Factors affecting the rate of transpiration

Hypothesis:

My hypothesis is that if the intensity of the wind is increased then the rate of transpiration of a plant will increase given that humidity, light, pressure and temperature stay the same.

Introduction:

Water normally leaves the plant as water vapour. The change from a liquid state to a vapour state requires the addition of energy which is provided by the sun, and it is this energy that maintains the flow of water through the entire plant. Transpiration can occur through the stomata, cuticle or lenticels.

Water is brought to the leaf in the xylem vessels. The xylem is part of the vascular bundles which spread to form a fine branching network throughout the leaf. The branches end in one or a few xylem vessels that possess little lignification. Water can therefore escape easily through their cellulose walls to the mesophyll cells of the leaf. There are 3 main theories of how the water moves from the roots to the leaf. The apoplast pathway, symplast pathway and vacuolar pathway.

The apoplast is the system of adjacent cell walls which is continuous throughout the plant. Up to 50% of a cellulose cell wall may be "free space" which can be occupied by water.

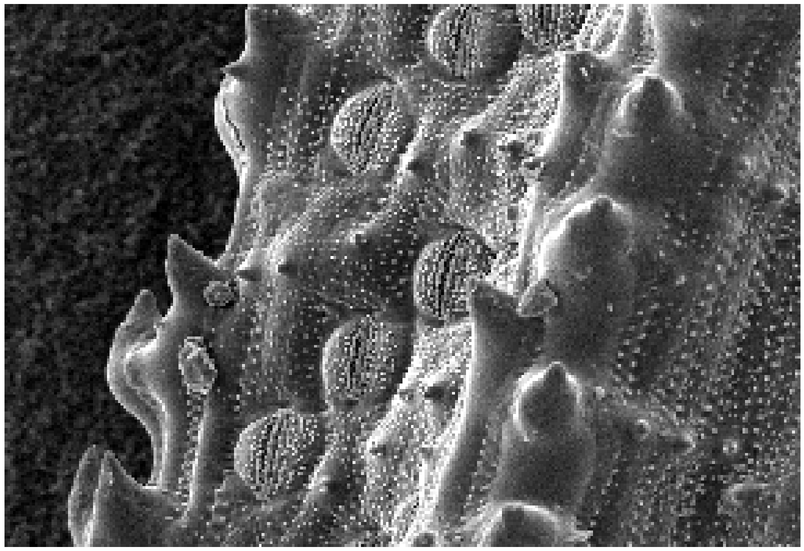
The symplast is the system of interconnected protoplasts in the plant. The cytoplasm of neighbouring protoplasts is linked by the plasmodesmata, the cytoplasmic strands which extend through pores in adjacent cell walls. Once water, and any solutes it contains, is taken into the cytoplasm of one cell it can move through the symplast without having to cross further membranes.

In the vacuolar pathway water moves from vacuole to vacuole through neighbouring cells, crossing the symplast and apoplast in the process and moving through membranes and tonoplasts by osmosis.

The three pathways described end with water evaporating into air spaces. From here water vapour diffuses through the stomata, from a high water potential inside the leaf to a much lower one outside the leaf. In dicotyledons, stomata are usually confined to, or are more numerous in, the lower epidermis.

Stomata are pores in the epidermis through which gaseous exchange takes place. They are found mainly in leaves, but also in stems. Each stoma is surrounded by two guard cells which, unlike the other epidermal cells, possess chloroplasts. The guard cells control the size of the stoma by changes in their turgidity.

