Final Report
UC-ANR
2016 Field Demonstration of Sorghum Grain Hybrids for California

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a globally important crop, ranking as the fifth most important cereal crop in the world in terms of total production behind wheat, rice, maize, and barley. The majority of US grain sorghum production is in Kansas and Texas, with only limited production in California; however, in the mid-1960s there were over 400,000 acres of grain sorghum planted in the state with reported yields of 70 bu acre^{-1} which was approximately double the national average. Sorghum is an attractive crop for the state — sorghum can remain productive under comparatively low water and nutrient conditions, and produces products such as bioenergy, food and livestock feed. Sorghum could therefore help reduce irrigation and nitrogen fertilizer use in California and be an important crop rotation cereal in many conservation tillage and farm rotational systems, whilst maintaining productive agricultural output. This project aims to facilitate the increased use of sorghum as a multi-purpose low-input crop for the California.

Sorghum is an annual crop that could be both a short-term and long-term solution for California's need for a sustainable bioenergy feedstock. Sorghum can be used in all the various processes for bioenergy production - starch-to-ethanol, sugar-to-ethanol, and lignocellulose-to-bioenergy. Sorghum grain is suitable for the production of ethanol, with ethanol yields per ton of grain being similar to that of corn. Under ideal conditions the total grain yield of sorghum is generally less than that of corn, however because sorghum can remain productive under lower input, or higher saline, conditions it may be a more suitable grain- ethanol crop in California under circumstances of low irrigation and fertilization. This was the first year of a multi-year evaluation of commercially available grain sorghum hybrids to evaluate their potential in the state.

The following is a summary of the sorghum grain trials conducted at the Kearney Agricultural Research & Extension (KARE) Center, the UC Davis Research Farm (UCDRF), the West Side Research & Extension Center(WREC), and the Desert Research and Extension Center (DREC) in 2016.

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Methods and Materials

Trials were established at KARE, UCDRF, WREC, and DREC. Irrigation was applied using furrow irrigation at KARE and a combination of overhead sprinklers and flood irrigation at WREC and UCDRF. Fertility applications followed similar recommendation for grain sorghums for the region. Other cultural practices and study information are listed below:

Trial Location:	KARE Planting, Parlier
Cooperator:	UC-ANR
Previous Crop:	Winter forage (Oats)
Soil Type:	Hanford sandy loam
Plot Size:	Four, 30 inch rows by 20 ft
Replications:	3
Study Design:	Split-Plot
Planting Date:	May 16, 2016
Planting Rate:	100,000 seed $acre^{-1}$
Seed Method:	Almaco 4 row plot planter
Fertilizer:	Ammonium sulfate at 250 lbs $acre^{-1}$ providing 52 units of N
Herbicide:	Dual Magnum at 1.3 pints per ac^{-1} as a pre-plant
Irrigation:	See narrative below
Grain Harvest Dates:	September 12, 19, and October 4, 2016

Trial Location:	Westside Research and Extension Center, Five Points
Cooperator:	UC-ANR Extension
Previous Crop:	Winter forage (wheat grown for silage-not taken to grain)
Soil Type:	Panoche clay loam
Plot Size:	Four, 30 inch rows by 20 ft
Replications:	3
Study Design:	Split-Plot
Planting Date:	June 3, 2016
Planting Rate:	100,000 seed acre-1
Seed Method:	Almaco 4 row plot planter
Fertilizer:	200 lbs acre-1 N-P-K 11-52-00 on May 2 and 100 lbs acre-1 N on June 17
Herbicide:	Dual Magnum at 24 oz ac-1 as a pre-plant on May 3; Clarity 8oz on June 24 and Prowl-H20 as layby at 24 oz ac-1 on June 28
Irrigation:	Sprinklers for pre-irrigation and stand establishment, gated pipe furrow irrigation subsequent irrigations – see narrative below for totals
Grain Harvest Date:	September 29 and November 15, 2016

