Quantitative Modeling in Biology for Undergraduate Students (QM BUGS)
Diagnostic Assessment

Choose the best response for each of the questions on plant transpiration.

Transpiration Exemplar

Transpiration is the process by which water is carried through plants from roots to small pores on the underside of leaves called stomata, where it is released as vapor into the atmosphere. The process is critical for plant cooling, accessing nutrients from the soil, providing water to plant cells to maintain rigidity, and supplying cells with hydrogen and oxygen atoms for cellular respiration. There are a number of atmospheric factors affecting transpiration. Answer the following questions on transpiration.

1. A biologist places a bag over a branch of a plant, leaves the bag on for a day, then comes back to observe the results (Figure 1). She sees water has collected in the bag. What does she hypothesize about her observation?

Figure 1

   a. Bag is permeable and dew passed through bag
   b. High humidity air was trapped when she placed bag over limb
   c. There is water in the bag released from the leaves
   d. Photosynthetic process releases water into bag
   e. Water condensed in the bag due to temperature difference inside and outside the bag

2. A biologist is studying transpiration of apple trees. She collected the data in Table 1 on two trees. The biologist compares variation in two variables to determine relationships. Which of the following is an important relationship between variables for her study?

Table 1. Data from apple trees in Brazil over 12 sampling days. (Pereira et al. 2011)

Day DJ (1-1-96)	Temperature T (Kelvin)	Length of Day N (hours)	Relative Humidity RH (%)	Leaf Area LA (m^2)	Transpiration Rate (TR) ($L\ H_20\ tree^{-1}\ day^{-1}$)	Stomatal Resistance (s) ($m\ s^{-1}$)
Tree 1						
184	289.8	15	92	9.3	7.3	302
188	292.3	15	75	9.3	15.1	509
191	292.5	15	73	9.3	15.3	550
198	292.1	15	68.3	9.3	12.8	572
200	293.5	15	68.9	9.3	16.6	602
205	296.4	15	82.6	9.3	10.9	475
Tree 2						
185	295.5	15	48	20.6	57.6	761
187	294.8	15	78	20.6	31.7	542
191	293.6	15	79	20.6	29.4	476
192	293.5	15	69.2	20.6	38.9	562
193	294.6	15	59.3	20.6	47.5	656
194	294.9	15	56.2	20.6	51.8	664

Twelve selected sampling dates throughout year (DJ number of days since January 1, 1996), Temperature (T in Kelvin), Length of Day (N photoperiod duration in hours), Relative Humidity (RH mean percent), Leaf Area (LA in square meters), Transpiration Rate (TR in leaf water transpired per tree per day), and Stomatal Resistance is resistence to evaporation of water from stomata (s in meters per second).

   a. Variation in transpiration by variation of length of day
   b. Variation in stomatal resistance by variation in leaf area
   c. Variation in leaf area by variation in humidity
   d. Variation in transpiration rate by variation in temperature
   e. Variation in transpiration rate by variation in stomatal resistance

3. Students were interested in the question: Will plants with larger leaves transpire more than those with smaller leaves? They conducted an experiment where they placed 3 different plants with small, medium and large leaves in sealed tubes (see apparatus in Figure 2). The plants were placed where they received the same amount of partial sunlight. The students measured temperature change (C°), relative humidity (%), and wind speed (mph) each day. They also measured the square area (cm^2) of each plant's leaf area. Over the course of two weeks they tracked the amount of water lost from the apparatus. Identify the variables that the students should use to answer their research question.

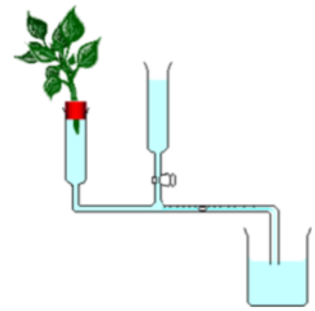

Figure 2

   a. **Temperature** increase triggers plant to open stomata which increases transpiration rate, so they should use temperature and water lost data
   b. **Relative humidity** of air surrounding plant rises making it harder for water from plant to evaporate, so they should use relative humidity and leaf area data
   c. **Leaf surface area** and light to determine increased photosynthesis
   d. **Light** makes photosynthesis possible, plant opens stomata to take in CO_2 which increases transpiration, so they should use light and water lost data
   e. **Leaf surface area** increases number of stomata which would increase transpiration, so they should use leaf surface area and water lost data

4. Transpiration is related to the rate of passage of water vapor exiting through the stomata of a leaf, which is called stomatal conductance. Stomatal conductance is a diffusion flux representing the movement of air from a region of high moisture concentration to a region of low moisture concentration across an area of leaf over a given time (Figure 2). Which of the following is an appropriate unit of measure for stomatal conductance?

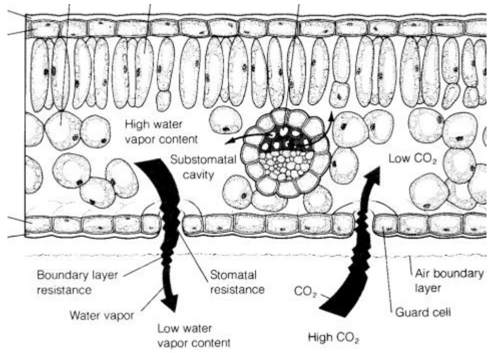

Figure 3

NOTE: A mole (mol) is the amount of substance, in this case water vapor, in a unit of air.

   a. mol air/meter x second
   b. mol air/meter^2
   c. mol air/meter^2/second
   d. mol air/meter^3/second
   e. second/meter^2 x mol air

5. Stomatal conductance R_{vs} is the rate of passage of water vapor exiting through the stomata (small pores) of a leaf. A steady state porometer (Figure 3) is an instrument that measures stomatal conductance by clamping it to the leaf surface, then computing the vapor flux between two locations on the diffusion path. The ratio of the change between vapor concentration at the leaf C_{vL} and the concentration at the first sensor C_{v1} to the combined stomatal resistance R_{vs} and resistance at the first sensor R_1 is used in the vapor flux computation. Which of the following expressions represents this ratio?

