Pea Lodging Final Report

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1 Introduction

Jamin is a Ph.D. student in the Department of Plant Sciences and Plant Pathology at MSU. The primary focus is his research is to associate variation in genetic expression with variation in the expression of several phenotypic traits. Genotypic and pheynotypic data were collected on 257 varieties of pea, from two locations (Bozeman and Moccasin), over 4 years. Phenotypic data includes percent lodging, tendril length, tendril node length, nodes at 1st flow, maximum number of nodes, germination, number of branches, plant height, plant length, average total yield, main stem diameter, tiller diameter, "comp" tiller diameter, and maturation time, totaling 14 traits. Data from 609 genetic markers were collected. The end result of Jamin's research will include a quantitative trait loci (QTL) analysis. Prior to the QTL analysis, understanding of the data and methods are necessary. The report includes:

- Evaluation of correlations in pheynotypic data

- Analysis of combining data from the different sites and years

- Exploration of the rate of missing data

- Explanation of significance thresholds for QTL

- Suggestions for future work

2   Correlation Plots

Correlation describes the strength and direction of a linear association. Specifically, this analysis examines Pearson Correlations because the variables are measured on a quantitative scale. Correlation is measured on a scale between -1 (a perfect negative linear association) and 1 (a perfect positive linear association). Correlation does not imply causal relationships. In examining, for instance, the relationship between lodging and stem width, the Pearson Correlation would only give information about the linear association between the two variables. A strong association between the two variables cannot be interpreted that changes in stem width cause changes in lodging; rather, we would simply say that the two variables are associated with each other. Other confounding variables, such as climate, may be driving both. Since the phenotypes in each year at each site are considered separate response values, we consider examining plots of correlation matrices for each site/year combination as well as for the entire dataset. This allows for direct examination of linear relationships between covariates; however, non-linear relationships may not be accurately measured by Pearson correlation. Further investigation of outlying values in the data may be necessary as Pearson correlations are sensitive to the presence of outliers in the data.

2.1   Sites and Years Combined

The correlation between pairwise explanatory variables of the phenotypic data were assessed using the a pairwise correlation matrix. We assessed the pairwise correlations across sites for pairs of explanatory variables which were measured within these sitesin at least two different years.

In Moccasin, only four variables were observed to have been measured both in 2015 and 2016. Of these variables, the length and main stem diameter of the plants are moderately correlated (r=-0.55). Also, the main stem diameter and root diameter of the plants are moderately correlated (r=0.45).

2.2 Bozeman in All Years

The pairwise correlation matrix below shows that germination which was measured in Bozeman for all 3 years has weak correlation against all the variables measured. Also results from Bozeman shows that tendril length node of the plant was moderately to strongly correlated with the average length and tendril length of the plant with correlation coefficients of 0.61 and 0.48 respectively. The branch number and tiller diameter of the plant were also moderately correlated (r = 0.47). The maturity time of the plant was strongly and moderately correlated with the maximum nodes (r=0.65) and nodes of 1st flow (r=0.48). In addition, a correlation coefficient of 0.81 was observed for nodes 1st flow and maximum nodes of the plants.

```
'data.frame': 787 obs. of  14 variables:
 $ prcnt_lodging      : num  17.3 NA 52.4 22.7 29.4 ...
 $ branch_numb        : num  3.07 3.12 3 3 2 ...
 $ plant_height       : num  42.4 NA 30 34 31.2 ...
 $ plant_length       : num  51.4 NA 63 44 44.2 ...
 $ mat_time           : num  NA NA NA NA NA NA NA NA NA NA ...
 $ germ               : Factor w/ 60 levels "","#DIV/0!","10",..: 55 1 25 4 28 50 21 50 23 21 ...
 $ tendril_length     : num  19.9 14.2 21.5 15 17 ...
 $ main_stm_diam      : num  2.74 NA 2.33 NA 3.04 ...
 $ tendril_length_node: num  18.2 14.2 20.3 15 14.8 ...
 $ nodes_1st_flow     : num  16.5 20 14 19 15 ...
 $ max_nodes          : num  21 25.5 23 23 19 18 24 19 22 19 ...
 $ avg_total_yield    : num  14.9 NA 10.8 10.9 12.9 ...
 $ tiller_diam        : num  3.27 NA 3.3 NA 3.39 ...
 $ comp_tiller_diam   : num  0.791 NA 1.218 NA 0.858 ...
```
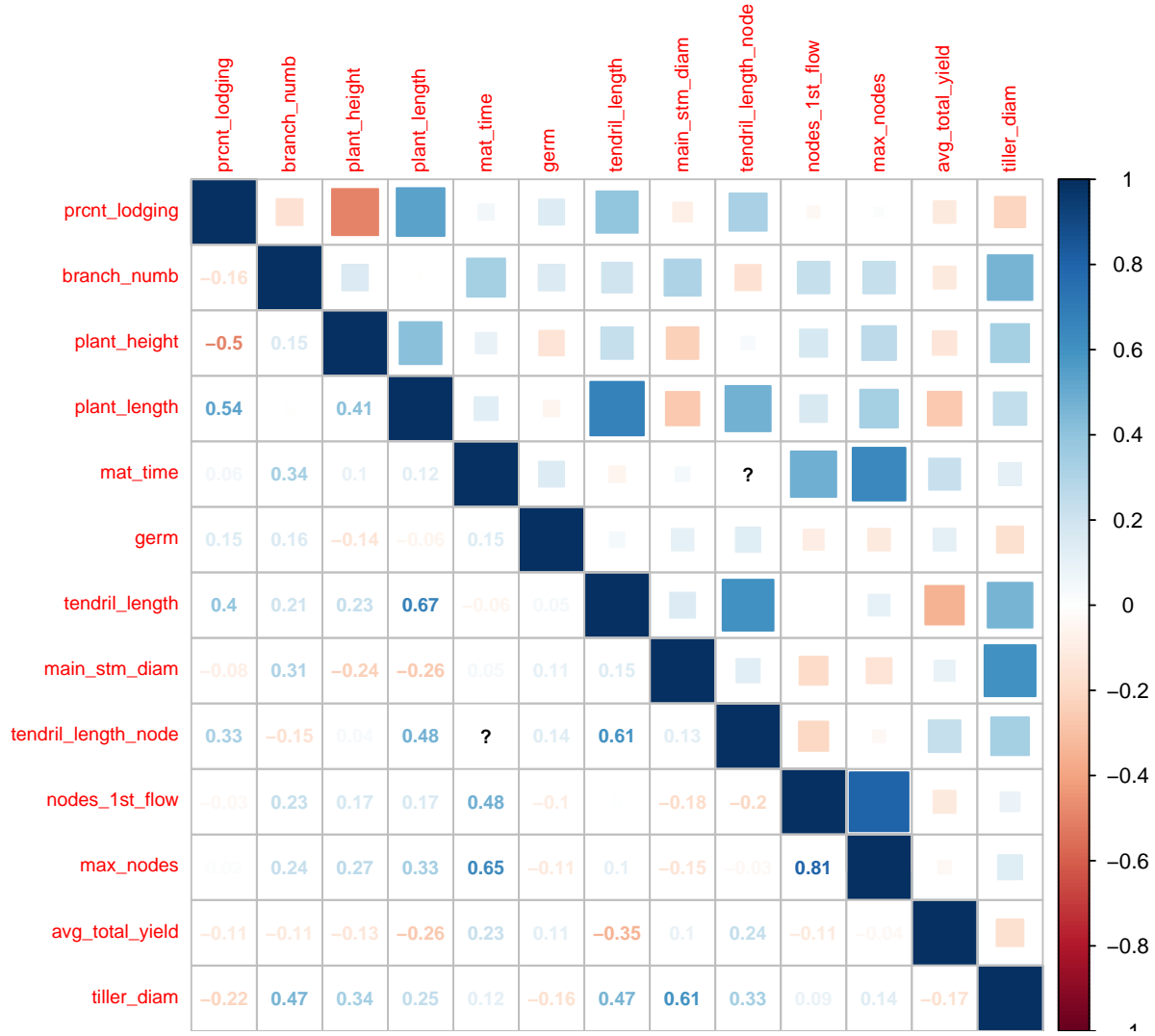
Figure 1: Correlation Plot for Bozeman (In All Years)

2.3   Bozeman by Year

We assessed the pairwise correlation of the different sites each year. In 2014, twelve pairs of explanatory variables had correlation coefficients between 0.42 and 0.91. The pairwise correlations are shown in the matrix below. Germination and total yield was strongly correlated (r=0.66) while the length and internode length of the plants recorded a very high correlation coefficient (r=0.91). In 2015 and 2016, of the pairwise combinations assessed, 28 combinations yielded correlation coefficients between 0.40 and 0.85. The results are presented in the pairwise correlation matrices below.

