Rice Notes
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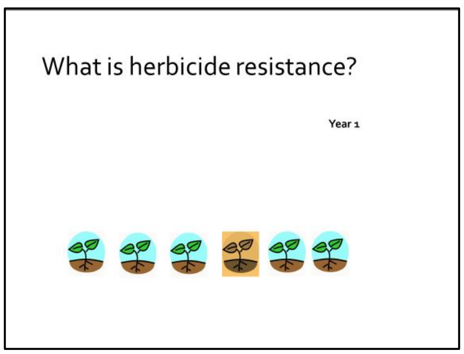
How Does Herbicide Resistance Evolve? An Illustrated Guide

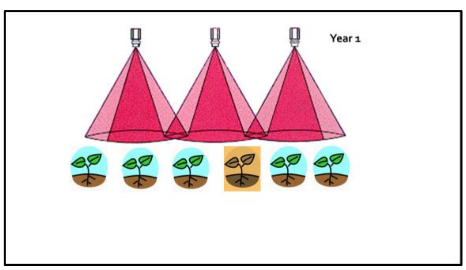
Whitney Brim-DeForest, UCCE Rice Advisor

We talk about herbicide resistance all of the time in California rice. But how does it evolve in a field? Understanding how herbicide management selects for resistant populations is an important part of preventing the problem from occuring in your fields.

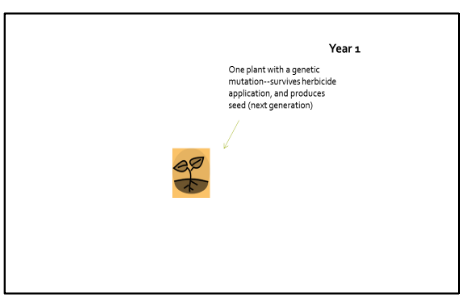
We have many weed species in CA rice that are confirmed to be herbicide resistant. The major herbicide-resistant species are: late watergrass, early watergrass, barnyardgrass, smallflower umbrella sedge, ricefield bulrush (roughseed), sprangletop, and redstem. **For this illustration of how herbicide resistance evolves in a field, we use redstem as our example.**



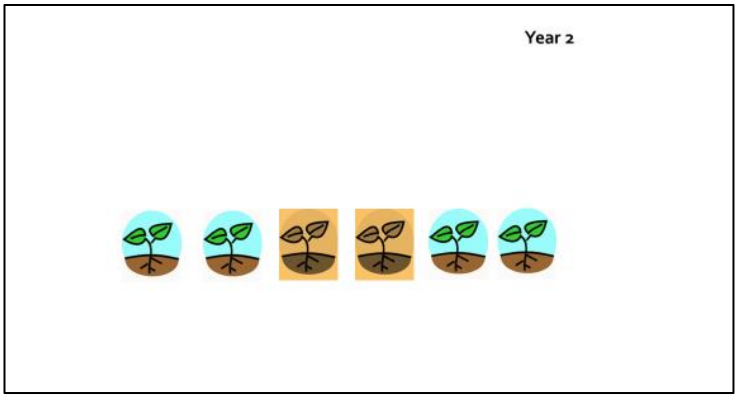
Year 1, Beginning of season: A population of redstem is found in a field and are emerging at the beginning of the season. In this illustration, the plants with the blue background are naturally susceptible to an herbicide (Granite SC). The plants with the yellow background are naturally herbicide resistant to Granite SC. There is nothing that the grower has done at this point to select for resistance. The genes that make the plant resistant are naturally found in the redstem population in the field.



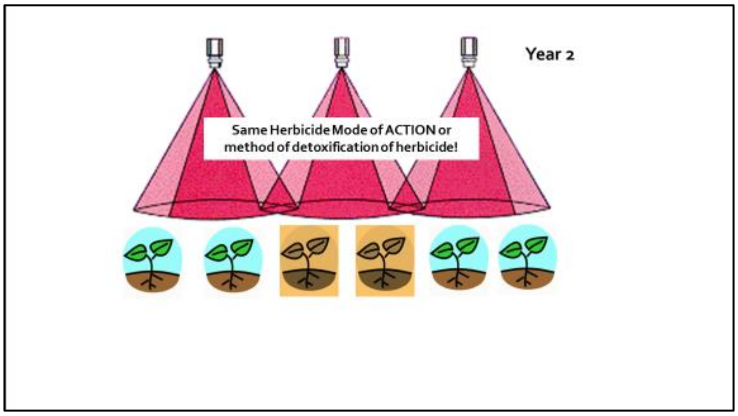
Year 1, Mid-season: The grower applies Granite SC.