Figure 4

a. $\frac{C_{vL}-C_{v1}}{R_{vs}+R_1}$
b. $(C_{vL}-C_{v1})(R_{vs}+R_1)$
c. $\frac{C_{vL}-C_{v2}}{R_{vs}+R_2}$
d. $\frac{R_{vs}+R_1}{C_{vL}-C_{v1}}$
e. $\frac{C_{vL}-C_{v1}}{R_{vs}-R_1}$

6. Relative humidity has a big impact on growing your indoor plants. Growers pay attention to the impact of temperature on plants, but often ignore humidity. A rule of thumb for growers is to have 70% relative humidity for vegetative growth, but this does not take into account temperature. Vapor Pressure Deficit (VPD) is the difference between the vapor pressure inside a leaf compared to the vapor pressure of the air. VDP can be calculated from the air temperature and relative humidity.VPD provides the grower with a better indicator of how plants really "feel" and react to the combination of humidity and temperature. For best growing conditions you should keep the VPD between 7.5 and 10.5 kilopascal units of pressure (Table 2). Which of the following is the correct analysis of your plant condition with respect to VPD?

    a. My plant has a leaf virus at 70 °F with VPD 3.7 kilopascal so increase relative humidity.
    b. My plant is exhibiting slow growth at 70 °F with VPD 14.9 kilopascal so increase relative humidity.
    c. My plant leaves wilted at 70 °F with VPD 13.7 kilopascal so decrease relative humidity.
    d. My plant is exhibiting slow growth at 70 °F with VPD 8.6 kilopascal so decrease relative humidity.
    e. My plant is forcing water out of the leaves at their edges at 70 °F with VPD 2.4 kilopascal so increase relative humidity.

Table 2: Vapor Pressure Deficit VDP

TEMP		RELATIVE HUMIDITY													
°C	°F	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%
15	59	0.0	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.8	7.6	8.5	9.4	10.2	11.1
16	61	0.0	0.9	1.8	2.8	3.7	4.6	5.5	6.4	7.3	8.2	9.1	10.0	10.9	11.8
17	63	0.0	1.0	2.0	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7	10.6	11.6	12.6
18	64	0.0	1.0	2.0	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4
19	66	0.0	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	14.3
20	68	0.0	1.2	2.4	3.5	4.7	5.9	7.0	8.2	9.4	10.6	11.7	12.8	14.0	15.2
21	70	0.0	1.2	2.4	3.7	4.9	6.2	7.4	8.6	9.9	11.1	12.4	13.7	14.9	16.1
22	72	0.0	1.3	2.6	3.9	5.3	6.6	7.9	9.2	10.5	11.9	13.2	14.5	15.8	17.2
23	73	0.0	1.4	2.8	4.2	5.6	7.0	8.5	9.9	11.3	12.7	14.1	15.4	16.8	18.2
24	75	0.0	1.5	3.0	4.5	5.9	7.4	8.9	10.4	11.9	13.4	14.9	16.4	17.9	19.4
25	77	0.0	1.6	3.2	4.8	6.4	8.0	9.5	11.1	12.7	14.3	15.9	17.4	19.0	20.5
26	79	0.0	1.7	3.4	5.1	6.7	8.4	10.1	11.8	13.4	15.1	16.8	18.4	20.1	21.8
27	81	0.0	1.8	3.5	5.3	7.1	8.9	10.7	12.4	14.2	16.0	17.8	19.6	21.3	23.1
28	82	0.0	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.1	17.0	18.9	20.7	22.6	24.5
29	84	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.1	24.1	26.1
30	86	0.0	2.1	4.2	6.4	8.5	10.6	12.7	14.8	17.0	19.1	21.2	23.3	25.4	27.5
31	88	0.0	2.2	4.5	6.7	9.0	11.2	13.4	15.7	17.9	20.2	22.4	24.6	26.9	29.1
32	90	0.0	2.4	4.7	7.1	9.5	11.9	14.2	16.6	19.0	21.3	23.7	26.1	28.4	30.8
33	91	0.0	2.5	5.0	7.5	10.0	12.5	15.0	17.6	20.1	22.6	25.1	27.6	30.1	32.6
34	93	0.0	2.7	5.3	8.0	10.6	13.3	15.9	18.6	21.2	23.9	26.5	29.2	31.8	34.5

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7. Two students in a biology lab are tasked with constructing a conceptual model to show how soil, plant, and atmosphere conditions impact tree transpiration. They have made a list of the reservoirs of water near a plant (see list to right). What step will help them achieve their goal of constructing a conceptual model?

