Tulips in Netherlands:

An Analysis of How Chilling Time Affects Germination

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Introduction

Background

- Tulips, introduced in the mid 1500's, have become a symbol of Netherlands
- 9 million bulbs produced each year
- Country's exportation economy and tourism industry benefit from these tulips
  - Make up 25% of Agricultural exports
  - Tourists from all over the world come to see the tulip fields at the end of May each year
- While tulips have thrived for hundreds of years, recent climate change threatens to drastically decrease the tulip yields

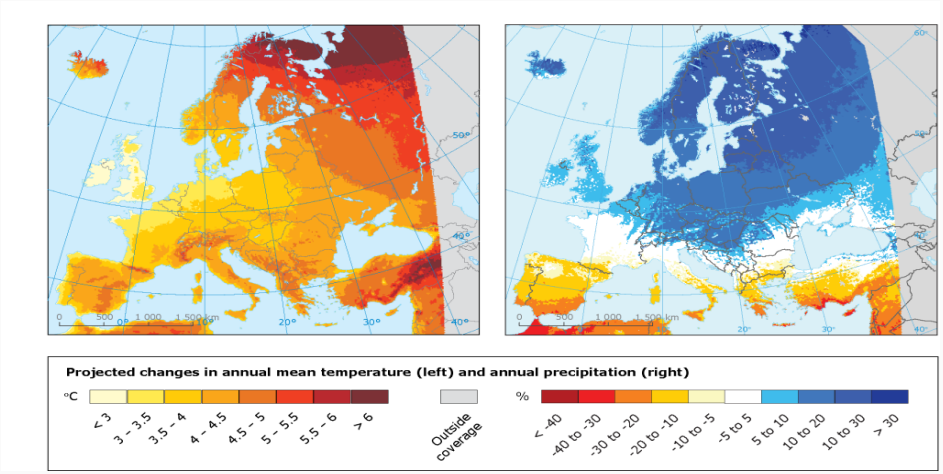
Tulips and Climate Change

Ideal environment for Tulips:

- Ideal planting time is the fall - bulbs need a “chilling time“ in order to bloom
- Once they bloom, they need lots of sunlight
- Need airy and well-drained soil

Climate Change in Netherlands

- Experienced twice the global temperature rise
- Expect precipitation to rise by up to 5%



Both of these climate change effects could potentially be devastating to the tulips in Netherlands.

The Experiment

Given this risk, scientists have begun to study how tulip growth is affected by these changes. Particularly, one scientist has recently run an experiment to evaluate how different "chilling times" affect whether a tulip germinates.

- Bulbs collected from fields in Netherlands between 2005 and 2009
- 210 bulbs from each of 12 different tulip populations
- Within the populations, tulips were randomly assigned to 7 different chilling times - 30 tulips from each population in each chilling time treatment
- Chilling times varied from 0 to 12 weeks, by two
- The scientist would plant the bulbs, administer their randomized chilling time, then record whether or not each bulb germinated.

Research Questions

How do lower chilling times affect different tulip populations? Purpose of analysis:

- Find whether the probability of germination for each chilling time is the same across all populations. Identify the populations that are the same/different - **Inferential**
- Determine whether there is an ideal chilling time, and whether it varies across populations - **Inferential**
- Find what effect a decrease from 10 to 8 weeks of winter/chilling time will have for tulips, and whether it varies across populations - **Inferential (Maybe also prediction)**

Exploring the Data

Descriptives

	Chilling Time (weeks)						
Population	0	2	4	6	8	10	12
1	0.40	0.97	0.83	0.87	0.87	0.97	0.90
2	0.13	0.53	0.73	0.73	0.83	0.90	0.83
3	0.00	0.53	0.80	0.83	0.97	0.90	0.87
4	0.00	0.17	0.53	0.60	0.73	0.90	0.73
5	0.33	0.87	0.67	0.73	0.70	0.57	0.50
6	0.00	0.03	0.07	0.40	0.43	0.80	0.67
7	0.00	0.00	0.10	0.33	0.47	0.83	0.67
8	0.00	0.03	0.27	0.33	0.33	0.30	0.30
9	0.00	0.00	0.00	0.00	0.07	0.60	0.60
10	0.00	0.17	0.10	0.53	0.87	0.87	0.83
11	0.00	0.00	0.20	0.23	0.67	0.83	0.47
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Population 12 was removed from the analysis because none of the tulips in that population germinated.

Data Exploration

Should Chilling Time be treated as a Categorical or Continuous Variable?

