A Pneumatic Device for Lifting Containers in Plant Water Use Studies

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ABSTRACT

Direct gravimetric determinations of whole-plant water use in container studies can be time consuming due to the tremendous labor required to physically lift containers for placement on weighing scales. Our objective was to design and construct a container-weighing system that could be rapidly deployed and required little physical labor. A custom-made support frame, equipped with a pneumatic lifting cylinder connected to a hanging scale, was constructed to lift large plastic containers (45 L) filled with a coarse sandy medium (>70 kg when saturated with water). Custom lifting arms designed to catch the handles of the plastic containers were constructed for attachment to the scale. The support frame weighing apparatus was positioned over the container, and the pneumatic lifting cylinder was activated only after lifting arms had been attached to the plastic container. As many as 25 large plastic containers could be weighed per hour with this system. The weighing system has been successfully used to follow plant water use patterns over time.

Available soil water can govern plant survival since overall plant growth is reduced under water deficit conditions due to decreased water potential, stomatal closure, and a subsequent decrease in photosynthesis (Boyer, 1970, 1982). An important historical aspect of plant research has focused on measuring plant water use patterns (Kramer and Boyer, 1995; Slavik, 1974). One method commonly used to directly track water use patterns is weighing the containers in which plants are grown. Although this technique is simple, it can be very labor intensive due to the need to physically lift these containers onto scales. This is especially true when large numbers of heavy containers are part of the experimental setup. Here we describe a simple container-weighing system that utilizes a pneumatic lifting device. This system has proven to be easy to operate, capable of weighing large soil-filled containers (45 L), and eliminates the physical requirement of lifting containers onto a weighing scale.

CONSTRUCTION AND OPERATION

The weighing system described herein consisted of four major parts: (i) the frame housing, (ii) a pneumatic cylinder, (iii) a hanging electronic weighing scale, and (iv) a lifting arm apparatus. A list of component parts and costs for the system is shown in Table 1, and detail specifications are discussed below and shown in Fig. 1–3. System testing was done at the soil bin facilities of the USDA-ARS National Soil Dynamics Laboratory, Auburn, AL.

The frame housing was constructed of aluminum tubing [22.2 mm (0.875 in) diameter]. The upright portion of the frame was made by bending a 3.4-m (134-in) length of tubing into a "U" shape (Fig. 1C and 2B). The legs of the upright frame were welded (perpendicular) to a 1.2-m (47.5-in) length of tubing that had been bent into a U shape, thereby forming the base of the frame (Fig. 2J). For stability purposes, two straight pieces of tubing [0.24-m (9.5-in) length] were welded to the upright frame (one on each side) and to the base of the U-shaped piece in a gusset fashion (Fig. 2K). For further stabilization, a 0.79-m (31-in) length of tubing was bent to a U shape and was welded near the midpoint of the upright tubing (Fig. 1I and 2I). Another piece of tubing [1.7-m (67-in) length] was bent at enough of an arc (top portion only) so that it could be welded to the top of the upright U shape piece; this piece was also welded to the two smaller U pieces located at the base and midway points of the main frame (Fig. 2H).

An aluminum plate [50.8 by 50.8 by 12.7 mm (2 by 2 by 0.5 in)] welded to the top of the upright frame was tapped to accept the threaded end of a pneumatic cylinder (Speedaire Model 6W128, Dayton Electronic MFG, Niles, IL; Fig. 1A and 2A). An air activation trigger mechanism was attached to the lowest port of the pneumatic cylinder and had fittings allowing it to be attached to a compressed air source (Fig. 1F and 2G). The layout of this mechanism was constructed in the following order from the pneumatic cylinder (see Fig. 3 for details). The cylinder, needle valve (Pneutrol Model N10SSK; Deltrol Fluid Products, Bellwood, IL), and trigger valve (ARO Model 201-C; Ingersoll-Rand Co., Bryan, OH) were connected together with standard pipe fittings and plumbed to a compressed air source [line pressure of 82.7×10^4 Pa (120 psi)] using a standard air hose and quick-disconnect couplings (Fig. 3). It is important to note that the system, as described, is rated for a maximum input of 137.9×10^4 Pa (200 psi).