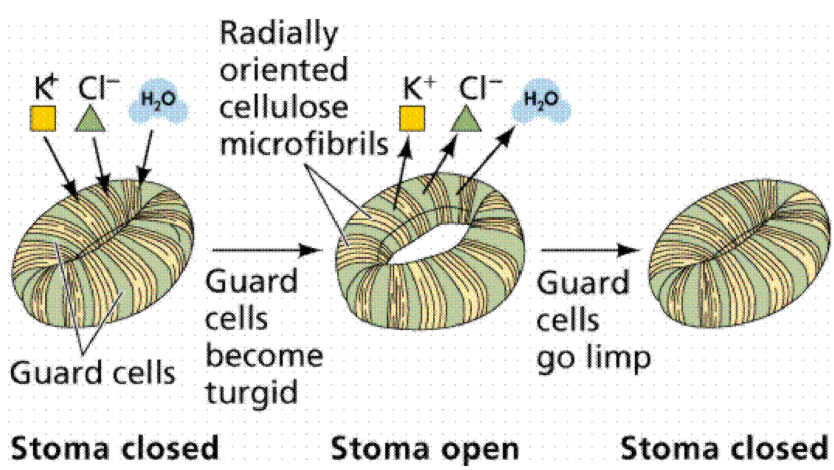
The guard cell walls are unevenly thickened (seen on various scanning electron microscopes images).



http://www.mcs.csuhayward.edu/sem/images/horsel4.gif

The wall furthest from the pore (called the dorsal wall) is thinner than the wall next to the pore (the ventral wall).

Also, the cellulose microfibrils that make up the walls are arranged so that the ventral wall is less elastic than the dorsal wall. Because the ends of the guard cells are joined, and also because the thin dorsal walls stretch more easily than the thick ventral walls, each cell becomes semicircular in shape. Thus a hole, the stoma, appears between the guard cells. When the guard cells lose water and turgidity, the pore closes.



gopher://wiscinfo.wisc.edu:2070/I9/.image/.bot/.130/Leaf/Corn_epidermal_peel.

This illustrates how the stomata opens and closes and how guard cells are involved in this action using K^+, Cl^- and water.

In still air a layer of highly saturated air builds up around the leaf, reducing the steepness of the diffusion gradient between the atmosphere inside the leaf and the external atmosphere. Any air movement will tend to sweep away this layer. This layer leads to closing of the stomata and transpiration rates decrease. A too high air movement also could lead to a closing of the stomata. This could be explained by too much water evaporating from the stomatal pores. Therefore the cell becomes flaccid and K^+ and Cl^- concentration increases. Therefore the guard cells start to become thinner and the guard cell decreases in length closing the stomatal pore.
When opening the stomata the cell becomes turgid, due to the inflate of water. The microfibrils tend to stop the cell increasing in diameter, so they can only expand by increasing in length opening a stoma.

The rate of transpiration can be affected by certain environmental changes. Temperature, humidity, air movement and light can affect the rate of transpiration.

If the air is still, water vapour diffusing out of the leaf will tend to accumulate around the stomata pores. This reduces the water potential gradient and slows down the rate of transpiration. But windy conditions dispers the water vapour. Increasing the gradient in water potential does increase the rate of transpiration.

The external factor which has the greatest effect on transpiration is temperature. The higher the temperature, the greater the rate of evaporation of water from mesophyll cells and the greater the saturation of the leaf atmosphere with water vapour. At the same time, a rise in temperature lowers the relative humidity of the air outside the leaf. The water potential increases inside the leaf while outside the leaf it decreases. The temperature of the leaf is raised by solar radiation. Pale-coloured leaves reflect more of this radiation than normal leaves and therefore do not heat up as rapidly. The pale colour is usually due to a thick coat of epidermal hairs, waxy deposits or scales, and is a xeromorphic feature.

Predictions

On increasing the wind speed the rate of transpiration will increase.
When there is no wind the rate of transpiration will be very slow. When increased to stage 1 (lowest wind speed) the rate of transpiration will show a high increase. When increased to stage 2 or 3 the increase in rate of transpiration will not be as high as the increase from no wind to stage 1 (lowest wind speed).

Pilot experiment

The pilot experiment was used to determine different key variables. The key variables in this experiment are temperature, humidity, light, type of plant, wind intensity as well as source of wind and distance of source of wind.

I started setting up the potometer finding out which plant will be the easiest one to use. I selected the one with a woody steam and a number of leaves on it. The leaves on the plant were evenly distributed. I set up the potometer using this plant.

I wanted to investigate the effect of wind intensity on the plant, and so I kept temperature, humidity light and the plant the same.