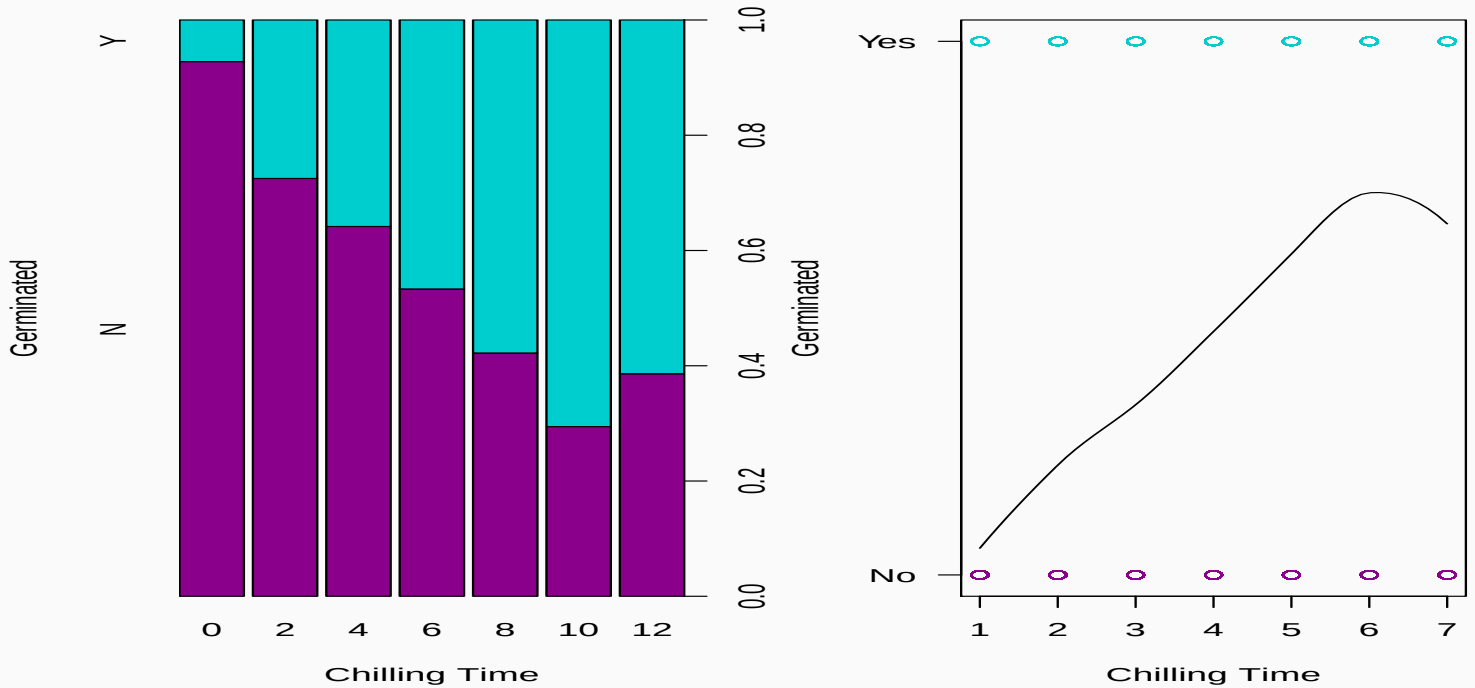


Figure 1: Overall Germination Proportions for Different Chilling Times

Model

Model Options

Response Variable is Categorical (Germination Y/N), and at least one of the Explanatory variables (Population) is Categorical.
Model Options for Binary Categorical Response:

- **Logistic Regression - Interpretability and Good for Inference**
- Probit Regression - Less Interpretability than Logistic Regression
- Discriminant Analysis - Assumes Normal Distribution of Explanatory Variables, makes no sense with Categorical Explanatory Variables
- K-Nearest Neighbors - Only good for prediction, Low interpretability
- Support Vector Machines - Only good for prediction, Low interpretability

Model Assumptions

The logistic regression model assumes that the observations are independent and that the relationships between the explanatory variables and the response (whether the tulip germinated) are linear (monotonistic).

- Again, should the chilling time be treated as a continuous or categorical variable?