Trial Location:	UC Davis Research Station, Davis
Cooperator:	UC-ANR
Previous Crop:	Small grains cover crop
Soil Type:	Reiff very fine sandy
Plot Size:	Four, 30 inch rows by 20 ft
Replications:	3 Main Plot, 3 subplot
Study Design:	Split-Plot
Planting Date:	May 12, 2016
Planting Rate:	100,000 seed acre^{-1}
Seed Method:	Wintersteiger Self Propelled Drill Planter
Fertilizer:	20 gallons per acre 8-24-6 pre-plant fertilizer, 100 units N as 32-0-0 side dress June 20
Herbicide:	
Irrigation:	See narrative below
Grain Harvest Date:	September 13th, September 26th, October 6th 2016

Hybrids were planted in four row plots on 30-inch raised beds. Stand counts were taken by counting every plant in the two center rows. Panicle emergence and flowering of each plot was rated weekly. Pest and disease observation were also taken at the time of flowering ratings. At harvest, plant height and lodging of each plot were recorded. Seed was harvested using an Almaco SPC 40 Plot Combine. Seed yield per plot and seed moisture were recorded simultaneously at harvest. Yield and moisture values together were used to estimate grain yield at 13% moisture.

Data manipulation and analysis was carried out in R (R Core Team, 2014). The UCDRF trial was designed as randomized complete split plot, with three harvest dates as the main plot and hybrids as the subplot, both with three replicates. The effect of variety, harvest date, and their interaction, on seed yield at this location was tested using an analysis of variance (ANOVA). The KARE and WREC trials were unreplicated complete split plot designs[6]. The effect of hybrid, harvest date, and their interaction, at the UCDRF, KARE and WREC locations where investigated using a linear mix model in the *lme4* package (Bates, et al., 2013).

Hybrid ranking in the context of genotype by environment interaction was explored using a GGE biplot in the *gge* package (Wright and Laffont, 2015) in R (R Core Team, 2014). For conceptual purposes, the different harvest dates were treated as separate trials.

Results

No major pest or diseases were observed at any of the locations. Problematic lodging was also not observed. Very low yields were obtained at the DREC, therefore the location is not considered in the analyses or data summary. The 2016 growing season was

[6] http://asq.org/quality-progress/2007/10/laboratory/when-should-you-consider-a-split-plot-design.html & http://www.personal.psu.edu/mar36/stat_461/split_plot/split_plot.html

characterized by little winter precipitation and poor soil moisture reserves throughout the growing season at the KARE and WREC locations. Trials at KARE, WREC, and UCDRF were irrigated as needed.

The first planting at KARE received a pre-plant irrigation of 2.96 inches on April 25, 2016 and a total of 20.04 inches of applied irrigation. The second planting at KARE received a preplant irrigation of 4.89 inches on May 23, 2016 and a total of 19.26 inches of applied irrigation. Rainfall totals from January through May 4, 2016 prior to the first planting at KARE were 6.49 inches, while the second planting had a total of 7.07 inches of rain prior to planting. Rainfall totals of 0.61 and 0.05 inches were recorded throughout the growing season for the two planting dates, respectively.

Cumulative rainfall between January and May at UCDRF was 11 inches, and soil sampling found at sowing the soil water above wilting point in top 5 ft of the soil profile at UCDRF was approximately 7.5 inches. Following sowing, 0.74 inches of additional rainfall was received. Throughout the season a total of 31 inches of furrow irrigation was applied in eight separate applications.

The effect of harvest time on seed yield: Both harvest date and hybrid had a significant effect on seed yield, but the interaction between the two was not significant and explains a comparatively small proportion of the total yield variance (Table 1).

Table 1: 2016 summary ANOVA of seed yield for sorghum hybrids tested at UCDRF, CA.