   Water in soil
   Water in atmosphere
   Water in plant stem
   Water in leaf
   Stomata
   Xylem

   a. Quantifying the size of each reservoir
   b. Defining the plant components (e.g., xylem, phloem, stomata)
   c. Arranging the reservoirs from largest volume to smallest volume
   d. Connecting as many reservoirs with the processes that moves water between them
   e. Connecting processes to get an idea of flow through the system

8. The two students develop a partially-complete conceptual model of plant transpiration (Figure 5). Some processes they labeled in the model, others they left as question marks (didn't know them), and other reservoirs or processes were not incorporated yet. What is their next step?
   a. Define each process that is known
   b. Add arrows between all of the remaining reservoirs
   c. Conduct a thought experiment about impact of soil drought on leaf water
   d. Determine what you both know about the gaps
   e. Find a quantitative model for each known process

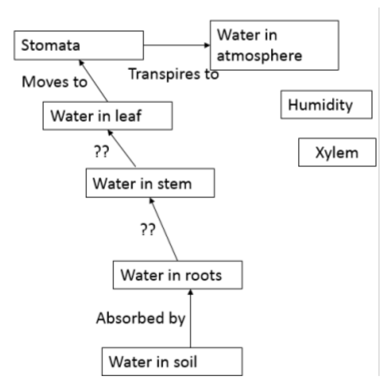


Figure 5

9. The biologist is working on building a model of Transpiration Rate (y-axis) by Temperature (x-axis) from the data in Table 3. She created a scatterplot of the data (Figure 6) and fit different models to the data. Which of the following is an appropriate strategy for modeling the data?

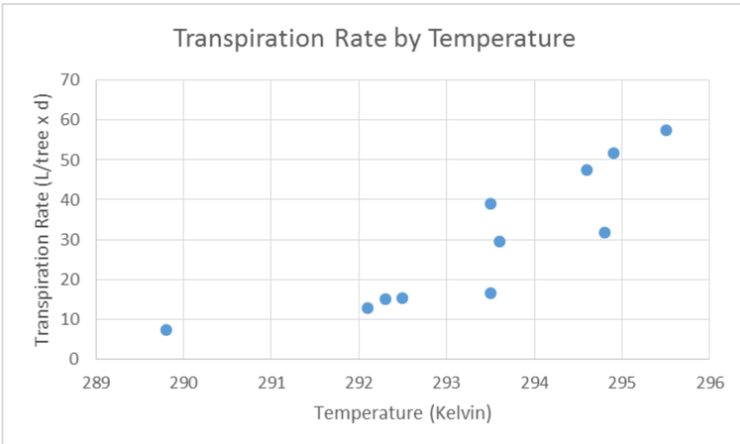


Figure 6

Table 3	
T (K)	TR (L/tree x d)
289.8	7.3
292.1	12.8
292.3	15.1
292.5	15.3
293.5	16.6
293.5	38.9
293.6	29.4
294.6	47.5
294.8	31.7
294.9	51.8
295.5	57.6
296.4	10.9

a. Fit a line that passes through the origin and another data point.
b. Fit multiple models and determine which has best fit.
c. Fit a linear model that passes through the most data points.
d. Fit a linear model that divides the data set in half.
e. Fit a non-linear model that passes through the first and last data points.

10. A biologist is working on creating a mathematical model of transpiration rate (TR) by humidity (H) from the transpiration data provided in Table 4. He uses a statistics tool to fit a linear model, quadratic model, and exponential model to the data. Based on which of the following criteria should he select a model for the data?

Linear: $TR = -1.17\ H + 111.08$ with $R^2 = 0.66$

Quadratic: $TR = 0.02\ H^2 - 3.79\ H + 199.47$ with $R^2 = 0.70$

Exponential: $TR = 528.54\ e^{-0.044H}$ with $R^2 = 0.62$

a. Data displays an exponential decay trend modeled by the negative power and the exponential model has the lowest R^2 value so select the exponential model.
b. Quadratic model has an additional H^2 term making the linear model simpler, but increases R^2 so select the quadratic model.
c. Linear model has the smallest constant value so select the linear model.
d. Linear model has fewer terms so it will be easier to use, so select the linear model.
e. Quadratic model H^2 term has a small positive coefficient, but data trend decreases so do not use quadratic model.

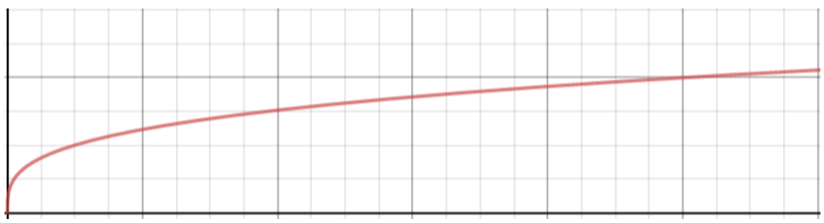
Table 4

Relative Humidity (%)	Transpiration Rate (TR) L/(tree x d)
48	57.6
56.2	51.8
59.3	47.5
68.3	12.8
68.9	16.6
69.2	38.9
73	15.3
75	15.1
78	31.7
79	29.4
82.6	10.9
92	7.3

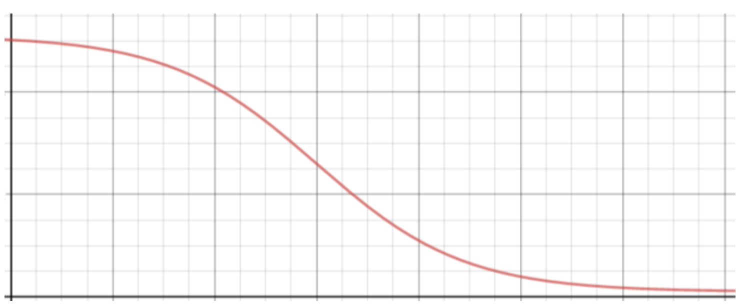
11. Which of the following models best represents the relationship between transpiration rate (vertical y-axis) and relative humidity (horizontal x-axis) for the data in Table 5?

