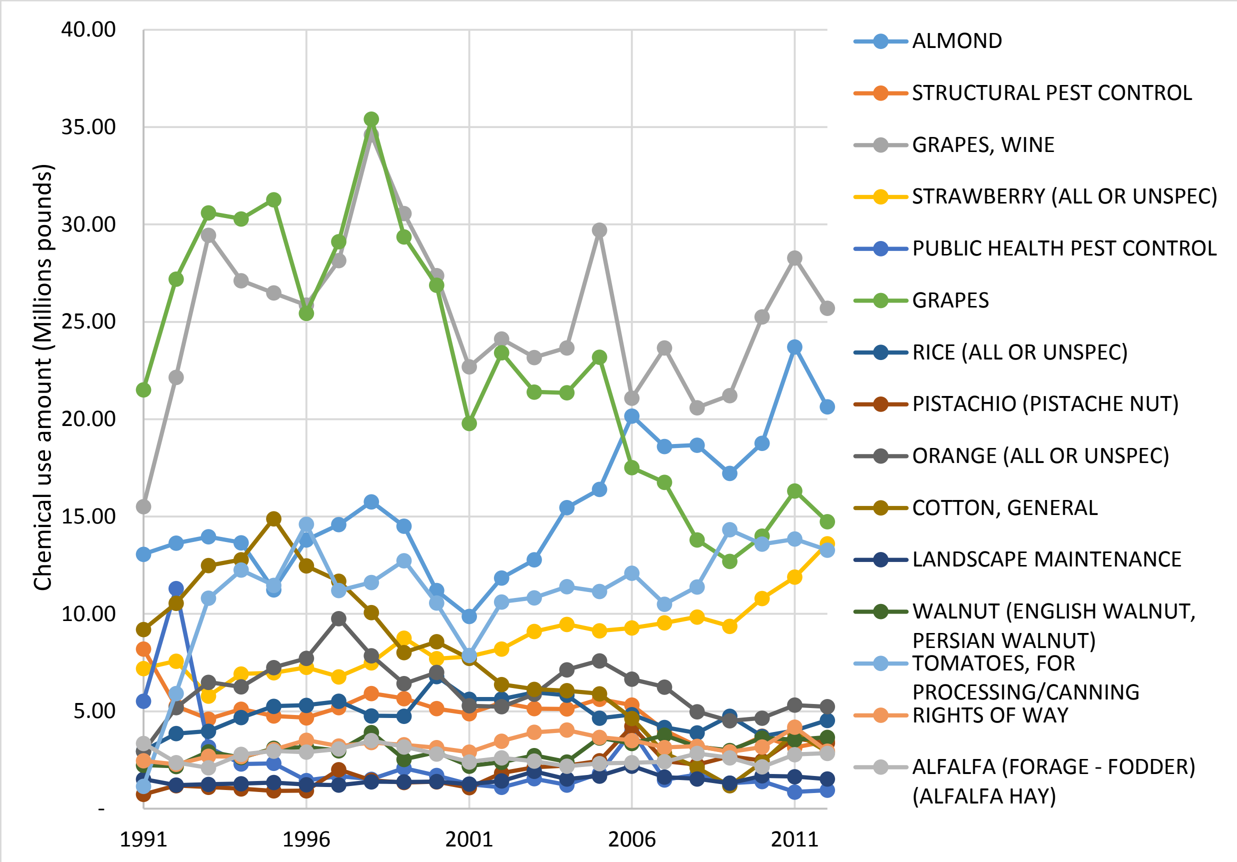

Figure 3. Historical chemical value trends of Top 15 end-use (in pounds)

3. Forecasting Methods

We have applied Richardson's Multivariate Empirical Probability Distributions (MVE) to State level production data for agricultural products using Simulation for Excel to Analyze Risk, SIMETAR (Richardson et al. 2000). This method uses non-normal distributions across variables and a time correlation matrix to generate correlated stochastic error terms that can be applied to any forecasted observations to be able to simulate the value of the variables. The variables are forecasted using trend and simulated 500 times to create the distribution. Available, data from 1960 – 2013 are used for historical correlation. Harvested area, unit price and production are collected from NASS (USDA, 2014). Table 3 provides the list of variables used for the forecast of agricultural commodities. The results of the forecast indicate a significant increase in several crops. For example, according to the PUR data, application of pesticides for the production of Almonds accounts for almost 18 percent of total end-use value and over 10 percent of total AI value for 2012. The production of almonds is forecasted to increase at an annual rate of 2.5 percent from 2013 to 2018. Figure 4 shows the distribution of important chemicals applied in almond production relative to the mill assessment revenue.