4
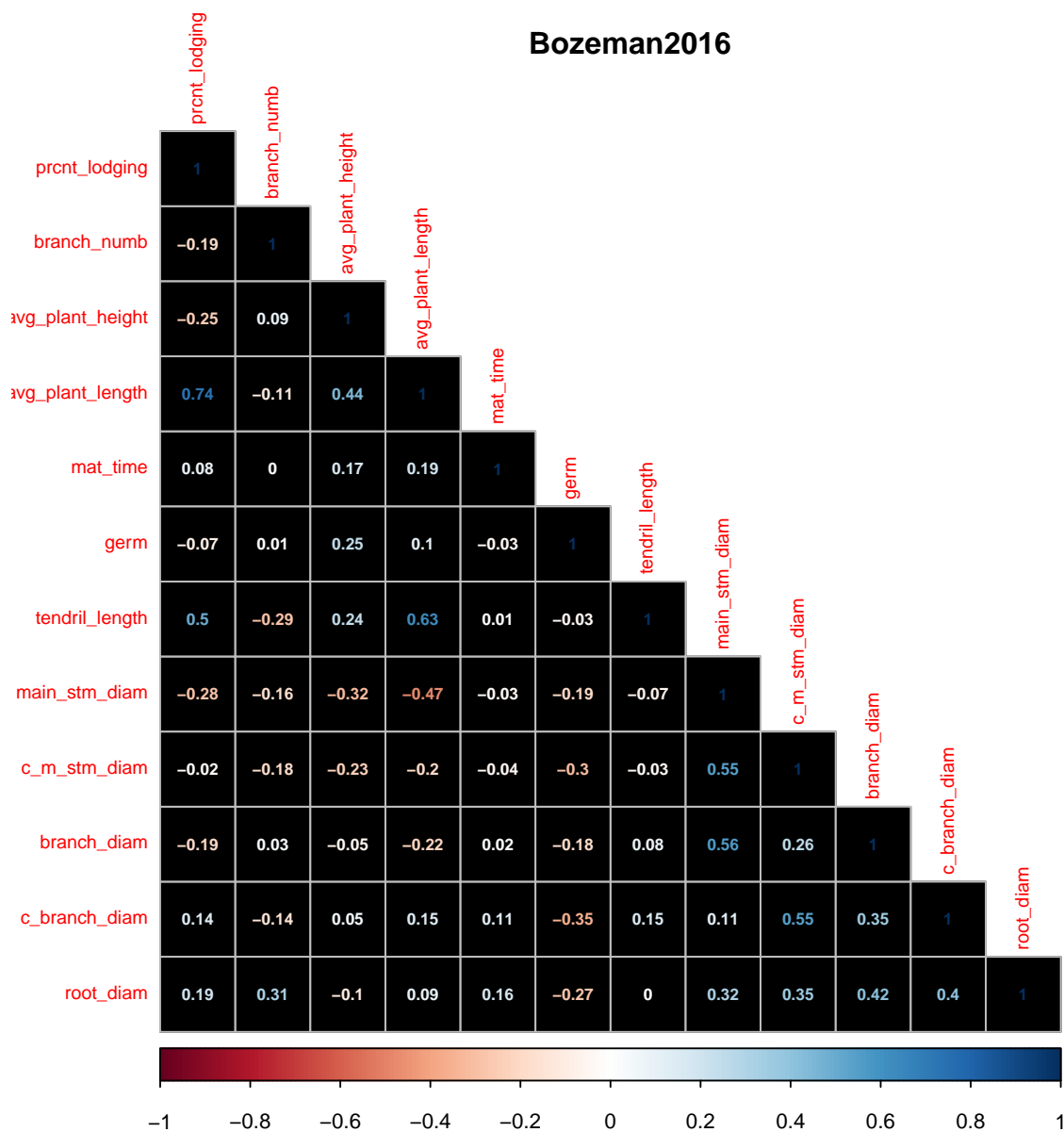
Figure 2: Correlation Plot for Bozeman in 2016
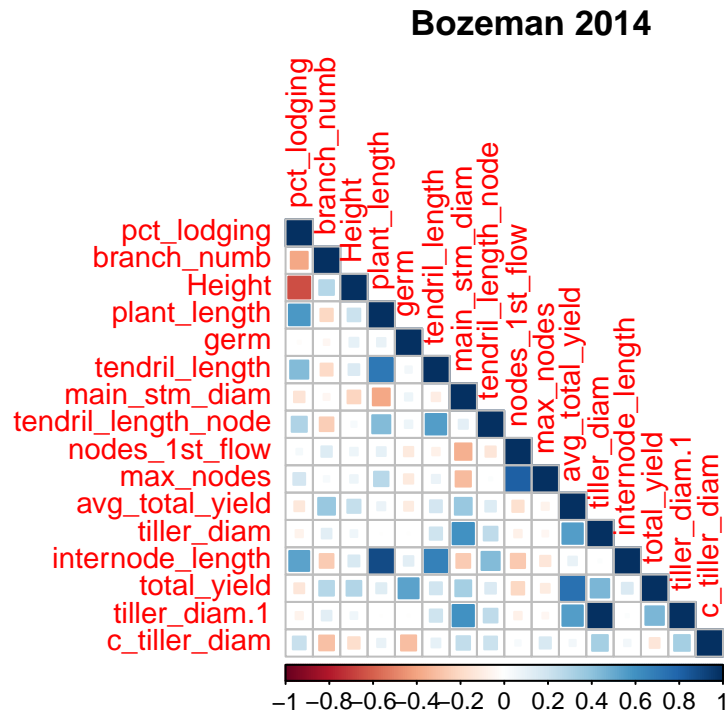
Figure 3: Correlation Matrix for Bozeman in 2014
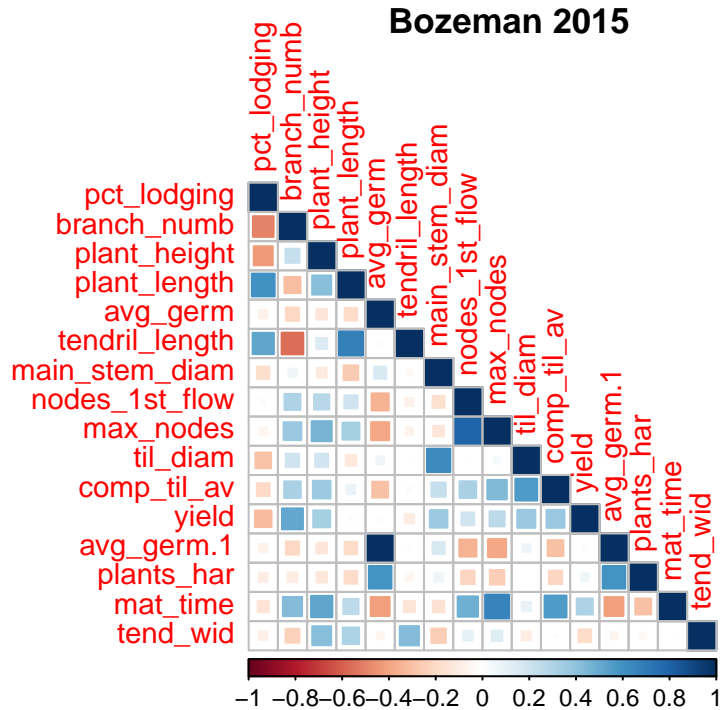
Figure 4: Correlation Matrix for Bozeman in 2015

2.4   Moccasin by Year

Examining the phenotypes at Moccasin in each year, we can see that several of the variables were relatively highly correlated in 2016. The strongest correlations were between tendril length and plant length, which makes sense, as well as between percent lodging and plant length. While none of the correlations would be interpreted as very strong, there are moderate postive and negative relationships in both years.
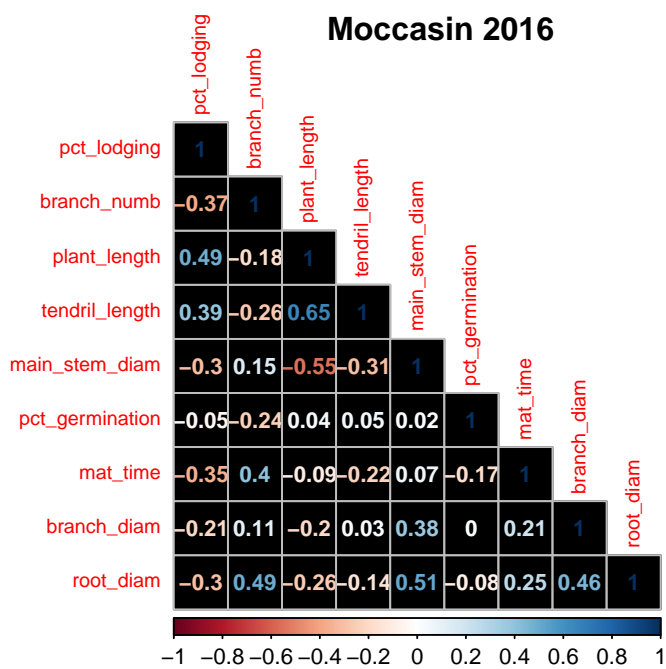
Figure 5: Correlation Matrix for Moccasin in 2016

In Moccasin in 2015, several notable correlations were found. Stress minus equation was strongly negatively correlated with tiller diameter, tiller compressed, tiller compressed flex, and flex after crushing. Lodging was found to be correlated with plant height as expected.

Moccasin 2015
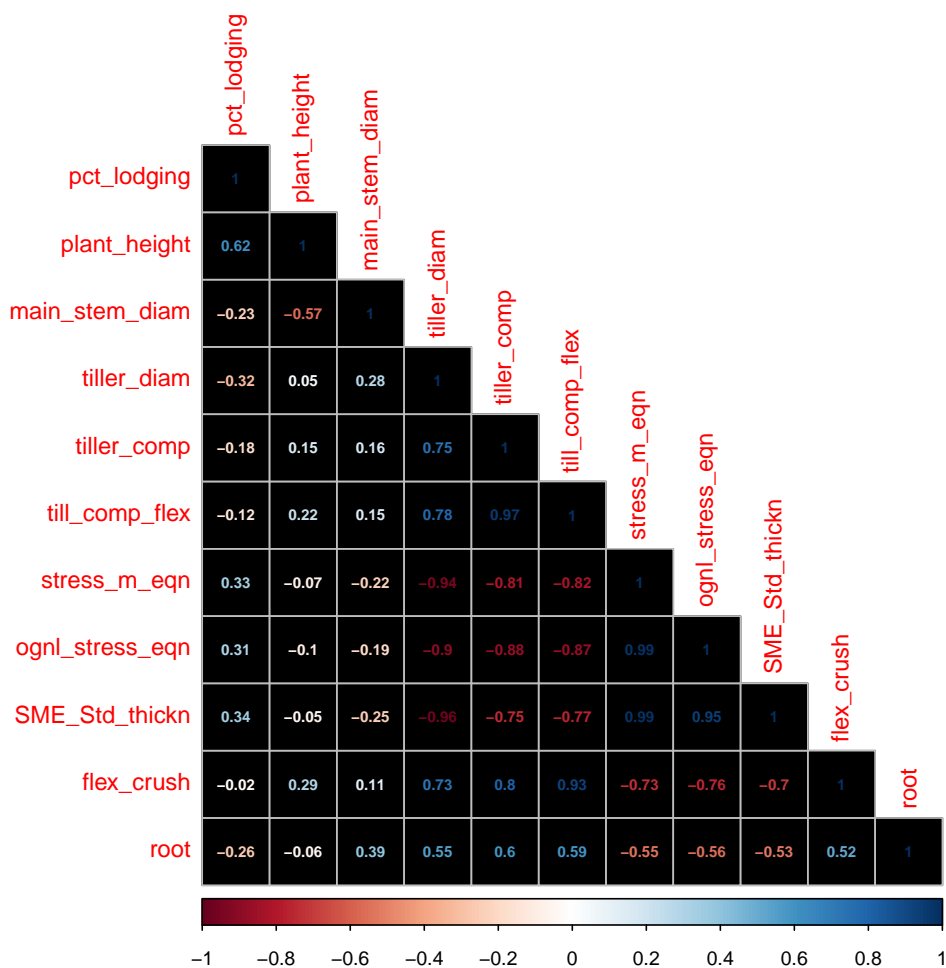
Figure 6: Correlation Matrix for Moccasin in 2015