Table 5	
Relative Humidity (%)	Transpiration Rate (TR) L/(tree x d)
48	57.6
56.2	51.8
59.3	47.5
68.3	42.8
68.9	39.6
69.2	38.9
73	22.3
75	21.1
78	18.7
79	16.4
82.6	10.9
92	7.3

a. 

b. 

c. 

d. 

12. The biologist knows the following about plant physiology.

The two major factors for plant transpiration rate are: 1) vapor-pressure deficit (VPD) the difference in water potential between the leaf and atmosphere surrounding the plant and 2) stomatal conductance (g) the resistance of the leaf stomata in releasing water from the plant.

Stomatal conduction is the rate of passage of water vapor exiting through the stomata of a leaf. Stomatal conduction is measured in *mol air* m^{-2} s^{-1} where *mol* is mole of air, *m* is measure of leaf area, and *s* is time.

VPD is measured in *kPa kilopascal pressure units (1 KPa = 0.01* kg/cm^2*)*. The transpiration rate is the rate of loss of water from the plant due to stomatal conductance rate allowing passage of water vapor by the water potential pressure difference.

Use this knowledge to select the best model of plant transpiration rate (TR) from those given below.

a. TR = g x VPD and is measured in *mol water* m^{-2} s^{-1}
b. TR = g/VPD and is measured in *mol air* m^{-2} s^{-1}
c. TR = g +VPD and is measured in *mol air* $m^{-2}s^{-1}$
d. TR = VPD/g and is measure in *mol water* m^{-2} s^{-1}
e. TR = G – VDP and is measured in *mol water* m^{-2} s^{-1}

13. The biologist runs a statistical test to determine if a difference in leaf area of 9.3 m^2 and 20.6 m^2 has a significant impact on plant transpiration rate (Table 6). The results of the t-test with an alpha level of 0.05 is provided in Table 7. Select the correct statement based on the t-test.

Table 6

Leaf Area LA (m^2)	Transpiration Rate (TR) ($L\ H_20\ tree^{-1}\ day^{-1}$)
Tree 1	
9.3	7.3
9.3	15.1
9.3	15.3
9.3	12.8
9.3	16.6
9.3	10.9
Tree 2	
20.6	57.6
20.6	31.7
20.6	29.4
20.6	38.9
20.6	47.5
20.6	51.8

Table 7

t-Test: Two-Sample Assuming Equal Variances

	9.3 area	*20.6 area*
Mean	13.0000	42.8167
Variance	11.9200	128.0217
Observations	6.0000	6.0000
Pooled Variance	69.9708	
Hypothesized Mean Difference	0.0000	
df	10.0000	
t Stat	-6.1739	
P(T<=t) one-tail	0.0001	
t Critical one-tail	1.8125	
P(T<=t) two-tail	0.0001	
t Critical two-tail	2.2281	

a. Since the mean for 20.6 m^2 area leaves is greater than that for 9.3 m^2 area leaves then the biologist can draw the conclusion that there is a significant difference in transpiration rate.
b. The hypothesized mean difference of 0 is less than the P value of 0.0001, so there is no significant difference.
c. The biologist chooses a significance level of $\alpha = 0.05$, so the p-value of 0.0001 indicates that there is no significant difference in transpiration rates between the 20.6 m^2 area leaves and the 9.3 m^2 area leaves.
d. The biologist does not have the data to say for sure that either the 20.6 m^2 area leaves or 9.3 m^2 area leaves will have greater transpiration rates, so he should use the one-tail test results.
e. The biologist chooses a significance level of $\alpha = 0.05$, so the p-value of 0.0001 indicates that the 20.6 m^2 area leaves have a significantly greater transpiration rate than the 9.3 m^2 area leaves.

14. A biologist is interested in extending the model to new leaf area sizes from the 20.6 m^2 area leaves and 9.3 m^2 area leaves on which transpiration data was collected. She plots the two data sets for the leaf area types on the same graph to compare trends (Figure 6). She also fits a line to each of the leaf area data sets separately to explore trends (Figures 7 & 8). What should she do to extend the models to other leaf area sizes, say 15 m^2 area leaves?

