An Apparatus to Monitor Soil CO₂

V.M. Russo and T.D. Abney

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Summary. The effect of soil CO₂ on the development of vegetable crops is not well-understood. An inexpensive and simple method for monitoring soil CO₂ levels is needed to study those effects. A soil gas extraction apparatus was constructed from polyvinyl chloride (PVC) pipe, tygon tubing, and Plexiglas. The apparatus was placed into soil covered with black plastic or spray-on mulch or left bare. Gas samples were collected twice weekly after canopy closure of eggplant (*Solanum melongena* L., cv Black Bell) and continued through the last harvest. A vacuum pump was used to pull gas samples from 16 inches (41 cm) below the soil surface for collection in an airtight foil bag. The CO₂ levels, recorded over time and between treatments, was determined with detector tubes available commercially and compared to gas chromatography results. Detector tube CO₂ levels were comparable to the samples from the same bags measured by gas chromatography. This system was able to monitor differences in soil CO₂ levels between treatments and over time.

Barley (*Hordeum vulgare* L.; Overstreet et al., 1940), potato (*Solanum tuberosum* L.; Arteca et al., 1979), and eggplant (*Solanum melongena* L.; Baron and Gorski, 1986) can absorb CO₂ through roots. Addition of CO₂ to irrigation water improved plant development and yield of cotton (*Gossypium hirsutum* L.; Mauney and Hendrix, 1988), wheat (*Triticum aestivum* L.; Nakayama and Bucks, 1980), and sweet orange [*Citrus sinensis* var. *bessie* (L.) Osbeck.; Labanauskas et al., 1971]. However, Hartz and Holt (1991) reported that elevated levels of CO₂ did not improve yield of tomato (*Lycopersicon esculentum* Mill.) or cucumber (*Cucumis*

sativus L.). A CO₂-enriched soil environment did not affect eggplant yield (Baron and Gorski, 1986).

Labanauskas et al. (1971) stated that high soil CO₂ could decrease soil pH and reduce the uptake of some nutrients. Also, Labanauskas et al. (1971), extrapolating from the work of Stemmet et al. (1962), suggested that CO₂ used in photosynthesis may be derived partly from CO₂ fixed by roots. Brown et al. (1959) stated that CO₂ increases P in solution, decreasing Fe uptake, which could lead to chlorosis. In soil, CO₂ can reduce root permeability and replace O₂, thereby reducing the rate of passive water movement (Kramer and Jackson, 1954). Presence of soil CO₂ can be either beneficial or detrimental to plant development. The importance of soil CO₂ in growth and morphogenesis of horticultural crops is not well-understood, and more work is needed to define these effects.

Soil CO₂ levels have been measured with an infrared gas analyzer (Hopen, 1967), and a gas chromatograph with a thermal conductivity detector (Baron and Gorski, 1981). This equipment is expensive and cumbersome. Hopen (1967) tried to make accumulation of this type of data more convenient by using gel-filled detector tubes. These are used in industry to monitor gas levels in the workplace. However, he found that the detector tubes were not sensitive enough for this purpose.

A convenient method to monitor ambient soil CO₂ is needed so that levels can be correlated with cultural treatments and plant development. An apparatus was designed to obtain and analyze root-zone soil CO₂. These measurements were obtained from under soil mulched in various ways. The accuracy of detector tubes containing a dry material that reacts to CO₂ was determined by comparison to gas chromatography.

The CO₂ collection apparatus is pictured in Fig. 1A. With the exceptions of portions made from tygon tubing or Plexiglas, all parts of the apparatus were of schedule 20 PVC tubing. The main body of the gas collection apparatus consisted of a tube [1.1 ft (0.3 m) long × 0.85 inch (2.2 cm) in diameter]. A sleeve, 0.85 inch (2.2 cm) wide × 0.5 inch (1.3 cm) long, was glued 0.85 inch (2.2 cm) down from the top of the main body of

the apparatus. A 0.85-inch-(2.2-cm-) diameter threaded male nipple was glued to the bottom of the apparatus body. The tygon tubing was pushed through a 0.31-inch-(0.8-cm-) diameter centrally located hole in a threaded cap [0.75 inch (1.9 cm) i.d. × 0.75 inch (1.9 cm) long], which was screwed onto the threaded nipple. Tygon tubing [≈1.4 ft (0.4 m) long × 0.31 inch (0.8 cm) o.d.] was extended out of the top of the apparatus. A 4-inch (10-cm) × 4-inch (10-cm) piece of Plexiglas with a 0.85-inch-(2.2-cm-) diameter centrally located hole was seated on the top of the sleeve. The Plexiglas provided stability to the apparatus in the soil.