Moccasin in All Years
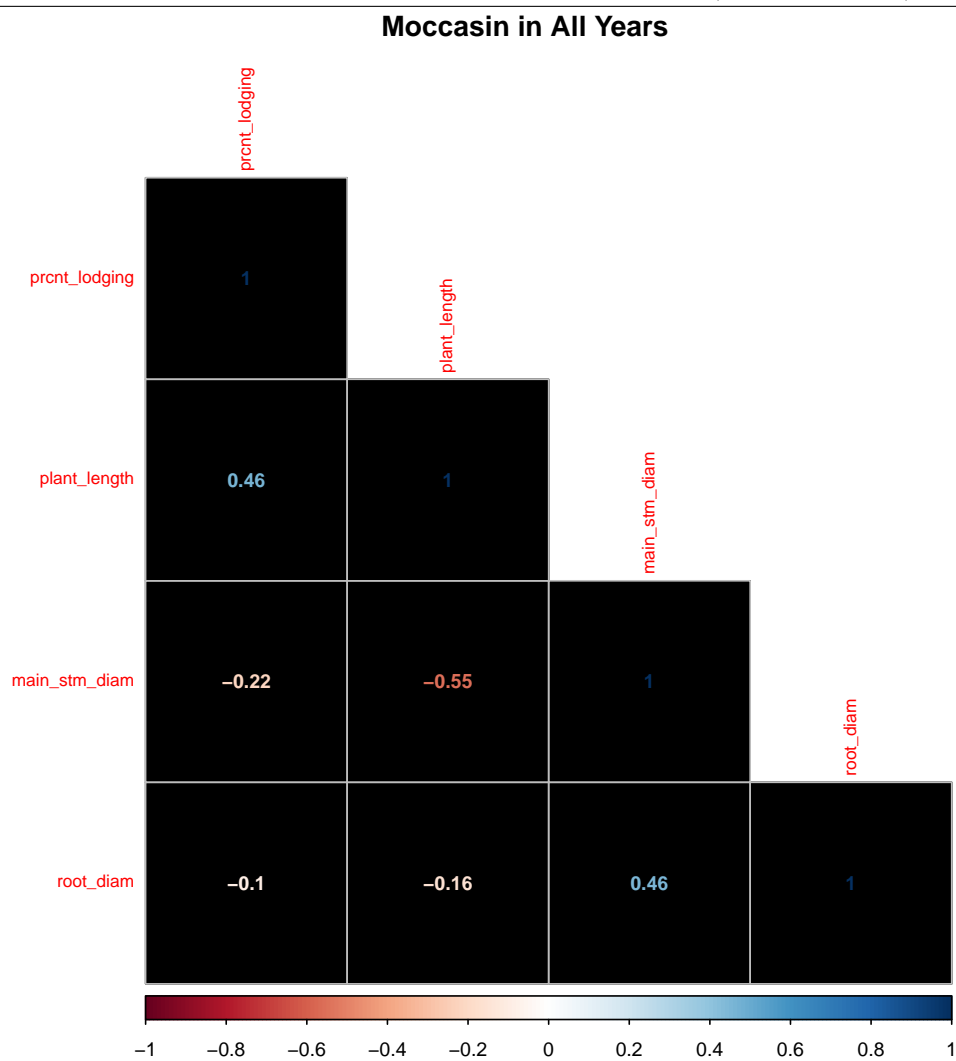
Figure 7: Correlation Matrix for Moccasin (In All Years)

3   Site Year Combinations for Lodging

3.1   Exploratory Analysis

The data were collected over a period of 4 field seasons at sites in Bozeman and 2 field seasons in Moccasin. Phenotypic data were analyzed in order to determine whether conditions were similar enough at each year/site combination to consider as a single dataset, or if they differ by enough that the sites and years need to be considered as different groups.

Though QTL analyses of all phenotypic traits is of interest, lodging is considered the primary response. Therefore, we examine the Percent Lodging measured at each site/year combination. Note that Percent Lodging is not measured in the 2013 Bozeman data; we did not include it in this analysis.

Visually, we can create beanplots (Kampstra 2008) to assess the differences mean percent lodging at each year/site combination. These show both the variability of the distribution, like a traditional boxplot would, as well as information about the skew and modes. Over all years in Bozeman it appears that the distribution of lodging was slightly more variable than for sites in Moccasin; however, for some reason in 2016 the Bozeman site exhibited positive skew. This indicates that in 2016, the majority of pea plants were lodged to a lesser degree than in 2015 or 2014. The thin horizontal black bars indicate the original data values; the bold black lines indicate group means.
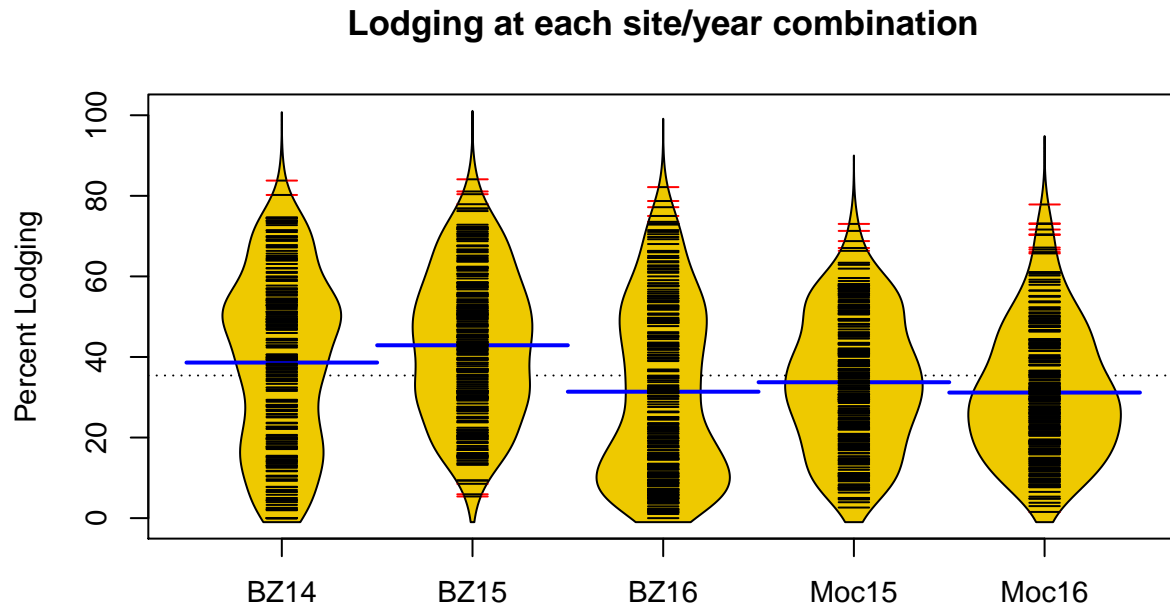
Figure 8: Comparative Beanplot of Site/Year Combinations

3.2 Interaction Plot

If the sites are reasonably similar, we would expect to see parallel lines that are either overlapping or very near each other. The dashed red line for Bozeman indicates that average percent lodging was higher in Bozeman than in Moccasin in both 2015 and 2016. The bars indicate the variability of lodging for each year in Bozeman - it appears that for most years, Bozeman was slightly more variable than Moccasin. While the blue line and red line are both decreasing from 2015 to 2016, the difference in slopes indicates that there may be some interaction between year/site combinations. This visualization indicates some evidence of a difference in lodging in each location and year. However, since there are no observations from Moccasin in 2014, we cannot formally test for a site by year interaction.

Interaction plot of lodging based on year and site
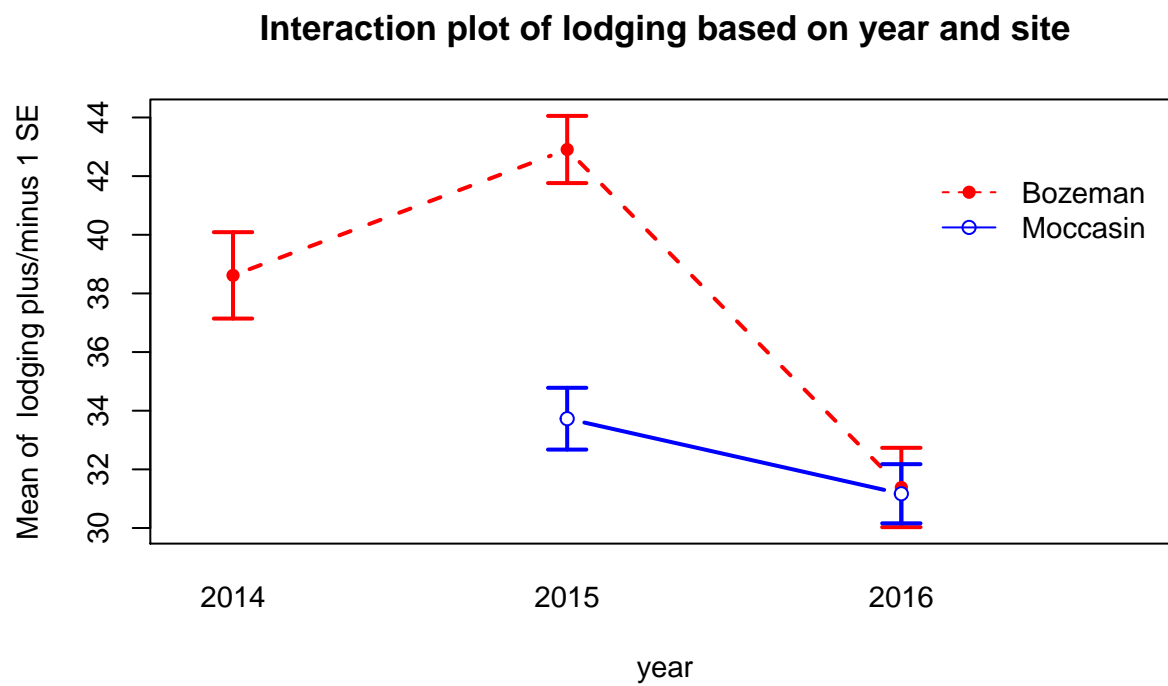
Figure 9: Interaction Plot for Sites and Years

3.3 Regression Model and Pairwise Comparisons

A model was fit to include all site and year combinations in order to test for differences between the combinations. Bozeman 2014 was treated as the baseline group. An overall F test using 4 and 1205 degrees of freedom to assess evidence against all site-year combinations yields a p-value less than 0.000001. There is strong evidence that the site/year combinations do not have all the same mean percent lodging.

