For convenience in weighing and in tabulating results, the weights were expressed in kg and the area occupied by the trees in m^2.

Total dry matter accumulation per m^2 of occupied land was essentially the same in both trees (Table 2). However, fruit production per m^2 of the small tree was 80.6% greater than that of the large tree. On the other hand, the large tree produced 2.6 times as much wood as the small tree.

Trunk cross-sectional area is often used as a measure of productive capacity and response to treatment (5, 7). In this study, the small tree produced more than 5 times as much fruit per unit of trunk cross-sectional area, and less than half as much wood, as the large tree.

The small tree had 34.0% less leaf tissue per unit area of occupied land than the large tree. This is in agreement with the results of Heinicke (4), who reported lower leaf area indices (LAI) for smaller trees. The small tree produced 60.4% more total dry matter per unit weight of leaves. In this case, greater leaf efficiency did not result in greater total dry matter accumulation per m^2 of occupied land because differences in leaf density offset differences in efficiency. However, this might not always be true because the differences in leaf density between the large and small trees compared in this study were greater than differences reported by Heinicke (4).

The distribution of the dry matter reveals significant differences between the trees (Fig. 1). In the small tree, 5 times as much dry matter went into fruit as into wood. In the large tree, the proportions of dry matter in fruit and wood were approximately equal. Heinicke (3) reported similar results with a somewhat larger tree. This reveals a fundamental disadvantage of the large tree; that is, a disproportionate amount of the products of photosynthesis may be diverted into the growth of unproductive wood. It would appear that this is a major factor contributing to the lower efficiency of large trees in fruit production. It is possible, of course, that the structure of the tree could influence its efficiency. A large central leader tree, with less unproductive wood and better light exposure of the foliage, might be somewhat more efficient than an open center tree with the same branch spread.

While the differences reported here are large and decisive, these data are not without limitations. No effort was made to estimate the increase in dry weight of the root system or the carbohydrates lost through respiration. It is assumed that differences in these areas would be proportional to other differences between the trees but, since one was a clonal rootstock and the other a seedling, this is not necessarily true. In any orchard, there are large individual differences between trees in size, structure, and productivity and trees of greater or lesser efficiency of both sizes undoubtedly exist. It is unfortunate that the nature of this investigation precluded the possibility of replication. However, extreme care was exercised in the selection of trees and these results should be fairly representative of many 'McIntosh' trees of these 2 sizes throughout the Hudson Valley.

Table 2. Relative efficiency of large and small 'McIntosh' apple trees in dry matter accumulation.

	Dry matter accumulated (kg) during the 1969 growing season[a]					
	Total		Per m^2		Per kg leaves	
Part of tree	Small tree	Large tree	Small tree	Large tree	Small tree	Large tree
Fruit	13.753	58.118	1.710	0.947	8.816	3.223
Leaves	1.560	18.029	.194	.294	-----	-----
Wood:						
Shoots	.072	2.343	.009	.038	.046	.130
Spurs	.331	2.958	.041	.048	.212	.164
Small branches	1.447	23.426	.180	.382	.928	1.229
Trunk and large branches	.738	24.112	.092	.393	.473	1.338
Total wood	2.588	52.839	.322	.861	1.659	2.931
Total	17.901	128.986	2.226	2.102	11.475	7.154

[a]Excluding roots.

Literature Cited

1. Cain, John C. 1969. Tree spacing in relation to orchard production efficiency. *N. Y. State Agr. Exp. Sta. Res. Circ.* 15:1-10.
2. Hatton, R. G. 1935. Apple rootstock studies. Effect of layered stocks upon the vigour and cropping of certain scions. *J. Pomol.* 13:293-350.
3. Heinicke, A. J. 1937. Some cultural conditions influencing the manufacture of carbohydrates by apple leaves. *Proc. N. Y. State Hort. Soc.* 82:149-156.
4. Heinicke, Don R. 1964. The micro-climate of fruit trees. III. The effect of tree size on light penetration and leaf area in Red Delicious apple trees. *Proc. Amer. Soc. Hort. Sci.* 85:33-41.
5. Preston, A. P. 1954. Apple rootstock studies: The M.IX crosses. *Rep. E. Malling Res. Sta, for 1953:* 89-94.
6. Preston, A. P. 1958. Apple rootstock studies: Thirty-five years' results with Lane's Prince Albert on clonal rootstocks. *J. Hort. Sci.* 33:29-38.
7. Preston, A. P., and J. Ingram. 1962. Apple rootstock studies: The behaviour of 12 clonal rootstocks at Luddington. *Exp. Hort.* 6:84-90.
8. Preston, A. P. 1967. Apple rootstock studies: Fifteen years' results with some M.IX crosses. *J. Hort. Sci.* 42:41-50.
9. Preston, A. P. 1968. Scion weight and cropping of Cox's Orange Pippin and Jonathan apples on some Malling and Malling-Merton rootstocks. *Rep. E. Malling Res. Sta. for 1967:* 98-102.

Dilution Technique for Calibration of Infrared Gas Analyzers for Use with Carbon Dioxide[1]

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Abstract. **A simple dilution technique is described for the calibration of infrared gas analysers for use with carbon dioxide. The technique involves determining the exact volume of a closed loop system, which includes analyser, circulating pump and connecting tubing. Successive dilutions with either known volumes of nitrogen gas with no carbon dioxide or span gas with known concentrations of carbon dioxide, provide a range of calculable concentration points from which the calibration curve can be plotted.**

The need for verifying and developing calibration curves for infrared carbon dioxide analysers has been recognized. The curve can be developed by purchasing several gas cylinders of differing carbon dioxide concentrations to obtain desired points along the curve. The carbon dioxide

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[1] Received December 1, 1969. Published with the permission of the Director, Research Programs Division, College of Agricultural and Life Sciences, University of Wisconsin.

concentrations of these cylinders must be known precisely and this poses a problem for the cost of several guaranteed analysis mixtures would be prohibitive for many laboratories. Several unanalysed mixtures can be purchased and a laboratory analysis of the mixtures undertaken by either precipitation of carbonate or absorption on sodium hydrate asbestos, although the procedures are rather tedius. Methods have been described for mixing of pure gases to obtain precise carbon dioxide concentrations but these require precision flowmeters and constant temperature control (1).