Table 3. Variables used to forecast agricultural production

Variable	Unit	Value
Crop Area	Acre	Mean $Acre^k$ * [1 + MVE (S_i, $F(S_i)$, $CUSD_1$)]
Sale Prices	$/Weight	Mean $Price^k$ * [1 + MVE (S_i, $F(S_i)$, $CUSD_2$)]
Production Amount	Weight	Mean $Amount^k$ * [1 + MVE (S_j, $F(S_j)$, $CUSD_3$)]

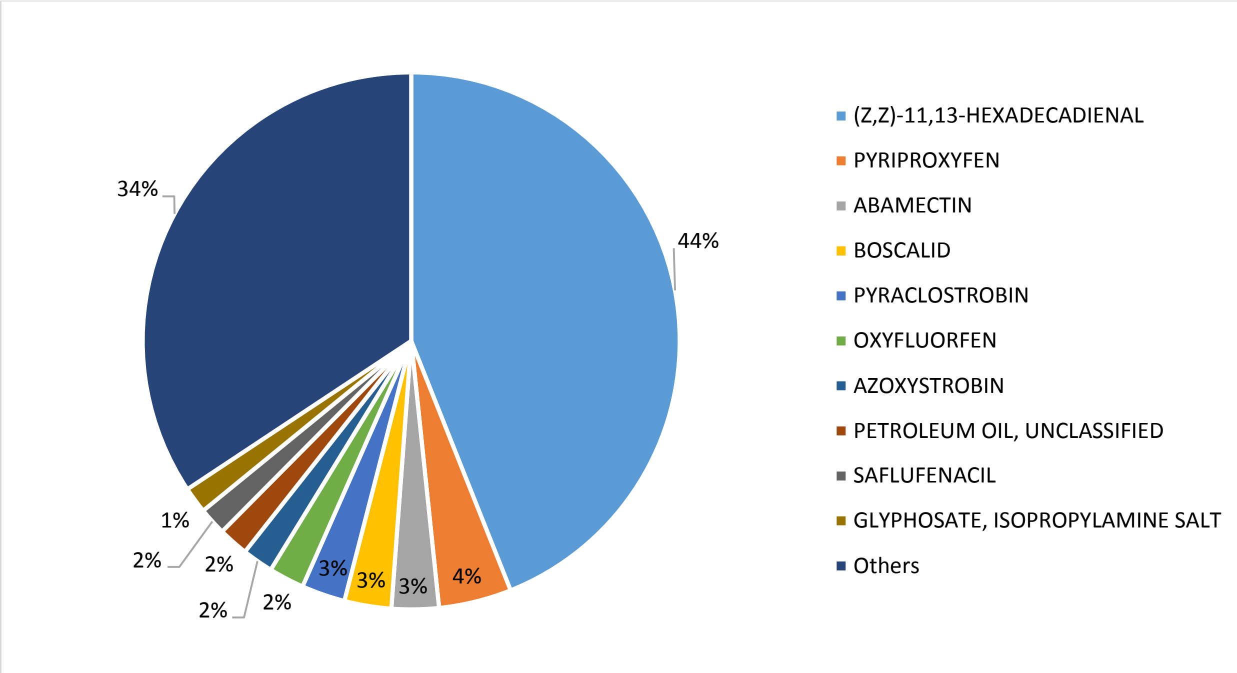

Figure 4. Chemical use distribution of : Almond Production, 2012.

Weight Matrix

The percentage of each chemical value based on end use commodities, a_{ij} is calculated to construct a weight matrix (W). A total of 33 end uses and 629 active ingredients are used to construct the matrix. The sum of chemical values for each end-use adds up to 100% in the weight matrix. An example of the matrix for selected end-uses and AIs is shown in Table 4.

$$W = \begin{bmatrix} a_{1,1} & \cdots & a_{1,629} \\ \vdots & \ddots & \vdots \\ a_{33,1} & \cdots & a_{33,629} \end{bmatrix} \tag{1}$$

Table 4. The weight matrix sample for selected end-uses and active ingredients for 2012

