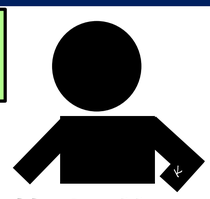
落ち葉に宇宙の神秘を見る

長崎県立大村高等学校

はじめに



裏向きが多い？

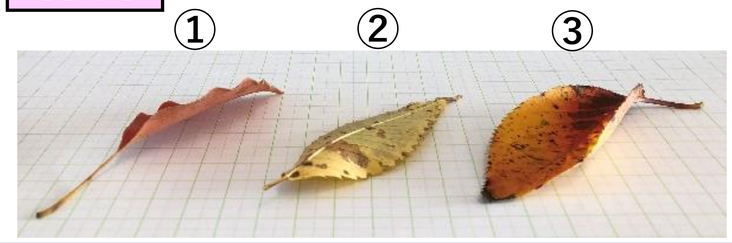
目的

①裏向きの落ち葉の方が有意に多いことの実証
②裏向きが多くなる物理的メカ ニズムの解明

結 論

①落ち葉は裏を上にしているものが有意に多い
②落下後の風による反転で裏葉が多くなる
③反転は風による垂直抗力と揚力で説明できる

材料



①クスノキ
②ケヤキ
③ソメイヨシノ（サクラ）

仮説１

落ち葉は
裏向き ＞ 表向き

実験１　落ち葉の採集と仮説検定

（１）採集
- 場所　大村高校の敷地内
- 時期　令和２年5月～8月

（２）仮説検定
- 帰無仮説　表葉と裏葉の割合は等しい
- 検定方法　χ^2 検定（片側検定、有意水準５％）

結果１　裏葉の方が有意に多い（p<0.05）

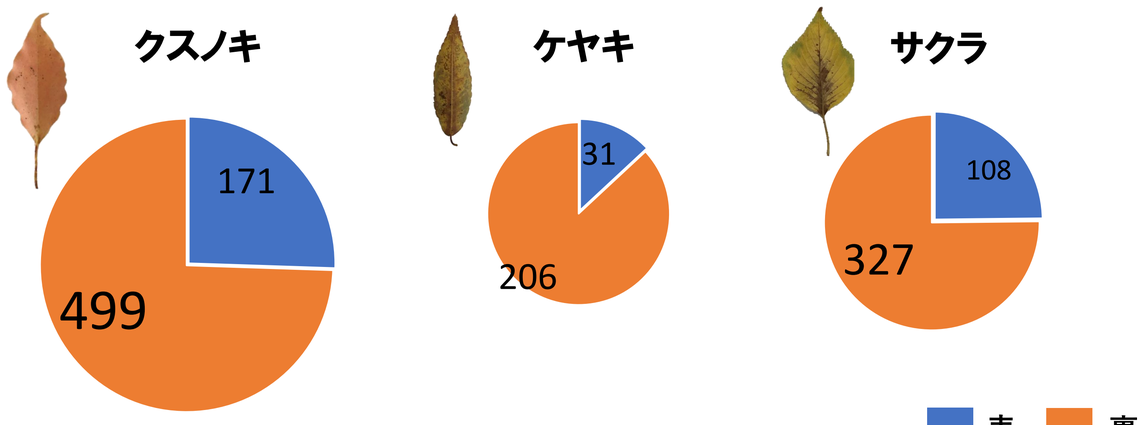


図１ 採集した表葉、裏葉の枚数

仮説２

葉の枚数は、落下直後から
裏向き ＞ 表向き

実験２　落ち葉の落下実験

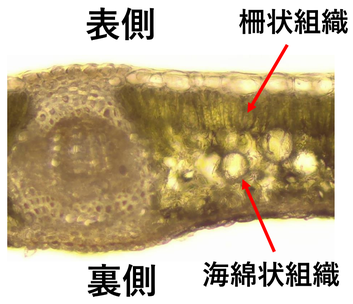


図２ クスノキの葉の断面

- 落下させた高さ　2.0 m
- 実験場所　生物室および物理室
- 落下枚数　３種それぞれ100枚

結果２

裏葉が多いことはない
ケヤキでは表葉が裏葉より多い（p<0.01）

➡ **表裏の偏りは落下後に生じる！**

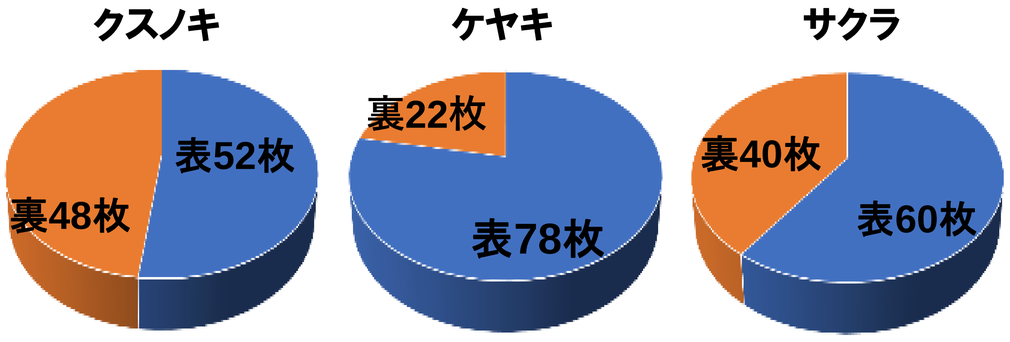