Error:	Block					
	Df	Sum Sq	Mean Sq			
Harvest	1	1597311	1597311			
Hybrid	1	88835882	88835882			
Error:	Block:Harvest					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Harvest	2	396065174	198032587	52.73	0.0186	*
Hybrid	2	36658894	18329447	4.881	0.1701	
Residuals	2	7511168	3755584			
Error:	Within					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Hybrid	33	9.248e+08	28024989	3.511	1.68E-08	***
Harvest:Hybrid	66	6.632e+08	10048453	1.259	0.113	
Residuals	213	1.700e+09	7983176			

The effect of harvest time, hybrid, and their interaction, and the proportion of the variance explained by the effects, varies depending on the site where the trial was conducted (Table 2). The interaction was only significant at Davis, but relative to the hybrid, the interaction still explained only a small proportion of the total variance.

Table 2: A summary the results of a linear mixed model analysis of seed yield for sorghum hybrids tested in California in 2016. Please note that the use of *p*-values in mixed models is a much-debated area, the method where a full model (with the fixed effect in question) is compared with the reduced model without the effect was used[7].

	UCDRF		KARE		WREC	
	P-value	Variance	P-value	Variance	P-value	Variance
Harvest	0.001	72%	0.057	49%	0.463	5%
Hybrid	0.000	21%	0.002	34%	0.000	83%
Harvest:Hybrid	0.004	7%	0.119	18%	0.108	12%

Hybrid ranking explored with a GGE biplot: For details regarding the theory and interpretation of biplots in the context of multi-environment trials please refer to Yan (2014). In general, hybrids in any location can be visually ranked by drawing a straight line from the individual hybrid that passes perpendicularly through the axis of the location. The arrow on the location axis indicates increasing yield, and the order of the hybrids on the axis is their yield rank. For example, 50315X is the highest yielding on the X3-KARE axis, and 54346X the lowest yielding, where as 85Y40 is the highest yielding at X1-Davis. The greater the angle between locations the more different the ranking of the varieties between the two. For the current data set, at the individual locations the ranks of the varieties change minimally between harvests (Figure 1). There are, however, possible rank differences between the locations. The ranking of varieties at the KARE and WSREC locations (San Joaquin Valley) are similar, but variety ranks at the Davis location (Sacramento Valley) are different.

7 http://www.bodowinter.com/tutorial/bw_LME_tutorial.pdf

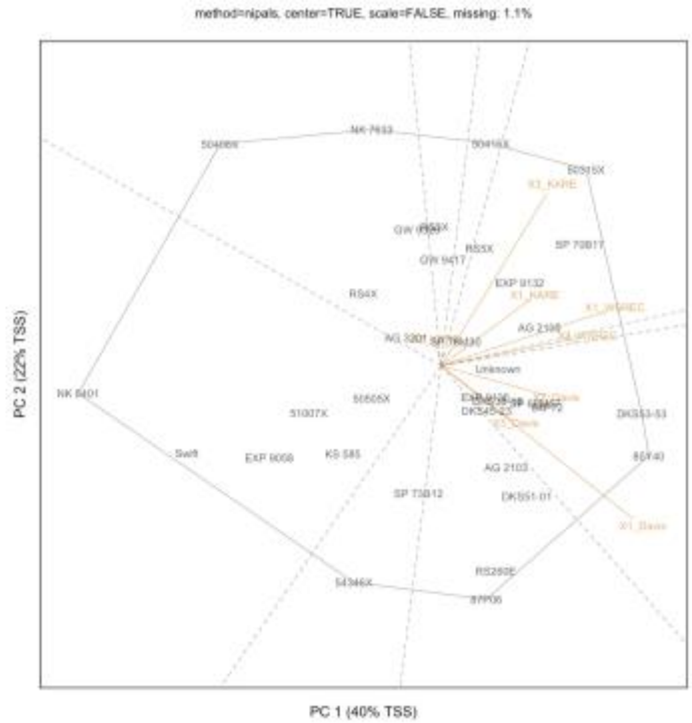

Figure 1: A GGE biplot of seed yield data for sorghum hybrids tested in California in 2016. Harvests: X1 = Early, X2 = Mid, X3 = Late.