The hanging scale (Model LPC-4; TCI Scales, Mukilteo, WA; Fig. 1B and 2C) was attached to the piston rod of the pneumatic cylinder using a rod clevis (model 6W171, Grainger, Lake Forest, IL) while the scale's slip hook (Fig. 2N) was attached to the lifting arm apparatus via a sling link (model 30765T85, McMaster Carr Supply Co., Atlanta, GA; Fig. 2D). This scale is designed for rugged outdoor conditions that encompass every day weighing applications such as fish hatcheries, sports fishing, charter boats, and light manufacturing/industrial applications. The scale is portable, self contained, and wash-down safe (it has a corrosion-resistant aluminum casing with seals). The scale contains strain gage steel tension load cells, and the electronics are state-of-the-art chip microcomputer technology. The scale operates on four C-cell batteries, which provide ≈750 h of continuous use. The calibration of the scale should only be done by

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Table 1. Components list and cost of items for the container weighing system.

Components	Cost
Pneumatic cylinder (Speedaire Model 6W128; Dayton Electronic MFG, Niles, IL)	$34
Trigger valve (ARO Model 201-C; Ingersoll-Rand Co., Bryan, OH)	$18
Needle valve (Pneutrol Model N10SSK; Deltrol Fluid Products, Bellwood, IL)	$33
Electronic weighing scale (Model LPC-4; TCI Scales, Mukilteo, WA)	$1195
Standard air hose and coupling	$24
Fittings	$9
Aluminum tubing	$150
Aluminum plate and bar	$40
Machined steel rod	$20
Steel plate	$10
Sling link and clevis	$65
TOTAL	$1598

a certified, factory-authorized weighmaster. The scale capacity is 100 kg (220 lbs), and it is capable of detecting changes in 0.02-kg (0.04-lbs) increments. The temperature range for operations is rated at −10 to 50°C (14 to 122°F).

The lifting arm apparatus (Fig. 1D) consisted of five pieces: one horizontal bar (Fig. 2E) with two attached vertical rods (Fig. 2F) and two metal plates (bent to attach to the container; Fig. 1G and 2L). The top horizontal piece (Fig. 2E) was an aluminum bar [356 by 28.6 by 19.1 mm (14 by 1.125 by 0.75 in)], which was attached, using a clevis (Fig. 2M) and sling link (Fig. 2D), at its midway point (in a hinging fashion) to the hanging scale. Near each end of the top horizontal bar, a 15.9-mm (0.625-in) hole was drilled, and the ends were machine-slotted (perpendicular to the drilled holes; see Fig. 1H for close-up view). The drilled holes accepted a very short piece of a steel rod [15.9 by 19.1 mm (0.625 by 0.75 in)] that was tapped to accept the threaded ends of the vertical steel rods [6.35-mm (0.25-in) diam., 558.8-mm (22-in) length; Fig. 2F], allowing the vertical steel rods to pivot freely. The base of each rod was welded to a steel plate [127 by 63.5 by 3.2 mm (5 by 2.5 by 0.125 in)] that had been bent (Fig. 1G and 2L) to hook under the handles of the 45-L plastic containers (Model 15T, Nursery Supplies Inc., Kissimmee, FL) for lifting purposes (Fig. 1E). The overall dimensions of the lifting system's frame was 1.63 m (64 in) in height by 0.48 m (18.75 in) in width and 4.22 kg (9.30 lbs) in weight; the weight of the hanging scales was 3.92 kg (8.64 lbs). This system was

Fig. 1. Photograph of weighing system positioned around a container to be weighed: (A) pneumatic cylinder, (B) hanging scale, (C) support frame, (D) lifting arm apparatus, (E) 45-L container filled with soil, (F) trigger mechanism for activating the pneumatic cylinder connected to compressed air source, (G) bent plate to catch container handle during lifting, (H) close-up view of one end of the top horizontal bar, and (I) middle "U"-shaped support tubing attached to upright frame.