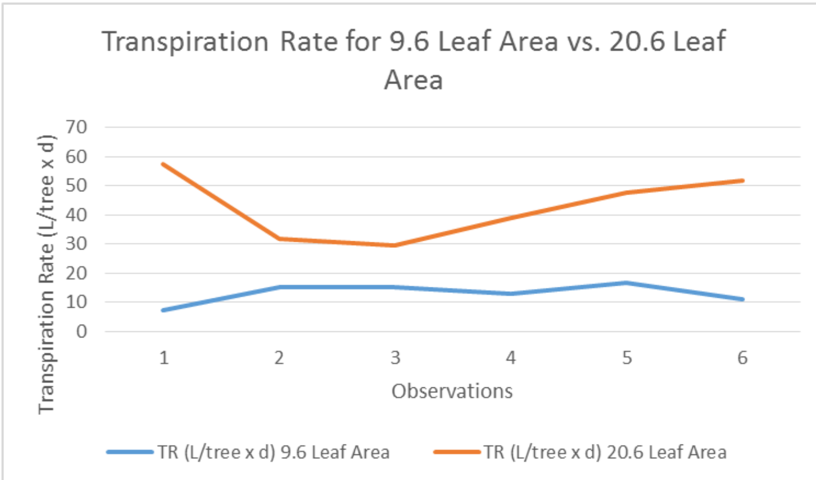


Figure 7

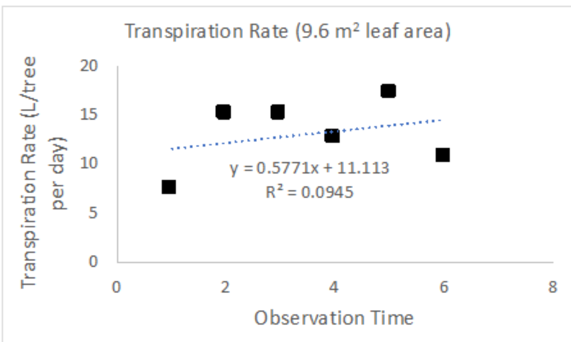


Figure 8

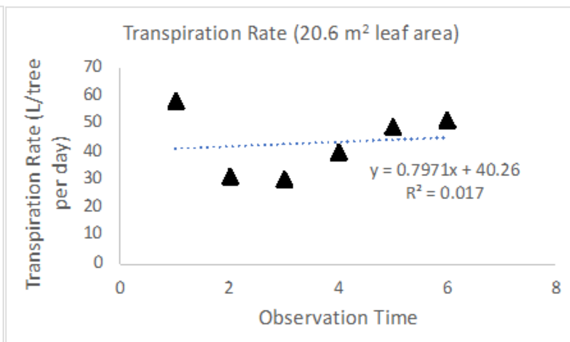


Figure 9

a. The model for 15 m^2 area leaves should have a positive trend less than the slope for the 9.3 m^2 area leaves.
b. The model for 15 m^2 area leaves should have a y-intercept value between that of the 20.6 m^2 area leaves (y-intercept 40.0) and the 9.3 m^2 area leaves (y-intercept 11.0).
c. The model for 15 m^2 area leaves should have a positive trend more than that of the slope for the 20.6 m^2 area leaves and the 9.3 m^2 area leaves.
d. The model for 15 m^2 area leaves should have a y-intercept value that is greater than that of the 20.6 m^2 area leaves (y-intercept 40.0).
e. You cannot use the existing models of transpiration rate by leaf size type to develop a new model for a different leaf size.

QI: Quantitative Interpretation - Model Deployment

15. The biologists determines a line of best fit for transpiration rate by stomatal resistance, determining both a linear graph and equation model (Figure 10). She then empirically tests the models against her direct observations (data points plotted in Figure 10). Empirical evidence is the record of one's direct observations or experiences. Which of the following is an appropriate empirical test of the models?

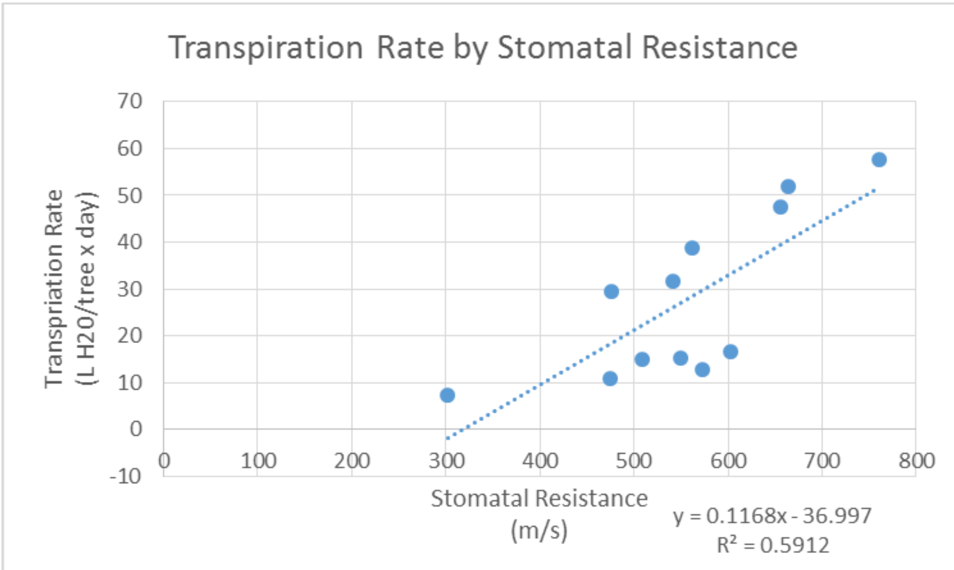


Figure 10

a. Seeing if the trend of the linear graph reflects the slope of the equation
b. Determining error between the equation model and collected data
c. Using the equation model to predict transpiration rate for a stomatal resistance of 850 m/s.
d. Comparing the equation model to the linear graph to see if they have same intercept
e. Using the equation model to find the transpiration rate for a stomatal resistance of 400 m/s.

16. Table 8 provides a chart of vapor pressure deficit (VPD) in Hectopascal (1 hPA = 100 Pascal) at given temperatures (rows) and humidity levels (columns). VPD tables are used by gardners to determine best conditions for plant growth. Biologists study VPD and determined that VPD is the saturated vapor pressure (SVP: how much water the air can hold at a given temperature) minus the actual vapor pressure (AVP at same temperature): VPD = SVP - AVP. Using this definition, a formula for VPD in terms of relative humidity (RH) and temperature (T) in Celcius can be derived:

Saurated Vapor Pressure (SVP in Pascals): $SVP = 610.7 \cdot 10^{7.5\,T\,/(237.3+T)}$
Acutal Vapor Pressure (AVP in Pascals): $VP = \frac{RH \cdot SVP}{100}$
So $VPD = SVP\left(1 - \frac{RH}{100}\right)$

Compare the table model with the formula model. Which of the following provides the best evidence for fit between the two models?