Yield summary

Summaries of the yields for the individual hybrids are presented below (Table 3). Given that harvest date and hybrid did not appear to interact strongly the seed yield shown is the average across all harvest dates.

Flowering: The reported maturity classes for the hybrids have some correlation with observed days to flowering but the correlation is imprecise (Figure 2), with considerable overlap between the reported classes. Days to flowering was continuous across the hybrids. Flowering time was very consistent across all locations (Figure 3). There was no correlation between seed yield and days to flowering (r^2=0.05).

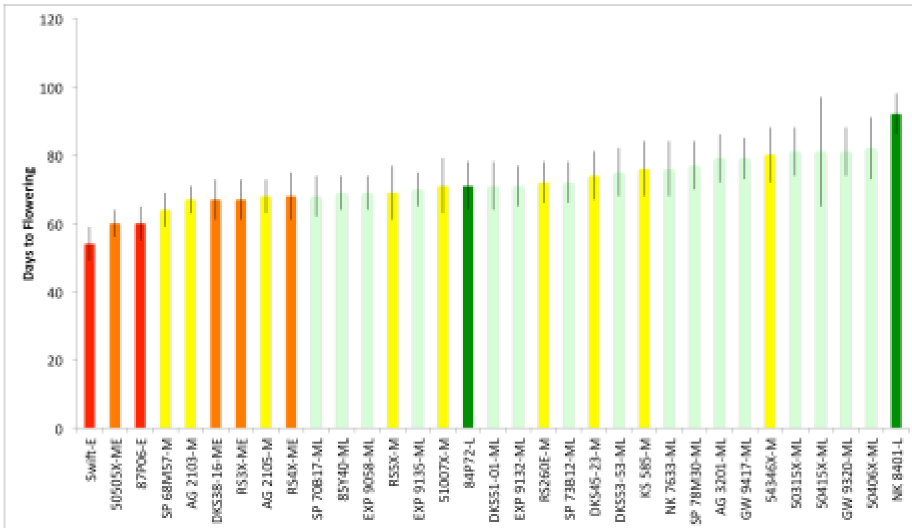

Figure 2: A summary of days to flowering for sorghum hybrids tested in California in 2016. Reported maturity class of the hybrids: E (red) = Early, ME (orange) – mid early, M (yellow) = Mid, ML (light green) – mid late, L (dark green) = Late.

Table 3: A summary of seed yield for sorghum hybrids tested in California in 2016 reported as lbs acre^{-1}.