Explanatory Variables in the Model

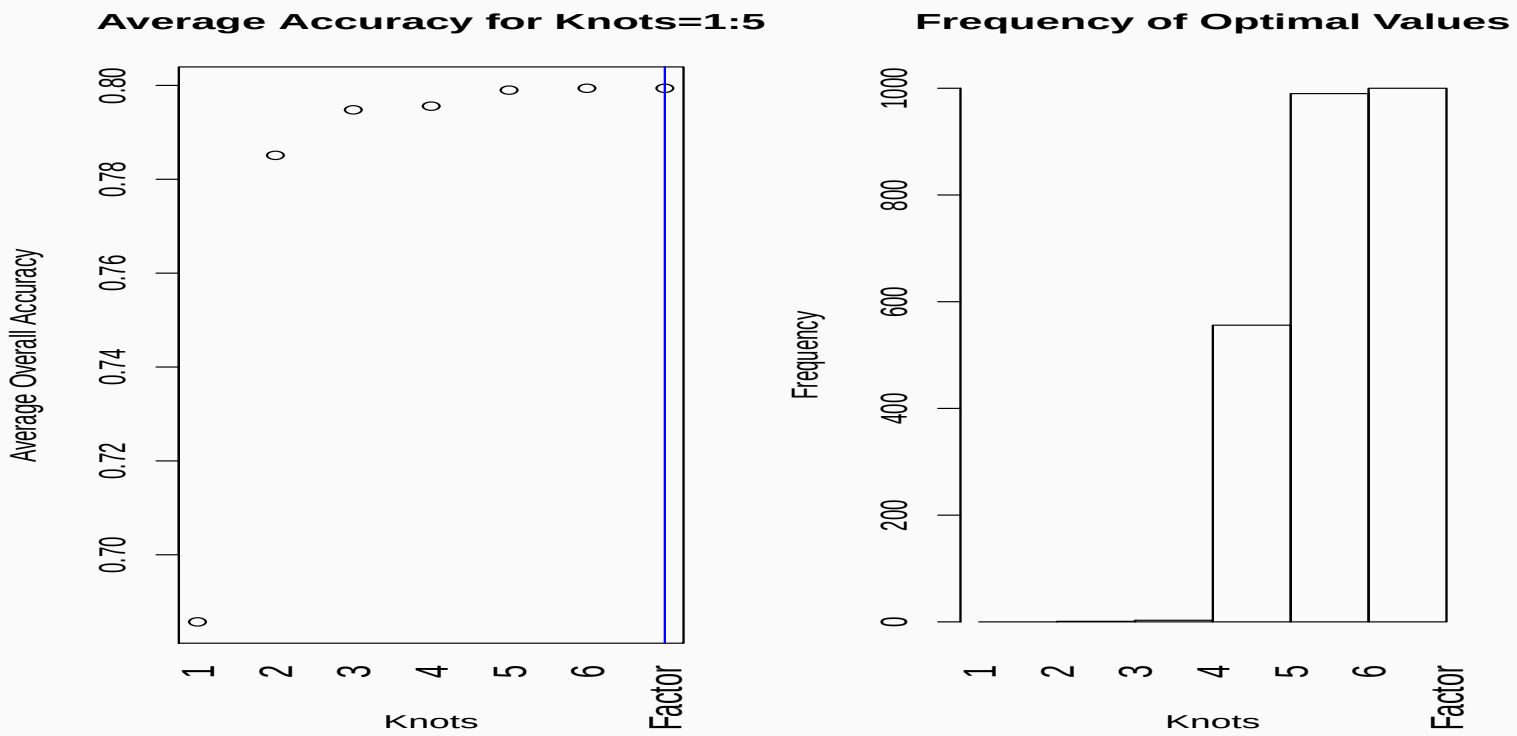


Figure 2: 10-Fold Cross Validation to find whether the number of knots for the splines for Chilling Time that optimize Overall Accuracy

Model Introduction

The logistic regression model can be written as follows:

$$Y_i \overset{\text{ind}}{\sim} \text{Bernoulli}(p_i) \qquad \log\left(\frac{p_i}{1-p_i}\right) = \mathbf{x_i'}\beta$$

- $Y_i \in \{0, 1\}$ - whether the i^{th} tulip germinated
- $p_i \in (0, 1)$ - probability that the i^{th} tulip germinated
- $\mathbf{x_i'}$ - explanatory variables
- β - coefficients, the estimated effect that each explanatory variable has on whether a tulip germinated
- The response value estimated from the regression model, $\log(p_i/(1-p_i))$, is the log odds ratio, and the coefficients are all interpreted in terms of this value.