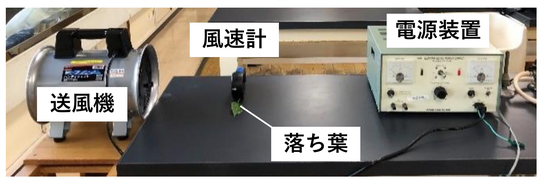
図３ 落下後の表葉，裏葉の枚数

仮説３

風による反転のしやすさ
裏向き ＜ **表向き**

実験３　風による反転のしやすさの違い

①反転風速の測定



②野外での観察

表葉

結果３　表葉が反転しやすい（p<0.01）

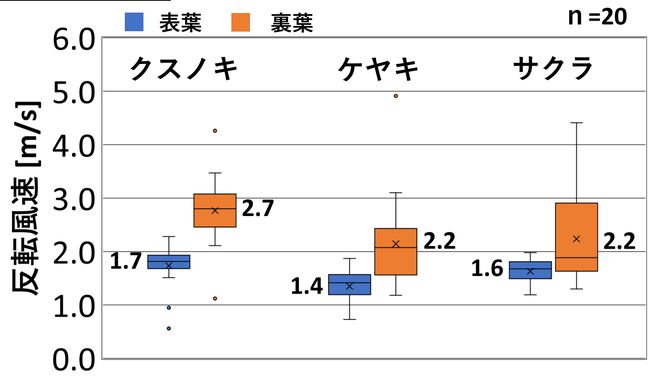


図４ 表葉と裏葉の反転風速の比較

仮説４

風による反転率　　葉の枚数
裏向き ＜ **表向き** ➡ **裏向き** ＞ 表向き

実験４　表葉・裏葉数の再現

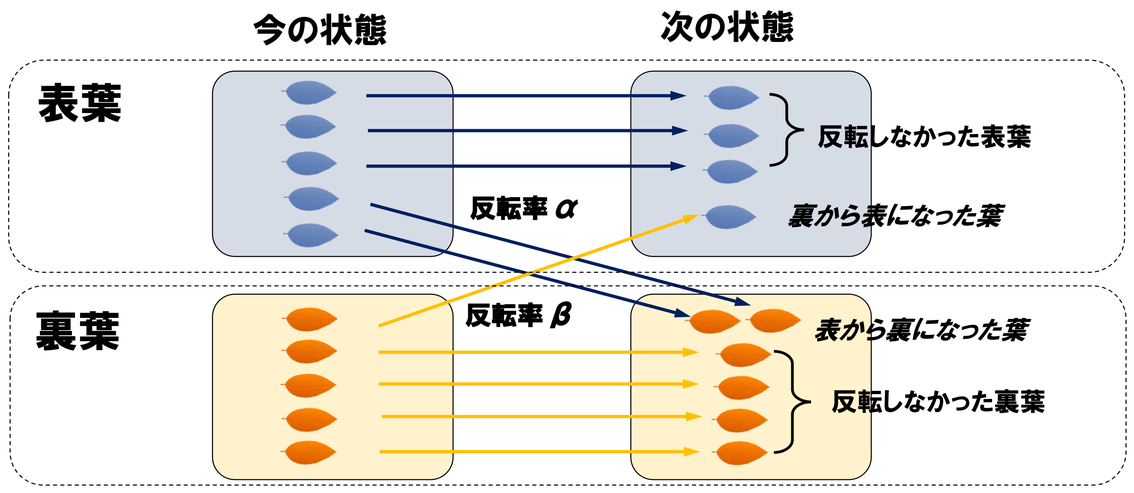


図５ 表葉・裏葉の推移モデル

漸化式

表葉　$a_{n+1} = (1-\alpha)a_n + \beta b_n$　（ⅰ）

裏葉　$b_{n+1} = (1-\beta)b_n + \alpha a_n$　（ⅱ）

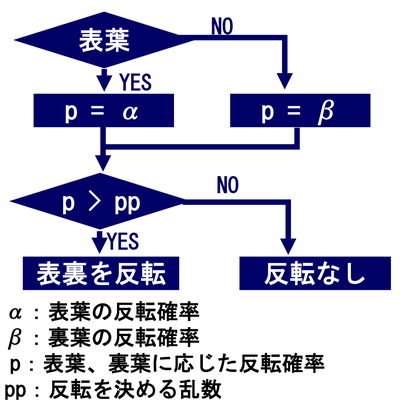
$a_n + b_n = N$　（Nは葉の総数）

一般項

$$a_n = (a_0 - \frac{\beta N}{\alpha+\beta})(1-(\alpha+\beta))^n + \frac{\beta N}{\alpha+\beta} \quad (ⅲ)$$

$$b_n = (b_0 - \frac{\alpha N}{\alpha+\beta})(1-(\alpha+\beta))^n + \frac{\alpha N}{\alpha+\beta} \quad (ⅳ)$$