Table 8

TEMP		RELATIVE HUMIDITY													
°C	°F	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%
15	59	0.0	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.8	7.6	8.5	9.4	10.2	11.1
16	61	0.0	0.9	1.8	2.8	3.7	4.6	5.5	6.4	7.3	8.2	9.1	10.0	10.9	11.8
17	63	0.0	1.0	2.0	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7	10.6	11.6	12.6
18	64	0.0	1.0	2.0	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4
19	66	0.0	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2	14.3
20	68	0.0	1.2	2.4	3.5	4.7	5.9	7.0	8.2	9.4	10.6	11.7	12.8	14.0	15.2
21	70	0.0	1.2	2.4	3.7	4.9	6.2	7.4	8.6	9.9	11.1	12.4	13.7	14.9	16.1
22	72	0.0	1.3	2.6	3.9	5.3	6.6	7.9	9.2	10.5	11.9	13.2	14.5	15.8	17.2
23	73	0.0	1.4	2.8	4.2	5.6	7.0	8.5	9.9	11.3	12.7	14.1	15.4	16.8	18.2
24	75	0.0	1.5	3.0	4.5	5.9	7.4	8.9	10.4	11.9	13.4	14.9	16.4	17.9	19.4
25	77	0.0	1.6	3.2	4.8	6.4	8.0	9.5	11.1	12.7	14.3	15.9	17.4	19.0	20.5
26	79	0.0	1.7	3.4	5.1	6.7	8.4	10.1	11.8	13.4	15.1	16.8	18.4	20.1	21.8
27	81	0.0	1.8	3.5	5.3	7.1	8.9	10.7	12.4	14.2	16.0	17.8	19.6	21.3	23.1
28	82	0.0	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.1	17.0	18.9	20.7	22.6	24.5
29	84	0.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.1	24.1	26.1
30	86	0.0	2.1	4.2	6.4	8.5	10.6	12.7	14.8	17.0	19.1	21.2	23.3	25.4	27.5
31	88	0.0	2.2	4.5	6.7	9.0	11.2	13.4	15.7	17.9	20.2	22.4	24.6	26.9	29.1
32	90	0.0	2.4	4.7	7.1	9.5	11.9	14.2	16.6	19.0	21.3	23.7	26.1	28.4	30.8
33	91	0.0	2.5	5.0	7.5	10.0	12.5	15.0	17.6	20.1	22.6	25.1	27.6	30.1	32.6

Vapor Pressure Deficit - orange = ideal, white = acceptable, light blue = too humid, dark blue = too dry

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a. Randomly select a relative humidity level and Celcius temperature, read the VPD value from the table, multiply by 100, and compare to the formula model output for the same values.
b. Randomly select a relative humidity level and Celcius temperature, read the VPD value from the table, and compare to the formula model output for the same values.
c. Randomly select a relative humidity level and Fahrenheit temperature, read the VPD value from the table, divide by 100, and compare to the formula model output for the same values.
d. Randomly select a relative humidity level and Celcius temperature, read the VPD value from the table, divide by 100 and compare to the formula model output for the same values.
e. You cannot compare the model values for *VPD*, since the models may be based on different plant species.

17. The graphs and functions in Figure 11 provide data on transpiration volume (ml water) by time in minutes for three plant species. The colored graphs are connected line graphs (top green graph for tropical sage, middle blue graph for horsetail, and bottom red graph for tickseed) and the black graphs are lines of best fit. What trends in transpiration volume can be determined from the models?

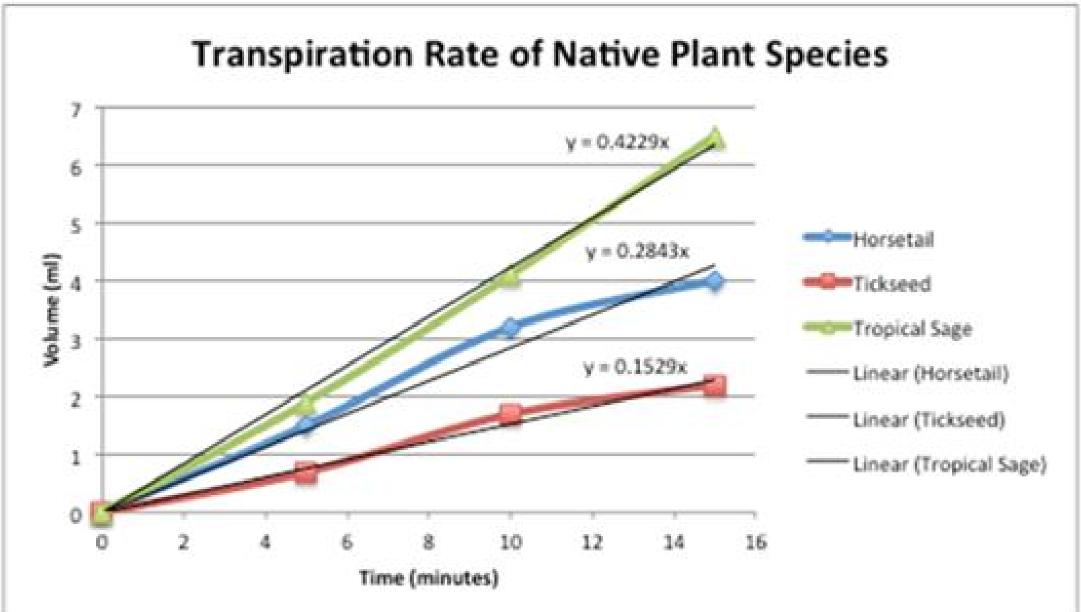

Figure 11

a. No trends can be determined from models of data, you must refer to the original data.
b. At 10 minutes the transpiration volume is approximately 4 ml for tropical sage plant species.
c. As time increases, transpiration volume increases at about the same rate for each plant species.
d. The transpiration volume rate for tropical sage between 10 and 15 minutes is about 0.42 ml/min.
e. The transpiration volume for tropical sage between 10 and 15 minutes is decreasing since the slope of the linear model is less than 1.

