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An ecophysiological approach to crop losses exemplified in the system wheat, leaf rust and glume blotch

I. A simple and accurate balance for the continuous measuring and recording of (evapo-)transpiration of plants in indoor experiments

P. TEGELAAR[1] and A. F. VAN DER WAL[2]

[1] IWECO-TNO, Delft
[2] Laboratory of Phytopathology, Agricultural University, Wageningen

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Abstract

A cheap and convenient balance for measuring and recording the transpiration rate of plants placed in pots, buckets, etc. is described. The essential mechanical part of the balance is a cross spring pivot. A change in weight on the balance arm causes an angular displacement of the arm with regard to the carrying structure. Torsion forces in the cross spring hinge compensate the change in weight, and a new stable equilibrium can be reached in any position of the balance arm within the limits of its movement (2° 40′). The position of the balance arm is transformed into millivolts DC by using a displacement transducer. The instrument can be loaded up to 25 kg (pots, soil, water, counterweights). The range of the balance is 500 grams, and the resolution of the output is better than 1 gram (1 ml). Other loads, ranges and resolutions can be realised by altering the characteristics of the cross spring pivot and the displacement transducer.

Introduction

Present research on the relation between yield loss in wheat and symptoms caused by pathogenic fungi requires accurate information on the (evapo-) transpiration rate of infected and non-infected plants over the full growth period of the plant, for the purpose of calculating stomatal resistances and energy budgets. A relatively cheap and covenient method of collecting this information in indoor experiments with pot plants was necessary. The payload of the instrument to be designed should be 25 kg, in view of the weights of buckets with soil and water. The resolution should be better than 1 g.

During the experiment, the position of the plants should be changed as little as possible for the transpiration measurement because of mutual interference with neighbour plants.

Loss of weight of plants in a container (pot, tube, bucket, etc.) was chosen as the basis of the measurement. As with lysimeters, corrections for the evaporation of the soil (or nutrient solution) can be made by comparison with plant free controls, and the increase in plant weight by CO_2 and/or water uptake can be taken into account.

These requirements were translated in mechanical terms as to designing a balance with a limited displacement of the arms, and with an output suitable to be recorded by a millivolt recorder.

Fig. 1. General view of the balance; CC = Part of the carrying structure; CSP = Cross spring pivot; CW = Counterweight; DT = Displacement transducer; PL = Payload; MA = Movable arm; S = Stop with screw.

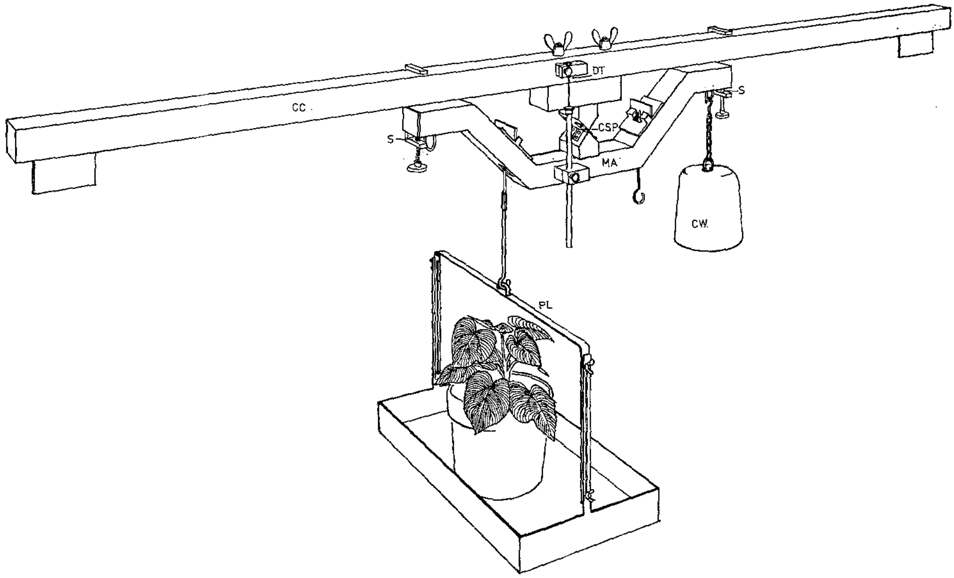


Fig. 1. Overzichtsbeeld van de balans; CC = deel van de draagconstructie; CSP = kruisveerscharnier; CW = contragewicht; DT = displacement transducer; PL = nuttige belasting; MA = beweegbare arm; S = aanslag met schroef.