We include 95 percent confidence intervals for the true mean percent lodging at each site-year combination. In order to get a better sense for which groups differ, we performed Tukey-Kramer pairwise comparisons to adjust for multiple testing. The results of that analysis are included below. The plot below shows differing pairwise combinations were between Bozeman 2015 and Bozeman 2014, as well as between Moccasin 2015 and Bozeman 2016, and between Moccasin 2016 with Bozeman in 2015 and 2016. Given that Bozeman 2015 had such a large mean relative to the other site/year combinations, this is not a surprising result.

F Test Results and Confidence Intervals for Lodging at Each Site			
Coefficients	**Mean**	**Lower Bound**	**Upper Bound**
Bozeman 2014	38.62%	36.08%	41.14%
Bozeman 2015	42.91%	40.55%	45.26%
Bozeman 2016	31.38%	29.07%	33.69%
Moccasin 2015	33.73%	31.36%	36.09%
Moccasin 2016	31.17%	28.86%	33.47%
F Test Results	$F_{4,1205} = 17.99$		P-value: <0.00001
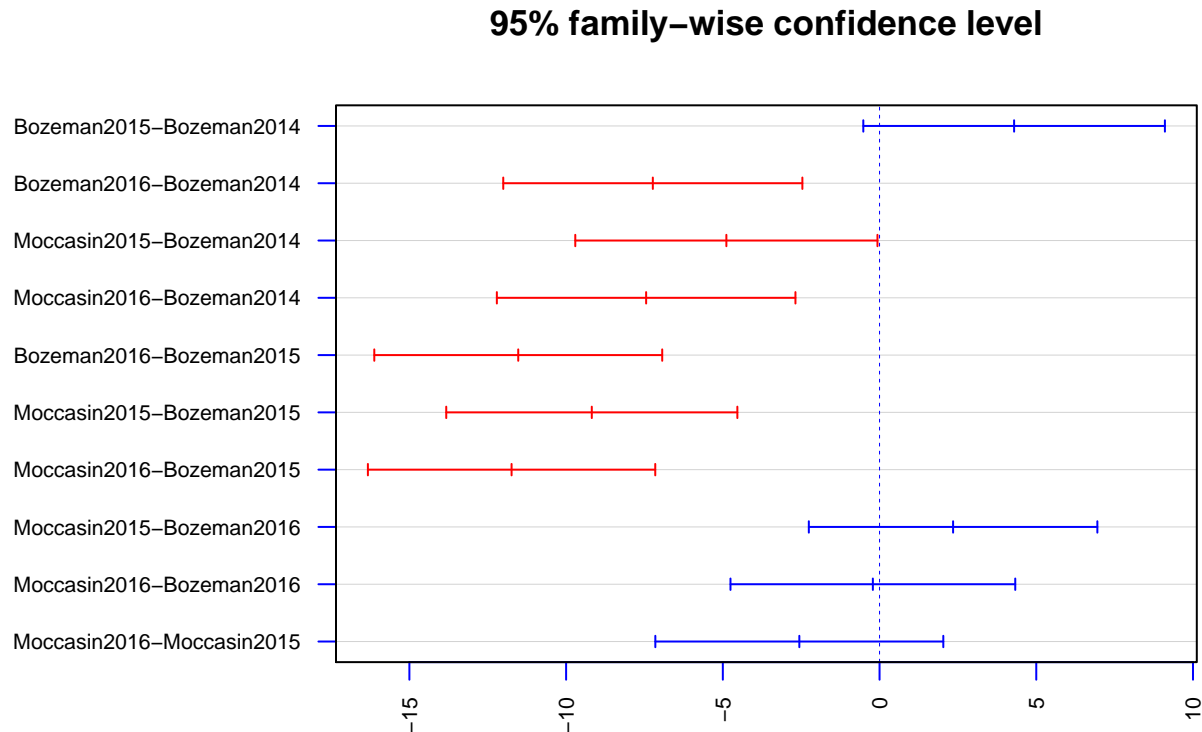
Figure 10: Multiple Comparisons of Lodging at Sites and Years

3.4 Discussion

This analysis indicates that the measurements taken at each site in each year should be treated separately; they should not be considered homogeneous enough to be taken as a single group. The inclusion of 2013 into the data is unlikely to change the results of this study because the differences between the combinations already considered are enough to justify splitting the dataset into separate groups. However, it may facilitate future calculations to consider converting lodging measurements in Bozeman in 2013 from likert-scale format (on a 1-4 scale) to the same "percent-lodging" variable that is used in subsequent years.

4   Missing Genetic Data

Quality of the genetic data can be explored through the percentage of varieties missing information at each genetic marker. Reviewing QTL literature may provide insight to acceptable missing rates. Plots are provided below to visualize the amount of missing data at each genetic marker and across each variety genotyped. Tables of missing rates are provided in the appendix. As the number of genetic markers and varieties are large, the tables will be more informative on the exact varieties with certain missing rates. Rates of missing-ness at each genetic marker are first shown across all makers, and then are broken into plots subsetted by genetic markers with less than 25% missing, less than between 25% and 30% missing, less than between 30% and 35% missing, and less than between 35% and 40%. All genetic markers had at least 60% of the data across all varieties.

4.1   All Markers
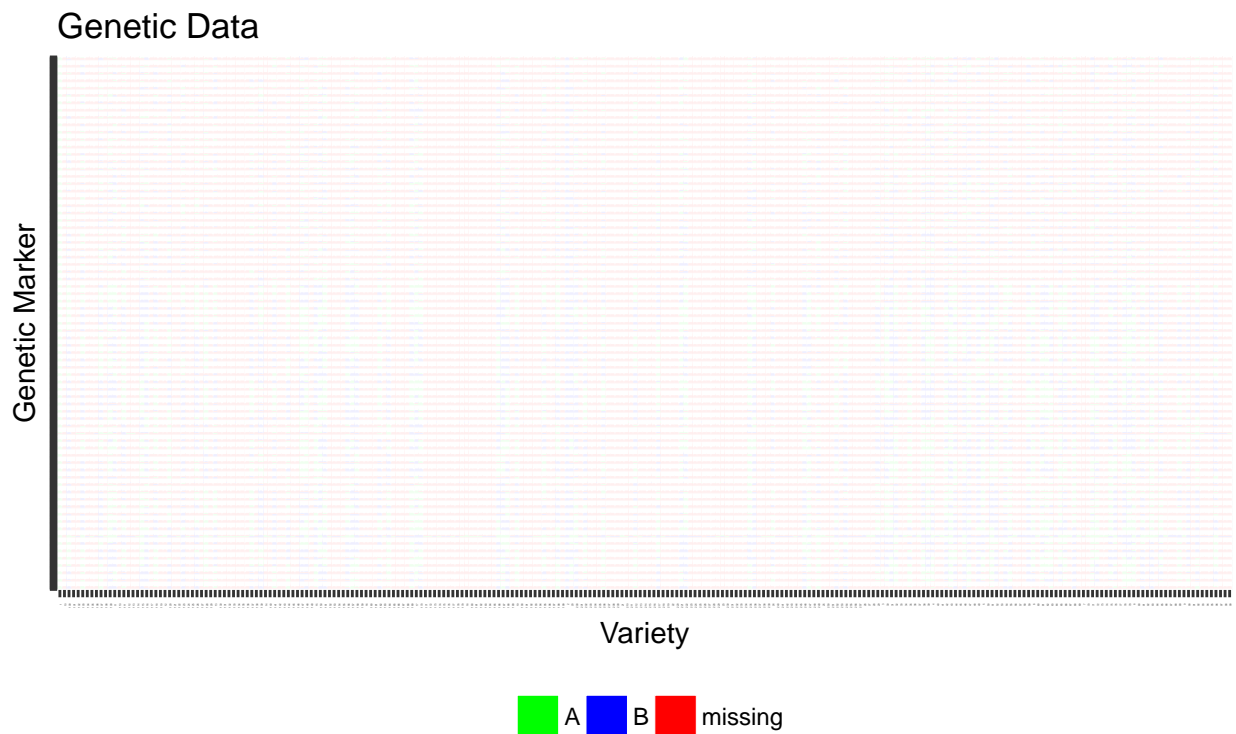
Figure 11: Missing Genetic Data Plot

4.2   Less than 25% Missing by Genetic Marker
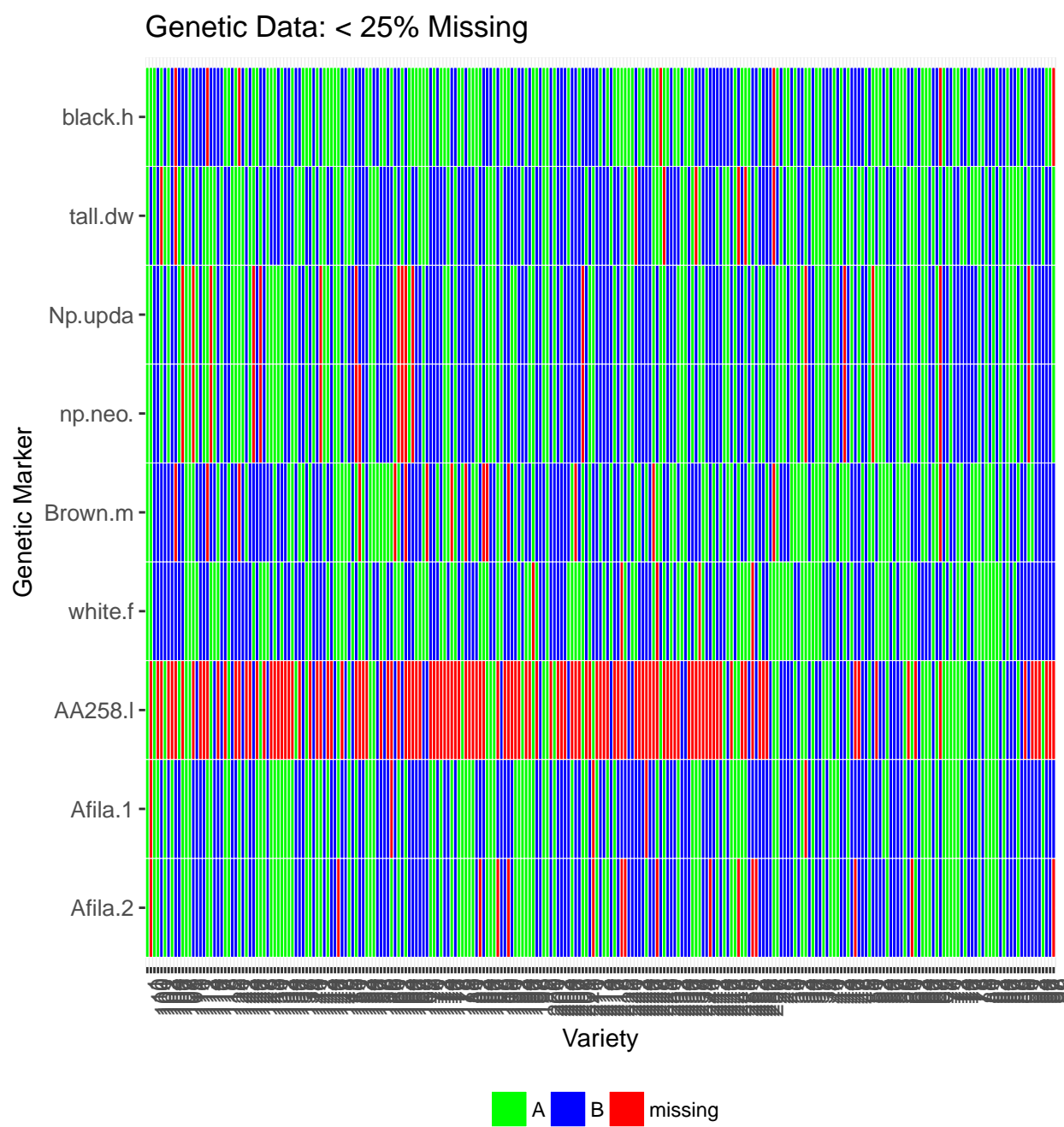
Figure 12: Less Than 25 Percent Missing

