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Buoyant Pot Method

——A new device for auto-irrigation——

(Research note)

By

Mamoru YOSHIMOTO[1]

Summary : A complicated instrument composed of a balance and a connected water supplier is indispensable for any conventional device for auto-irrigation based on the constant weight method. The balance can be omitted by floating the pot in water, as it moves up and down with water loss by evapo-transpiration and with water gain by irrigation, respectively, and this up-and-down movement can be used for starting and stopping the water supplier. Further, the water supplier can be also omitted by supplying water through an open tube attached to the bottom of the pot which is opend and closed by the movement of the pot with a valve at a definite depth in water. A simple and efficient device for auto-irrigation based on this principle consists of a buoyant pot which has, at its bottom, an open tube with a rough or grooved inner wall and a buoyant regulater which has mercury as a valve in a cup suspended from floats. The structure of the pot and the regulator is described in detail, stability of the pot in water is examined, and the means of evaluation of sensitivity and precision are presented. Advantages and disadvantages are also discussed.

Preface

It is often necessary or desired to keep the soil moisture in pots constant by supplying automatically as much water as the water loss by evapo-transpiration in various researches pertaining to plants and soils as well as practical cultivation. Various methods[1] have been reported since the beginning of this century, and the constant weight method is one of them. Tamai[2] suggested in 1956 that the method seemed to be rather unpromising because of its expensive complicated instruments for insufficient accuracy which was inevitable as the weight measured included the varying weight of growing plants. In fact, no remarkable development has been made in the method since then. However, the method is, according to the author's opinion, not useless as the accuracy can be improved by correction of the weight if an information is available about the weight of growing plants. Improvements should be made in the simplicity and cost of the devices employed in the method. The device reported here is such a trial. A pot in the device floated on water, moving up and down with change in weight. replaces the balance for starting and stopping the connected water supplier, and even the water supplier is replaced by an open tube attached to the bottom of the pot, opened and closed by the up and down movement of the pot with a valve at a definite depth in water. Thus simplicity and inexpensiveness are realized in this device.

1. Principle

A buoyant pot with an open tube at its bottom is set just above mercury in a cup at definite depth under the water surface. While the lower end of the tube is in contact with

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(1) Forest Soil Division

mercury, water does not enter the pot. When the pot becomes lighter with water loss by evapo-transpiration, it rises due to the difference between buoyancy and gravity. As soon as the tube leaves the mercury surface, water enters the pot through the tube. Then it becomes heavier and sink until the tube end touches the mercury again and the water supply stops. This up and down movement of the pot is repeated and the weight of the pot is kept constant so long as the water depth to the mercury surface (h) is kept constant, since gravity is equal to buoyancy as the pot is floating, and buoyancy which corresponds to the volume of the under-water part of the pot is constant when h is constant.

Instead of the mercury which works a valve, any valve can be used with the tube of the buoyant pot if it can efficiently open and close the tube when the pot moves up and down. Any other water supplying device can be connected to a buoyant pot without tube at its bottom, if the up and down movement of the pot can, directly or indirectly, start and stop the water supply. However, this paper does not deal with these modifications, as the combination of a buoyant pot with a tube and mercury is considered at present to be the most efficient and the cheapest.

2. Pot

Structure of the pot: There is no restriction of shape, size, weight, and material of the pot so long as gravity and buoyancy are balanced and stability is secured. A float is attached to the upper part of the pot to give extra buoyancy when the outside volume of the pot is insufficient. A ballast is attached to the bottom of the pot to give extra weight when the weight of the pot (including soil and plants) is insufficient or to secure sufficient stability to prevent capsizing, if necessary. The side and the bottom of the pot should be coated to make it completely water-proof if the material is permeable. The diameter of the tube should be large enough to allow free entry of water and mercury, and its length should be slightly larger than the possible height of mercury inside the tube, that is h/13.6.* A tube with a smooth inner wall is not desirable and it is recommended to cut V-shaped grooves in it for rapid water supply, as shall be described later. The upper end of the tube should be covered with an appropriate plate of porous material so that the soil particles do not fall into the tube. It is recommended that for smooth water movement spongy strings or perforated tubes are led from the upper end of the tube to the soil surface through the soil. It is not necessary to attach the tube to the center of the bottom of the pot; any position on the bottom or even on the side near the bottom is fine as long as the pot does not become inclined. The only stipulation is that the tube is vertical

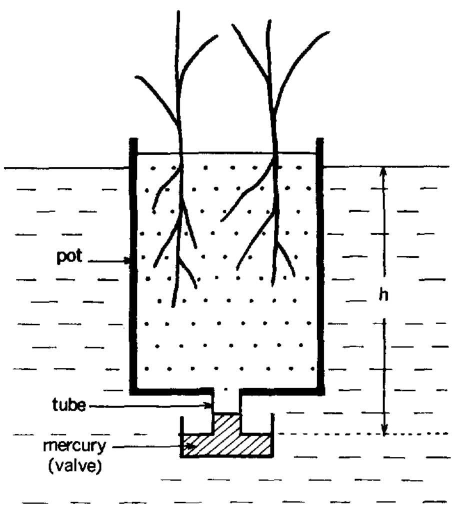

Fig. 1. Principle of the buoyant pot method

* All dimensions are expressed in c.g.s. system; and the specific gravity of mercury is 13.6 and that of water 1.0; through all discussions in this paper.