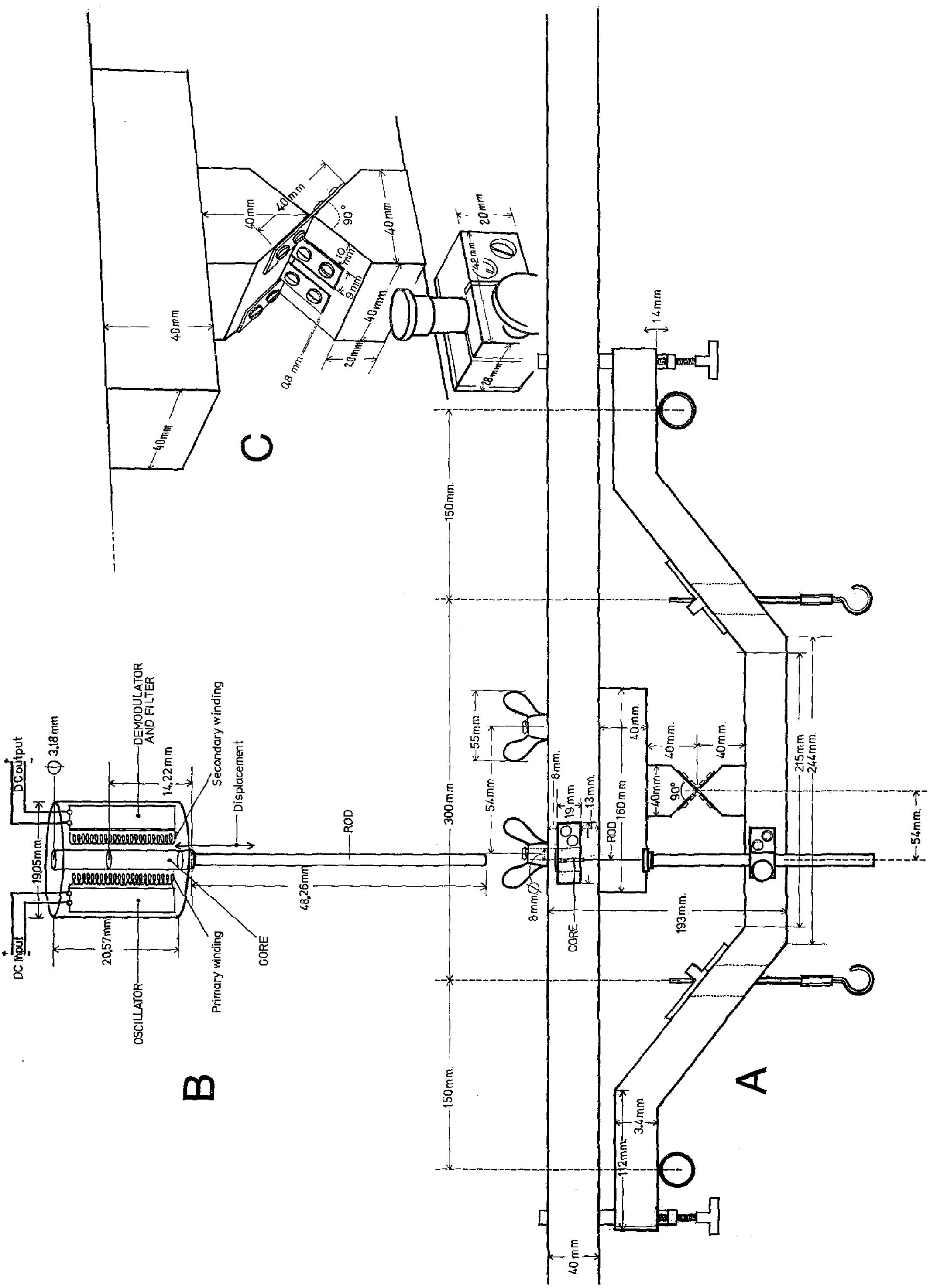
The mechanical part of the balance

A cross spring pivot balance (Fig. 1). The movable arm (MA) is fastened to the carrying structure with four leaf springs placed cross-wise at an angle of 90° (Fig. 1 and 2). The payload of the object under study can be compensated by a suitable counterweight at the opposite end of the balance arm.

Changes in weight of the object or the counterweights cause a small angular displacement of the balance arm. Within the designed limits of the angular displacement, any position of the arm can be stable as a result of the equilibrium between the bending forces in the leafsprings and the momenta on the arm. In this design a cross spring pivot has a number of advantages. It needs no maintainance, no wear will occur, and under normal static loading conditions no fatigue is to be expected.

Fig. 2. Constructional details of the balance. A: Front view and proportions of the balance. B: Diagram and proportions of the displacement transducer. C: General view and proportions of the cross spring pivot.

Fig. 2. Constructiedetails van de balans. A: Vooraanzicht en afmetingen van de balans. B: Schema en afmetingen van de 'displacement transducer'. C: Overzichtsbeeld en afmetingen van het kruisveerscharnier.


A
B
C
DC Input
DC Output
3.18 mm
19.05mm
14.22 mm
20.57mm
DEMODULATOR AND FILTER
OSCILLATOR
Primary winding
Secondary winding
Displacement
ROD
CORE
48.26mm
300mm
150mm
150mm
54mm
55mm
8mm
8mm
19mm
13mm
160 mm
40mm
90°
215mm
244mm
54mm
193mm
112mm
34mm
40 mm
14mm
20mm
42mm
28mm
0.8 mm
9mm