18. A quadratic model for transpiration rate (*TR*) with respect to temperature (*T*) is

$$TR = 1.70\ T^2 - 987.36\ T + 143211$$

The biologist notices a discrepancy between the predicted values for *TR* and the actual transpiration rate data collected (Table 9). What is the best explanation for the discrepancy?

Table 9

Temperature (T) (Kelvin)	Transpiration Rate (TR) Data	Model Predicted TR Values
289.8	7.3	6.5
292.3	15.1	14.8
292.5	15.3	16.4
292.1	12.8	13.4
293.5	16.6	26.3
295.5	57.6	56.5
294.8	31.7	44.4
293.6	29.4	27.5
293.5	38.9	26.3
294.6	47.5	41.2
294.9	51.8	46.0

a. The table and quadratic model represent different trees which explains the difference in the data and predicted values.
b. The table provides the exact value for *TR* data so the quadratic model is wrong since there should be no error in the estimate.
c. The quadratic model provides the actual transpiration rates, so data was collected incorrectly causing an error in the estimate.
d. The data table and quadratic model represent different days on which data was collected which explains the difference in the data and predicted values.
e. The quadratic model provides an estimate to the *TR* values in table and the difference is due to an error in the estimate.

19. Use the graph or equation model in Figure 12 to predict what happens to transpiration rate if the temperature is 300 K? Select the best answer.

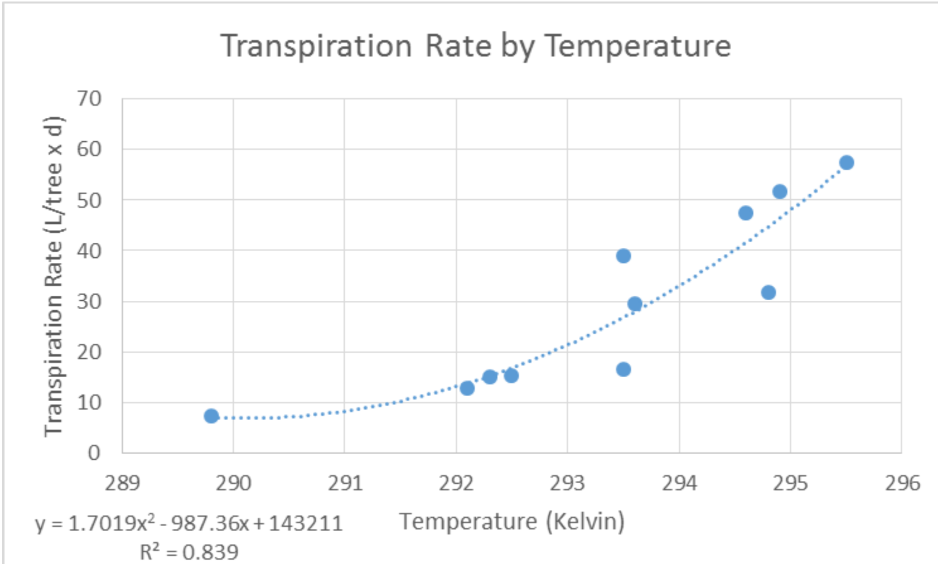

Figure 12

a. Data was only collected between 289 and 296 degrees Kelvin, so you can't make a prediction for transpiration rate at 300 degree Kelvin.
b. You cannot extend the graph of the best fit curve to make an estimate above 296 degree Kelvin.
c. Transpiration rate is increasing at a nonlinear rate as temperature increases, at 300 degree Kelvin the transpiration rate is over 70 *L/(tree x d*).
d. Above 296 degrees Kelvin the transpiration rate remains at a constant value, so with 4 degrees increase from 296 to 300 Kelvin the transpiration rate grows to approximately 58.5 *L/(tree x d*).
e. Transpiration rate increases at a constant rate of about 1.7, so with 5 degrees increase from 295 to 300 degrees Kelvin the transpiration rate grows to approximately 56.5 *L/(tree x d*).

20. In addition to temperature, relative humidity has an impact on transpiration rates. Figure 13 provides a graph of transpiration rate versus relative humidity. A biologist forms a model for transpiration rate versus temperature using data from the humid Florida Everglades. How would the biologist have to revise the transpiration rate versus temperature model for a climate with different relative humidity, say the dry Mojave Desert in California?