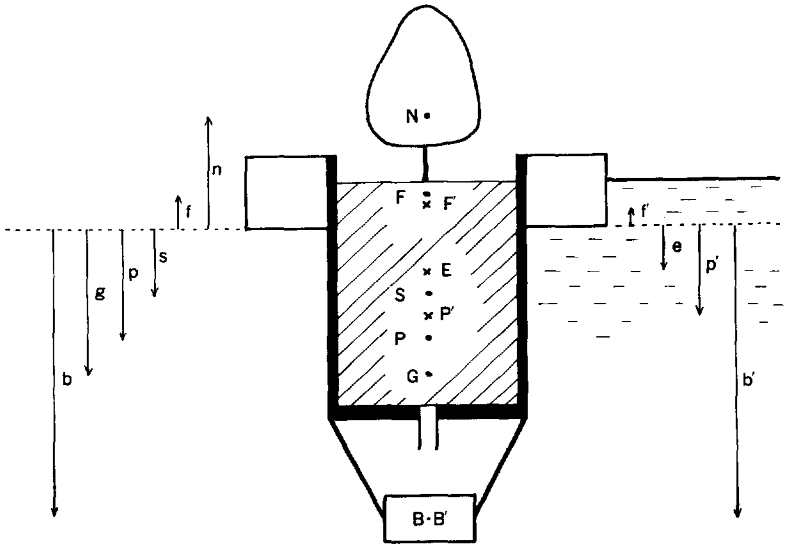

Fig. 2. Centers of gravity and buoyancy

G and E are the center of gravity and buoyancy of the whole, respectively; and other symbols are explained in the text.

and its lower end is horizontal.

Stability of the pot: The condition of stability of the buoyant pot is that the center of buoyancy is above that of gravity. Assuming a buoyant pot which is symmetric against a vertical axis, the following inequality and equations should be realized:

$$g>e \qquad \cdots\cdots (1)$$

$$(g-n)N+(g-f)F+(g-p)P+(g-s)S+(g-b)B=0 \qquad \cdots\cdots (2)$$

$$(e-p')P'+(e-f')F'+(e-b')B'=0 \qquad \cdots\cdots (3)$$

$$N+F+P+S+B=P'+F'+B' \qquad \cdots\cdots (4)$$

where g, n, f, p, s, and b are the distance of the center of gravity of the whole, the plant, the float, the pot, the soil and the ballast from an arbitrary horizontal plane, respectively; N, F, P. S, and B are their gravity, respectively; e, p', f', and b' are the distance of the center of buoyancy of the whole, the pot, the float, and the ballast from the plane, respectively; P', F', and B', are their buoyancy, respectively; and the distances above the plane are negative, the others being positive. Then,

$$nN+fF+pP+sS+bB>p'P'+f'F'+b'B' \qquad \cdots\cdots (5)$$

This inequality is the condition of stability of the buoyant pot. When the horizontal plane is taken on the level with the lower end of the float, the pot is divided into two parts by the plane, and p_1' and p_2' are the distance of the center of buoyancy of the upper part and the lower part of the pot from the plane, respectively, and P_1' and P_2' are their buoyancy, respectively. When the cross-sectional area of the float is A_F, and that of the upper part of the pot is A, their sides being vertical, P_1' and F' are expressed as $-2Af'$ and $-2A_Ff'$, respectively, because p_1' is equal to f'. Then the equations (3) and (4) and the inequality (5) are replaced by the followings:

$$(e-p_2')P_2'-2f'(e-f')(A+A_F)+(e-b')B'=0 \qquad \cdots\cdots (3')$$

$$N+F+P+S+B=p_2'-2f'(A+A_F)+B' \qquad \cdots\cdots (4')$$

$$nN+fF+pP+sS+bB>p_2'P_2'-2f'^2(A+A_F)+b'B' \quad \cdots\cdots (5')$$

They lead to the following inequalities:

$$f'<\frac{s}{2}\sqrt{\frac{s^2}{4}-\frac{J}{2(A+A_F)}} \quad \cdots\cdots (6)$$

$$S>P_2'+B'-N-F-P-B-s(A+A_F)+\sqrt{s^2(A+A_F)^2-2(A+A_F)J} \quad \cdots\cdots (7)$$

Here, $J=(s-p_2')P_2'+(s-b')B'-(s-n)N-(s-f)F-(s-p)P-(s-b)B.$

These inequalities (6) and (7) indicate the lower limit of the underwater part of the float and of the weight of the soil, respectively, for securing stability of a given buoyant pot in which plants are grown to a definite size. When no float is attached to the pot, the horizontal plane is taken on an appropriate level under the water surface and the terms pertaining to the float are excluded. When no ballast is attached, the terms pertaining to the ballast are excluded.

3. Regulator

Structure of the regulator: The depth to the mercury surface can be kept constant either by keeping the water surface at a constant level above the fixed mercury cup or by moving the mercury cup as to follow the shift of the water surface. The former is well known and the latter is, therefore, described here.

A mercury cup is suspended from floats by slender arms which are movable up and down as to adjust the water depth to the mercury surface. When the arms are fixed, the mercury surface is always at a constant depth under the water surface. The total basal area of the floats is 12.6* times the inside basal area of the mercury cup and the sides of the floats and the inner side of the cup are vertical so that the water depth to the mercury surface is not changed by the varied quantity of mercury in the cup. The basal area of the cup should be large enough to have a flat surface of mercury larger than the cross-sectional area of the tube of the pot. The tube should always be on the flat surface and never be on the curved surface near the wall of the cup; then, some kind of stopper is attached to the regulator (or the pot) to restrict the horizontal movement of the pot (or the regulator) if they otherwise move freely. The initial quantity of mercury in the cup should be large enough to secure the remaining mercury in the cup after removal of possible amount of mercury in the tube of the pot. Some weihts are loaded on the floats for adjustment and correction as shall be mentioned later.