To increase the wind intensity I used a fan with 3 different stages. Stage 1 (slowest air movement), stage 2 (middle air movement), and stage 3 (fastest air movement). To insure that the wind was evenly spread over the plant I found out the distance at which the fan had to be placed. The fan should not be too close to the plant or otherwise not all of the plant had wind, also the fan should not be too far away from the plant, or the plant would not get enough wind. Using a distance of 30cm, 50cm, 70cm, 90cm, 110cm, 130cm, and 150cm I found out that at a distance from 70cm the wind was spread evenly over the plant, therefore I used this distance as the default.

I introduced a bubble into the system and started to observe the time needed for it to travel to 10cm. I found out that the time was at about 24s. Therefore I used a time interval of 20s.

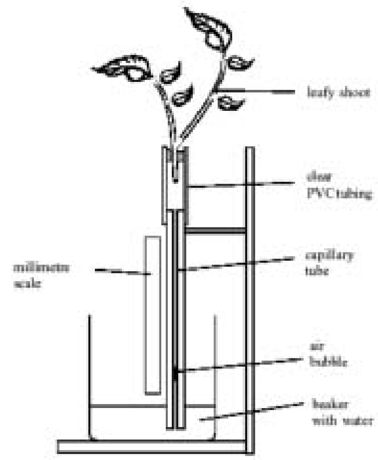
Risk

For this experiment the only risk is involved when cutting the steam using a sharp knife or scalpel. There is no risk in using the potometer on its own.

By cutting only a small part of a tree, I did not harm the tree very much and therefore, from the ethical point of view, I did not brake any of the ethical laws.

Method:

This is the potometer I used in this experiment:



The leafy shoot on the top, a clear PVC tubing, a capillary tube (d=1.3mm), a beaker containing water and a millimetre scale. I then introduced a bubble into the system and counted the mm it travelled up in 20s over a period of 200s.

1. Use a leafy shoot with a round, woody stem
2. As soon as the shoot is cut off, the cut end is placed in a suitable container of water such as a bucket. In the laboratory, a second cut is made, under water, to remove about 5 cm from the end of the shoot. These precautions are to prevent air locks in the xylem.
3. The potometer is assembled in a sink full of water. After the shoot I fit through the hole in the rubber tubing, the last 3 cm of bark is removed. This prevents any sap from the phloem from blocking the xylem.
4. When the potometer is assembled, the end of the capillary tube remains in the water, by placing in a small beaker of water.
5. To introduce a bubble into the capillary tube, I lift the tube out of the water in the beaker, blotted with a paper towel, then replace into the water when an air bubble has entered the end of the tube. The air bubble is between 3 and 6 mm long.
6. Do not use Vaseline on the potometer in the hope that this will make a water-tight seal!
7. When the potometer is set up and the air bubble is moving at a steady rate, I record the movement of the bubble along the scale, at suitable time intervals.
8. The key variables have to be kept constant.

Precautions:

1. take great care when cutting the stem
2. the stem should be cut under water
3. make sure that the potometer is air tight and that no air bubbles are in the system
4. do not use Vaseline to make sure that the xylem will be closed by the Vaseline

The results were noted down into a table:

Table

Measurment	1st check	2nd check	3rd check	Average
In mm/20s				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Average				$\sum_{ave}$

For the calculation part of this experiment I measure the diameter of the capillary tube which is 0.0013m or 1.3mm. Therefore the radius is 0.00065. The formula for the rate of transpiration is $\pi r^2 \cdot$(distance travelled($\sum_{ave}$)) / leaf area / time. The $\sum_{ave}$ in this experiment is the sum of the averages I obtained from the 3 experiments. The leaf area is .221m² and the time was 200s. To complete the table repetitions of the same experiment have to be taken. Therefore I repeat every experiment at least 3 times.

The room temperature (23°C), pressure, humidity, light are kept constant to an extend. This is due to that pressure cannot be influenced as well as humidity. Temperature can be affected by heaters in the room and light by turning them on or off.