		Davis		KARE		WREC	
Hybrid	Company	Mean	StdDev	Mean	StdDev	Mean	StdDev
AG 2103	Alta Seed	16,599	1,051	10,429	3,988	18,524	1,346
AG 2105	Alta Seed	14,606	5,550	13,238	3,150	19,184	1,052
AG 3201	Alta Seed	14,555	3.049	11,851	3,719	17,836	1,305
SP 70B17	Chromatin/Sorghum Partners	16,662	2,160	15,033	3,299	17,892	1,955
SP 68M57	Chromatin/Sorghum Partners	15,586	1,668	10,479	3,807	19,118	855
SP 73B12	Chromatin/Sorghum Partners	15,575	1,742	10,466	3,972	17,573	829
SP 78M30	Chromatin/Sorghum Partners	15,196	2,247	12,346	3,370	17,701	832
KS 585	Chromatin/Sorghum Partners	14,069	1,379	10,256	5,114	16,918	1,700
NK 7633	Chromatin/Sorghum Partners	12,877	3,513	12,882	1,332	17,479	1,370
NK 8401	Chromatin/Sorghum Partners	11,735	4,202	9,379	4,483	11,984	1,657
85Y40	Dupont Pioneer	18,851	1,216	13,145	2,393	18,314	1,619
87P06	Dupont Pioneer	17,442	3,222	10,466	3,915	17,246	1,954
84P72	Dupont Pioneer	16,931	1,441	11,848	3,692	17,904	1,154
EXP 9135	Gayland Ward	16,056	2,015	12,169	2,476	17,295	2,015
EXP 9132	Gayland Ward	15,672	2,622	13,833	2,832	17,474	2,024
EXP 9058	Gayland Ward	14,963	2,355	11,460	2,263	11,896	7,258
GW 9417	Gayland Ward	14,715	2,567	12,736	1,960	17,521	917
GW 9320	Gayland Ward	13,510	3,673	12,947	3,377	18,490	1,244
DKS53-53	Monsanto DeKalb	18,460	1,696	12,316	2,525	19,350	1,547
DKS51-01	Monsanto DeKalb	17,059	5,230	12,254	4,732	17,551	1,339
DKS45-23	Monsanto DeKalb	16,286	2,609	11,121	5,272	18,056	1,240
DKS38-16	Monsanto DeKalb	16,041	1,935	11,461	3,146	18,061	1,101
RS260E	Richardson Seed	16,424	1,670	10,693	4,754	18,149	2,506
RS5X	Richardson Seed	15,146	3,348	13,354	1,961	18,390	832
Swift	Richardson Seed	13,880	2,699	10,645	3,805	11,331	3,320
RS3X	Richardson Seed	13,605	2,668	13,339	1,700	17,659	1,258
RS4X	Richardson Seed	12,926	1,692	12,043	3,712	16,433	877
50315X	Scott Seed	16,260	3,353	14,845	3,158	19,014	1,818
54346X	Scott Seed	16,107	5,828	8,767	5,015	16,597	1,099
50505X	Scott Seed	14,860	6,139	11,972	3,516	16,339	933
50415X	Scott Seed	13,645	3,715	12,475	4,241	19,951	1,094
51007X	Scott Seed	13,229	3,807	11,701	5,925	15,135	1,428
50406X	Scott Seed	11,336	4,635	11,845	3,189	15,787	2,105
Mean		**15,256**		**11,925**		**17,287**	
Standard Deviation		3,455		3,744		2,608	
Standard error		192		208		177	
CV%		27		24		23	