Adjustment of the regulator: The proper water depth (h) to the mercury surface can be given by changing the length of the arms of the regulator so that the distance between the lower end of the floats and the mercury surface (or the bottom of the empty cup if the bottom is horizontal), becomes h_A in the following equation, when the total weight of the regulator at that time is R, the solid volume of the cup and arms is C_A, and the basal area of the floats is A_{RF};

$$h_A=h-\frac{R-C_A}{A_{RF}} \quad \cdots\cdots (8)$$

Otherwise, adjustment of the regulator can also be done by adding or removing appropriate weights. A gauge shown in Fig. 3 is recommended to be used for adjustment of the regulator. It consists of a scale and two straight tubes connected with a flexible tube. One

* Difference in specific gravity between mercury and water.

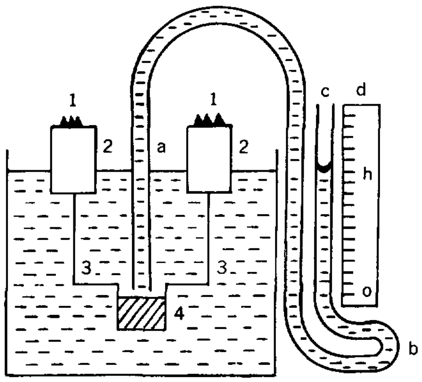

Fig. 3. Adjustment of the regulator with the gauge

1 : weights, 2 : float, 3 : arm, 4 : mercury cup, a : fixed tube, b : flexible tube, c : movable tube, d : scale

of the straight tubes which is similar to the tube of the pot is fixed vertically inside a water container, and the other which is transparent is movable along the scale which is fixed vertically outside the water container. The joints of the tubes are situated at the upper end of the fixed tube and the lower end of the movable tube. The lower end of the fixed tube is on a level with the zero of the scale. All of the tubes are filled with water and the water level is set nearly h above the zero on the scale. A regulator loaded with excess weights on the floats is put so as to place the mercury cup under the fixed tube and the water level is set just to h above the zero on the scale by raising or lowering the movable tube. Then, the movable tube is lowered slightly and the lowered meniscus of water in the tube is spontaneously raised very closely to the former level. After taking off a weight from each float of the regulator, the movable tube is raised so as to bring the meniscus of water in the tube to the same level as before, and is lowered again. This procedure is repeated till the water flow from the container is stopped by the mercury surface in contact with the fixed tube and consequently the meniscus of water in the movable tube is not raised. At that time the adjustment of the regulator is completed.

4. Correction

The whole weight of the buoyant pot including the soil and the plants is kept constant, and the weight of soil water correspondingly decreases with the increase of the weight of the growing plants. The difference should be corrected. Besides. the weight of soil water is sometimes needed to be changed according to the design of the experiment or to the growing program in which the soil moisture content is to be changed from one level to another at a certain stage of plant growth. In such cases, correction is made easily by changing the water depth to the mercury surface of the regulator.

This can be done by putting (or taking) appropriate weights on (or off) the floats of regulator, instead of changing the length of the arms of the regulator. The amount of weight to be added or removed ($\varDelta W$) is calculated from the following equation:

$$\varDelta W = \frac{A_{RF}}{A} \varDelta N \qquad \cdots\cdots (9)$$

when A_{RF} is the total basal area of the fioats of the regulator, A is the cross-sectional area of the pot (and of the fioat of the pot, if attached), and $\varDelta N$ is the desired amount of correction.

5. Sensitivity and precision

Sensitivity and precision of the buoyant pot with proper posture: When a buoyant pot is raised up because of water loss by evapo-transpiration and the tube end of the pot leaves the mercury surface, the lowest part of the mercury column in the tube is exposed to water; but it does not flow out and is held as a column with slightly curved surface by the the surface tension of mercury. At that time, the water pressure outside the tube is greater than the pressure of the mercury in the tube at the tube end, because the water pressure decreases from h to $(h-d)$ and the mercury pressure decreases from h to $h-13.6d$, when d is the opening between the tube end and the mercury surface. This difference in pressure between outside and inside the tube increases with increasing opening between the tube end and the mercury surface, and it makes water intrude into the tube with smooth inner wall against the surface tension of mercury around the tube end as soon as the opening exceeds the threshold shown in Fig. 4. The decrease in the weight of the pot at that time is dA when the opening is d and the cross-sectional area of the pot (and the float if attached) is A. This indicates the sensitivity of the buoyant pot which has a tube with a smooth inner wall.

On the other hand, water intrusion into a tube with a rough inner wall occurs as soon as the tube end leaves the mercury surface, because fine cavities on the inner wall are not filled with mercury and serve as channels for water. A buoyant pot with such a tube is extremely sensitive but it is not necessarily precise. The rate of water intrusion is too slow, while the opening is small, to gain enough water against the rapid water loss by vigorous evapo-transpiration, and the pot continues to be raised up increasing the rate of water intrusion until the water gain compensates for the water loss. It is rational to assume that the rate of water intrusion (v) is directly proportional to the difference between outside and inside water pressure and inversely proportional to the length of water channels along the mercury column in the tube. The former is $h-d-t$ and the latter is $m-d$ when t is the length of the tube, m is the whole height of the mercury column, and d is the opening between the tube end and the mercury surface.