Results

I measured a time interval of 20s and achieved the following results:

Measurement under normal conditions

Measurment	1^{st} check	2^{nd} check	3^{rd} check	Average
In mm/20s				
1	6	7	6	6.33
2	6	7	7	6.67
3	6	6	7	6.33
4	7	7	7	7.00
5	6	6	7	6.33
6	6	7	7	6.67
7	7	7	7	7.00
8	4	6	7	5.66
9	6	7	6	6.33
10	6	6	7	6.33
Average	6.0	6.6	6.8	$\sum_{ave}$64.65

Calculation of the rate of transpiration:

$\pi r^2 \cdot$distance travelled($\sum_{ave}$) / leaf area / time

$\pi \cdot (0.00065m)^2 \cdot 0.06465m / .221m^2 / 200s = 1.941 \cdot 10^{-9}$ dl m^{-2} s^{-1}

$1.941 \cdot 10^{-9}$ dl m^{-2} $s^{-1} \cdot 60s = 1.164 \cdot 10^{-7}$ dl m^{-2} min^{-1}

Measurement at air current using fan stage 1

Measurement	1^{st} check	2^{nd} check	3^{rd} check	Average
In mm/20s				
1	8	7	9	8.00
2	7	8	8	7.67
3	9	9	7	8.33
4	8	9	7	8.00
5	8	8	8	8.00
6	7	7	9	7.67
7	8	8	8	8.00
8	8	8	8	8.00
9	7	7	8	7.33
10	8	8	7	7.67
Average	7.8	7.9	7.9	$\sum_{ave}$78,67

Calculation of the rate of transpiration:

$\pi r^2 \cdot$distance travelled($\sum_{ave}$) / leaf area / time

$\pi \cdot (0.00065m)^2 \cdot 0.07867m / .221m^2 / 200s = 2.362 \cdot 10^{-9}$ dl m^{-2} s^{-1}

$2.362 \cdot 10^{-9}$ dl m^{-2} $s^{-1} \cdot 60s = 1.417 \cdot 10^{-7}$ dl m^{-2} min^{-1}

Measurement at air current using fan stage 2

Measurement	1st check	2nd check	3rd check	Average
In mm/20s				
1	9	9	9	9.00
2	8	9	9	8.67
3	9	9	8	8.67
4	9	8	8	8.33
5	8	8	9	8.33
6	8	8	7	7.67
7	8	7	8	7.67
8	8	7	8	7.67
9	7	7	9	7.67
10	7	8	9	8.00
Average	8.1	8.0	8.4	$\sum_{ave}$81.68

Calculation of the rate of transpiration:

$\pi r^2 \cdot$distance travelled($\sum_{ave}$) / leaf area / time

$\pi \cdot (0.00065m)^2 \cdot 0.08168m / .221m^2 / 200s = 2.453 \cdot 10^{-9}$ dl m^{-2} s^{-1}

$2.453 \cdot 10^{-9}$ dl m^{-2} $s^{-1} \cdot 60s = 1.472 \cdot 10^{-7}$ dl m^{-2} min^{-1}

Measurement using fan stage 3

Measurement	1st check	2nd check	3rd check	Average
In mm/20s				
1	8	10	9	9.00
2	9	9	9	9.00
3	9	8	9	8.67
4	8	8	8	8.00
5	9	8	9	8.67
6	7	9	7	7.67
7	8	8	9	8.67
8	8	9	8	8.67
9	8	8	7	7.67
10	7	8	9	8.00
Average	8.1	8.5	8.4	$\sum_{ave}$84.02

Calculation of the rate of transpiration:

$\pi r^2 \cdot$distance travelled($\sum_{ave}$) / leaf area / time

$\pi \cdot (0.00065m)^2 \cdot 0.08402m / .221m^2 / 200s = 2.523 \cdot 10^{-9}$ dl m^{-2} s^{-1}

$2.523 \cdot 10^{-9}$ dl m^{-2} $s^{-1} \cdot 60s = 1.514 \cdot 10^{-7}$ dl m^{-2} min^{-1}

Analysing results

Analysing evidence and drawing conclusions

(For graph A)

Under normal conditions the results show that there is a linear increase of water uptake by the water. From this it is possible to calculate the gradient of the line. The gradient of this line is 0.324. By increasing the wind speed to stage 1 (lowest wind speed) the water uptake by the plant increases and this line again is linear and also has a gradient. The gradient increased to 0.393. This means that this line is steeper than the one described before.