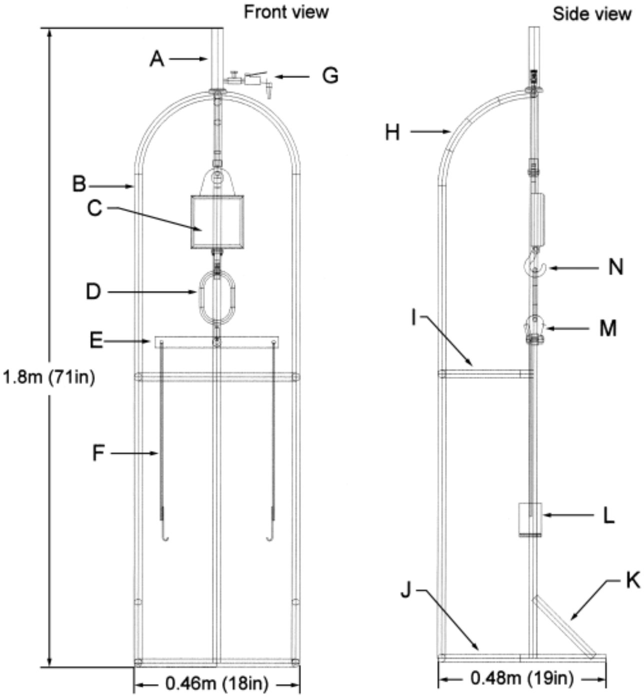

Fig. 2. Schematic of weighing system: (A) pneumatic cylinder, (B) main upright tube ("U" shaped) of the support frame, (C) hanging scale attached to pneumatic cylinder, (D) sling link, (E) horizontal bar of lifting arm apparatus attached to hanging scale's slip hook using a clevis and sling link, (F) vertical rods hinged to top horizontal bar, (G) trigger mechanism for activating the pneumatic cylinder (see Fig. 3 for details), (H) rear upright tube of the support frame, (I) middle U-shaped support tubing attached to upright frame, (J) base U-shaped tube, (K) gusset support tubing attached to upright frame and U-shaped base tubing, (L) bent plate to catch container handle during weighing attached to vertical rod, (M) clevis, and (N) slip hook.

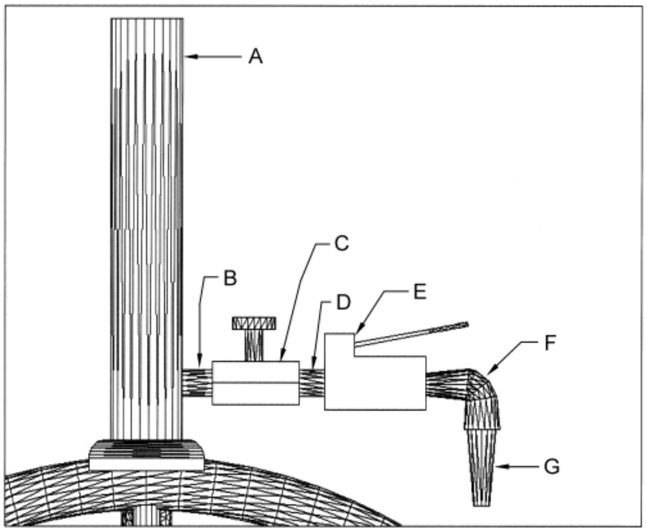

Fig. 3. Schematics of trigger mechanism: (A) pneumatic cylinder, (B) pipe nipple [3.2 mm (0.125 in)], (C) needle valve, (D) pipe nipple [3.2 mm (0.125 in)], (E) trigger valve, (F) male to female 90° pipe elbow [3.2 mm (0.125 in)], and (G) male hose plug [3.2 mm (0.125 in)] to connect to source air coupler.

tested using both a large stationary air compressor and a small portable compressor [i.e., 125-L (33-gal) system) at a line pressure of 82.7×10^4 Pa (120 psi)].