4.3   25% - 30% Missing by Genetic Marker

Genetic Data: 25% – 30% Missing
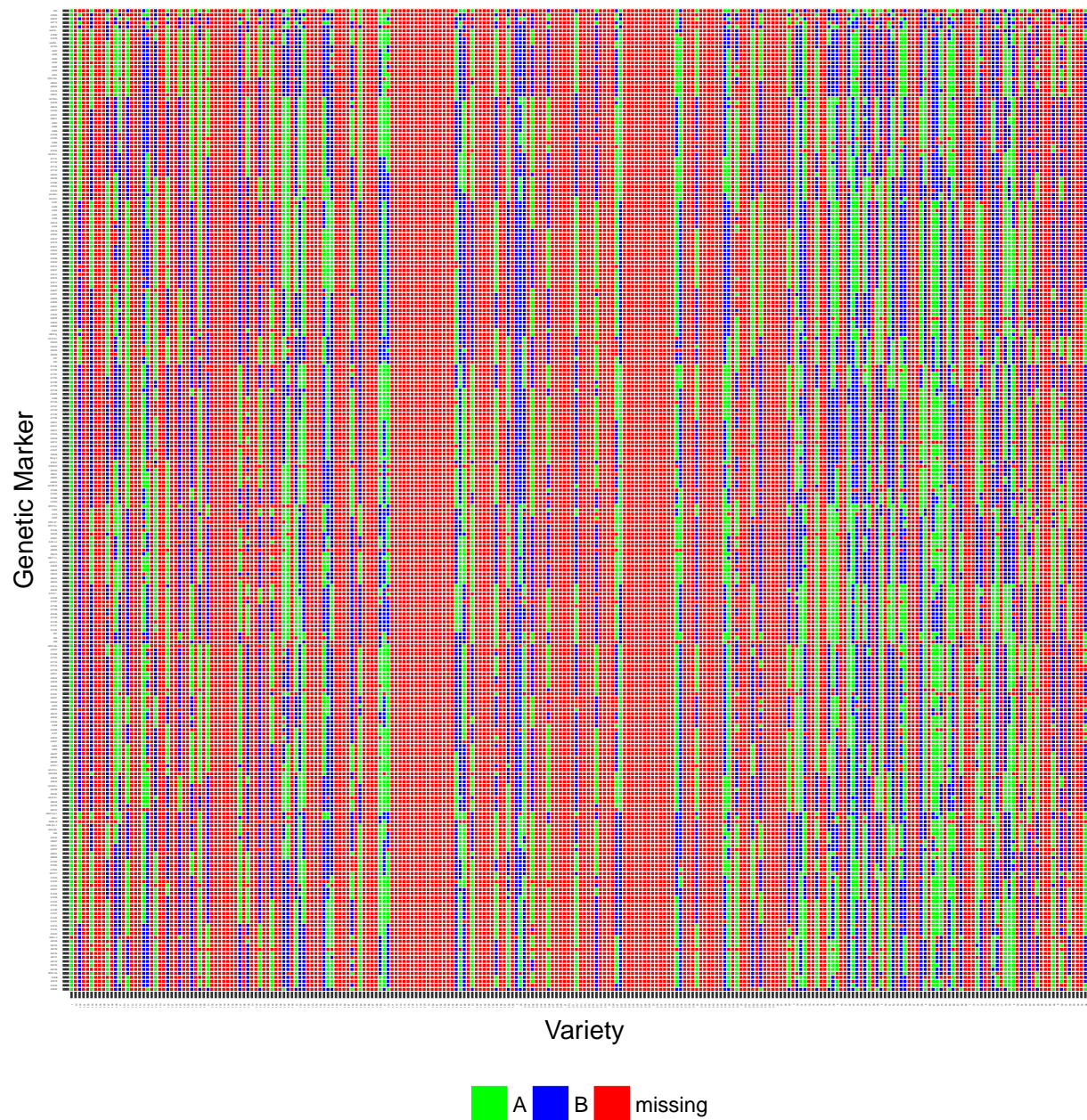
Figure 13: 25-30 Percent Missing Data

4.4   30% - 35% Missing by Genetic Marker
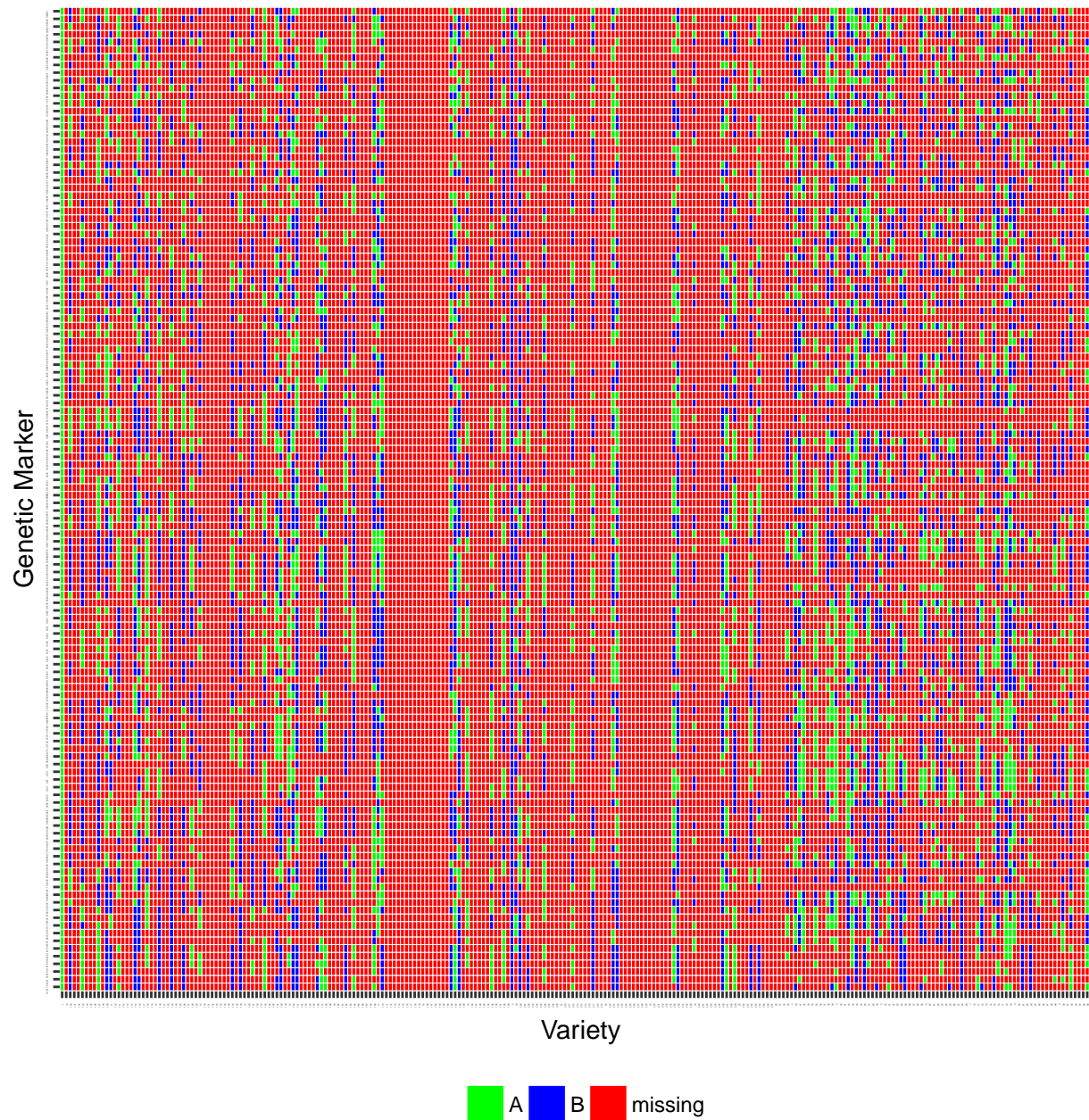
Figure 14: 30-35 Percent Missing Data