Model Specification

In a logistic regression model the predicted probabilities ($\hat{p}_i$) and the classifications associated with those probabilities ($\hat{y}_i$) are calculated as follows:

$$\hat{p}_i = \frac{\exp(\mathbf{x_i'}\beta)}{1 + \exp(\mathbf{x_i'}\beta)} \qquad \hat{y}_i = \begin{cases} 1 & \text{if } \hat{p}_i > c \\ 0 & \text{if } \hat{p}_i \leq c \end{cases} \tag{1}$$

Where $c \in (0, 1)$ is the cutoff probability such that observations with a predicted probability above c are classified as severe.

Model Specification Cont.

- I choose the c that leads to the highest overall classification accuracy.
- Opposed to trying to minimize other accuracy metrics (e.g. false positives or false negatives).
- Figure 3 shows the accuracy associated each cutoff value and that a cutoff value of 0.53 leads to the highest classification accuracy.

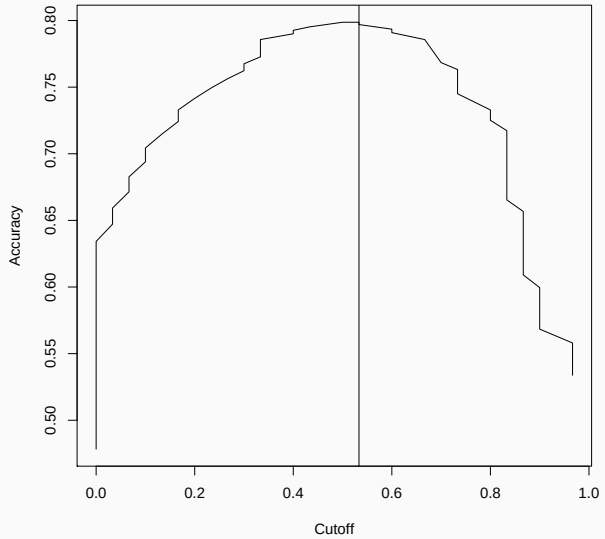
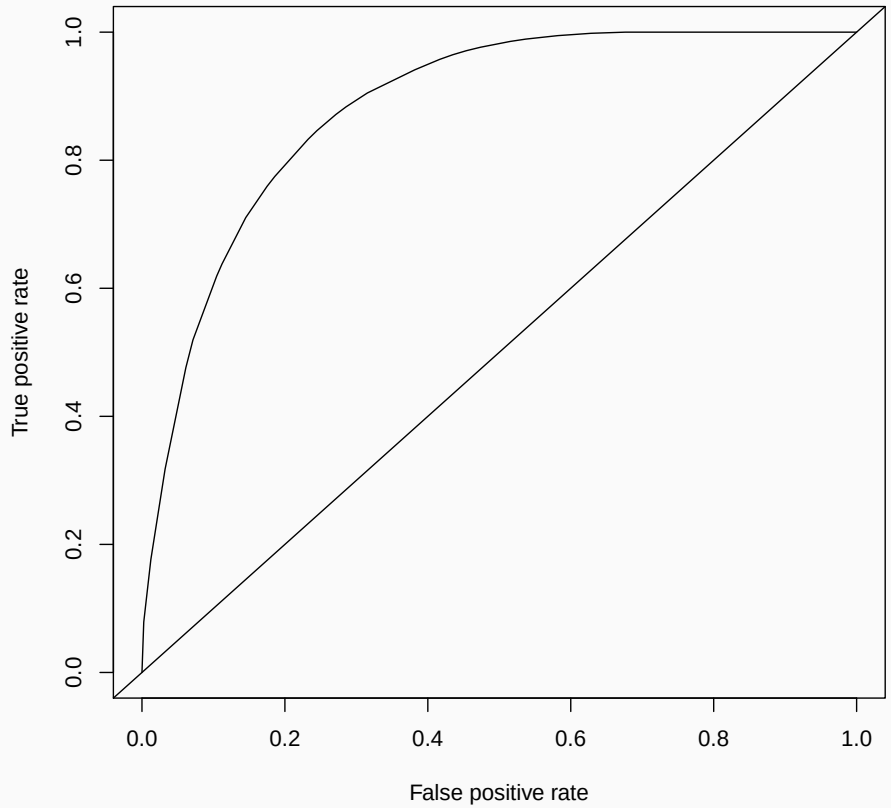


Figure 3: Prediction Accuracy by Cutoff Value

Results

Model Fit

The ROC curve shows the trade off between false and true positives and the area under the curve (AUC) is 0.883 which measures model fit.