On increasing the speed to stage 2 (intermediate wind speed) the gradient again increases but now only to 0.404, which is very similar to the stage 3 (maximum wind speed) gradient 0.417. Both lie almost on top each other until 120s were reached. After that time the graphs slightly deviate each other.

This indicates that an increase of 21.3% was achieved by increasing the wind speed from 0 to stage 1(lowest wind speed).

The other increases in percentages are shown by this table:

Graph (gradient)	Increase in gradient from normal	Increase in gradient from stage before
normal conditions (0.324)	0.324	0.324
Stage 1(lowest speed) (0.393)	0.069 ($^+$21.3%)	0.069 (21.3%)
Stage 2(intermediate speed) (0.404.)	0.080 ($^+$24.7%)	0.009 (2.3%)
Stage 3(maximum speed) (0.417)	0.093 ($^+$28.7%)	0.013 (3.2%)

(The calculation is shown in the appendix on page 19)

This table only shows the increase in percentage by the gradient. This means that it only shows the speed of uptake of water. This means that under stage 1 conditions the water was taken up 21.3% faster then under normal conditions.

By increasing the wind speed the speed does not have to increase linear with the increasing wind speed. By looking at the table it is clearly seen that the increase in gradient from stage 1 to 2 is a little less then of that from 2 to 3.

(For graph B)

There is a significant difference between the wind speed 1(lowest wind speed) results and the results under normal conditions.

At no wind speed the rate of transpiration was $1.165 \cdot 10^{-7}$ dl m^{-2} min^{-1}; by increasing the wind speed to stage 1 (lowest wind speed) there was an increase to $1.417 \cdot 10^{-7}$ dl m^{-2} min^{-1}. This means an increase of $0.253 \cdot 10^{-7}$ dl m^{-2} min^{-1} was measured. At stage 2 (intermediate wind speed) the rate of transpiration was $1.472 \cdot 10^{-7}$ dl m^{-2} min^{-1}. It again increased, but this time only by $0.055 \cdot 10^{-7}$ dl m^{-2} min^{-1}. Increasing the wind speed again to stage 3 (fastest wind speed) a rate of $1.514 \cdot 10^{-7}$ dl m^{-2} min^{-1} was measured. This means this time it increased for only $0.042 \cdot 10^{-7}$ dl m^{-2} min^{-1}.

This means that a 21.7% increase was achieved by increasing the speed from 0 speed to stage 1 (lowest wind speed). By increasing the speed again to stage 2 (intermediate wind speed) the percentage increase shrunk to 3.8% and by increasing the speed again to stage 3 the percentage increase was only 2.8%. Therefore I assume increasing the wind speed will decrease the percentage increase of the rate of transpiration. Therefore at some point of wind speed there should be a 0% increase.

From this results the shape of the curve is a slightly curved shaped. This is due to the high increase in rate of transpiration from the no wind result to the wind speed 1 result (called an exponential curve similar to $y = x^{1/2}$).

On increasing the wind speed an increase of rate of transpiration is measured. The increase of percentages is different from wind speed to wind speed. There is a decrease in percentage tending to 0.

Wind speed	Increase in percentage	Increase from stage before
0	normal condition no increase	--
1	21.7%	21.7%
2	26.5%	3.8%
3	30.0%	2.8%

(The calculation is shown in the appendix on page 19)