For small angular displacements Hooke's law applies, viz. that the deformation of a leaf spring is proportional to the deforming force. In the balance described the maximum angular displacement from the horizontal position is for 1° 20′, or in total 2° 40′. This comes to a 14 mm stroke at the end of the arm, 300 mm from the axis of rotation. Stops at the ends of the arm limit its movement. By means of screws through the stops the arm can be blocked to enable major changes in the load to be made, such as removing counterweights or containers with soil. This blocking is necessary to avoid distortion of the cross spring pivot.

In designing this type of balance attention had to be payed to the following points:

1. pivot stiffness [kg m rad $^{-1}$];
2. maximum load of the balance arm [kg];
3. elongation of the leaf springs [m]

The stiffness of a cross spring pivot. The pivot stiffness (K) is defined as the ratio between the torsion momentum (M) acting on the pivot and the resulting angular displacement (Q). For the balance depicted in Fig. 1 and 2, the following values have been determined experimentally:

momentum (M) : 7.5×10^{-2} kg m
angular displacement (Q) : 2° 40′ (= 0,0465 rad)

$$\text{pivot stiffness } K = \frac{M}{Q} = \ : 1.61 \text{ kg m rad}^{-1}.$$

From the characteristics of the spring material and the dimensions of the springs the expected pivot stiffness can be calculated, following Wunsch's experimental formula (Ong Bing Jong).

$$K = n. \frac{E \times I}{1 + 8.9 \times 10^{-4}}$$

where: E = Young's modulus of elasticity [kg m $^{-2}$]; I = moment of inertia [m^4]; 1 = free length of the leaf spring [m]; n = number of leaf springs.

The stiffness of the cross spring pivot is proportional to the number of springs, the modulus of elasticity of the leaf spring material, and the width of the leaf springs; it is a third power of the thickness of the leaf springs. K is inversely proportional to the free length of the leaf springs.