4.5   35% - 40% Missing by Genetic Marker

Genetic Data < 35 % − 40% Missing
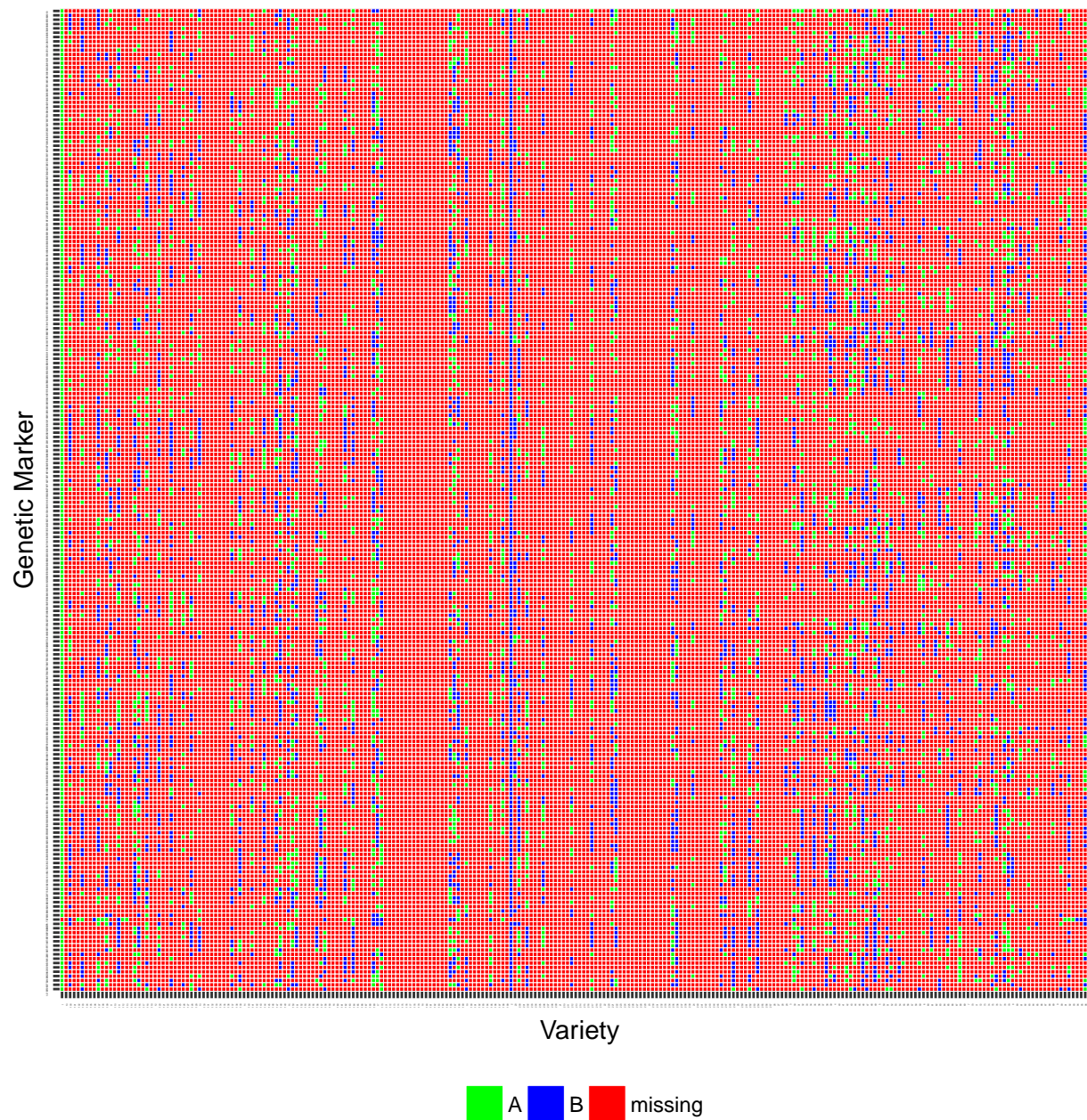
Figure 15: 35-40 Percent Missing Data

5   Setting Significance Thresholds

The pea genetic data include over 600 genetic markers. When a QTL analysis is done, a significance test is done at each genetic marker to test for an association between the average quantiative trait and the genotype. Multiple testing problems are quite common in genetic analyses. Jamin mentioned he would like to use LOD for setting a significance threshold. LOD is an abbreviation for the log-odds. LOD is the log_{10} likelihood ratio comparing the null that there is not a QTL to the alternative, that there is.

Null Model, $H_o : y_i \sim N(\mu, \sigma^2)$ i.e., there is no genetic dependency between the phenotype and the genotype. We define the Residual Sum of Squares (RSS_0) to be the squared difference between the expected mean lodging for each marker and the overall mean lodging under the null model.

- Where the maximum likelihood estimates (MLEs) for parameter estimates $\mu = \bar{y}; \sigma^2 = RSS_o/n$ are used.

Alternative Model, $H_a : y_i|g_i \sim N(\mu_{g_i}, \sigma^2)$

- Where g_i = genotype of individual i at the marker (loci); each genotype group has a different mean; σ^2 = pooled RSS = RSS_1; again the MLEs.

LOD = $\frac{n}{2} \times log_{10}(\frac{RSS_o}{RSS_1})$

LOD is related to the F statistic. LOD = $\frac{n}{2} \times [F(\frac{df}{n-df-1} + 1)]$ and similar to the F statistic, large LOD values are associated with strong evidence against the null hypothesis, suggesting that there is a relationship between the genetic loci and the phenotype. Since F statistics help find p-values, and LOD is related to F statistics, by setting genome wide adjusted LOD thresholds, we can easily convert these back to genome wide adjusted p-values. Broman and Sen (2009) provide a simulation based method for generating genome wide adjusted LOD thresholds, and the corresponding genome-wide adjusted p-value thresholds in Section 4.3 using the `QTL` package in R (Broman et al. 2003).

6   Future Work

Future work with Jamin should be more focused with the QTL analysis and developing p-value based thresholds for drawing statistical conclusions. Jamin currently is using the MapDisto macro in Excel and QTL Cartographer to do preliminary QTL analyses. Both programs provide extensive documentation on their functions. R is a common program for statisticians to use, and discussion around whether packages such as `QTL` in R or outside programs should be used in the final analysis would be beneficial. While identifying specific genetic markers associated with the most variation in phenotypic traits is the end goal of the project, a QTL analysis has many steps that should be taken before using outputted results. Broman and Sen (2009) is a good reference for a basic QTL

analysis. Because Jamin is interested in genetic variation associated with all phenotypic traits, the correlations between the traits should be accounted for in the final analysis. Adding in the recommendation to not combine across sites and years, we suggest the direction of the final QTL analysis done to be in a multi-trait, multi-environment setting. A resource for an introduction to the multi-trait, multi-environment setting in QTL analyses is referenced by Margarido et al. (2015).

References

Margarido et al. 2015. *Multi-trait multi-environment quantitative trait loci mapping for a sugarcane commercial cross provides insights on the inheritance of important traits*. Mol Breeding 35:175.

Broman and Sen. 2009. *A guide to QTL mapping with R/QTL*. New York: Spring Science+Business Media. Retrieved from

`http://link.springer.com/book/10.1007%2F978-0-387-92125-9`.

Appendix

Tables of Missing Rates by Genetic Marker

	A2594	A1617	A1621	A1619	A1618	A1624	A1615	A1622	A7578	C20B	AD51.ba	A6734	A6726	A6730	A6732	A6733	A6731	A6737	A6724	A6729
Count	164.00	194.00	199.00	202.00	195.00	199.00	185.00	163.00	163.00	170.00	166.00	209.00	162.00	161.00	161.00	210.00	166.00	190.00	163.00	182.00
Percent	0.27	0.32	0.33	0.33	0.32	0.33	0.30	0.27	0.27	0.28	0.27	0.34	0.27	0.26	0.26	0.34	0.27	0.31	0.27	0.30

	A6738	A6725	A6728	A004..s	A1623	A1620	A1303	A1616	A1331	A1325	A1327	A1329	A1330	A1332	A1409	A1408	A2407	A1405	A1404	A1402
Count	193.00	163.00	165.00	173.00	185.00	162.00	161.00	168.00	164.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	161.00	187.00	169.00	193.00
Percent	0.32	0.27	0.27	0.28	0.30	0.27	0.26	0.28	0.27	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.31	0.28	0.32

	A1403	A1024	ad147.l	A7384	A7380	A7302	A7302.1	A2197	A6889	A6891	A2259	A2257	A2256	A2521	A5967	A2340	A26	A26.dpn	A26.dpn.1	Ab56..D
Count	176.00	162.00	163.00	162.00	163.00	163.00	211.00	226.00	164.00	163.00	187.00	170.00	201.00	161.00	162.00	162.00	161.00	165.00	165.00	182.00
Percent	0.29	0.27	0.27	0.27	0.27	0.27	0.35	0.37	0.27	0.27	0.31	0.28	0.33	0.26	0.27	0.27	0.26	0.27	0.27	0.30

	Afila.2	Afila.l	Afila.1	AA258.l	AD51.ba.1	A6953	A5189	A6757	A6755	A6648	AA473.L	A6762	A6758	AA332.L	A4834	A4832	AA5.Mid	AA372.L	white.f	white.f.1
Count	16.00	163.00	5.00	129.00	166.00	218.00	192.00	171.00	161.00	161.00	164.00	162.00	162.00	162.00	161.00	163.00	171.00	166.00	5.00	161.00
Percent	0.03	0.27	0.01	0.21	0.27	0.36	0.32	0.28	0.26	0.26	0.27	0.27	0.27	0.27	0.26	0.27	0.28	0.27	0.01	0.26

	A6085	A6086	A6087	A854	A853	A4507	A4500	A337	A4495	A4496	A7738	A7732	A4497	A298	A7055	A4292	A6470	A5495	A5502	A220
Count	163.00	167.00	163.00	162.00	162.00	171.00	163.00	172.00	173.00	195.00	208.00	215.00	205.00	162.00	169.00	161.00	162.00	199.00	166.00	171.00
Percent	0.27	0.27	0.27	0.27	0.27	0.28	0.27	0.28	0.28	0.32	0.34	0.35	0.34	0.27	0.28	0.26	0.27	0.33	0.27	0.28

	A5501	A5494	A5499	A5491	A5498	A299	A1561	A7736	A4494	A4508	A4502	A4501	A7729	A7734	A7733	A4499	A7740	A7258	A7257	AD51.Ba
Count	184.00	166.00	190.00	169.00	198.00	202.00	181.00	180.00	163.00	162.00	162.00	161.00	166.00	165.00	161.00	219.00	163.00	164.00	167.00	171.00
Percent	0.30	0.27	0.31	0.28	0.33	0.33	0.30	0.30	0.27	0.27	0.27	0.26	0.27	0.27	0.26	0.36	0.27	0.27	0.27	0.28

	A5204	A5213	A5165	A5193	A5191	Brown.m	A60	A56	A61	A55	A57	A59	A5226	A58	A5229	LKA.F5.	A7184	A7183	A7181	A7185
Count	223.00	224.00	206.00	217.00	227.00	16.00	190.00	182.00	190.00	168.00	165.00	193.00	220.00	208.00	189.00	186.00	162.00	192.00	164.00	164.00
Percent	0.37	0.37	0.34	0.36	0.37	0.03	0.31	0.30	0.31	0.28	0.27	0.32	0.36	0.34	0.31	0.31	0.27	0.32	0.27	0.27