End-Use	Chemical Name / Codes	Sulfur 560	Oxyfluorfen 1973	Abamectin 2254	Imidacloprid 3849	Pyriproxyfen 4019	Azoxystrobin 4037	Trifloxystrobin 5321	Methoxyfenozide 5698	Pyraclostrobin 5759	Acetamiprid 5762
Almond	3001	0.09%	2.13%	2.84%	0.04%	4.38%	1.86%	0.36%	1.41%	2.62%	0.12%
Structural pest control	10	0.00%	0.00%	0.00%	1.52%	0.69%	0.00%	0.00%	0.00%	0.00%	0.07%
Grapes, wine	29143	9.71%	1.84%	1.77%	6.23%	0.00%	0.73%	3.13%	2.00%	5.80%	0.26%
Strawberry (all or unspecified)	1016	0.38%	0.11%	0.76%	0.84%	1.44%	0.42%	0.27%	0.18%	3.85%	1.04%
Public health pest control	50	0.00%	0.00%	0.00%	0.06%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%
Grapes	29141	7.34%	1.08%	1.79%	6.22%	0.10%	0.68%	3.90%	1.72%	4.24%	0.07%
Rice (all or unspecified)	28072	0.00%	0.00%	0.00%	0.00%	0.00%	10.52%	1.40%	0.00%	0.00%	0.00%
Pistachio (Pistache nut)	3011	1.13%	2.91%	0.01%	0.61%	0.10%	0.34%	1.23%	1.93%	1.63%	1.01%
Orange (all or unspecified)	2006	0.01%	0.08%	1.45%	8.39%	30.55%	0.07%	0.00%	0.00%	0.00%	1.24%
Cotton, general	29121	0.01%	1.30%	4.46%	2.07%	11.53%	4.53%	0.00%	0.53%	1.16%	6.74%
Landscape maintenance	30	0.02%	0.09%	0.04%	4.21%	0.49%	0.90%	0.19%	0.00%	0.56%	0.01%
Walnut (English walnut, Persian walnut)	3009	0.00%	3.14%	4.86%	1.60%	8.44%	0.05%	0.01%	1.54%	0.07%	3.67%
Tomatoes, for processing/canning	29136	12.48%	0.78%	0.93%	10.12%	0.04%	7.60%	0.08%	1.34%	5.51%	0.39%
Rights of way	40	0.00%	2.49%	0.00%	0.11%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Alfalfa (forage - fodder) (alfalfa hay)	23001	1.42%	0.01%	0.23%	0.00%	0.00%	0.01%	0.00%	2.94%	0.07%	0.00%
Peach	5004	0.95%	0.77%	1.13%	0.02%	7.20%	0.05%	0.24%	0.87%	1.54%	0.21%

Forecasted results are multiplied with the weighted matrix to find the individual impact of end-uses on chemical demand.

$$W^F = S^F \cdot W \tag{2}$$

The summation of each row gives the chemical amount required for each end-use commodities and the summation of each column gives the demand for each chemicals. Next, we use these results to find total chemical demand for each commodity or the amount of chemical required for the forecasted year.

4. Results

4.1. Agricultural end-use commodities forecast

The results of the forecast for 25 agricultural end-use commodities are reported in Table 5. As previously noted, the most recently available PUR data is 2012, thus we have considered 2012 as the base year for this analysis and set the production index as 100. The results provide an estimate of the expected change in demand for chemicals associated with the various end use commodities relative to the chemical amount applied as reported in the 2012 end-use information in.

Table 5. Baseline future production index for agricultural end-use commodities

25 End Use Commodities	2012	2013	2014	2015	2016	2017	2018
Almond	100	106	101	105	109	115	118
Grapes, wine	100	106	98	99	101	103	105
Strawberry	100	100	104	108	112	115	120
Grapes	100	121	117	118	118	119	119
Rice	100	105	105	106	107	108	109
Pistachio	100	85	94	100	105	111	115
Orange	100	94	94	93	92	90	89
Cotton, general	100	75	60	53	45	37	29
Walnut	100	99	93	95	98	100	103
Tomatoes, for processing/canning	100	96	102	104	105	106	108
Alfalfa	100	93	103	103	103	103	102
Peach	100	91	116	117	117	117	118
Lettuce, leaf	100	99	96	93	90	88	84
Lettuce, head	100	89	106	101	97	92	87
Nectarine	100	83	139	133	134	135	132
Carrots, general	100	98	124	126	126	126	128
Corn (forage - fodder)	100	91	110	113	116	120	123
Broccoli	100	103	135	123	123	132	134
Tangerine	100	120	102	111	115	119	125
Onion	100	98	116	117	118	119	120
Cherry	100	89	103	106	111	116	119
Spinach	100	93	140	145	150	153	159
Watermelons	100	86	90	90	89	89	89
Corn, human consumption	100	108	106	106	108	108	109
Peppers	100	93	100	101	102	103	104

4.2. Forecast for Non – agricultural and aggregated end-uses

Time Trend is used to forecast chemical use for non-agricultural and aggregated end-uses. These end uses include structural pest control, landscape, right of way, public health, uncultivated agricultural area, other agricultural end-uses and other non-agricultural end-uses (Figure 5).