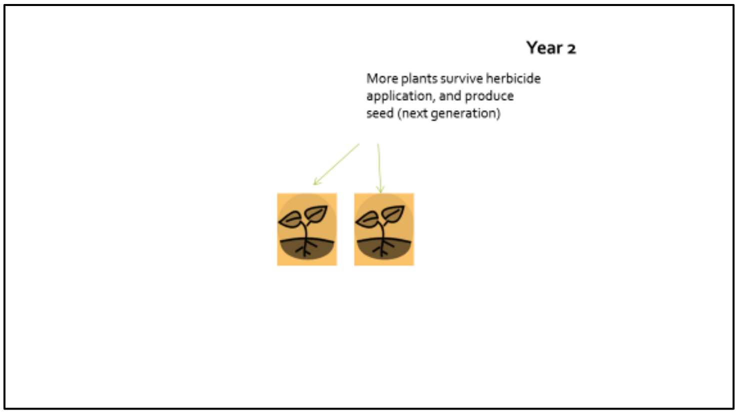
Year 1, End of season: One herbicide resistant plant survives. This plant goes on to produce seed, and the seeds are deposited onto the soil surface, where they are tilled into the soil seedbank at the end of the season.



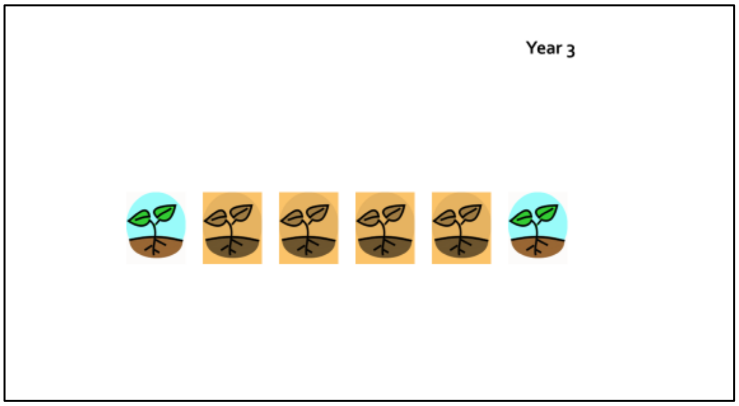
Year 2, Beginning of season: The redstem population emerges from the soil at the beginning of the season. Because there are more seeds in the soil seedbank from the resistant plants, more of the emerged plants are resistant to Granite SC this year (yellow background = herbicide resistant).



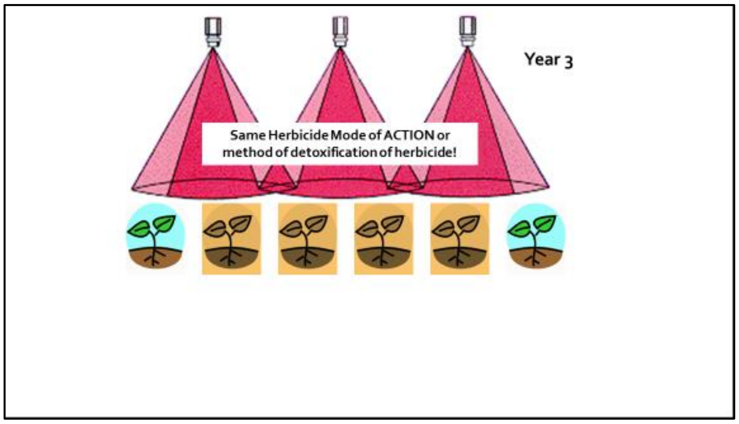
Year 2, Mid-season: The grower again applies Granite SC or another herbicide with the same mode of action (Regiment, Halomax/Sandea or Londax).