	A7182	A2446	A7188	A7186	A7187	A7356	A7357	A7298	A4307	AA107..	A6492	A7814	A7814.1	A5160	A7346	A7339	A7371	A7340	A7359	A7369
Count	163.00	162.00	161.00	169.00	200.00	207.00	178.00	166.00	196.00	164.00	163.00	161.00	191.00	216.00	196.00	213.00	220.00	216.00	216.00	217.00
Percent	0.27	0.27	0.26	0.28	0.33	0.34	0.29	0.27	0.32	0.27	0.27	0.26	0.31	0.35	0.32	0.35	0.36	0.35	0.35	0.36

	A7348	A2431	A6253	A6252	A6254	A6622	A4829	AD73.f.	AB111.L	A6075	A6995	A4460	AA5..Lo	A4461	A6994	A2246	A1025	AD174.L	CDC.27.	A836
Count	217.00	218.00	164.00	164.00	162.00	163.00	164.00	164.00	162.00	163.00	181.00	162.00	162.00	165.00	199.00	169.00	162.00	164.00	170.00	161.00
Percent	0.36	0.36	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.30	0.27	0.27	0.27	0.33	0.28	0.27	0.27	0.28	0.26

	A836.1	NCPA.F2	A5200	A430	A420	A413	A145	A422	A428	A432	A421	A423	A425	np.neo.	Np.upda	AD270.L	tall.dw	A1063	A1066	A1064
Count	213.00	219.00	198.00	186.00	200.00	166.00	201.00	163.00	203.00	184.00	189.00	207.00	186.00	18.00	17.00	169.00	8.00	161.00	163.00	162.00
Percent	0.35	0.36	0.33	0.31	0.33	0.27	0.33	0.27	0.33	0.30	0.31	0.34	0.31	0.03	0.03	0.28	0.01	0.26	0.27	0.27

	A1065	AA285.D	A6802	A6800	A6801	A6160	P628.Hi	A7837	A2100	A5640	A783	A5896	A2004	A2342	A9.lg.4	A2343	A1996	A2002	A2006	A1221
Count	179.00	164.00	162.00	162.00	166.00	162.00	182.00	171.00	200.00	206.00	220.00	226.00	187.00	208.00	162.00	202.00	183.00	190.00	163.00	164.00
Percent	0.29	0.27	0.27	0.27	0.27	0.27	0.30	0.28	0.33	0.34	0.36	0.37	0.31	0.34	0.27	0.33	0.30	0.31	0.27	0.27

	A1224	A2012	A2008	A1223	A2007	A2341	A2001	A7189	A7192	A7193	A7197	A7196	A296	AGAT.Hi	A2181	A4598	A7749	A4852	A6542	A1785
Count	166.00	176.00	162.00	163.00	163.00	162.00	161.00	161.00	163.00	163.00	164.00	168.00	162.00	185.00	185.00	162.00	162.00	228.00	194.00	161.00
Percent	0.27	0.29	0.27	0.27	0.27	0.27	0.26	0.26	0.27	0.27	0.27	0.28	0.27	0.30	0.30	0.27	0.27	0.37	0.32	0.26

	A1788	A1783	A1787	A1782	A1786	A30	A37	A5406	A5399	A5402	A5404	A5400	A5398	AA315.L	A5517	A4825	A4826	A4824	AB23.lg	AA81
Count	161.00	161.00	161.00	169.00	167.00	164.00	161.00	183.00	167.00	166.00	169.00	165.00	194.00	163.00	183.00	227.00	227.00	205.00	161.00	165.00
Percent	0.26	0.26	0.26	0.28	0.27	0.27	0.26	0.30	0.27	0.27	0.28	0.27	0.32	0.27	0.30	0.37	0.37	0.34	0.26	0.27

	A4808	A4804	A4806	A1822	A4337	A4807	A4809	A4805	A1821	A4827	A2144	PYDC.UN	A5227	A5157	A7606	A7611	A7618	A7613	A7621	A7610
Count	161.00	162.00	175.00	162.00	163.00	162.00	162.00	162.00	162.00	168.00	195.00	205.00	222.00	207.00	162.00	165.00	164.00	164.00	164.00	170.00
Percent	0.26	0.27	0.29	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.32	0.34	0.36	0.34	0.27	0.27	0.27	0.27	0.27	0.28

	A7604	A7608	A7607	A7602	A7601	A7615	A7614	A7603	A7619	A446	A2518	A448	A451	A452	A449	A447	A445	A444	A4546	AA374.1
Count	164.00	162.00	162.00	162.00	162.00	163.00	163.00	163.00	162.00	161.00	164.00	163.00	163.00	163.00	161.00	163.00	194.00	204.00	192.00	163.00
Percent	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.27	0.27	0.27	0.26	0.27	0.32	0.33	0.32	0.27

	AA224.1	A7224	A7223	A1580	A5439	A5420	A7133	A7134	A7132	A7131	AA335.L	A1006	A1004	A1002	A1007	A995	A996	A1003	A1008	A999
Count	161.00	165.00	163.00	161.00	161.00	161.00	162.00	162.00	161.00	161.00	161.00	188.00	188.00	176.00	162.00	187.00	172.00	173.00	166.00	161.00
Percent	0.26	0.27	0.27	0.26	0.26	0.26	0.27	0.27	0.26	0.26	0.26	0.31	0.31	0.29	0.27	0.31	0.28	0.28	0.27	0.26

	A998	A997	A6901	A1001	A1000	A6634	black.h	A4409	AC76b.l	A1555	A6561	A1915	A1916	A6560	A6563	A1912	RPL15S.	A641	A642	A649
Count	161.00	161.00	162.00	163.00	161.00	162.00	7.00	162.00	163.00	226.00	167.00	165.00	201.00	163.00	162.00	203.00	172.00	161.00	166.00	161.00
Percent	0.26	0.26	0.27	0.27	0.26	0.27	0.01	0.27	0.27	0.37	0.27	0.27	0.33	0.27	0.27	0.33	0.28	0.26	0.27	0.26

	A645	A640	A638	A647	A7763	A4828	aa456..	A1978	A1980	aa416..	A258	A260	A246	A66	A253	A259	A236	A250	A5553	A5574
Count	171.00	162.00	161.00	161.00	163.00	206.00	161.00	161.00	166.00	164.00	215.00	222.00	224.00	219.00	214.00	224.00	221.00	221.00	224.00	222.00
Percent	0.28	0.27	0.26	0.26	0.27	0.34	0.26	0.26	0.27	0.27	0.35	0.36	0.37	0.36	0.35	0.37	0.36	0.36	0.37	0.36

	A5562	A5582	A5575	A5567	A5552	A5550	A5545	A5563	A5547	A1434	A1551	A6408	A470	A474	A6451	A6449	A6454	A846	A6751	A850
Count	223.00	222.00	217.00	220.00	224.00	220.00	218.00	215.00	217.00	206.00	209.00	184.00	230.00	226.00	219.00	221.00	219.00	222.00	215.00	213.00
Percent	0.37	0.36	0.36	0.36	0.37	0.36	0.36	0.35	0.36	0.34	0.34	0.30	0.38	0.37	0.36	0.36	0.36	0.36	0.35	0.35

	A2680	A3067	A3050	A635	A3598	A5728	A5477	A5478	A5479	A6575	A6049	A6044	A6742	A6297	A4690	A791	A6751.1	A846.1	A850.1	A5311
Count	222.00	220.00	217.00	205.00	199.00	211.00	208.00	209.00	206.00	171.00	214.00	219.00	220.00	198.00	206.00	220.00	215.00	222.00	213.00	192.00
Percent	0.36	0.36	0.36	0.34	0.33	0.35	0.34	0.34	0.34	0.28	0.35	0.36	0.36	0.33	0.34	0.36	0.35	0.36	0.35	0.32

	A5895	A6329	A6339	A1058	A5537	A244	A257	A232	A243	A237	A240	A6955	A6934	A4750	A4734	A4757	A2714	A6947	A938	A4792
Count	223.00	193.00	224.00	191.00	226.00	216.00	220.00	223.00	219.00	213.00	215.00	219.00	217.00	217.00	216.00	225.00	180.00	214.00	203.00	220.00
Percent	0.37	0.32	0.37	0.31	0.37	0.35	0.36	0.37	0.36	0.35	0.35	0.36	0.36	0.36	0.35	0.37	0.30	0.35	0.33	0.36

	A4786	A4783	A4779	A2316	A2303	A2319	A2317	A2672	A2672.1	A6484	A5008	A7378	A7075	A6222	A7013	A7008	A1185	A4855	A5951	A6557
Count	223.00	224.00	222.00	220.00	222.00	225.00	214.00	165.00	224.00	223.00	215.00	215.00	189.00	224.00	230.00	231.00	189.00	205.00	215.00	226.00
Percent	0.37	0.37	0.36	0.36	0.36	0.37	0.35	0.27	0.37	0.37	0.35	0.35	0.31	0.37	0.38	0.38	0.31	0.34	0.35	0.37

	A6574	A6554	A4510	A4511	A4512	A5124	A5063	A7422	A948	A6573	A6550	A6532	A5654	A5623	A3512	A1461	A1070	A3634	A790	A785
Count	224.00	225.00	226.00	222.00	220.00	208.00	228.00	203.00	208.00	221.00	223.00	214.00	216.00	231.00	224.00	205.00	191.00	219.00	219.00	218.00
Percent	0.37	0.37	0.37	0.36	0.36	0.34	0.37	0.33	0.34	0.36	0.37	0.35	0.35	0.38	0.37	0.34	0.31	0.36	0.36	0.36

	A786	A6511	A6495	A1252	A7372	A7660	A5131	A5638	A7242	A7252	A7245	A653	A660	A661	A657	A652	A5987	A5988	A6817	A6820
Count	215.00	213.00	211.00	212.00	214.00	180.00	207.00	199.00	218.00	225.00	223.00	222.00	223.00	227.00	217.00	219.00	222.00	197.00	210.00	213.00
Percent	0.35	0.35	0.35	0.35	0.35	0.30	0.34	0.33	0.36	0.37	0.37	0.36	0.37	0.37	0.36	0.36	0.36	0.32	0.34	0.35

	A6819	A2747	A1044	A7142	A7138	A7144	A7146	A6507	A6512	A6506	A6496	A6127	A6123	A6120	A6122	A6125	A6124	A6121	A4028	A4641
Count	212.00	225.00	190.00	223.00	231.00	225.00	227.00	223.00	226.00	220.00	219.00	226.00	224.00	229.00	221.00	223.00	221.00	217.00	195.00	207.00
Percent	0.35	0.37	0.31	0.37	0.38	0.37	0.37	0.37	0.37	0.36	0.36	0.37	0.37	0.38	0.36	0.37	0.36	0.36	0.32	0.34