Evaluation evidence and procedures

On increasing wind speed the rate of transpiration increased. There was a high increase in rate of transpiration from no wind to stage 1 (lowest wind speed). This can be explained by referring to the theoretical part. When the air is still a high saturated layer of air is around the stomatal pores. This decreases the diffusion gradient across the stomata and the air. Less water can evaporate out from the leaves. On increasing the wind speed to stage 1 (lowest wind speed) this layer of high saturated air is blown away and the diffusion gradient increases. Therefore more water can evaporate out of the leaf. On increasing the wind speed to the next stage, stage 2 (intermediate change), the increase is not as high as before because there is no layer of high saturated air present which can be blown away. The increase then is due to the specific heat capacity of the water. As the air moves over the leaf and the stomata water evaporates cooling down the plant. When the speed is increased more water is taken up by the air and the plant slowly starts to dry out, therefore the rate of transpiration must be increased. Increasing the wind speed to stage 3 (highest wind speed) again more water is taken up by the air and the stomata on the leaves start to close slowly due to water being drawn out of the stomata. This leads then to a decrease in the rate of transpiration.

The experiment shows that on increasing wind speed an increase in the rate of transpiration is achieved. Also it is clearly seen that at a point the increase of rate of transpiration will equal 0%. At this point so much water is drawn out of the stomata that the pores close and the rate of transpiration slows down.

Some results show anomalies. The gradient increase from stage 1 to stage 2 is lower than the gradient increase from stage 2 to stage 3. This is because the gradient only shows the speed of water uptake by the plant. The speed of water uptake is affected by certain conditions. A change in wind speed at a point on the leaf could decrease the water uptake and the anomaly arises. This change in wind speed could take place when the wind hits the leaf from below and turns the leaf around making the area where the stomatal pores are not being blown at. This would lead to a lower transpiration rate and the effect is an anomaly in the results. Therefore the repetitions I made. The anomaly I experience in the gradient is not the fact that something went wrong, because I repeated the experiment 3 times, and the results were similar. The only explanation given is that, when increased to stage 2 (intermediate wind speed) the stomatal pores started to close after being affected by the wind. Therefore the starting point is higher than at stage 1 (lowest wind speed) but the speed at which water is taken up is steady and similar to the stage 1 (lowest wind speed) speed. Also the stage 3 (highest wind speed) results are very similar to the stage 2 (intermediate wind speed) results.

It shows that from stage 2 (intermediate wind speed) the stomata are affected and reacting on the fact that wind is blowing on the leaves.
Anomalies in the results section were achieved because the bubble in the potometer sometimes made a jump or got stuck for a second. Those results were mostly eliminated due to repeating the experiment.

Experimental limitations

There was only limited time to improve the experiment changing different key variables, or increasing the number of repetitions. Further investigation on the effect of temperature as well as the effect of humidity would lead to an interesting investigation. More repetitions could be made having more time. Therefore the results would be more exact.
The control of the wind speed in this experiment could only be achieved using a simple fan. Therefore only arbitrary units can be given when drawing the graph. An exact wind speed may lead to better results and graphs.
Improvements could be made by using a fan where a determination of the exact wind speed can be made. The graph produced from this would give a much better result.
When introducing a bubble into the system the bubble should be always the same size because the bubble might flow up slower when it is bigger due to the force acting between the bubble and the capillary tube.

Extending the investigation

Further investigation on the effect of temperature, different speeds of wind, different distances as well as different positions of the wind origin would improve this experiment.
Using different plants as well as changing different key variables humidity for instance also would improve this experiment.

Appendix

Bibliography

Biological Science1&2 3rd edition by D.J. Taylor, N.P.O Green, G.W. Stout Editor: R.Soper

Extended results

Increasing temperature using hairdryer stage 1

Measurement	1st check	2nd check	3rd check	Average
In mm/20s				
1	8	10	11	9.67
2	8	11	10	9.67
3	8	10	12	10.00
4	9	12	12	11.00
5	9	10	11	10.00
6	9	11	10	10.00
7	10	12	11	11.00
8	9	10	12	10.33
9	10	12	11	11.00
10	11	10	12	11.00
Average	9.1	10.8	11.2	$\sum_{ave}$103.67

Calculation of the rate of transpiration:

$\pi r^2 \cdot$distance travelled($\sum_{ave}$) / leaf area / time

$\pi \cdot (0.00065m)^2 \cdot 0.10367m / .221m^2 / 200s = 3.113 \cdot 10^{-9}$ dl m^{-2} s^{-1}