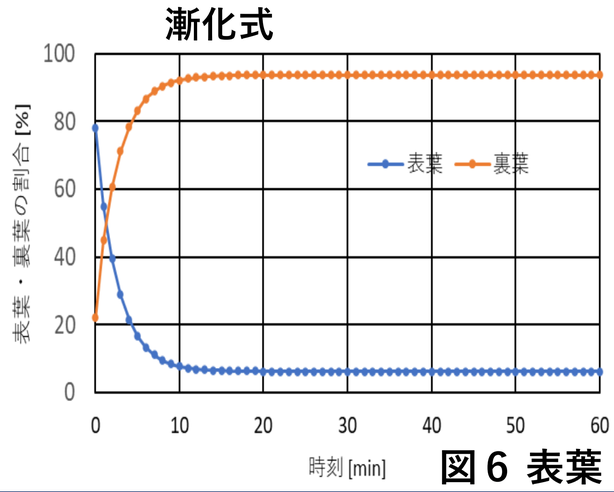
シミュレーション



α：表葉の反転確率
β：裏葉の反転確率
p：表葉、裏葉に応じた反転確率
pp：反転を決める乱数

結果４　反転率の違いが葉の枚数を左右

漸化式



シミュレーション

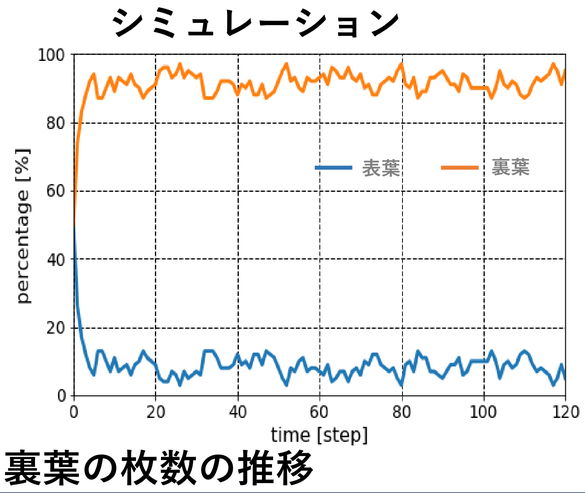


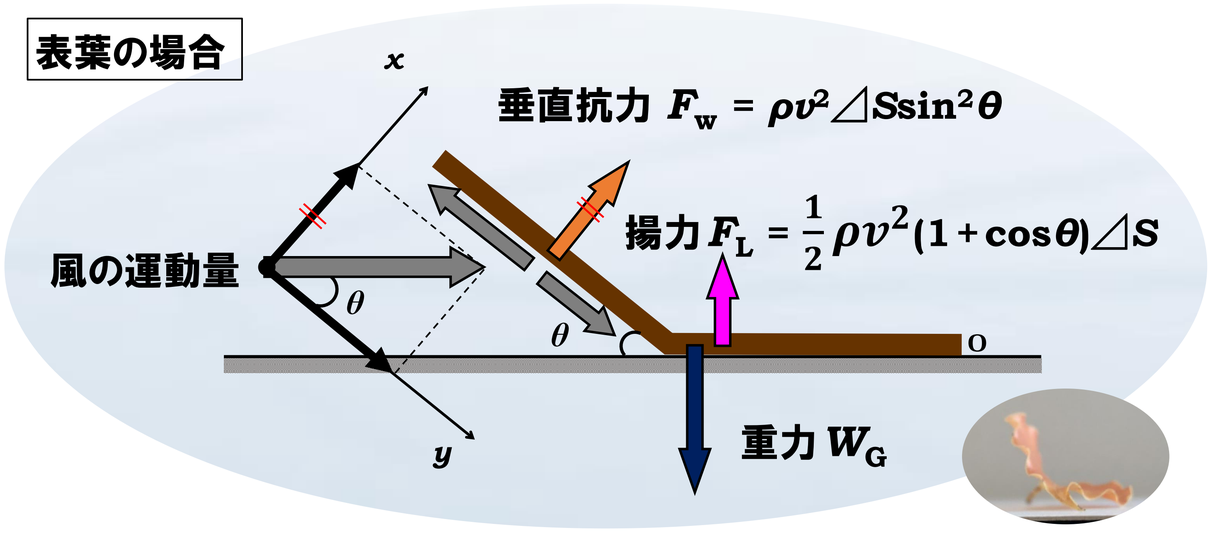
図６ 表葉・裏葉の枚数の推移

仮説５　反転の原因

➡ 風による垂直抗力と揚力

実験５　反転風速の理論値と実験値の比較

表葉の場合



裏葉の場合

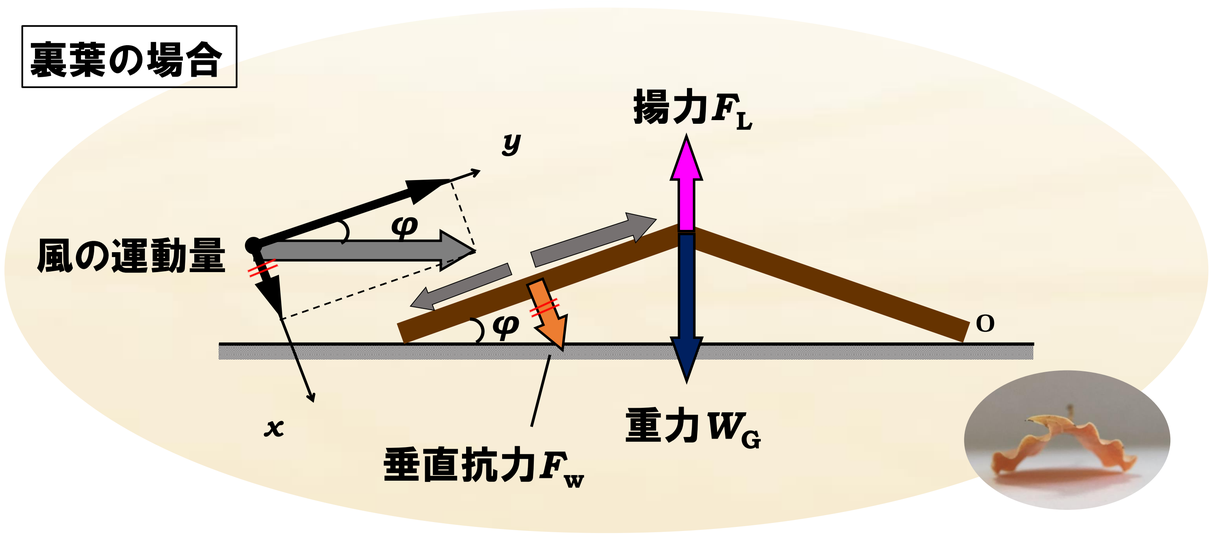


図７ 風により生じる垂直抗力と揚力

O点のまわりのモーメントのつりあい

表葉の場合

$$\rho v^2 \Delta S \sin^2\theta \times l_W + \frac{1}{2}\rho v^2(1+\cos\theta)\Delta S \times l_L = W_G \times l_G \quad \text{より}$$

$$\text{反転風速 } v = \sqrt{\frac{2W_G \times l_G}{\rho \Delta S(2l_W \sin^2\theta + l_L(1+\cos\theta))}}$$

裏葉の場合

$$\text{反転風速 } v = \sqrt{\frac{W_G \times l_G}{\rho \Delta S(l_G \cos\varphi - l_W \sin^2\varphi)}}$$

ρ：空気の密度（以後の計算では1.2 kg/m^3 とした）
l_W, l_L, l_G：それぞれ重力，揚力，垂直抗力の作用線までの距離

結果５　理論値と実験値がほぼ一致

➡ **垂直抗力と揚力が原因**

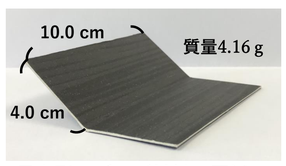
表１ 反転風速の理論値と実験値（実際の落ち葉）

試料 No.	表葉		裏葉	
	理論値 [m/s]	実験値 [m/s]	理論値 [m/s]	実験値 [m/s]
1	1.6	1.8	2.4	3.0
2	1.9	2.2	2.9	2.7
3	1.7	1.9	2.7	2.7
4	1.7	1.9	2.4	4.3
5	1.6	1.8	2.8	3.2
	理論値と実験値のずれ：12 %		理論値と実験値のずれ：17 %	

表２ 反転風速の 理論値と実験値（長方形モデル）

※：± の後の値は標準偏差 (n=10)

θ	反転風速 [m/s]		理論値と実験値のずれ
	実験値	理論値	
20°	2.51±0.013*	2.75	9.5%
30°	2.49±0.021*	2.60	4.4%
40°	2.51±0.017*	2.48	1.2%
50°	2.60±0.028*	2.40	7.8%