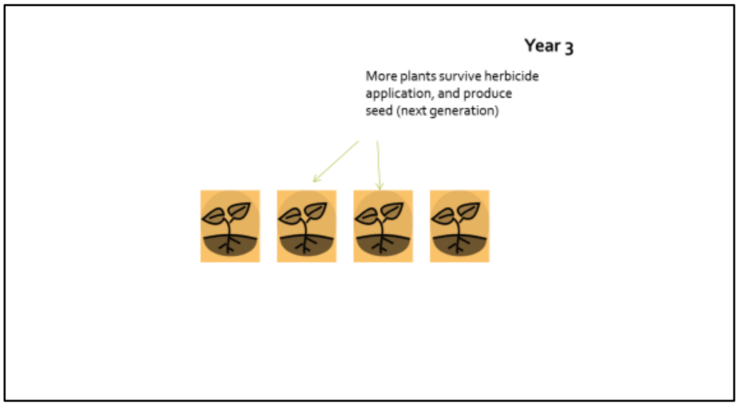
Year 2, End of season: All of the herbicide resistant plants again survive the herbicide application. Again, they go on to produce seed, and the seeds are deposited onto the soil surface, where they are tilled into the soil seedbank.



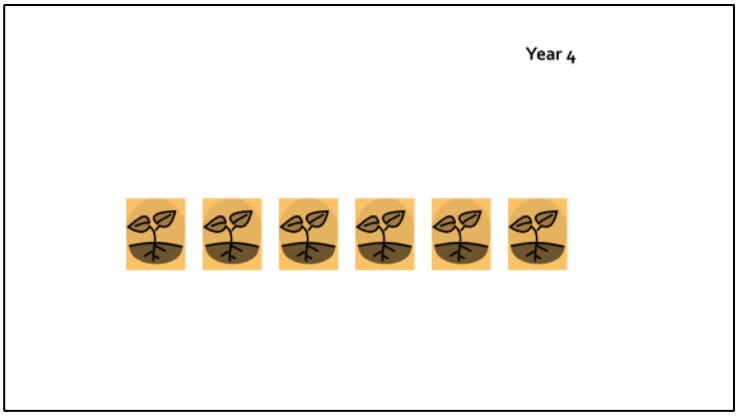
Year 3, Beginning of season: The redstem population emerges from the soil at the beginning of the season. There are even more herbicide resistant plants than the previous 2 years, as the proportion of herbicide resistant seed in the soil has increased.



Year 3, Mid-season: For the third year, the grower applies Granite SC or another herbicide with the same mode of action (Regiment, Halomax/Sandea or Londax).



Year 3, End of season: All of the herbicide resistant plants again survive the herbicide application. Again, they go on to produce seed, and the seeds are deposited onto the soil surface, where they are tilled into the soil seedbank.



Year 4, Beginning of season: The redstem population emerges from the soil at the beginning of the season. This year, all of the plants are herbicide resistant, as the soil seedbank contains mostly herbicide resistant redstem seed.

The illustrations above are an example of how herbicide resistance evolves and is selected for in a field. A grower may not notice during the first year or two, as there are just a few plants that survive the herbicide applications. However, if the grower continues to use the same herbicide year after year, or the same herbicide mode of action, eventually, the population of redstem (or another weed species) will shift to become composed of only plants that are herbicide resistant.

The best way to prevent the development of herbicide resistance is to rotate herbicide modes of action, both between seasons and within seasons. Refer to the UC Herbicide Susceptibility Chart for CA rice when planning an herbicide program (http://rice.ucanr.edu/files/229946.pdf)

Summary of 2016 University of California Rice Variety Trials

Luis Espino, UCCE Rice Advisor

Every year, the University of California Cooperative Extension, in cooperation with the Rice Experiment Station (RES), conducts rice variety trials in several locations of the Sacramento and San Joaquin Valleys. Three broad variety categories are included in the trials:

Preliminary breeding lines: those that have been selected by RES breeders to be evaluated on a statewide basis because of promising characteristics observed at the RES. They are tested in two- replication trials.