Model Fit and Predictive Power

In-Sample Measurements

Metric	Value
AUC	0.883
Sensitivity	0.832
Specificity	0.768
Positive Predicted Value	0.767
Negative Predicted Value	0.833
Overall Accuracy	0.799

Cross Validated Measurements

Metric	Value
AUC	0.864
Sensitivity	0.825
Specificity	0.768
Positive Predicted Value	0.767
Negative Predicted Value	0.833
Overall Accuracy	0.796

Model Results

	Estimate	Lower CI	Upper CI	p-value
ChillingTime0:Population1	-0.41	-1.43	0.62	0.28
ChillingTime2:Population1	3.37	0.57	6.16	0.00
ChillingTime4:Population1	1.61	0.26	2.96	0.00
ChillingTime6:Population1	1.87	0.40	3.35	0.00
ChillingTime8:Population1	1.87	0.40	3.35	0.00
ChillingTime10:Population1	3.37	0.57	6.16	0.00
ChillingTime12:Population1	2.20	0.52	3.87	0.00
ChillingTime0:Population2	-1.87	-3.35	-0.40	0.00
ChillingTime2:Population2	0.13	-0.87	1.14	0.72
ChillingTime4:Population2	1.01	-0.12	2.15	0.01
ChillingTime6:Population2	1.01	-0.12	2.15	0.01
ChillingTime8:Population2	1.61	0.26	2.96	0.00
ChillingTime10:Population2	2.20	0.52	3.87	0.00
ChillingTime12:Population2	1.61	0.26	2.96	0.00

Question 1: Is the probability of germination for each chilling time the same across all populations?

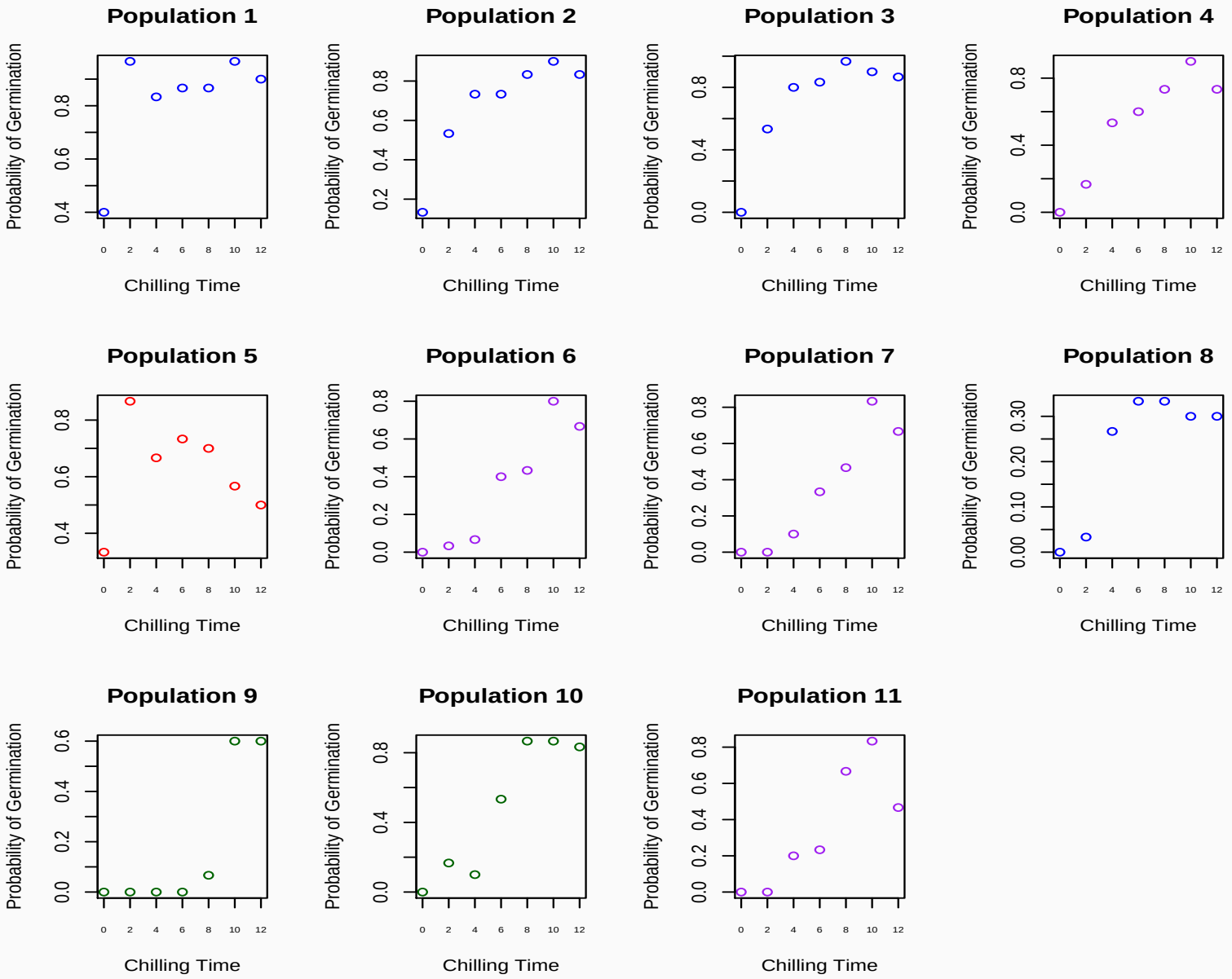
Likelihood Ratio Test:

$$\text{LR} = \frac{\text{Reduced Model (only includes Chilling Time)}}{\text{Full Model (includes interaction of Chilling Time with Population)}}$$

p-value$<$0.0000

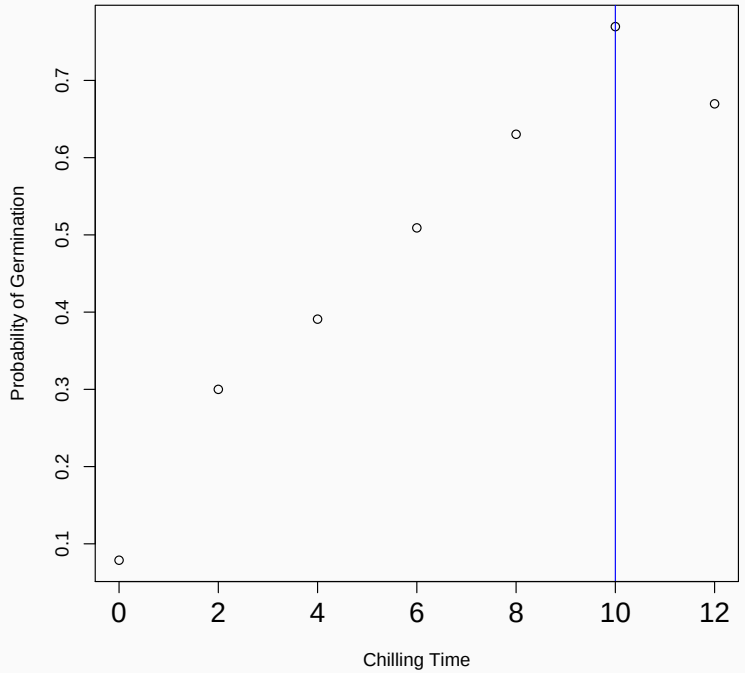
- The difference in the chilling time between populations is significant.

Question 1a: Which populations are same/different?