長方形モデル（材料：厚紙）

考 察　落ち葉が湾曲する意味とは？

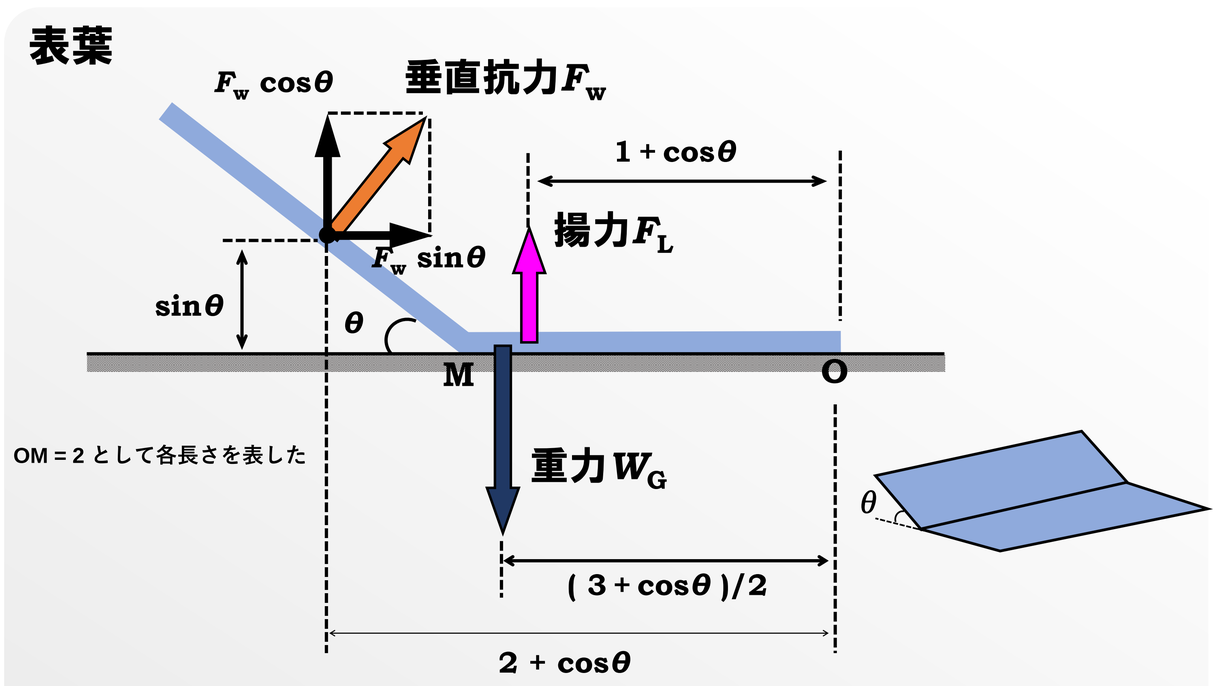


図８ 落ち葉の長方形によるモデル化

$$v = \sqrt{\frac{W_G(3+\cos\theta)}{\rho\Delta S(2\sin^2\theta\cos\theta(2+\cos\theta) + (1+\cos\theta)^2 + 2\sin^4\theta)}}$$

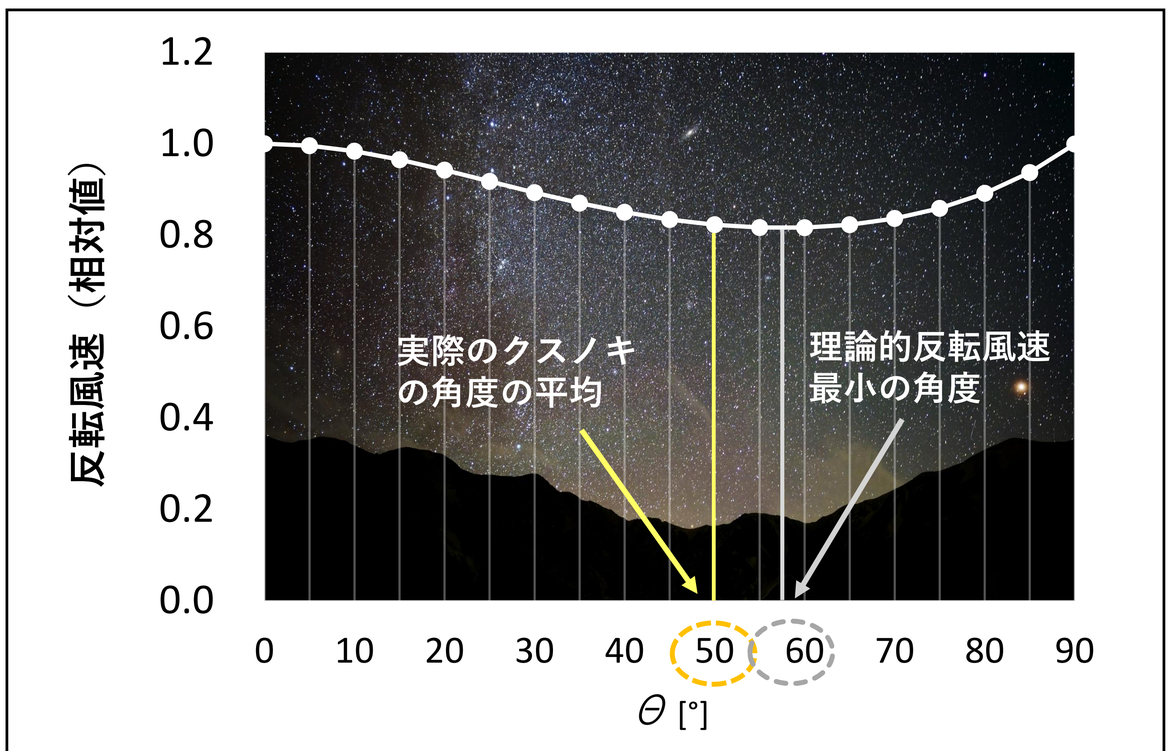


図９ 長方形モデルにおける表葉の角度と反転風速の関係
反転風速は $\theta = 0°$ のときを1 とした相対値

落ち葉の湾曲は表葉の反転風速を最小にする角度に近い

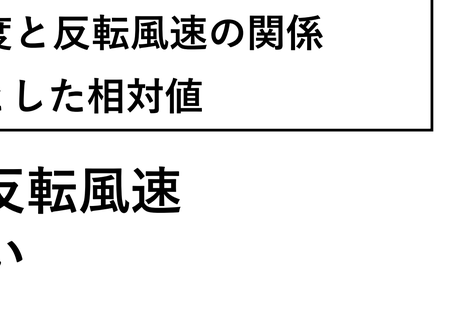
1. 葉の湾曲角度 ＝ 反転風速最小の角度？
2. 裏向きのメリット

生物学的な進化や適応戦略上の意義は？

- 飛ばされにくい ⇒ 自分の養分へ？
- 落ち葉が早く分解される？

今後の展望

裏葉の方が分解されやすい？
⇒表葉・裏葉の分解速度の計測
（屋上にて実験中）



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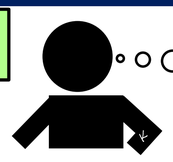
［３］武居 昌宏，『マンガでわかる流体力学』，Ohmsha，2009
［４］T. Terada, On the motion of a peculiar type of body falling though air – Camellia Flower ,Scient Pap. Inst. Phys. Chem, Res., XX, pp.114-127,1933

Feeling the wonder of the cosmos through fallen leaves

Omura High School

Introduction



Face-down fallen leaves are more common than face-up ones ?