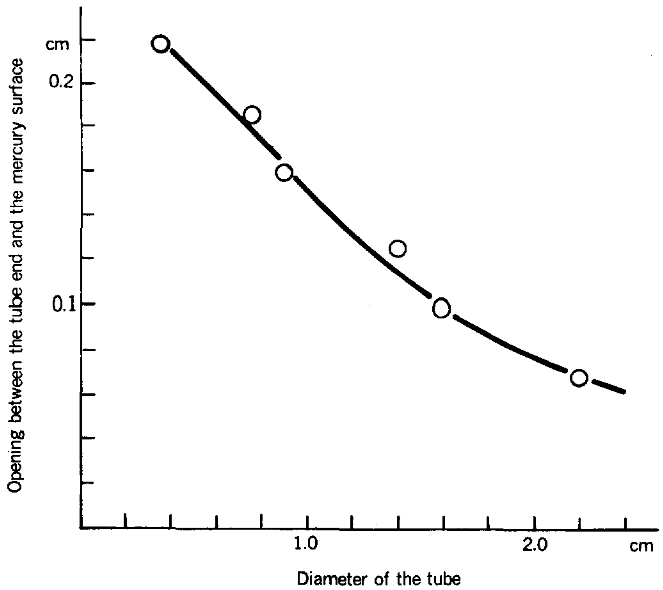

Fig. 4. Thresholds of water intrusion into tubes with smooth inner walls

$$v=\frac{k(h-d-t)}{m-d} \qquad \cdots\cdots (10)$$

The value of k is proportional to the square of d, according to the results of experiments with polyethylene tubes which have different diameter and different grooves, as shown in Fig. 5.

$$k=k_0 d^2 \qquad \cdots\cdots (11)$$

Here, k_0 is a constant specific to the tube and it depends upon roughness of the inner wall of the tube or the number and size of the V-shaped grooves, as shown in Fig. 6.

The total pressure of the whole mercury column and the overlaying water on the mercury column is always balanced with the pressure of the outside water on the mercury surface in the cup.

$$13.6m+\{t-(m-d)\}=h \qquad \cdots\cdots (12)$$

Consequently,

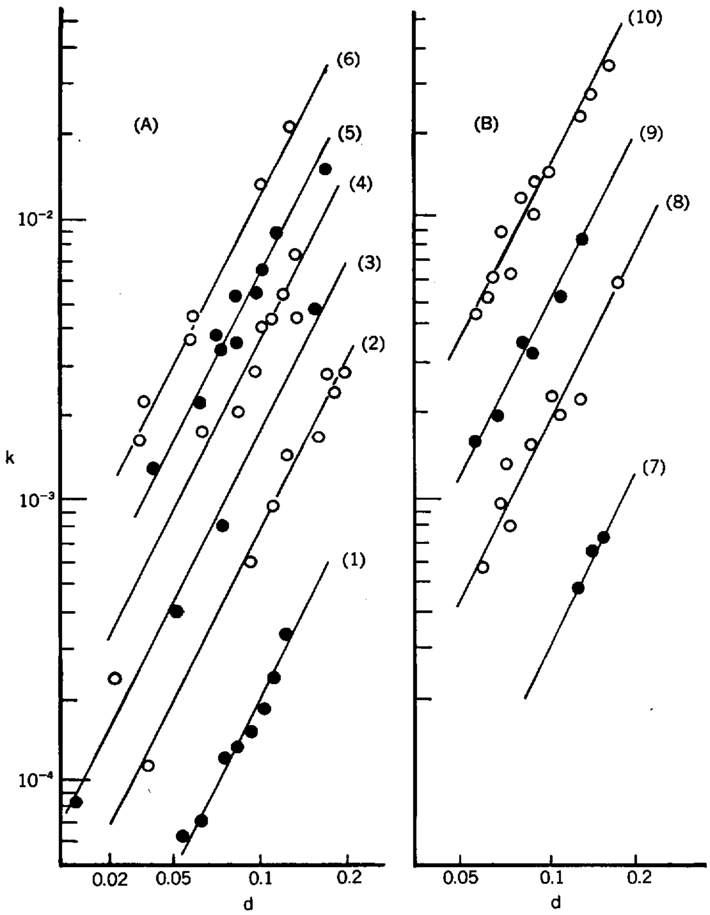

Fig. 5. The value of k related to the opening d

(1) non-grooved, (2) 10 fine grooves, (3) 20 fine grooves, (4) 20 medium grooves, (5) 30 medium grooves, (6) 30 coarse grooves, (7) non-grooved, (8) 10 medium grooves, (9) 20 medium grooves, (10) 40 coarse grooves; (A) 0.9 cm in diameter, (B) 1.4 cm in diameter