Legg and Parkinson (1) have described an accurate method of calibrating differential infrared gas analysers, by increasing the gas pressure in the sample cell. This technique of pressurizing the gas mixture in the sample cell is mainly applicable to differential analysers, where a relatively small concentration range is required for calibration. When one wishes to calibrate an analyser over a wide range of carbon dioxide concentrations, the following procedure has been developed. This procedure requires a precise analysis of only one gas mixture, and the remaining concentration points are obtained by dilution using a small air pump and standard laboratory supplies.

A closed loop system for the carbon dioxide analyser is set up utilizing a small diaphragm pump (Thiberg recirculating pump) to circulate an air sample. The sample is circulated through the analyser alone or alternately through both the analyser and a sample flask, through use of three-way valves at the inlet and outlet of the sample flask. Copper or glass tubing should be used to connect the system, for plastic and rubber tubing are permeable to carbon dioxide.

The volume of the closed system must be determined precisely before proceeding with the dilutions for the standard curve. This can be obtained as follows:

1) Estimate the volume of the sample tube of the analyser, pump and connecting tubing.
2) Select a sample flask with approximately the same volume as the estimated value of the analyser pump and connecting tubing. Determine the volume of the sample flask (Vf) and connecting tubing exactly by measurement of the quantity of water that it will hold. Dry the sample flask and tubing completely.
3) Connect sample flask into the system and flush with nitrogen[2]. Disconnect the nitrogen line, close the system and operate the pump for at least 10 minutes to insure that the analyser remains at 0, indicating that there are no leaks in the system.
4) By-pass the flask by turning the 3-way valves and flush the remaining portion of the system with a desired high-span carbon dioxide-air mixture (concentration of this must be known precisely). Disconnect the high-span gas mixture and close the system[3]. Turn valves to reconnect the sample flask, containing nitrogen, to the closed system and operate the pump until the analyser reading stabilizes.
5) Stop pump and observe reading (A) on analyser.
6) Repeat steps in paragraphs 3 and 4, but flush system first with high-span gas (in 3) and with nitrogen (in 4).
7) Stop pump and observe reading (B) on analyser.
8) Calculate volume of analyser sample cell, pump and connecting tubing (V_s) with the formula:

$$V_s = \frac{V_f \times A}{B}$$

V_f = volume of flask and attached tubes
V_s = volume of analyser, pump and attached tubes
A = analyser reading of step 5
B = analyser reading of step 7

This calculation assumes linearity between the A and B readings for the concentration of carbon dioxide. Since this is not the case, readings of A and B should be very close so that deviations from linearity for A and B points will not be significant. This error can be eliminated entirely if procedures 3 through 7 are repeated, with adjustment of the volume of the sample flask each time. When equal readings of 5 and 7 are attained, V_s and V_f are equal.

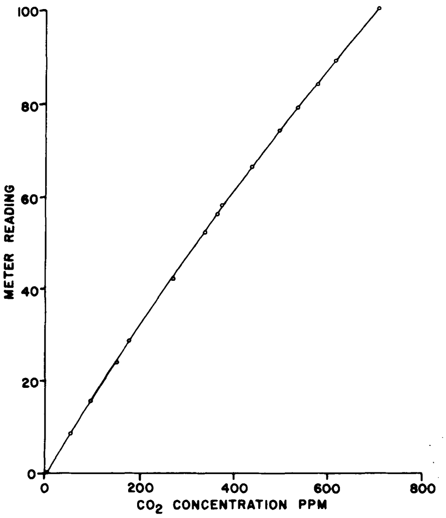

Fig. 1. Standard curve for infrared carbon dioxide analyzer obtained by means of dilution procedure.

The standard curve is obtained by successive controlled volume dilutions of the gas in the system. The first point on the curve is obtained with the data from steps 3, 4 and 5 of the preceding section and calculation of the concentration with the following formula

$$C_d = \frac{(V_f \times C_f) + (V_s \times C_s)}{V_s + V_f}$$

C_d = calculated concentration of CO_2
C_f = concentration of CO_2 in flask and connecting tubing before mixing
C_s = concentration of CO_2in analyser, pump and connecting tubing before mixing

A second point for the curve is obtained by retaining the gas in the sample flask and flushing only the analyser with nitrogen. Then following mixing the second concentration point can be calculated. This procedure is then repeated several times to obtain additional points. By varying the procedure to flush the analyser with high-span carbon dioxide-air mixture instead of nitrogen, concentration points at desired intervals along the standard curve can be obtained. A standard curve obtained with this procedure is shown in Figure 1.

Literature Cited

1. Legg, B. J. and K. J. Parkinson. 1968. Calibration of infrared gas analysers for use with carbon dioxide. *J. Sci. Inst. Ser.* 2, 1:1003-1006.

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[2] Avoid establishing a pressure or suction against the pump while flushing the system with nitrogen or span gas: introduce the flushing gas into a small open test tube from which the pump draws the gas for the analyser system. The flow rate of the flushing gas must exceed the flow rate of the analyser system to avoid contamination from atmospheric air.

[3] Stop the pump before opening the system or when disconnecting gas cylinders.