In the design depicted the leaf spring material was phosphorus bronze with E = 1.05×10^{10} kg m^{-2}, width 0.01 m, thickness 0.8×10^{-3} m, the number of springs was four, the free length 0.01 m. For these rectangular strips I = 1/12. (0.01). (0.8). 10^{-3} m^4 (Kronig, 1958). The calculated value of K is 1.65 kg m rad^{-1}, which is in good agreement with the experimentally determined value.

The maximum load on the balance arm. The maximum load on the arm, including the weight of the arm itself, depends on the tensile strength of the leaf spring material and the area of the horizontal cross section of the strips.

For a 90° spring pivot, the maximum load Pmax is

$$\text{Pmax} = \frac{\sigma_t \cdot \frac{n}{2} \cdot F}{0.707}$$

in which σ_t = tensile strength [kg m^{-2}]; F = b.h [m^2]; n = number of leaf springs. In this formula the bending stresses and the stress concentration factor due to the screwholes have been neglected.

The tensile strength of phosphorus bronze is 70 to 105 $\times$ 10^6 kg m^{-2}. For n = 4, F = 8 $\times$ 10^{-6} m^2 and σ_t = 70 $\times$ 10^6 kg m^{-2}, the maximum load

$$Pmax = \frac{70 \times 10^6 \cdot \frac{4}{2} \cdot 8 \times 10^{-6}}{0.707} = 1585 \text{ kg}$$

To be sure that the instrument behaves linearly within the elastic range of the leaf spring material, a safety factor 5 is taken into account, so that the maximum load on this cross spring pivot is restricted to 300 kg. The payload used (25 kg) is far under the calculated maximum.

The elongation of the leaf springs. In the case mentioned, the tensile force in each pair of springs is $P = \frac{1}{2}\sqrt{2}.\ 300 = 210$ kg. With a cross section of 2 $\times$ 8 mm^2 or 16 $\times$ 10^{-6} m^2 the strain in the leaf spring material

$$\varepsilon = \frac{\sigma}{E} = \frac{P}{F\,E} = 1250.10^{-6}$$

For an effective spring length of 0.01 m the elongation of the springs is then 1.25 $\times$ 10^{-5} m = 12.5 μm, which is fully negligible in relation to the maximum displacement of the balance arm. In the performance of this balance no measurable deviations will occur because of an elongation of the leaf springs.

The electronic part of the balance

A displacement transducer was used to convert the position of the balance arm to a proportional electrical output, in this case a mV DC. Since the displacement of the balance arm is proportional to the forces that caused it, the output is also proportional to these forces.

The Hewlett-Packard displacement transducer, type 7DCDT (Fig. 2b) consists of a differential transformer fed by a 6 V DC stabilised power supply unit (Hewlett-Packard technical data 10/68). The built-in oscillator converts the DC input into an AC supply voltage, which is used to excite the primary winding of the transformer. The axial coreposition determines the voltage induced in the secondary winding. The resulting output, after demodulation and filtering, is a DC voltage proportional to the coreposition with respect to the electrical centre of the transducer.

The body of the transducer, containing oscillator, transformer, demodulator and filter, is mounted on the carrying structure of the balance: the core of the transducer is connected to the movable arm (MA) of the balance (Fig. 1) in such a way that the core can move in the coil of the transformer and that the horizontal position of the arm coincides with the electrical zero point of the transducer.

The end of the balance arm moves + or − 7 mm at a distance of 300 mm from the axis of rotation of the cross spring pivot. The displacement transducer, having a full range of + or − 1.27 mm should therefore be mounted at a distance of approximately 54 mm from the axis of rotation. The output of the 7DCDT transducer is + or − 1.5 V DC. Adaption of the output to the range of the recorder to be used is not difficult.