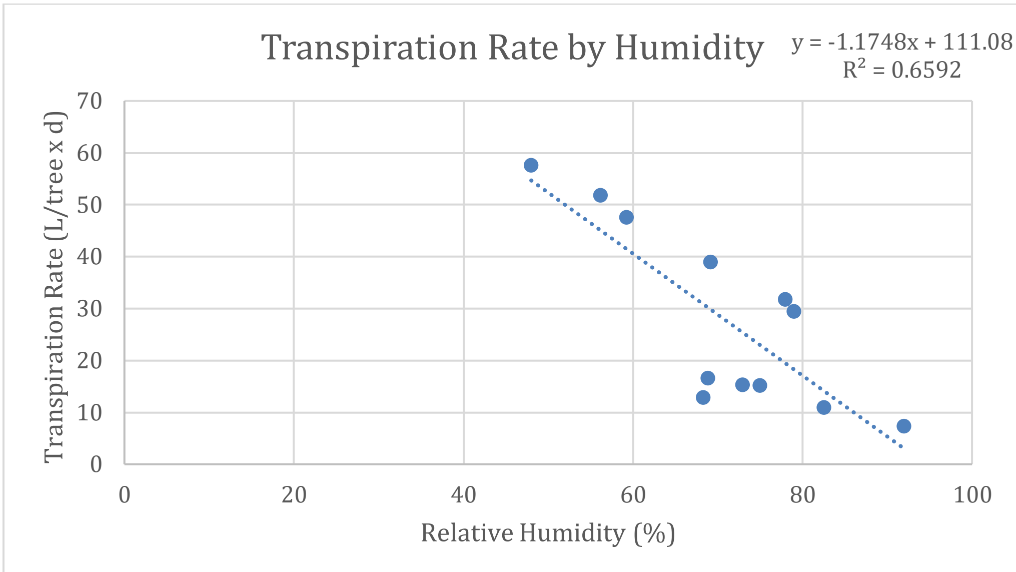

Figure 13

a. Lower relative humidity relates to decreased transpiration rate, so the Everglades transpiration rate by temperature model would have to be revised to account for lower transpiration rates at the same temperature for the Mojave desert.
b. Lower relative humidity causes a decrease in transpirtaton rate, so the Everglades transpiration rate by temperature model would not change for the Mojave desert.
c. Higher relative humidity causes a decrease in transpiration rate, so the Everglades transpiration rate by temperature model would have to be revised to account for higher transpiration rates at the same temperature for the Mojave desert.
d. Higher relative humidity causes a decrease in transpiration rate, so the Everglades transpiration rate by temperature model would have to be revised to account for lower transpiration rates at the same temperature for the Mojave desert.
e. Can't compare the three variables of relative humidity, temperature and transpiration rate, only two variables at a time can be compared.

21. A scientific model of transpiration has which of the following characteristics? Select all that apply.
    a. A set of known science concepts that explain the phenomena being studied
    b. Models are physical objects of the phenomena being studied, not ideas
    c. A representation of the phenomena being studied, such as an equation, diagram, or graph
    d. A model of the phenomena being studied must be unique
    e. The experiment used to test the phenomena is part of the model

22. A model for transpiration should consists of which of the following? Select all that apply.
    a. Model consists of objects such as the stomata and leaves
    b. Model consists of theories like cohesion of water
    c. Model consists of processes in which objects participate such as the effect of wind speed on transpiration
    d. Model consists of objects and theories, but not processes
    e. Model consists of objects and processes, but not theories

23. The biologist evaluates the transpiration rate by stomatal resistance equation model to determine if it is acceptable for informing planting of apple trees. Which of the following are qualities of a model being acceptable? Select all that apply.
    a. The equation model generates answers that are the same as the data collected.
    b. The equation model includes all variables affecting transpiration rate.
    c. The equation model explains observations made by the researcher.
    d. The equation model is consistent with other models or theories of transpiration rate.
    e. The equation model predicts the behavior of transpiration when humidity is increased.

24. Which of the following are characteristics of a good model? Select all that apply.
    a. Model may not be unique, not always possible or even desirable to exclude all but one model.
    b. The development of a model should be based on accepted theories and not on experiments and observations.
    c. A model does not need to be consistent with other accepted models.
    d. Models are ideas explaining a phenomena, not just equations or graphs.
    e. Models are informed by an experiment and observations.

25. Which of the following represent the purpose and utility of a model? Select all that apply.
    a. Models influence and constrain the kinds of research questions that guide future work of scientists.
    b. Models are applied to explain reality.
    c. Models are based on collected data and are not meant to be used to make predictions about future events.
    d. Models are assessed for how well they explain real-world phenomena.
    e. Models do not influence or constrain the kinds of questions that guide future work of scientists.

26. The major steps of the modeling process are provided below. Arrange the letters labeling each process in the order in which the steps should occur.
    a. Create model
    b. Analyze data
    c. Biological interpretation of findings
    d. Formulate hypothesis
    e. Run experiment
    f. Identify variables
    g. Revise model

Rate your level of agreement for each of the following questions on modeling.

27. I would be able to determine the variables needed to create a model, identifying both properties of the variables useful in building a model and an appropriate unit of measure for the variables.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

28. I am capable of developing a testable hypothesis.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

29. I am capable of using descriptive statistics such as center (mean, mode, median) and spread (range, standard deviation) to describe a data set.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

30. I am capable of making informal comparisons using descriptive statistics to support arguments.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

31. I am capable of conducting a formal statistical test to determine significance of a hypothesis.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

32. I am capable of creating my own model of a biological phenomena.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

33. I am capable of reasoning with models to improve my understanding of a real-world concept.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

34. I am capable of refining a model to extend it to a new situation.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

35. I am capable of reasoning with models to make predictions.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

36. I am capable of determining trends in data and defending those trends using biological arguments.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

37. I am capable of determining trends in data and defending those trends using mathematical arguments.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

38. I am capable of translating between two models to explore differences in the models.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4