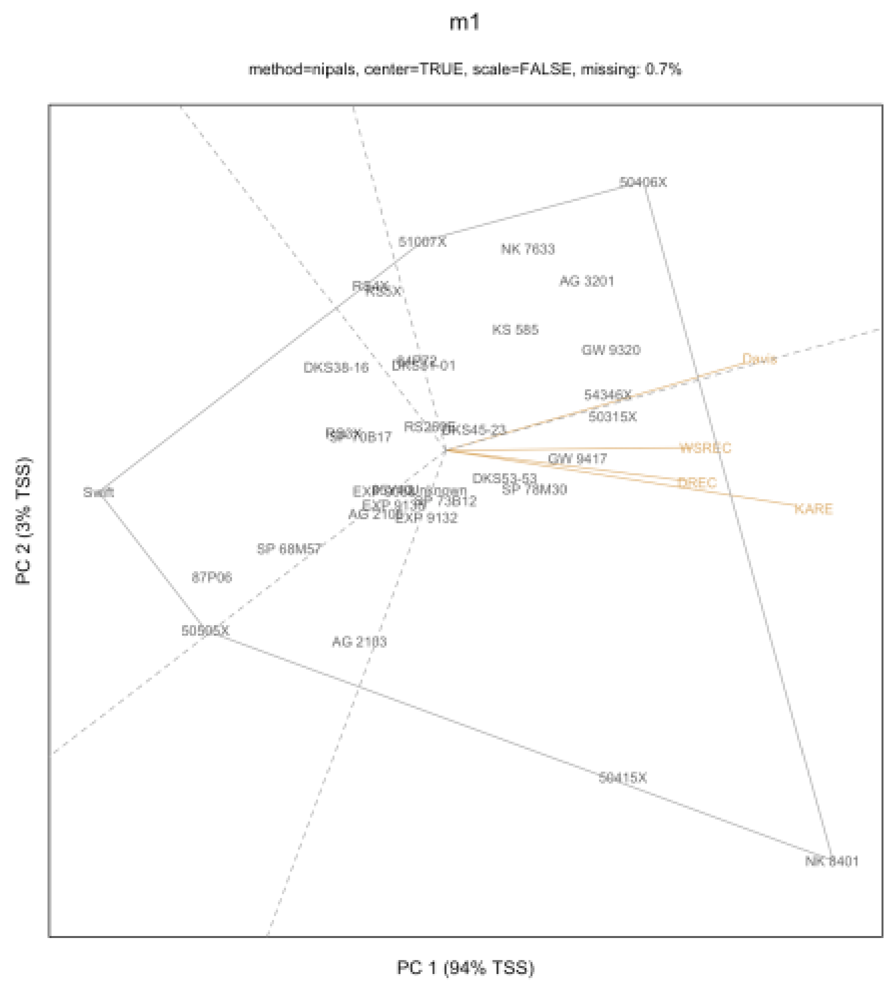

Figure 3: A GGE biplot of days to flowering for sorghum hybrids tested in California in 2016.

Discussion

Multiple analyses conducted here suggest that both harvest date and hybrid have a large effect on the seed yield of grain sorghum in California, but the interaction between the two has a comparatively small impact. In practical terms, this means that the identification of well-adapted grain sorghum lines in California is strongly dependent on the hybrids, and where they are grown, rather than when they are harvested. Figure 4 below illustrates what is being observed in the analyses using seed yields for the highest and lowest yielding varieties at West Side, as well as with some mid-yielding varieties. The figure shows there are large differences in terms of yield (nearly 10 thousand kg/ha) between varieties, and there are also both positive and negative changes in yield between early and large harvests within varieties, however the actual ranking of the varieties changes very little – the highest and lowest yielding varieties maintain their ranks. The large residuals (not presented) in the analyses could also suggest that changes in rank of a few thousand kg/ha are the result of unexplained experimental error.

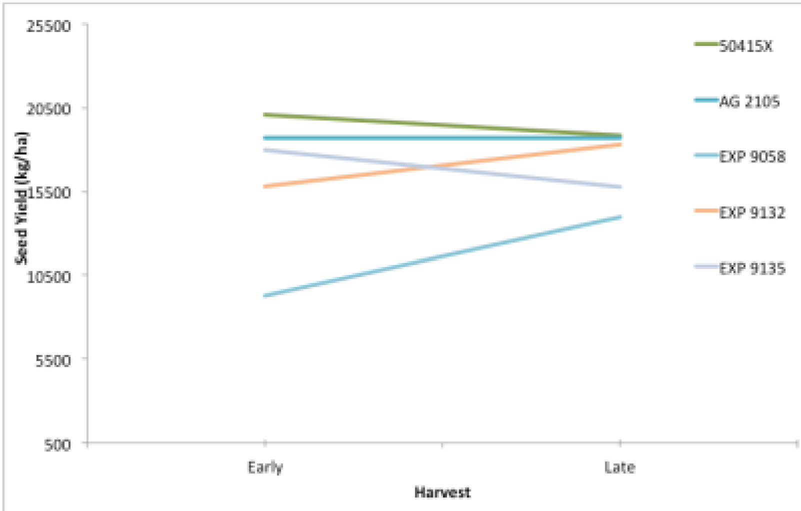

Figure 4: Summarized seed yield data for grain sorghum grown at the WSREC location in 2016.

The genotype-by-environment pattern observed in the analysis is very similar to what was found in the analysis of sorghum seed yield data from the 2012-2014 variety trial work, which evaluated a different population of hybrids in California. The analysis therefore suggests significant crossover type genotype-by-environment effects may be occurring for sorghum grain yield in California, with the Sacramento and San Joaquin Valleys differing from each other. Selection of future research locations, variety recommendations, and hybrid performance summaries will need to take this into account. Additional trial locations in the Sacramento and San Joaquin Valleys are needed to test if two mega-environments are present.