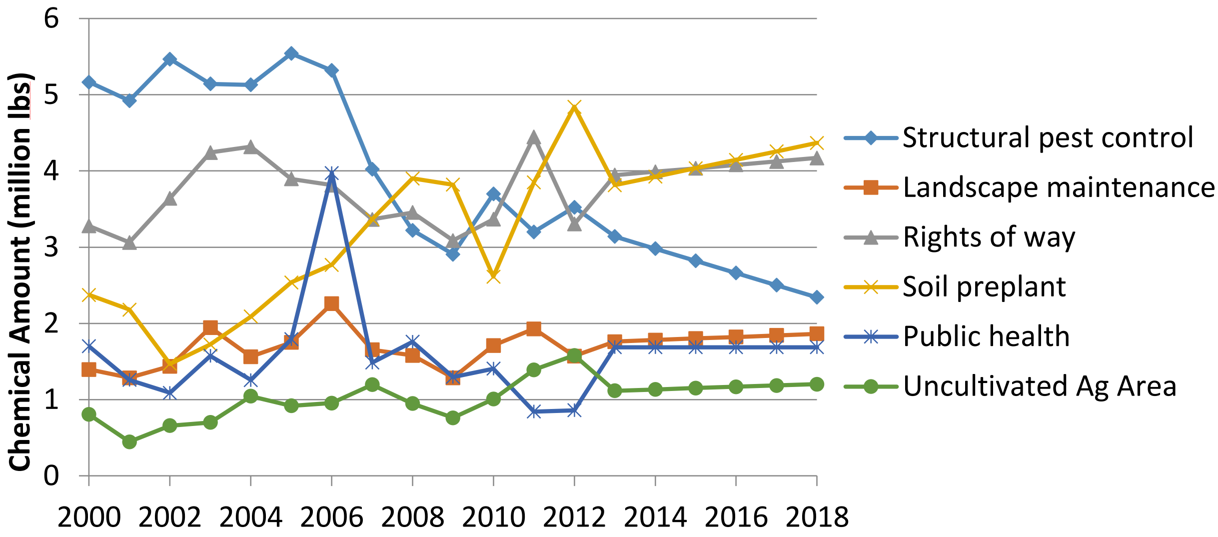

Figure 5. Baseline projection for chemical amount demand of Non – agricultural and other end-uses

4.3. Combined Total Forecast

Using equation (2), the summation of the rows and columns give the forecast. The results are reported in Table 6.

Table 6. Total forecast of pesticide demand per end-use commodity (pounds)