The use of the balance

At the Laboratory of Phytopathology, balances of this type have now been used almost continuously for over a year. Data about transpiration of uninfected plants and plants infected with *Puccinia recondita* Rob. ex. Desm., *Septoria nodorum* Berk., separate and in combination, were collected in experiments of the class multiple input-multiple output (Zadoks, 1972). Experiments of this kind need efficient measurement of individual responses in order to cope with the problem of limited labour supply and the necessity of measuring numerous responses in the same experiment. Results obtained with these balances will be published later. The load has mostly been a

Fig. 3. A typical output of the balance on a strip chart recorder, representing the transpiration of potted wheat plants under constant day conditions, and different but equally constant night condition.
↑ PP = change of the plantposition (14 mm).
↓ CW = change of the counterweight position.

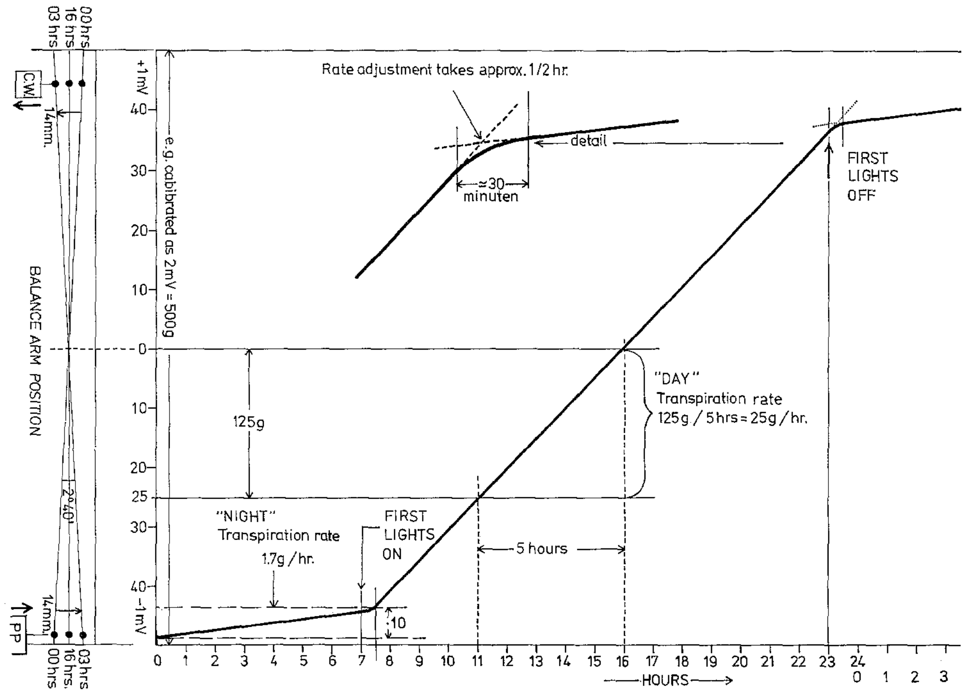


Fig. 3. Een karakteristieke uitkomst verkregen met de balans op een schrijver met papierstrook, voorstellende de transpiratie van potplanten van tarwe onder constante dag- en andere, maar eveneens constante nacht-omstandigheden.
↑ *PP = verandering van de positie van de plant (14 mm).*
↓ *CW = verandering van de positie van het contragewicht.*

bucket with soil, water and plants, weighing about 12 kg. This load was suspended at a distance of 150 mm from the axis of rotation. At the other end of the arm, 300 mm from the axis, a counterweight of lead of about 6 kg was attached. The range of the balance was about 500 grams. Calibrations were carried out with stamped analytical weights.

When the counterweight end of the arm just touched its lower stop, and approximately 500 ml of water was added to the bucket with plants, the arm moved over 2° 40′ so that the end of the arm with the bucket just touched its lower stop. The bucket with plants lost weight by evaporation and transpiration and the weight lost weight by evaporation and transpiration and the weight loss was recorded until 500 ml of water had gone. Then the balance was again arrested by the lower stop of the arm's counterweight end, and additional watering or additional taring were necessary to get the balance back in range.