The highest yielding varieties tend to be rated as mid-late lines by the seed suppliers. In contrast, yields and days to flowering do not correlate well. The lack of a correlation between seed yield and time to maturity suggests the genotype-by-environment pattern is not related to phenology. The pattern is also not clearly associated with soil type. The reason for the effect is therefore unclear and requires future research.

The reported maturities for the sorghum hybrids are not reliable in California and therefore should not be used for the purposes of experimental blocking. If identification of the best-adapted hybrid is the purpose of the work, it is suggested that the different maturity classes should not be separated and that all hybrids be harvested simultaneously. If the effect of harvest time on yield is of interest then separate, replicated, blocks with all varieties should be established with different harvest dates.

Yield recommendations should not be based on data from single seasons and/or locations. The hybrids tested here should be tested in at least two more seasons to draw reliable conclusions regarding their performance under Californian production conditions.

The residuals obtained from the analyses were large relative to other model effects. This indicates that experimental error needs to be reduced by increasing plot size and/or replication. This was also a conclusion from the analysis of data from the 2013-2015 trials.

Poor yields were observed at the DREC location. This was also observed in the, 2012-2014 variety trial work, and was attributed to high temperatures during seed set. To address this, earlier sowing with shorter season varieties should be considered.

References

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Appendix

Table 4: A summary of seed yield by harvest for sorghum hybrids tested in California in 2016 reported as lbs acre^{-1}. Harvests: 1 = Early, 2 = Mid, 3 = Late.

	Davis_1	Davis_2	Davis_3	KARE_1	KARE_2	KARE_3	WSREC_1	WSREC_3
50315X	12830	18105	17846	16452	13223	14858	19783	18245
50406X	6499	12700	14810	9948	13332	12255	15915	15658
50415X	10078	16050	14806	15547	9482	12395	20584	19319
50505X	12688	13287	18605	12969	13893	9054	16010	16667
51007X	13771	13886	12030	12911	14136	8055	14987	15283
54346X	13123	16057	19141	9126	11764	5410	17094	16099
84P72	16284	16621	17888	13598	10209	11738	18455	17353
85Y40	19001	18618	18935	14644	12354	12436	18004	18624
87P06	17809	16088	17977	11192	12699	7509	17126	17366
AG 2103	15554	16866	17378	10750	10983	9553	19491	17556
AG 2105	16493	17341	9983	14945	14157	10610	19172	19196
AG 3201	11486	17242	14637	13300	13451	8803	16800	18873
DKS38-16	16185	14554	16889	10502	11619	12264	17377	18746
DKS45-23	13365	17639	17855	14415	9897	9052	17308	18804
DKS51-01	16927	18731	15517	14861	13584	8318	16803	18300
DKS53-53	17477	18783	19119	12363	11521	13062	19221	19479
EXP 9058	13686	16225	14979	12032	11954	10395	9491	14300
EXP 9132	14399	17798	14820	16527	12423	12550	16197	18751
EXP 9135	15459	17432	15278	12065	13472	10970	18430	16160
GW 9320	11219	13611	15701	13315	14243	11285	18702	18278
GW 9417	12450	15918	15775	12259	13056	12894	17476	17566
KS 585	13102	13533	15571	10693	12603	7470	16188	17648
NK 7633	8894	15072	14667	12749	12249	13648	16919	18038
NK 8401	7502	12917	14785	9964	11382	6791	12409	11560

RS260E	17148	16069	16056	14380	11741	5957	16693	19604
RS3X	12696	15102	13017	14167	13486	12365	17380	17938
RS4X	12285	13750	12744	15335	11009	9785	16916	15950
RS5X	12384	14680	18373	13245	13871	12945	18148	18633
SP 68M57	16487	15372	14829	12161	8160	11117	19644	18592
SP 70B17	15019	17937	17029	16330	14198	14572	17773	18012
SP 73B12	13842	16952	15930	12307	12733	6358	18092	17053
SP 78M30	12930	17361	15298	14342	13038	9658	18297	17104
Swift	11120	16283	14238	12729	11251	7956	10034	12629