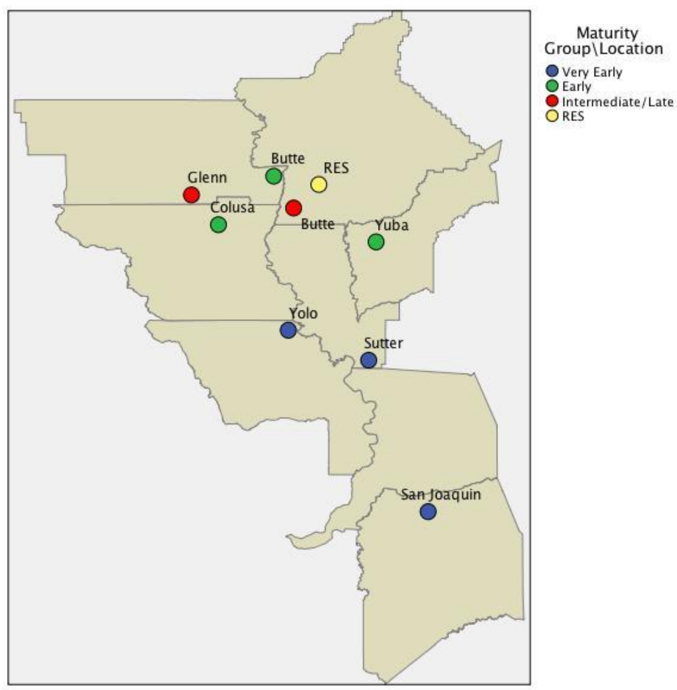
Advanced breeding lines: these lines are more promising; typically they have been tested first as preliminary. They are tested in four-replication trials. The best of the best may undergo seed increase and be considered for release as new rice varieties after several years of testing.

Commercial varieties: varieties released by the RES and planted in commercial fields.

The entries and varieties included in the trials can be grouped in three maturity groups:

1. Very early maturity group (<80 days to 50% heading)
2. Early maturity group (81-90 days to 50% heading)
3. Intermediate/late maturity group (>90 days to 50% heading)

The trials are conducted at the RES and in grower fields. On-farm trials are planted in the most appropriate location for the maturity group of the entries, taking into consideration weather but also the field variety of the location to avoid early or late harvesting. More than one maturity group is included in the trials so as to compare the performance of preliminary and advanced lines to "standards" such as M-202 or M-206.



Each entry is grown in 200 ft^2 plots. Cooperating growers manage the trials as part of the field. Plots are harvested using a research plot combine, and yields are converted to lbs/acre at 14% moisture. The complete report (2015 Agronomy Progress Report) is published on the UC Rice On-line website (http://rice.ucanr.edu/).

Table 8. Grain Yield (lb/acre @14% moisture) Summary of Very Early Rice Varieties by Location and Year (2012-2016)

Location	Year	**M104**	M105	M206	Calmochi 101	S102	L206
	2012	**10260**	9950	10420	8500	9370	10020
Biggs (RES)	2013	**9710**	9150	8610	8580	9120	9970
	2014	**8150**	7680	9200	6540	7640	8580
	2015	**8580**	8150	9350	7940	9520	8910
	2016	**.**	10380	10250	7490	8960	10100
Location Mean		**9175**	9062	9566	7810	8922	9516
	2012	**8990**	9590	9320	7500	8470	9570
Sutter	2013	**9510**	9940	9710	8340	9300	9700
	2014	**9510**	10380	9710	7780	8770	9440
	2015	**9520**	10350	9900	7990	9190	9820
	2016	**.**	11630	11110	9420	10720	9260
Location Mean		**9383**	10378	9950	8206	9290	9558
	2012	**9610**	9560	9900	7450	8400	9060
Yolo	2013	**9420**	9670	9790	7830	8380	9000
	2014	**9610**	10150	9770	7580	8980	8760
	2015	**8150**	7210	7490	5560	6940	7740
	2016	**.**	10420	10980	9290	9530	10090
Location Mean		**9198**	9402	9586	7542	8446	8930
	2012	**8460**	8340	8990	7880	8180	7570
San Joaquin	2013	**8140**	8220	8410	7680	7960	8180
	2014	**9680**	9660	9390	8440	8480	8660
	2015	**9650**	9260	9970	8750	9240	8400
	2016	**.**	.	.	.	.	.
Location Mean		**8983**	8870	9190	8188	8465	8203
Loc/Years Mean		**9184**	9428	9573	7936	8781	9052
Yield % M104		**100.0**	**102.7**	**104.2**	**86.4**	**95.6**	**98.6**
Number of Tests		**16**	19	19	19	19	19

Table 14. Grain Yield (lb/acre @14% moisture) Summary of Early Rice Varieties by Location and Year (2012-2016)