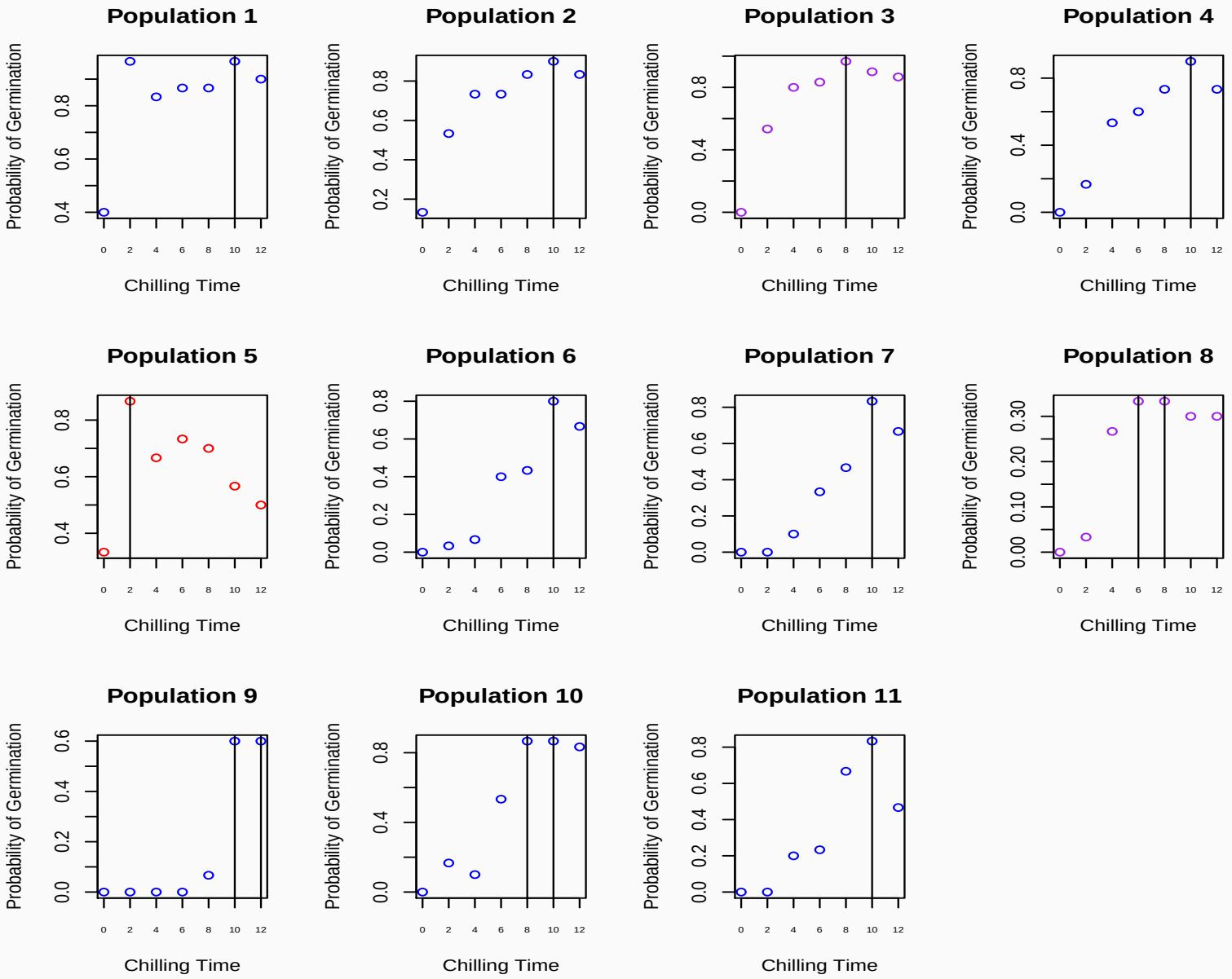
Question 2: Is there an "ideal" chilling time?

Overall Predicted Probabilities for Each Chilling Time



	Chilling Time (weeks)						
	0	2	4	6	8	10	12
Overall	0.08	0.30	0.39	0.51	0.63	**0.77**	0.67

Question 2a: Does this ideal chilling time vary by population?



Question 3: What effect will a decrease from 10 to 8 weeks of winter/chilling time have for tulips?

F test used to test whether there is a significant overall decrease in the probability of germination from 10 to 8 weeks of winter/chilling time

$$\text{F} = (C\hat{\beta})'(CV(\hat{\beta})(C)')^{-1}(C\hat{\beta}) \ / \ \text{df}$$

(p-value=0.0009). Difference is significant and the probability drops by 14% overall.