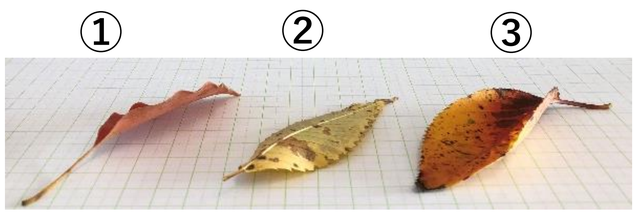
Objectives

① To verify that the number of face-down fallen leaves(FDL) is larger than that of face-up fallen leaves(FUL)
② To clarify the mechanism of this phenomenon

Conclusions

① The number of FDL is significantly more than that of FUL
② Wind after leaves falling on the ground makes the number of FDL larger than that of FUL
③ Flipping is explained by normal force and lift generated by wind

Materials



①Camphor tree
②Zelkova
③Prunus yedoensis （Cherry tree）

Hypothesis 1

The number of FDL > The number of FUL

Experiment 1

Collecting fallen leaves and hypothesis testing

（1）Collecting fallen leaves:
- Place : Omura High School's courtyard
- Time period : May.2020.～August.2020.

（2）Hypothesis testing:
- Null hypothesis:
  The ratio of both FUL and FDL is the same
- Testing method:
  χ^2 test（one-sides test、significance level＝5％）

Result 1

The number of FDL is significantly more than that of FUL （$p<0.05$）

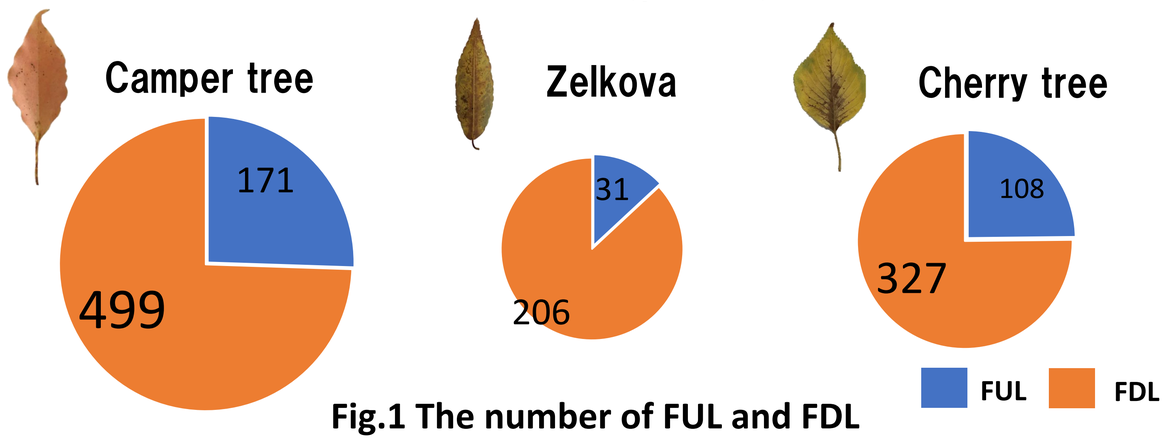


Fig.1 The number of FUL and FDL

Hypothesis 2

Just after falling
The number of FDL > The number of FUL

Experiment 2

Dropping leaves

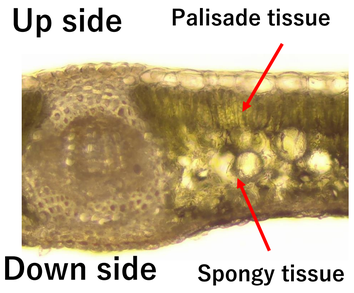


Fig.1 Section of Camper leaf

- Dropping height : 2.0 m
- Experiment location : Biology lab. & Physics lab.
- Number of leaves dropped : 100 leaves for each species

Result 2

The number of FDL was not greater than that of FUL.
For Camphor tree, the number of FUL was significantly greater than that of FDL. ($p<0.01$)

The phenomenon that FDL are more common than FUL occurs after falling on the ground.

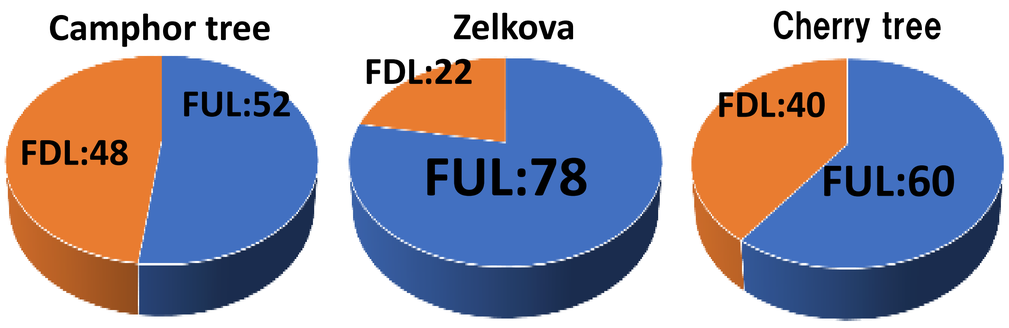


Fig.3 The number of FUL and FDL falling on the ground

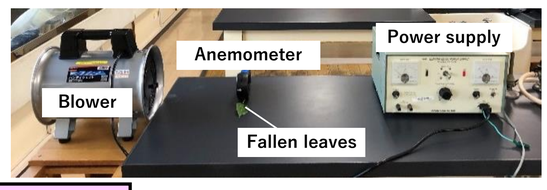
Hypothesis 3

The tendency to be flipped by wind
FUL > FDL

Experiment 3

Difference in ease of flipping between FUL and FDL

①Measurement of wind velocity*



②Field observation

FUL

Result 3

FUL was easier to flip than FDL （$p<0.01$）

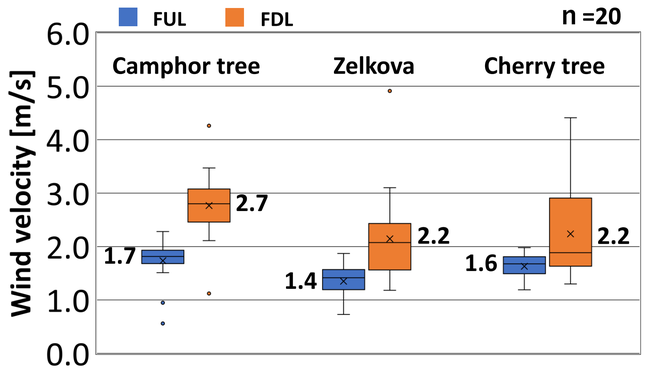


Fig.4 Comparison of wind velocity for FUL and FDL *velocity at which fallen leaves began to flip