Fig. 3 shows a record of weight loss by wheat plants in a bucket wtith soil during a 24-hour cycle in a growth chamber. Because of the reaction of the stomata the transpiration rate increased almost by a factor 10 after the lights were switched on. The time needed by the plants to adapt from darkness to light transpiration rate to the light period rate was 20 to 30 minutes. It took about another 30 minutes to adapt to the darkness transpiration rate after the lights were switched off. 'Twilight', the period from the ignition of the first lamp till that of the last one lasts half an hour. At the end of the light period the lamps are also switched off in half an hour. The transpiration rate can be derived directly from a record as shown in Fig. 3, if no corrections (for e.g. soil evaporation) are needed.

Samenvatting

Een ecofysiologische benadering van 'schade', geïllustreerd aan het systeem tarwe, bruine roest en kafjesbruin.
I. Een eenvoudige en nauwkeurige balans voor de continue meting en registratie van (evapo-)transpiratie van planten in binnen proeven.

Tijdens het onderzoek naar het verband tussen de opbrengstderving en de aantasting door pathogene schimmels bij tarwe, bleek de wenselijkheid om nauwkeurig geïnformeerd te zijn over de transpiratie van zieke en gezonde tarwe.

Transpiratie was slechts één van de te meten responsies in proeven van de klasse 'multiple input- multiple output' (Zadoks, 1972). Proeven van deze klasse maken het gebruik van efficiënte meetmethoden voor iedere responsie afzonderlijk noodzakelijk om te voorkomen dat essentiële responsies niet of slecht worden gemeten wegens tijdgebrek.

Voorts diende de positie van de planten waaraan gemeten werd, zo weinig mogelijk te worden veranderd ten behoeve van de meting, omdat de gemeten transpiratie vergelijkbaar moest zijn met de transpiratie van andere, niet gelijktijdig gemeten planten in de proef.

Een goedkope en weinig arbeid vragende methode wordt beschreven om de transpiratie van planten in kas- en klimaatkamerproeven nauwkeurig te meten en te registreren. Het werktuigkundige deel van het apparaat is een balans met een kruisveer-

scharnier (Fig. 1 and 2c). Aan de beweegbare arm (MA) worden een pot of een emmer met planten gehangen. Het gewicht daarvan wordt gecompenseerd door een contragewicht (CW) aan het andere einde van de arm. Wordt de arm uit de horizontale stand gebracht door waterverlies van de bak met planten, dan ontstaat een torsiemoment in het kruisveerscharnier, dat tegengesteld werkt aan het moment, dat de balansarm uit de horizontale stand bracht. Wanneer beide momenten met elkaar in evenwicht zijn heeft de balansarm een nieuwe, stabiele positie. De verplaatsing van de arm is gering; de hoekverdraaiing is maximaal 2° 40′, gelijk staande met een maximale slag van de arm op 300 mm afstand van de rotatieas van 14 mm. Het elektronische deel van de balans is een 'displacement transducer' (Fig. 2b). Hiermee wordt de positieverandering van de arm ten opzichte van de draagconstructie gemeten en omgezet in een gelijkspanning. De opnemer bestaat uit een differentiaaltransformator, die aan de draagconstructie is bevestigd, terwijl de beweegbare kern aan de arm is verbonden. De maximale slag van de kern is 2.54 mm. De uitgangsspanning van de opnemer is evenredig met de verplaatsing van de arm, en dus met de gewichtsverandering aan de arm.

Het ijken gebeurt met geijkte analytische gewichten. Een typisch transpiratiepatroon voor planten onder een dag/nachtritme met overigens constante dag- en nachtomstandigheden wordt in Fig. 3 gegeven. De transpiratiesnelheid is hier overdag bijna 10 maal de 'nacht'-snelheid.

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Addresses

P. Tegelaar, Instituut voor Werktuigkundige Constructies IWECO-TNO, Leeghwaterstraat 5, P.O. Box 29, Delft, the Netherlands.

A. F. van der Wal, Laboratorium voor Fytopathologie, Landbouwhogeschool, Binnenhaven 9, Wageningen, the Netherlands.