Location	Year	Calhikari 201	S102	**M202**	M105	M205	M206	M209	Calmati 202	L206
Biggs (RES)	2012	8680	9500	**9770**	10250	10530	9980		7990	10510
	2013	8490	8640	**7640**	7820	9230	8160		5700	8420
	2014	6220	7320	**7010**	8570	9140	9240		6310	8640
	2015	8580	10050	**8570**	8610	8720	9620	9490	6790	9360
	2016	7310	9020		10380	10690	10780	10950	7150	11060
Location Mean		7856	8906	**8248**	9126	9662	9556	10220	6788	9598
Butte	2012	8080	8220	**8650**	9490	9600	9240		7910	9380
	2013	7840	8650	**7870**	9640	8960	9020		6450	9390
	2014	8310	8570	**8360**	9070	9140	9610		7210	9730
	2015	7180	8810	**7550**	9350	7780	9370	8580	6370	9810
	2016	8080	9480		10060	9640	10400	10220	7850	10050
Location Mean		7898	8746	**8108**	9522	9024	9528	9400	7158	9672
Colusa	2012	7430	7460	**8630**	8620	9130	9680		5340	9400
	2013	7840	7220	**9140**	9750	8930	9660		5970	10250
	2014	7740	8080	**8720**	9100	9370	9280		6150	9380
	2015	8940	9200	**9820**	10500	10050	9850	10490	6660	9940
	2016	8590	9050		10390	9730	9960	9600	7850	8670
Location Mean		8108	8202	**9078**	9672	9442	9686	10045	6394	9528
Yuba	2012	6080	7970	**9220**	8510	8840	9240		5570	9100
	2013	8040	9280	**8950**	9330	9650	9750		5750	9590
	2014	7290	7420	**8010**	8590	9120	8950		5460	9260
	2015	8490	8740	**9860**	9970	9650	9940	10240	6950	9840
	2016	7310	8300		9110	8430	9090	8760	5310	8670
Location Mean		7442	8342	**9010**	9102	9138	9394	9500	5808	9292
Loc/Years Mean		7826	8549	**8611**	9356	9317	9541	9791	6537	9523
Yield % M202		**90.9**	**99.3**	**100**	**108.7**	**108.2**	**110.8**	**113.7**	**75.9**	**110.6**
Number of Tests		20	20	**16**	20	20	20	8	20	20

Table 19. Grain Yield (lb/acre @14% moisture) Summary of Intermediate/
Late Rice Varieties by Location and Year (2012-2016)

Location	Year	M205	M402	**M202**	M-209	L206
Biggs (RES)	2012	11210	10260	**11090**		11180
	2013	9730	9830	**8700**		9460
	2014	10550	10040	**8870**		10340
	2015	9880	8450	**8150**	9710	9520
	2016	9460	9370	**.**	9900	10490
Location Mean		10166	9590	**9203**	9805	10198
Glenn	2012	8220	8260	**7660**		7680
	2013	8400	8970	**8270**		8870
	2014	8910	8910	**8510**		8870
	2015	9420	8710	**8560**	9620	9910
	2016	8490	9850	**.**	8520	9290
Location Mean		8688	8940	8250	9070	8924
Sutter	2012	9630	9040	**9690**		9890
	2013	8540	6900	**7890**		8720
	2014	8680	7020	**9030**		9660
	2015	.	.	**.**	-	.
Butte	2016	9110	6900	**.**	9010	9530
Location Mean		8990	7465	**8870**	9010	9450
Loc/Years Mean		9281	8665	**8774**	9295	9524
Yield % M202		**105.8**	**98.8**	**100**	**105.9**	**108.5**
Number of Tests		14	14	**11**	5	14

Biological Characteristics of Weedy Rice Compared to Cultivated Rice

Luis Espino, UCCE Rice Advisor

The history of weedy rice in California goes back to the beginnings of rice cultivation in the State. By 1917, weedy rice was considered to be one of the most injurious rice seed pests, together with watergrass and rogue rices. No one knows for sure where this weedy rice came from, but most likely it was brought in with the seed during the time when rice was being experimented with as a possible crop for the Sacramento Valley. With the wide adoption of continuous flooding and certified seed during the 1950s, the weedy rice problem went away, and California had been considered to be "practically free" of weedy rice since then. Then, in 2003, a field was found infested in Glenn County. By 2008, three fields were confirmed infested in two counties. After that, weedy rice finds were a bit of a trickle, with only a handful of fields confirmed infested. The trickle turned into a flood in 2016, when almost 30 fields were found infested in all the major rice producing counties of the Sacramento Valley and in one field in the San Joaquin Valley. So far, five different weedy rice types have been identified.