Hypothesis 4

If the flipping ratio of FUL > FDL then The number of FUL < FDL

Experiment 4

The transition of number of FUL & FDL

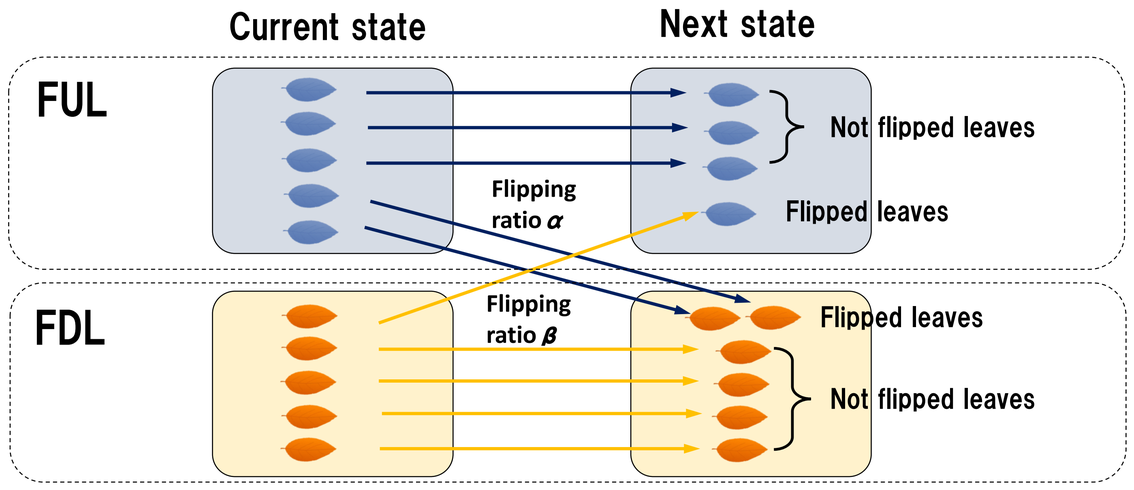


Fig.5 The transition model for FUL and FDL

Recurrence formula

FUL $a_{n+1} = (1-\alpha)a_n + \beta b_n$ (i)
FDL $b_{n+1} = (1-\beta)b_n + \alpha a_n$ (ii)

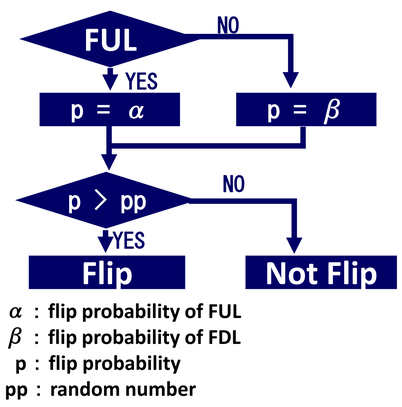
$a_n + b_n = N$
(N : total number of leaves)

General term

$a_n = (a_0 - \frac{\beta N}{\alpha+\beta})(1-(\alpha+\beta))^n + \frac{\beta N}{\alpha+\beta}$ (iii)

$b_n = (b_0 - \frac{\alpha N}{\alpha+\beta})(1-(\alpha+\beta))^n + \frac{\alpha N}{\alpha+\beta}$ (iv)

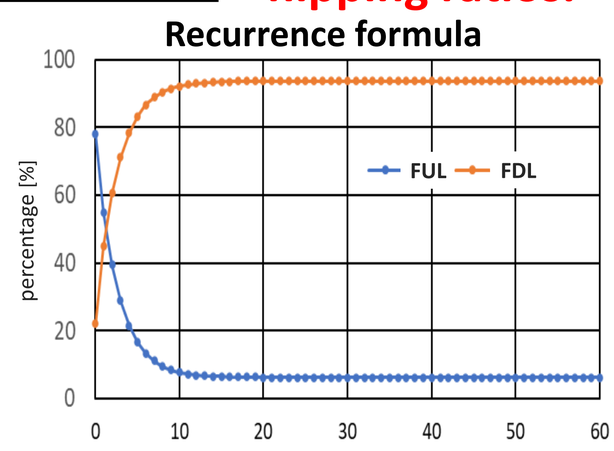
Simulation



α : flip probability of FUL
β : flip probability of FDL
p : flip probability
pp : random number

Result 4

The number of FUL and FDL depends on flipping ratios.