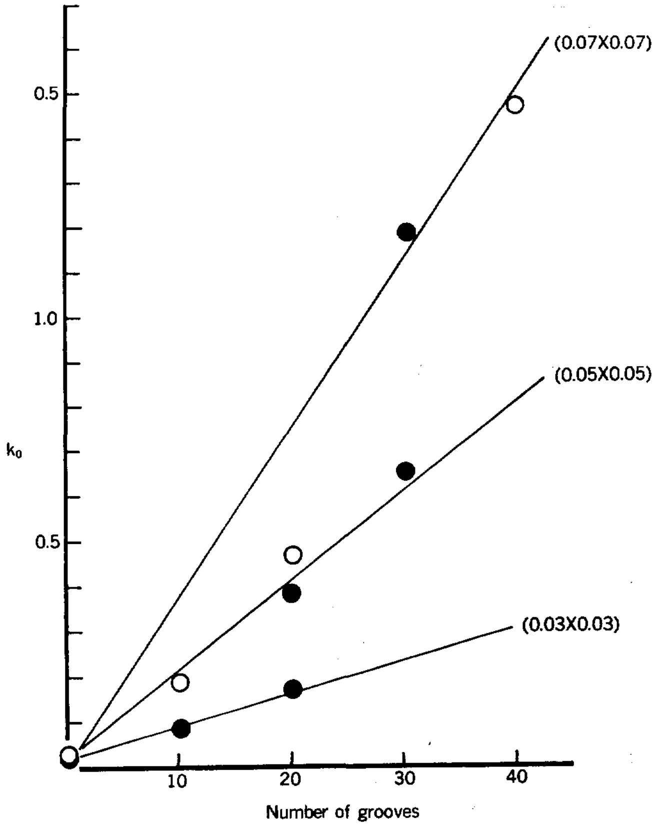

Fig. 6. The increasing value of k_0 with increasing number and size (width X depth) of V-shaped grooves on the inner wall of polyethylene tubes

○ : 1.4 cm in diameter, ● : 0.9 cm in diameter

$$v=\frac{12.6k_0d^2(h-t-d)}{h-t-13.6d} \qquad \cdots\cdots(13)$$

The following equation gives an approximate value of v as d is usually far smaller than h:

$$v \fallingdotseq 12.6k_0d^2 \qquad \cdots\cdots(14)$$

When the maximum rate of evapo-transpiration of a buoyant pot in a growing period is v_{max}, the rate of water intrusion should be also v_{max} to compensate for the water loss of the pot, and the opening between the tube end and the mercury surface should be d_{max} in the following equation:

$$d_{max} \fallingdotseq \sqrt{\frac{v_{max}}{12.6k_0}} \qquad \cdots\cdots(15)$$

The decrease in the weight of the pot at that time is $d_{max}A$, when A is the cross-sectional area of the pot (and the float if attached). The ratio of $d_{max}A$ to the weight of the soil or the soil water in the pot indicates the precision of the buoyant pot. Thus the precision of a buoyant pot depends upon the rate of evapo-transpiration as well as the structure of the pot.

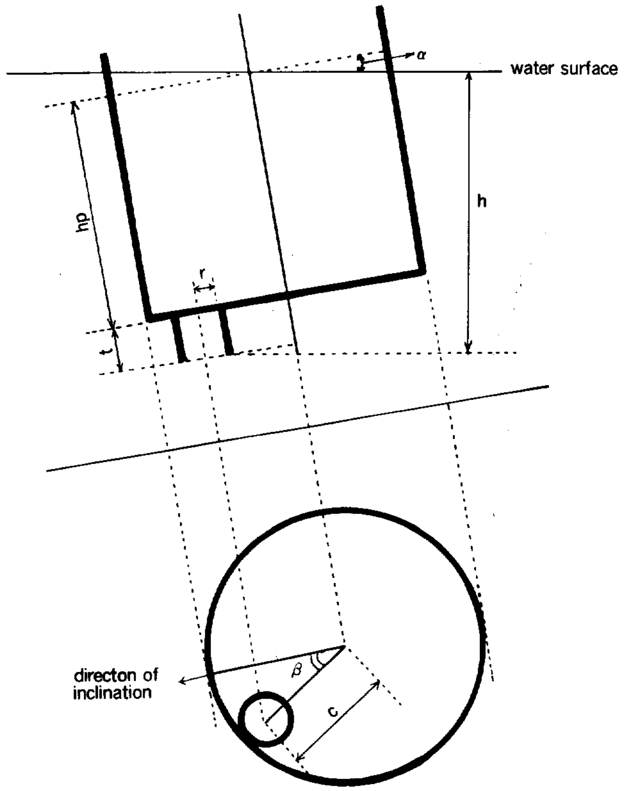

Fig. 7. Volume of the underwater part of an inclined pot

For example, assuming that the cross-sectional area of a buoyant pot is 540 cm², the value of k_0 of the tube is 1.5, and it contains 12 kg soil including 5 kg soil water, the maximum error of the pot is 0.07% of the soil weight or 0.18% of the soil water content when the maximum evapo-transpiration rate is 0.005 g/sec, and it is 0.1% of the soil weight or 0.24% of the soil water content when the maximum evapo-transpiration rate is 0.01 g/sec. In any case, the precision of the buoyant pot is enough for most experiments as well as practical cultivation.

Errors of an inclined pot: Another consideration is needed assuming that the pot is inclined by asymmetric growth of the plant. The volume of the underwater part of the inclined pot is different from that of the pot with proper posture, even if the tube end is situated in the same depth. When the former is V_h' (excluding the tube) and the latter is V_h (also excluding the tube), the angle of inclination is α, the angle from the direction of inclination to the direction from the center of the bottom to the center of the tube on the bottom of the pot is β, the distance between the center of the bottom and the center of the tube is c, the length and the radius of the tube are t and r, respectively, the basal area of the pot is A, the length of the axis of symmetry between the surface of water and the bottom is h_p, and the side of the pot is vertical to the bottom,