The California rice industry should be on high alert about this weed. Weedy rice is present in all other rice production areas of the world, and everywhere it is present, it is considered a serious problem. Weedy rice cannot be killed with herbicides, because the herbicides that kill weedy rice also kill cultivated rice. There are several biological characteristics that make weedy rice such a big problem. In California, we know very little about the biological characteristics of the weedy rice types we have, but we can use information generated in the southern US and other places to understand why weedy rice is such a big deal.

Seed shattering: This is one of the main characteristics that make weedy rice weedy. Table 1 shows a comparison of three cultivated rice varieties used in the south during the 1990s and 13 weedy rice types from different southern rice producing states. Shattering on the cultivated varieties was very low, but on the weedy rice types it ranged from moderate to high. Weedy rice types with high shattering tend to be weedier because their seeds are not removed from the field at harvest; seeds stay in the field and germinate the following season, stealing nutrients, water, space and sunlight from the cultivated variety.

Germination and dormancy: Table 1 also shows the germination and dormancy of cultivated and weedy rice seeds right after harvest. Cultivated rice has very high germination and very low dormancy, while weedy rice types are the opposite. What this means is that seeds that shatter have the capacity to remain in the field dormant and viable until the next season, when they can germinate.

Wintering resistance: In South Korea, researchers left weedy and cultivated rice seeds exposed in fallow rice fields during winter for four months, protected by a screen to avoid predation by animals. When they tested germination after the experiment, they found that weedy rice had more than 80% germination, while cultivated rice had only about 5%.

Plant growth: Growth of weedy rice from Arkansas was measured under greenhouse conditions for two years and compared to the cultivar Wells. On average, weedy rice plants were 31 inches in height, while the Wells cultivar was only 23 inches. Weedy rice plants produced 7.5 tillers, while Wells only produced three. Weedy rice plants had an average of 56 root tips, while Wells only had 11.

These are some examples of biological characteristics that explain why weedy rice is so problematic. In California, research is needed to determine which of the weedy rice types we have are more problematic and design strategies to manage them in the field. UCCE will be conducting research this year and will be working with growers to implement practices to prevent and manage weedy rice infestations.

Sources:

Noldin, J. A., J. Chandler, and G. McCauley. 1999. Red rice (*Oryza sativa*) biology. I. Characterization of red rice ecotypes. Weed Technology 13: 12-18.

Sales, M., N. Burgos, V. Shivrain, B. Murphy, and E. Gbur. 2011. Morphological and physiological responses of weedy red rice (*Oryza sativa* L.) and cultivated rice (*O. sativa*) to N supply.

Baek, J., and N. Chung. 2012. Seed wintering and deterioration characteristics between weedy and cultivated rice. Rice. 5:21.

Rice type	Ecotype/cultivar name	Shattering Index[1]	% Germination	% Dormancy
Weedy	AR1	5	5	93
Weedy	AR2	5	2	90
Weedy	AR3	5	8	91
Weedy	AR4	7	3	94
Weedy	LA1	5	0	97
Weedy	LA2	3	17	77
Weedy	LA3	7	0	97
Weedy	LA4	9	2	94
Weedy	LA5	9	3	94
Weedy	TX1	9	0	93
Weedy	TX2	1	5	87
Weedy	TX3	9	0	96
Weedy	TX4	9	3	93
Cultivated	Lemont	1	92	7
Cultivated	Mars	1	95	2
Cultivated	Maybelle	1	95	3

[1]Shattering index scale: 1, very low (<1%); 3, low (1-5%); 7, moderately high (26-50%); 9, high (>50%).

Useful Websites

University of California Rice Online: www.rice.ucanr.edu

The UCANR Rice group has put together a website that now provides resources on a variety of topics related to rice production in California. New tools include the Phosphorous Fertilizer Budget and Application Calculator, as well as the Rice Degree Day Model. If you need assistance with the website or more information on how to use the tools, feel free to contact Whitney (wbrimdeforest@ucanr.edu) to arrange a time to go over the website together.

UC Rice Blog: www.ucanr.edu/blogs/riceblog

The UCCE rice advisors post timely information on the blog about important information related to the industry including new pests and pesticides, rice meetings, and anything else we find that we think may be of interest. Subscribe to the blog by signing up here: www.ucanr.edu/blogs/blogcore/subscribe.cfm

2016 CALIFORNIA RICE WEED HERBICIDE SUSCEPTIBILITY CHART