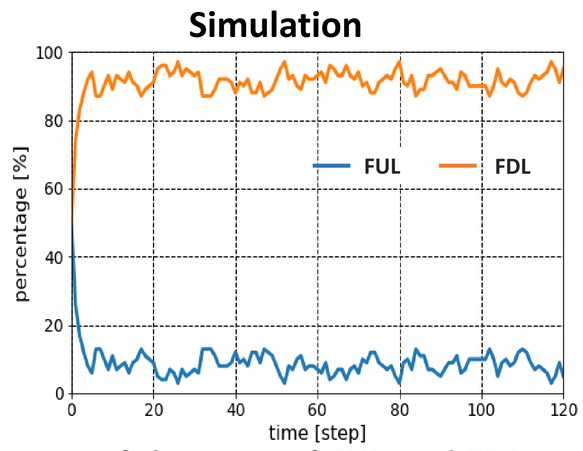


Fig.6 The transition of the ratio of FUL and FDL

Hypothesis 5

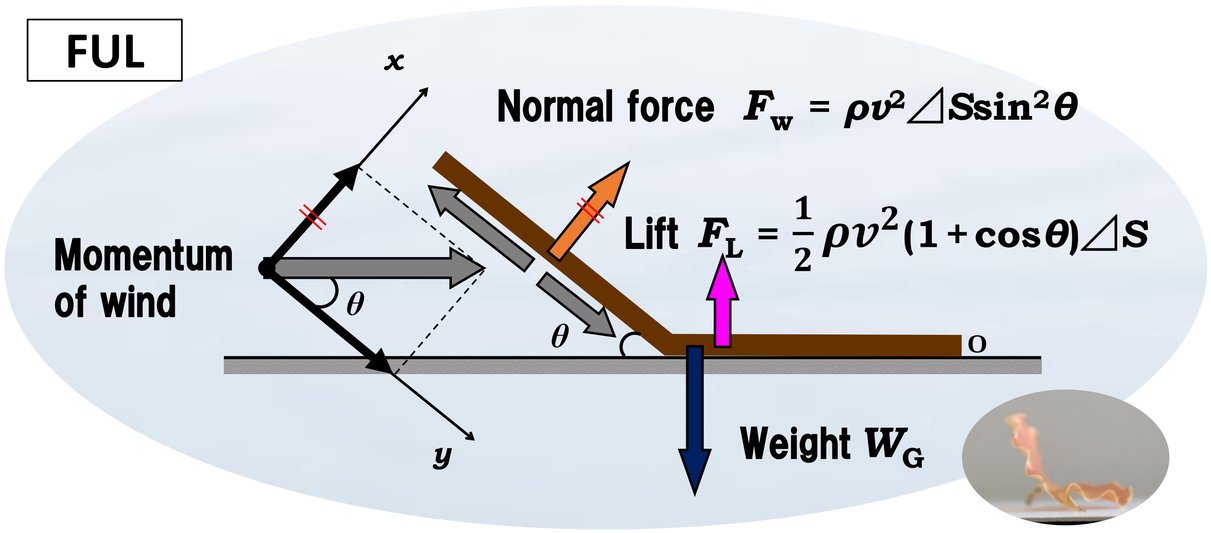
The cause is :

⇒ Normal force & lift generated by wind

Experiment 5

Comparing theoretical and experimental values

FUL



FDL

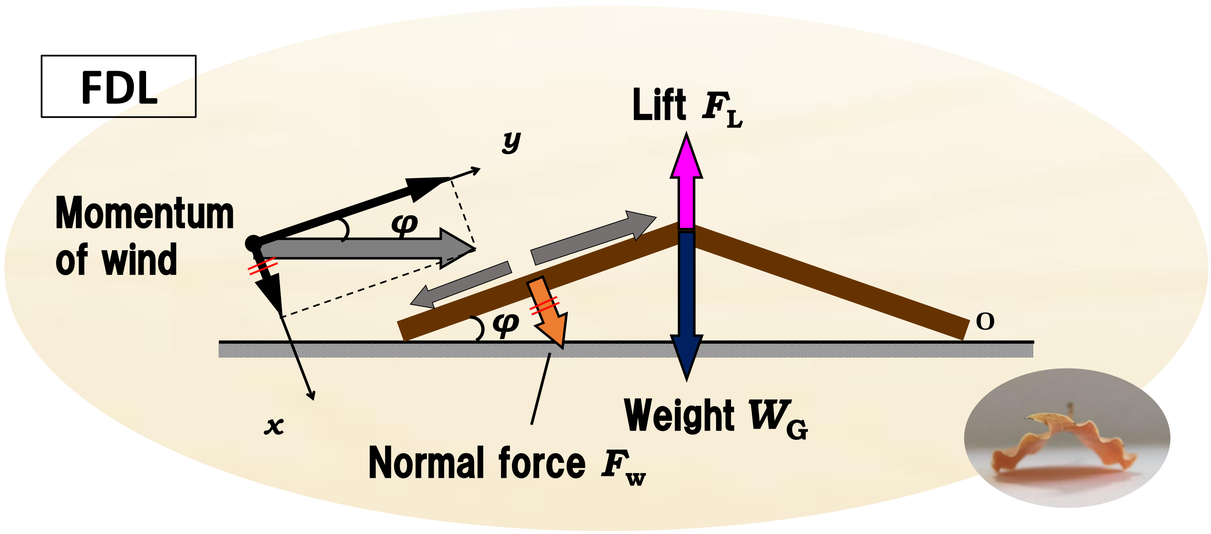


Fig.7 Normal force and lift generated by wind

Balance of moments of force around O

FUL

$$\rho v^2 \Delta S \sin^2\theta \times l_W + \frac{1}{2}\rho v^2(1+\cos\theta)\Delta S \times l_L = W_G \times l_G$$

$$\text{Wind velocity } v = \sqrt{\frac{2W_G \times l_G}{\rho \Delta S(2l_W \sin^2\theta + l_L(1+\cos\theta))}}$$

FDL

$$\text{Wind velocity } v = \sqrt{\frac{W_G \times l_G}{\rho \Delta S(l_G \cos\varphi - l_W \sin^2\varphi)}}$$

ρ : Air density （= 1.2 kg/m^3 ）

l_W, l_L, l_G : Distances from normal force , lift , or weight to line of action

Result 5

Experimental values were approximately equal to theoretical ones

⇒ The cause is normal force & lift

Table 1 Theoretical and experimental wind velocity for flipping (fallen leaves)

Sample No.	FUL		FDL	
	Theoretical [m/s]	Experimental [m/s]	Theoretical [m/s]	Experimental [m/s]
1	1.6	1.8	2.4	3.0
2	1.9	2.2	2.9	2.7
3	1.7	1.9	2.7	2.7
4	1.7	1.9	2.4	4.3
5	1.6	1.8	2.8	3.2
	Deference between two values : 12 %		Deference between two values : 17 %	

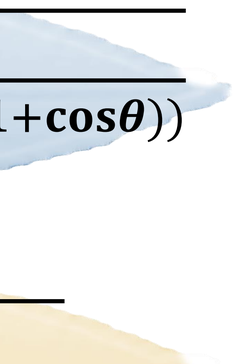
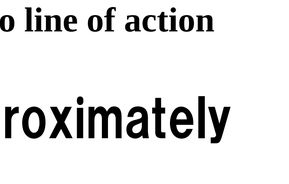


Table 2 Theoretical and experimental wind velocity for flipping (rectangle model) ※ : standard deviation (n=10)

θ	Wind velocity [m/s]		Deference between two values
	Experimental	Theoretical	
20°	2.51±0.013*	2.75	9.5%
30°	2.49±0.021*	2.60	4.4%
40°	2.51±0.017*	2.48	1.2%
50°	2.60±0.028*	2.40	7.8%



Rectangle model
(material : cardboard)