$$V_h = (h-t)A \quad \cdots\cdots(16)$$

$$V_h' = h_pA \quad \cdots\cdots(17)$$

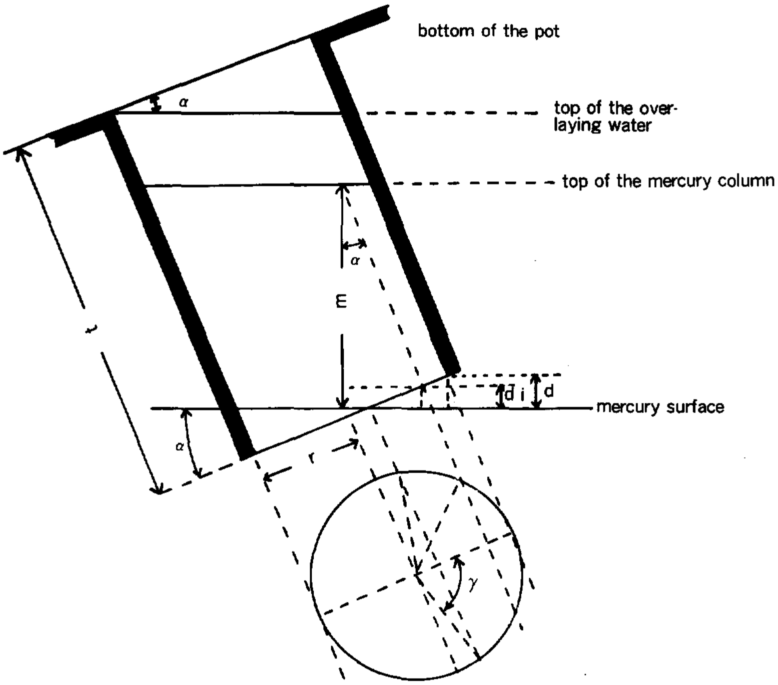

Fig. 8. The tube end of an inclined pot

$$h_p+t+(c\cos\beta-r)\tan\alpha=\frac{h}{\cos\alpha} \qquad \cdots\cdots(18)$$

Then,

$$V_h'-V_h=A\left\{h\left(\frac{1}{\cos\alpha}-1\right)-(c\cos\beta-r)\tan\alpha\right\} \qquad \cdots\cdots(19)$$

As the difference in the volume of the underwater part is equal to that of the weight of the pot, the equation gives the error in the weight of the inclined pot at its full weight.

Further, the condition of water intrusion into the inclined pot is different from that into the upright one. When the inclined pot is a little raised up, the lower part of the inclined tube end is still under the mercury surface and is not effective for water intrusion. Furthermore, the water pressure inside the tube, namely the height to the top of the overlaying water from the tube end, and the length of water channels through the *V*-shaped grooves on the inner wall of the tube, namely the oblique distance to the top of the mercury column from the tube end, vary continuously from the uppermost point to the lowermost points on the arc of the tube end above the mercury surface. Thus, the following equations (23), (24), (25), and (26) replace the previously mentioned equations (10), (11), (12), and (13), respectively:

$$\cos\gamma=\frac{r-\dfrac{d}{\sin\alpha}}{r} \qquad \cdots\cdots(20)$$

$$\overline{d_i}=r\sin\alpha\left(\frac{\sin\gamma}{\gamma}-\cos\gamma\right) \qquad \cdots\cdots(21)$$

$$\overline{d_i^2}=r^2\sin^2\alpha\left\{\frac{1}{2}-\frac{3\sin 2\gamma}{4\gamma}+\cos^2\gamma\right\} \qquad \cdots\cdots(22)$$

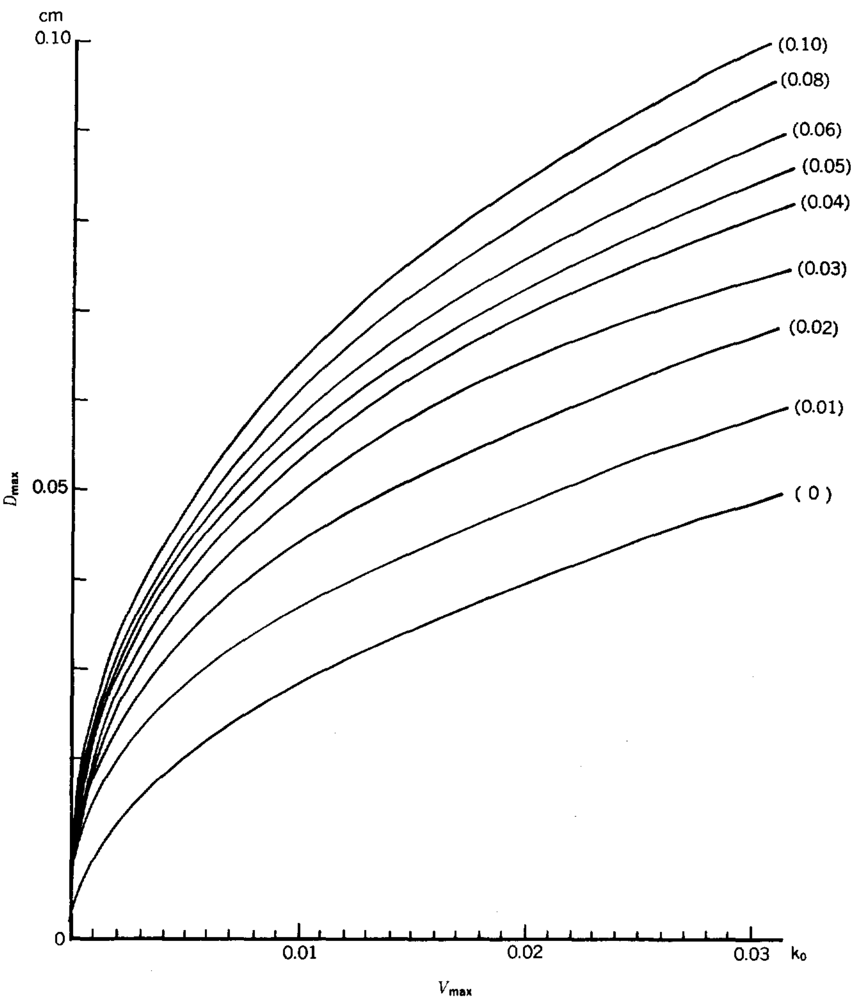

Fig. 9. The needed lift (d_{max}) for the maximum rate of evapo-transpiration (v_{max}) of an inclined pot