	2013	2014	2015	2016	2017	2018
Almond	21,940,615.18	21,483,153.24	23,084,567.44	24,616,132.99	26,310,246.26	28,376,568.09
Grapes, Wine	3,654,740.27	3,471,086.25	3,646,119.81	3,822,724.40	4,003,964.00	4,194,623.52
Strawberry (All Or Unspec)	25,637,069.52	27,515,902.71	29,380,655.49	31,337,738.07	33,385,250.53	35,608,577.65
Grapes	16,504,525.46	16,402,963.80	16,968,476.04	17,559,797.57	18,158,342.20	18,790,051.60
Rice (All Or Unspec)	997,139.95	1,021,499.89	1,060,540.95	1,105,265.82	1,150,749.98	1,195,692.18
Pistachio (Pistache Nut)	12,576,366.85	14,305,706.55	15,571,597.82	16,781,416.72	18,190,581.71	19,830,766.74
Orange (All Or Unspec)	4,262,899.92	4,381,982.41	4,456,254.32	4,535,712.14	4,596,279.03	4,656,438.01
Cotton, General	2,518,713.81	2,089,823.69	1,871,901.14	1,641,833.49	1,385,491.08	1,122,091.22
Walnut (English Walnut, Persian Walnut)	5,185,536.41	5,003,057.98	5,295,229.27	5,598,825.65	5,916,645.85	6,232,621.04
Tomatoes, For Processing/Canning	2,781,096.77	3,049,221.93	3,185,630.02	3,332,313.33	3,484,210.53	3,637,456.81
Alfalfa (Forage - Fodder) (Alfalfa Hay)	1,415,694.31	1,616,582.51	1,659,726.40	1,704,573.96	1,750,623.52	1,796,908.37
Peach	3,332,864.90	4,391,828.46	4,536,903.17	4,688,273.08	4,844,816.99	5,000,624.05
Lettuce, Leaf (All Or Unspec)	13,131,307.67	13,084,645.98	13,153,505.63	13,133,947.32	13,078,192.04	12,922,930.59
Lettuce, Head (All Or Unspec)	2,616,673.96	3,220,769.69	3,169,527.35	3,115,350.78	3,044,639.83	2,959,252.92
Nectarine	2,371,403.10	4,118,320.27	4,171,708.17	4,242,726.71	4,351,459.43	4,350,964.82
Carrots, General	2,686,073.21	3,517,373.87	3,635,915.66	3,758,923.68	3,888,982.22	4,028,423.99
Corn (Forage - Fodder)	820,098.30	1,015,333.73	1,075,721.22	1,139,821.68	1,207,227.65	1,279,394.45
Broccoli	935,032.23	1,197,601.08	1,191,720.16	1,304,284.63	1,371,465.10	1,424,101.10
Tangerine (Mandarin, Satsuma, Murcott, Etc.)	5,816,189.54	5,186,221.61	5,577,029.99	6,074,117.47	6,470,015.31	7,000,940.63
Onion (Dry, Spanish, White, Yellow, Red, Etc.)	1,130,605.58	1,384,398.33	1,436,295.33	1,496,036.50	1,553,097.59	1,616,376.27
Cherry	6,383,857.50	7,582,368.60	8,126,987.06	8,674,540.52	9,297,270.75	9,965,489.95
Spinach	842,207.88	1,309,102.33	1,392,435.97	1,482,318.17	1,572,156.23	1,663,454.86
Watermelons	253,987.05	274,430.79	281,991.68	289,187.21	297,430.05	305,594.68
Corn, Human Consumption	995,335.05	1,005,669.70	1,039,859.29	1,080,237.84	1,115,672.60	1,158,044.51
Peppers (Fruiting Vegetable), (Bell,Chili, Etc.)	1,680,380.08	1,858,028.86	1,936,577.55	2,015,990.78	2,100,374.71	2,184,402.82
Structural Pest Control	1,204,106.07	1,207,772.16	1,210,574.53	1,212,458.04	1,213,365.05	1,213,235.26
Public Health Pest Control	694,860.86	523,525.31	519,280.90	514,310.65	508,574.84	502,031.99
Landscape Maintenance	522,040.34	545,723.81	570,358.46	595,980.04	622,625.59	650,333.49
Rights Of Way	284,042.54	295,265.37	306,905.94	318,979.20	331,500.64	344,486.28
Soil Application, Preplant-Outdoor (Seedbeds,Etc.)	1,427,474.79	1,515,877.23	1,608,299.09	1,704,901.98	1,805,853.56	1,911,327.83
Uncultivated Agricultural Areas (All Or Unspec)	1,003,378.87	1,044,548.76	1,087,285.81	1,131,646.98	1,177,691.27	1,225,479.74
Other Ag Com	16,586,065.22	17,012,738.64	17,450,085.00	17,898,360.67	18,357,827.81	18,828,754.46
Other Nonag Com	12,572,033.83	13,419,957.92	14,307,442.62	15,236,098.44	16,207,596.91	17,223,672.80
Total Pesticide Demand	174,764,417.02	185,052,483.47	193,967,109.26	203,144,826.50	212,750,220.84	223,201,112.71

5. Summary

We have constructed the connection in a weighted matrix between the chemicals and end-use commodities based on the data to determine the future demand for pesticides. Forecasting end-use commodities and using this connection provide us a better understanding of future structure for the pesticide use. This method can include some other factors, such as changes in regulatory policy and weather that will influence the pesticide demand. The model will incorporate future changes in pesticide use by changing underlying variables we have included in the model; for example we have included almonds as one of the end-use agricultural commodity, if almond production is increased in future, this change will be reflected in changes to the pesticide demand.

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