Discussion

The meaning of fallen leaves being curved

FUL

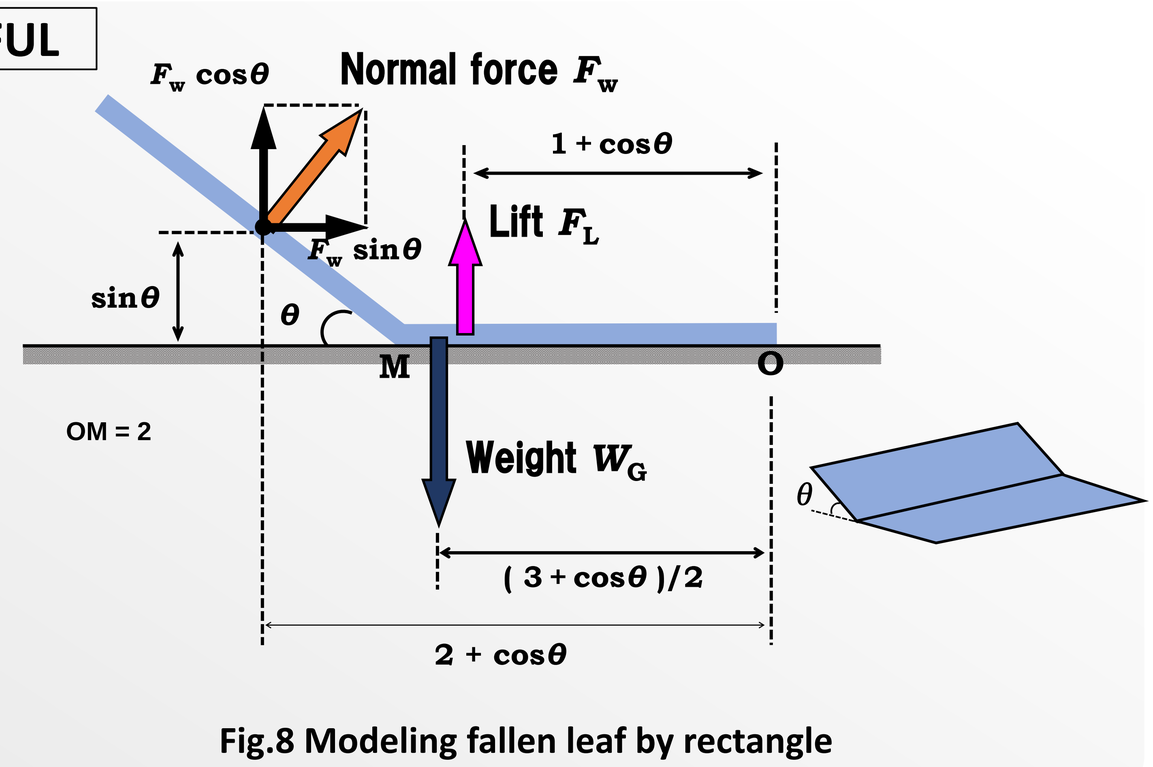


Fig.8 Modeling fallen leaf by rectangle

$$v = \sqrt{\frac{W_G(3+\cos\theta)}{\rho \Delta S(2\sin^2\theta\cos\theta(2+\cos\theta) + (1+\cos\theta)^2 + 2\sin^4\theta)}}$$

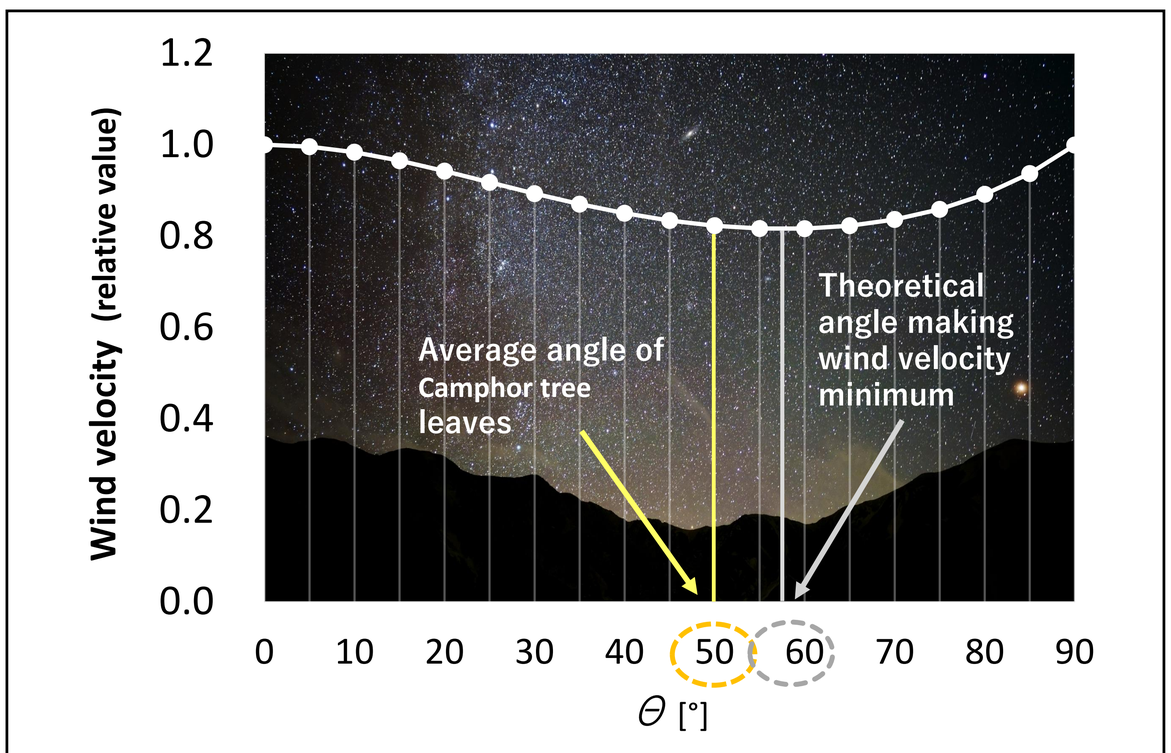


Fig.9 Relation between curvature angle of FUL and wind velocity for flipping

The curvature of fallen leaves is close to the angle which makes the wind velocity needed for flipping leaves minimal.

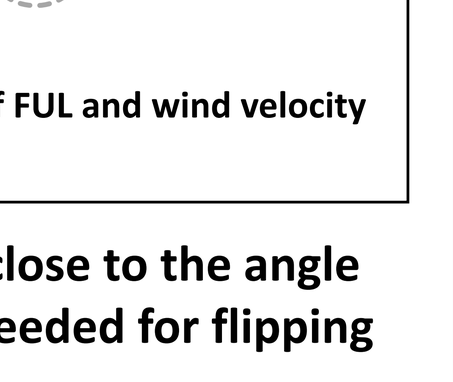
1. Curvature of leaf
   = the angle making necessary wind velocity to flip leaves minimal ?
2. Merits of FDL :
   Evolutional or adaptational strategy ?
   - Hard to blow away ⇒ Nutrition for themselves ?
   - Easy to decompose ?

Future studies

FDL is easier to decompose ?

⇒ Measuring decomposition speed

(Experimenting on the rooftop)



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