The frame was designed such that it could be easily positioned around the container from the side or lifted for direct placement over the container. After proper positioning of the frame, the lifting arm apparatus was connected to the hanging scale and the container. Once connected to a compressed air source, the pneumatic cylinder was activated by the trigger mechanism to lift the container in one smooth motion. The following steps were necessary in the activation of the trigger mechanism for container weighing: (i) the needle valve was closed; (ii) the trigger valve handle was depressed to allow flow of compressed air; (iii) the needle valve was opened slowly, while keeping the trigger valve handle depressed, to lift the container; (iv) the needle valve was closed, the trigger valve handle was released, and after the weighing scale had stabilized, the weight of the container was recorded; and (v) the needle valve was opened slowly to release air pressure, allowing the container to return gently to the ground surface.

DISCUSSION

This system employed a pneumatic cylinder connected to a hanging scale housed in a support frame to facilitate the weighing of containers. This system worked efficiently using both a large stationary air compressor and a small portable compressor and could be operated by one person. Before weight measurements, the scale is zeroed by pressing the zero button (no weight on scale), and then in our case the weighing arm apparatus is attached and the system is tared. On repeated occasions, this system successfully lifted 45-L containers filled with soil weighing over 70 kg; we were able to weigh as many as 25 containers per hour. In our study, we were interested in characterizing drying cycles rather than daily water use; as such, adequately watered containers were weighed every 2 to 4 d while water-stressed containers were weighed every 10 to 12 d. At these time increments, we had no problem detecting changes in container weight. However, daily water use could have been detected with this apparatus (e.g., calculated daily weight differentials varied from 0.3 to 0.6 kg). These changes are well within the limits of the scale. Containers have been weighed with this scale repeatedly (up to 10 times in a row) with the same weight being recorded each time.

The pneumatic cylinder device was easily activated to lift the containers in a smooth motion. Use of the pneumatic cylinder generates some motion when the container is lifted. Our protocol was to slightly touch the container to stop the motion. As a test of wind-induced movement, we lifted the container while a large industrial shop fan was blowing (at the highest setting) directly on the system. Using an anemometer, we obtained a measurement of 8.64 m s^{-1} (1700 ft min^{-1}). Although this wind speed generated slight motion of the container, we observed no change in the display of the weighing scale relative to the reading before turning on the fan. The heavy weight of these large containers may have worked in our favor, and it is possible that susceptibility to wind-induced motion would be greater if one used smaller containers.

The primary objective for developing this pneumatic cylinder device was to lift and weigh containers while reducing physical labor and also protecting the plant. In the past, we have lifted containers onto scales, which is back-breaking work. This is especially true in confined or restricted work areas. Further, under such conditions, the movement of containers onto the scales can easily damage the aboveground plant.

It is important to note that the support frame of this system can be easily modified to handle containers of different size or weight; for example, the frame dimensions could be altered to accommodate larger plants (e.g., both in height and width). Further, frame size modifications can be adjusted to match space requirements as dictated by operations occurring in growth chambers, greenhouses, or outdoor settings. If overhead structural support is available (such as in a greenhouse), the lifting device could be attached to the structural support for lifting the containers; after lifting, a platform-type scale could be place beneath the container for weighing. In these cases, smaller containers are often used; thus, the investigator will need to select a platform-weighing scale capable of detecting weight changes, as well as adjusting the length of the vertical lifting arm rods, according to specific experimental objectives. It would also be possible to alter the frame design by making it a bit wider and shorter and attaching two pneumatic cylinders to two upright supports for pushing up on the container handles (rather than pulling up) to place a platform scale underneath the container. A tripod-type frame could also be used with the pneumatic cylinder (either with the weighing scale in-line or for lifting the container for placement onto a platform scale). In addition, different types of hanging scales (i.e., size or capacity) could be selected to meet application needs. As in many experiments, the investigator will need to evaluate available methods and modify them as needed or select another method.

In meeting our experimental objectives, the weighing system has performed efficiently and reliably. The use of this pneumatic-assisted weighing system was less labor intensive since it eliminated the need to physically lift the containers onto a weighing scale.

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