	A340	A1600	A1595	A1605	A1606	A1594	A5147	A5171	A5828	A4766	A5826	A5815	A5814	A5830	A5816	A5810	A5811	A5817	A780	A693
Count	193.00	226.00	226.00	230.00	226.00	226.00	231.00	226.00	224.00	222.00	219.00	223.00	226.00	221.00	216.00	219.00	212.00	221.00	227.00	218.00
Percent	0.32	0.37	0.37	0.38	0.37	0.37	0.38	0.37	0.37	0.36	0.36	0.37	0.37	0.36	0.35	0.36	0.35	0.36	0.37	0.36

	A771	A7866	A7758	A6752	A6749	A475	A5646	A472	A1177	A1095	A1092	A1096	A5750	A1452	A6363	A1758	A1770	A2041	A5972	A391
Count	219.00	214.00	204.00	214.00	215.00	230.00	209.00	227.00	221.00	219.00	220.00	227.00	217.00	224.00	192.00	217.00	220.00	211.00	226.00	222.00
Percent	0.36	0.35	0.33	0.35	0.35	0.38	0.34	0.37	0.36	0.36	0.36	0.37	0.36	0.37	0.32	0.36	0.36	0.35	0.37	0.36

	A393	A392	A6422	A6415	A6411	A6403	A6418	A3936	A3934	A3935	A2556	A5188	A4079	A4101	A7222	A7221	A7220	A1868	A1867	A1665
Count	218.00	210.00	227.00	223.00	223.00	221.00	215.00	217.00	216.00	226.00	213.00	217.00	230.00	225.00	226.00	221.00	229.00	218.00	203.00	214.00
Percent	0.36	0.34	0.37	0.37	0.37	0.36	0.35	0.36	0.35	0.37	0.35	0.36	0.38	0.37	0.37	0.36	0.38	0.36	0.33	0.35

	A811	A5703	A1060	A1046	A7643	A7633	A7300	A2443	A7301	A7276	A6789	A7274	A7148	A7147	A7139	A6218	A6217	A6219	A5752	A5733
Count	221.00	196.00	225.00	217.00	227.00	224.00	225.00	214.00	219.00	229.00	198.00	222.00	227.00	228.00	218.00	223.00	223.00	223.00	223.00	225.00
Percent	0.36	0.32	0.37	0.36	0.37	0.37	0.37	0.35	0.36	0.38	0.33	0.36	0.37	0.37	0.36	0.37	0.37	0.37	0.37	0.37

	A5775	A4430	A4428	A4427	A4425	A4365	A1038	A3654	A5779	A1348	A1349	A1350	A1343	A5228	A5259	A1123	A1109	A20	A927	A928
Count	225.00	219.00	223.00	224.00	229.00	225.00	224.00	209.00	215.00	227.00	216.00	222.00	215.00	190.00	224.00	222.00	226.00	176.00	221.00	227.00
Percent	0.37	0.36	0.37	0.37	0.38	0.37	0.37	0.34	0.35	0.37	0.35	0.36	0.35	0.31	0.37	0.36	0.37	0.29	0.36	0.37

	A926	A930	A925	A6359	A6360	A6357	A6060	A6058	A6056
Count	214.00	222.00	223.00	227.00	218.00	225.00	224.00	217.00	210.00
Percent	0.35	0.36	0.37	0.37	0.36	0.37	0.37	0.36	0.34

Tables of Missing Rates by Variety

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20
Count	2.00	2.00	600.00	172.00	266.00	226.00	605.00	203.00	600.00	603.00	241.00	600.00	230.00	600.00	223.00	600.00	181.00	600.00	221.00	294.00
Percent	0.01	0.01	2.33	0.67	1.04	0.88	2.35	0.79	2.33	2.35	0.94	2.33	0.89	2.33	0.87	2.33	0.70	2.33	0.86	1.14

	X21	X22	X23	X24	X25	X26	X27	X28	X29	X30	X31	X32	X33	X34	X35	X36	X37	X38	X39	X40
Count	602.00	603.00	601.00	261.00	602.00	600.00	603.00	600.00	246.00	190.00	238.00	212.00	600.00	600.00	197.00	600.00	600.00	195.00	224.00	600.00
Percent	2.34	2.35	2.34	1.02	2.34	2.33	2.35	2.33	0.96	0.74	0.93	0.82	2.33	2.33	0.77	2.33	2.33	0.76	0.87	2.33

	X41	X42	X43	X44	X45	X46	X47	X48	X49	X50	X51	X52	X53	X54	X55	X56	X57	X58	X59	X60
Count	600.00	184.00	210.00	195.00	601.00	213.00	177.00	602.00	165.00	599.00	194.00	238.00	601.00	292.00	233.00	600.00	600.00	600.00	224.00	600.00
Percent	2.33	0.72	0.82	0.76	2.34	0.83	0.69	2.34	0.64	2.33	0.75	0.93	2.34	1.14	0.91	2.33	2.33	2.33	0.87	2.33

	X61	X62	X63	X64	X65	X66	X67	X68	X69	X70	X71	X72	X73	X74	X75	X76	X77	X78	X79	X80
Count	269.00	308.00	252.00	600.00	209.00	291.00	600.00	189.00	600.00	600.00	242.00	216.00	600.00	600.00	174.00	235.00	600.00	165.00	185.00	600.00
Percent	1.05	1.20	0.98	2.33	0.81	1.13	2.33	0.74	2.33	2.33	0.94	0.84	2.33	2.33	0.68	0.91	2.33	0.64	0.72	2.33

	X81	X82	X83	X84	X85	X86	X87	X88	X89	X90	X91	X92	X93	X94	X95	X96	X97	X98	X99	X100
Count	244.00	600.00	248.00	600.00	280.00	600.00	600.00	600.00	282.00	267.00	600.00	190.00	600.00	600.00	600.00	173.00	600.00	600.00	602.00	182.00
Percent	0.95	2.33	0.96	2.33	1.09	2.33	2.33	2.33	1.10	1.04	2.33	0.74	2.33	2.33	2.33	0.67	2.33	2.33	2.34	0.71

	X101	X102	X103	X104	X105	X106	X107	X108	X109	X110	X111	X112	X113	X114	X115	X116	X117	X118	X119	X120
Count	601.00	601.00	170.00	601.00	601.00	603.00	164.00	602.00	200.00	603.00	187.00	600.00	600.00	603.00	187.00	205.00	601.00	194.00	601.00	158.00
Percent	2.34	2.34	0.66	2.34	2.34	2.35	0.64	2.34	0.78	2.35	0.73	2.33	2.33	2.35	0.73	0.80	2.34	0.75	2.34	0.61

	X121	X122	X123	X124	X125	X126	X127	X128	X129	X130	X131	X132	X133	X134	X135	X136	X137	X138	X139	X140
Count	601.00	603.00	174.00	601.00	601.00	226.00	601.00	227.00	601.00	601.00	601.00	601.00	601.00	601.00	601.00	601.00	209.00	601.00	219.00	601.00
Percent	2.34	2.35	0.68	2.34	2.34	0.88	2.34	0.88	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	0.81	2.34	0.85	2.34

	X141	X142	X143	X144	X145	X146	X147	X148	X149	X150	X151	X152	X153	X154	X155	X156	X157	X158	X159	X160
Count	207.00	601.00	603.00	182.00	601.00	601.00	209.00	178.00	601.00	185.00	178.00	603.00	603.00	601.00	601.00	209.00	198.00	209.00	601.00	601.00
Percent	0.81	2.34	2.35	0.71	2.34	2.34	0.81	0.69	2.34	0.72	0.69	2.35	2.35	2.34	2.34	0.81	0.77	0.81	2.34	2.34

	X161	X162	X163	X164	X165	X166	X167	X168	X169	X170	X171	X172	X173	X174	X175	X176	X177	X178	X179	X180
Count	602.00	195.00	603.00	171.00	604.00	601.00	603.00	601.00	156.00	178.00	601.00	601.00	601.00	601.00	601.00	601.00	602.00	601.00	601.00	602.00
Percent	2.34	0.76	2.35	0.67	2.35	2.34	2.35	2.34	0.61	0.69	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34

	X181	X182	X183	X184	X185	X186	X187	X188	X189	X190	X191	X192	X193	X194	X195	X196	X197	X198	X199	X200
Count	601.00	601.00	601.00	602.00	602.00	186.00	167.00	194.00	602.00	601.00	603.00	601.00	601.00	601.00	187.00	601.00	601.00	183.00	601.00	196.00
Percent	2.34	2.34	2.34	2.34	2.34	0.72	0.65	0.75	2.34	2.34	2.35	2.34	2.34	2.34	0.73	2.34	2.34	0.71	2.34	0.76

	X201	X202	X203	X204	X205	X206	X207	X208	X209	X210	X211	X212	X213	X214	X215	X216	X217	X218	X219	X220
Count	601.00	209.00	601.00	601.00	601.00	200.00	601.00	602.00	601.00	601.00	601.00	192.00	601.00	601.00	601.00	601.00	178.00	601.00	601.00	602.00
Percent	2.34	0.81	2.34	2.34	2.34	0.78	2.34	2.34	2.34	2.34	2.34	0.75	2.34	2.34	2.34	2.34	0.69	2.34	2.34	2.34

	X221	X222	X223	X224	X225	X226	X227	X228	X229	X230	X231	X232	X233	X234	X235	X236	X237	X238	X239	X240
Count	172.00	186.00	602.00	601.00	601.00	602.00	601.00	602.00	603.00	602.00	601.00	601.00	601.00	601.00	173.00	169.00	601.00	601.00	602.00	601.00
Percent	0.67	0.72	2.34	2.34	2.34	2.34	2.34	2.34	2.35	2.34	2.34	2.34	2.34	2.34	0.67	0.66	2.34	2.34	2.34	2.34

	X241	X242	X243	X244	X245	X246	X247	X248	X249	X250	X251	X252	X253	X254	X255	X256	X257
Count	601.00	602.00	601.00	601.00	601.00	179.00	219.00	601.00	249.00	601.00	602.00	189.00	602.00	186.00	601.00	601.00	601.00
Percent	2.34	2.34	2.34	2.34	2.34	0.70	0.85	2.34	0.97	2.34	2.34	0.74	2.34	0.72	2.34	2.34	2.34