The parenthesized figures show the value of $r \sin \alpha$.

$$v_i = \frac{k_i\{(h-\overline{d_i}) - (t\cos\alpha - 2r\sin\alpha + d - \overline{d_i})\}}{\dfrac{m-\overline{d_i}}{\cos\alpha}} \quad \cdots\cdots (23)$$

$$k_i = \frac{\gamma}{\pi}\overline{d_i^2}k_0 \quad \cdots\cdots (24)$$

$$13.6m + (t\cos\alpha - 2r\sin\alpha - m + d) = h \quad \cdots\cdots (25)$$

$$v_i = \frac{12.6\gamma k_0(h - t\cos\alpha + 2r\sin\alpha - d)\overline{d_i^2}\cos\alpha}{\pi(h - t\cos\alpha + 2r\sin\alpha - d - 12.6\overline{d_i})} \quad \cdots\cdots (26)$$

when α is the angle of inclination, γ is half of the central angle against the arc above the mercury surface (radian), d, $\overline{d_i}$, and $\overline{d_i^2}$ are the maximum, the mean, and the mean square of the distance from the arc of the tube end to the mercury surface, m is the height of the mercury column, and t and r are the length and the radius of the tube, respectively.

Assuming that α is not large and d is too small compared with h,

$$v_i \fallingdotseq 12.6\frac{\gamma}{\pi}k_s\overline{d_i^2} \qquad \cdots\cdots (27)$$

The lift of the inclined pot, namely d in the above mentioned equations, should be d_{max} corresponding to v_{max} in Fig. 9, which is derived from the equation (27), when the maximum rate of evapo-transpiration of the inclined pot is v_{max}. Then, the water depth to the uppermost point of the tube end of the inclined pot at the maximum rate of evapo-transpiration is $h-d_{\mathrm{max}}$, which replaces h in the formerly mentioned equation (19):

$$V'_{h-d_{\mathrm{max}}} - V_{h-d_{\mathrm{max}}} = A\left\{(h-d_{\mathrm{max}})\left(\frac{1}{\cos\alpha}-1\right)-(c\cos\beta-r)\tan\alpha\right\} \qquad \cdots\cdots (28)$$

$$V_h - V_{h-d_{\mathrm{max}}} = d_{\mathrm{max}}A \qquad \cdots\cdots (29)$$

$$V'_{h-d_{\mathrm{max}}} - V_h = (V'_{h-d_{\mathrm{max}}} - V_{h-d_{\mathrm{max}}}) - (V_h - V_{h-d_{\mathrm{max}}}) \qquad \cdots\cdots (30)$$

$$V'_{h-d_{\mathrm{max}}} - V_h = A\left\{\frac{h-d_{\mathrm{max}}}{\cos\alpha} - h - (c\cos\beta - r)\tan\alpha\right\} \qquad \cdots\cdots (31)$$

The last equation gives the error in the weight of the inclined pot at the maximum rate of evapo-transpiration. When the errors exceed the limit of allowance, the posture of the pot should be corrected with an appropriate counter-balance.

Strictly speaking, another error is made by the buoyancy of mercury for the part of the tube end of the inclined pot under the mercury surface. But it is negligible and not further discussed.

6. Advantages and disadvantages

The advantages of this device are considered to be as follows:

This device can be easily constructed with commonly available materials at a low cost.

The amount of soil and the soil moisture content can be varied in a wide range, and it is easy to correct or change the soil moisture content at any time of growing. It is very sensitive to the water loss by evapo-transpiration and keeps soil moisture very close to the desired level.

No energy is needed for water supply and it can be used where electricity is not available. It can be moved easily from one place to another if needed.

No care is required except an intermittent supply of water to the water container in which the device is placed. Any accident can never happen as no complicated mechanical or electrical device is used.

The disadvantages of this device are considered to be as follows:

The correction should be made repeatedly while the plants are growing and information about the weight of the plants at various growth stages are indispensable for correction.

The device should be always protected from wind and rain which create errors even if the pot does not capsize or sink.

It is not suitable to grow too tall plants with heavy foliage or fruit at the crown.