$3.113 \cdot 10^{-9}$ dl m^{-2} $s^{-1} \cdot 60s = 1.868 \cdot 10^{-7}$ dl m^{-2} min^{-1}

Increasing temperature using hairdryer stage 2

Measurement	1st check	2nd check	3rd check	Average
In mm/20s				
1	14	14	13	13.67
2	14	13	13	13.33
3	14	13	14	13.67
4	14	14	14	14.00
5	13	14	14	13.67
6	14	14	13	13.67
7	14	14	14	14.00
8	13	13	14	13.33
9	14	14	14	14.00
10	13	13	14	13.33
Average	13.7	13.6	13.7	$\sum_{ave}$136.67

Calculation of the rate of transpiration:

$\pi r^2 \cdot$distance travelled($\sum_{ave}$) / leaf area / time

$\pi \cdot (0.00065m)^2 \cdot 0.13667m / .221m^2 / 200s = 4.104 \cdot 10^{-9}$ dl m^{-2} s^{-1}

$4.104 \cdot 10^{-9}$ dl m^{-2} $s^{-1} \cdot 60s = 2.462 \cdot 10^{-7}$ dl m^{-2} min^{-1}

Those results show that on increasing temperature and wind the transpiration rate increases rapidly. An increase of $5.191 \cdot 10^{-7}$ dl m^{-2} min^{-1} or an increase of 111.42% was measured from standard lab conditions to the hairdryer stage 2. The increase between stage 1 and stage 2 of the hairdryer was at 31.8% almost exactly the half of the increase from standard lab conditions to stage 1 which was 60.4%. This indicates that on increasing the temperature and wind speed the plants respiration rate increases quickly and it looses water very quick. As well as animals do by sweating.

Calculations:

Calculation for the gradient of the different graphs.

Using $\frac{\Delta y}{\Delta x}$ = gradient, I used the results from the table Δy being the distance moved and Δx being the time it moved.

Taking then the average of these results give

time	Normal Conditions	gradients	time	Air Movement 2	gradients
20	6,33	0,334	20	9,00	0,434
40	13,00	0,317	40	17,67	0,434
60	19,33	0,350	60	26,34	0,417
80	26,33	0,317	80	34,67	0,417
100	32,66	0,334	100	43,00	0,384
120	39,33	0,350	120	50,67	0,384
140	46,33	0,283	140	58,34	0,384
160	51,99	0,317	160	66,01	0,384
180	58,32	0,317	180	73,68	0,400
200	64,65	0,323	200	81,68	0,408
	average	0,324		average	0,404

time	Air Movement 1	gradients	time	Air Movement 3	gradients
20	8,00	0,384	20	9,00	0,450
40	15,67	0,417	40	18,00	0,434
60	24,00	0,400	60	26,67	0,400
80	32,00	0,400	80	34,67	0,434
100	40,00	0,384	100	43,34	0,384
120	47,67	0,400	120	51,01	0,434
140	55,67	0,400	140	59,68	0,434
160	63,67	0,367	160	68,35	0,384
180	71,00	0,384	180	76,02	0,400
200	78,67	0,393	200	84,02	0,420
	average	0,393		average	0,417

The percentages from this are then calculated:

0.324 = 100%
0.393 – 0.324 = 0.069
0.00324 = 1% therefore → 0.069 = 21.3%
using this I calculate all percentages for the gradients

Calculation for the percentage increase in the rate of transpiration:

I took the results of the calculations done under each table:

Normal conditions	1,16456E-07
Stage 1 lowest wind speed	1,41747E-07
Stage 2 intermediate wind speed	1,47171E-07
Stage 3 highest wind speed	1,51387E-07

Because all of them have the extension E-07 I only use the following numbers:

1.164 The differences of each are taken like this :;
1.417 1.417-1.164 = 0.253
1.472 1.472-1.164 = 0.308
1.514 1.514 -1.164 = 0.350

From this I calculated the percentages:

1.164 = 100%
0.01164 = 1% → 0.253 = 21.7%
and so on…