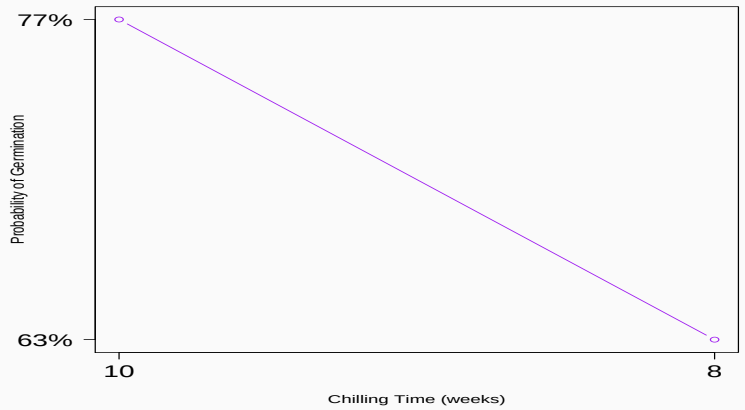
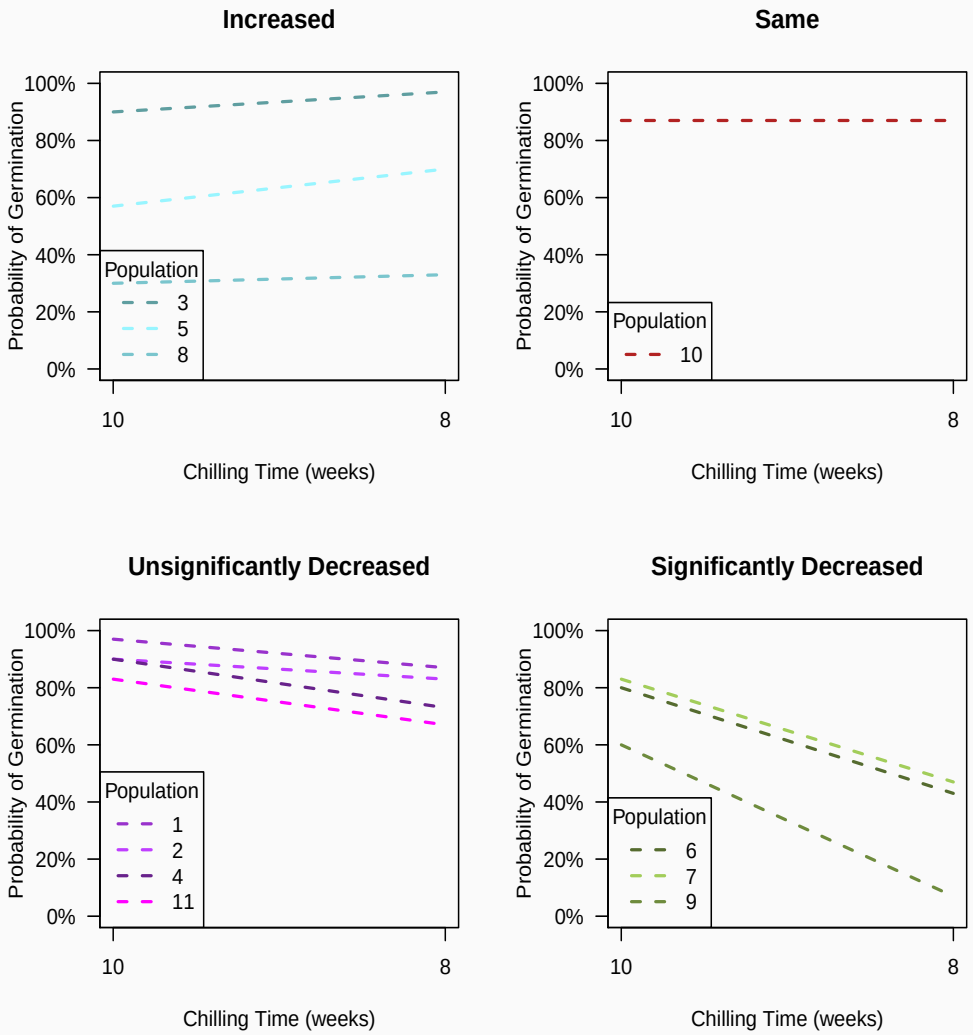


Figure 5: Change of Probability of Germination as Chilling Time Decreases from 10 weeks to 8 weeks

Question 3a: Is it the same for each population?

Table 1: Difference in Germination between 10 and 8 weeks of Chilling Time

Population	F value	p-value	Direction
1	1.69	0.19	Decrease
2	0.57	0.45	Decrease
3	0.97	0.32	Increase
4	2.60	0.11	Decrease
5	1.14	0.29	Increase
6	7.96	**0.00**	Decrease
7	8.12	**0.00**	Decrease
8	0.08	0.78	Increase
9	13.74	**0.00**	Decrease
10	0.00	1.00	Same
11	2.15	0.14	Decrease



Conclusions

- Question 1: The probability of germination for each chilling time is significantly different between populations, although some populations follow similar trends in germination.
- Question 2: 10 weeks is the ideal overall chilling time for the tulips, however, some populations vary in their ideal chilling time.
- Question 3: A decrease from 10 to 8 weeks of chilling time significantly decreases overall germination by, on average, 14%. However, some populations' germination actually increased when the chilling time dropped - these are the ones that should be focused on as climate change decreases winter time.

Shortcomings and Future Research

Shortcomings:

- The model does not account for times other than the 0-12 (by two) weeks
- The analysis focuses on tulips collected 9+ years ago

Future Research:

- Researchers should continue to collect information on tulips and look at how germination at different chilling times changes/remains the same over multiple more recent years.