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（研　究　資　料）

浮　鉢　式　自　動　灌　水　法

吉　本　　衛[(1)]

摘　　要

従来の定重量式自動灌水法では，植木鉢の重量変化を検知する秤と，これに連動する給水装置とを組合せた複雑な器械が必要であった。簡単な装置で同様の自動灌水ができれば，植物や土壌の研究にも，実用上の栽培にも有用であろうと思われる。そこで，工夫を凝らした結果，次のようにすればよいと考えた。植木鉢を水に浮べ，蒸発散による重量減少のための浮上と，灌水による重量増加のための沈下とを利用して，給水装置の弁を開閉させれば，秤を省くことができる。さらに，植本鉢の底に開管を付け，この開管を植木鉢の浮沈に応じて開閉する弁を一定水深に設置し，水をこの開管を通じて植木鉢に供給するようにすれば，給水装置も省くことができる。浮力不足の場合は植木鉢に浮子を付け，重量不足の場合は底に重錘を付ければよい。植木鉢の水中での安定は，重心が浮心より下方にあればよく，植木鉢，土壌，植物，浮子および重錘のそれぞれの重量・浮力および重心・浮心の位置から判定できる。開管を開閉する弁としては，容器に入れた水銀を用い，水銀面を一定水深に保つため，容器を浮子から吊り下げ，この浮子におもりを載せておき，これを加減して水銀面の深さを調節するようにすれば便利である。水銀を弁とした場合，管端が水銀に接していると水は管に侵入せず，管が上昇して水銀面から管端が離れると水が侵入するが，管の内壁が滑かなときは，管端と水銀面との間隔が管径に応じた一定距離に達するまで，水銀の表面張力のため水の侵入が始まらないのに反し，管の内壁が粗であれば，その微細凹部が水銀に充たされず，水の通路となって，管端が水銀面から離れると直ちに水の侵入が始まること，および管の内壁に多数の V 型縦溝を刻むと水が侵入し易く，その侵入速度は近似的に管端と水銀面との間隔の 2 乗の 12.6 倍に正比例し，その比例常数は縦溝の大きさと数に依存することが，種々の管を用いた実験から判った。水の侵入速度が植木鉢の蒸発散速度に等しくなるまで植木鉢は浮上するので，その浮上距離と植木鉢の断面積の積が植木鉢の重量の誤差となる。これを試算した結果，管の縦溝の大きさと数が充分であれば，高精度の自動灌水が可能と推定された。植物の偏倚生長で植木鉢が傾いたときに生ずる誤差の推定も可能で，これが大きい場合は釣り合いおもりで修正すればよい。この装置は，大小各種のものが容易に廉価で製造できること，精度が高いこと，土壌重や土壌水分を広範囲に変えられること，栽培中いつでも補正や変更が容易で，装置の移動も容易であること，故障が考えられないこと，電力その他のエネルギーが不要なこと等の利点をもつが，他方，生育中の植物体の重量増加による誤差の補正が必要なこと，風雨の影響を避けねばならないこと，重心の高い植物の栽培に不適なこと等の欠点もあると考えられる。以上の考察にもとづく試作品は順調に作動し，この自動灌水法が実用可能であることを示した。

1984 年 7 月 2 日受理

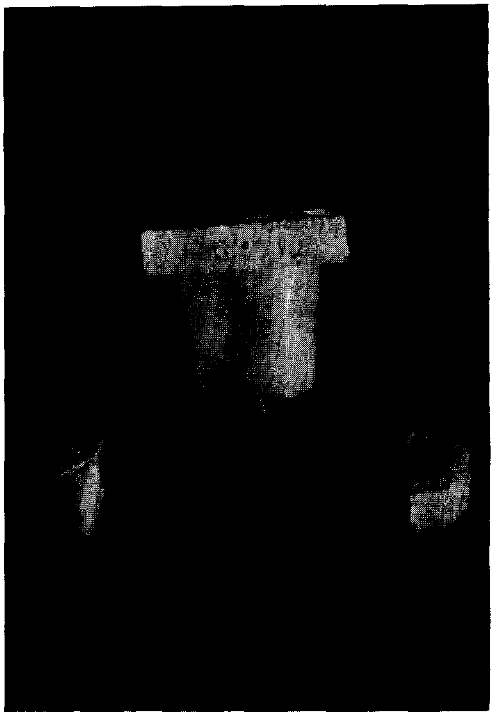
(1) 土じょう部

Appendix

The buoyant pot and regulator manufactured for trial by the author are shown in the following photographs.

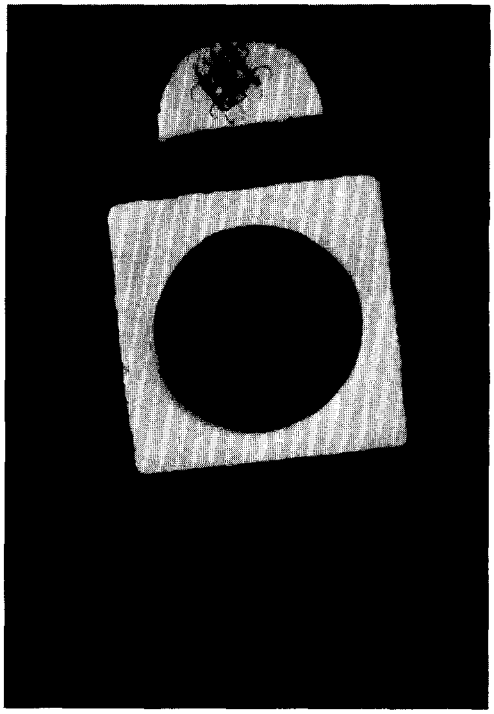
The materials used for them are a 360 cc polyethylene cup as the pot, a chip of polyethylene straw as the tube of the pot, plates of foam-polystyrene as the floats of the pot and the regulator, a little polyethylene dish as the mercury cup, pieces of wire as the arms of regulator, and metal paper-clips as the weights on the floats.

The device worked as successfully as expected, keeping the weight of the pot constant throughout the 3 week experiment period, while the control pot (without tube at the bottom) placed in the same water container decreased in weight from 270 g to 210 g through evaporation.



Side view

The loop of wire attached to the regulator is a stopper to restrict the pot.



Floating situation, overlooked