Prior to attaching the unthreaded top cap [0.85 inch (2.2 cm) in diameter], with a 0.31-inch-(0.8-cm-) diameter centrally located hole, the protruding tygon tubing was inserted through the hole. The cap was secured by friction on the apparatus body. A 1.37-inch (3.5-cm) diameter × 2.12-inch-(5.4-cm-) long collar was secured to the bottom cap. A receiving chamber was constructed from a 5.25-inch-(13.3-cm-) long × 1.1-inch-(2.7-cm-) wide piece of tubing with thirty 0.16-inch (0.4-cm) holes drilled to allow gas entry to the collection tube. The receiving chamber was glued to the collar. The threaded joint above the receiving chamber was not glued to allow access if it became necessary to replace the tygon tubing. The tygon tube extended past the bottom cap about 0.5 inch (1.3 cm) and past the top cap 4.5 inches (11.4 cm). Nylon mesh was wrapped around the receiving chamber and secured with wire twist ties.

Raised beds, 15 ft (4.6 m) long × 3 ft (0.9 m) wide, on 6-ft (1.8-m) centers, were formed on east-west rows on a Bernow fine-loamy, siliceous, thermic Glossic Paleudalf soil at Lane, Okla. Preplant fertilizer was incorporated into the soil. Black plastic (1 mil thick) [4 oz/yd² (100 g·m⁻²) of a black spray-on mulch (The Continental Products Company, Euclid, Ohio) was applied to some beds. Other beds were left untreated (bare soil). Treatments were replicated three times in a randomized complete block. Six-week-old 'Black Bell' eggplant seedlings were transplanted on 1.5-k (0.5-m) spacings on 16 Apr. 1991. A 2-ft-(0.6-m-) long × 1.3-inch-(3.3-cm-) diameter hollow pipe was driven ≈1.7 ft (0.5 m)

U.S. Department of Agriculture, Agricultural Research Service, South Central Agricultural Research Laboratory, POB 159, Lane, OK 74555

Fig. 1. Gas collection apparatus and collection and analysis of samples. (A) Cross-section of apparatus placed into soil: a) pinch clamp, b) tygon tubing, c) non-threaded cap, d) Plexiglas plate, e) sleeve, f) main body, g) threaded nipple, h) bottom cap and collar, i) receiving chamber. (B) Gas collection apparatus in soil connected to collection bag through a vacuum pump. (C) Sample being drawn from the collection bag by a hand-held pump through a detector tube for analysis.

into the soil at the middle of the beds and then removed. A gas collection apparatus was placed into the hole and the soil was packed around the apparatus and the Plexiglas plate. The bottom of the receiving chamber was at a depth of 1.7 ft (0.5m), with the opening of the tygon tube 1.3 ft (0.4 m) below the surface. A vacuum pump was connected temporarily to the top of the gas extraction tube from the collection apparatus using a nipple with a 0.4-inch (1-cm) o.d. A pump, drawing a vacuum of 4 liters/min, was used to remove ambient soil gasses and collect the gasses in a foil bag (Fig. 1B), as described by Hopen (1967). The pump was turned off and the tygon collection tube extending above the top of the apparatus was closed

with a pinch clamp.

Beginning ≈ 3 weeks after canopy closure, samples were taken weekly between 1300 and 1330 HR on Tuesdays and Fridays. Soil gas samples were drawn as described previously, but, in this case, the delivery tube joined the vacuum pump to 30.51-inch³ (500-cm³) collection bag (Calibrated Instrument, Inc., Ardsley, N.Y.) (Fig. 1B). The tube from the pump was connected to a twist valve built into the collection bag. The valve on the bag was opened, the pinch clamp was opened, and the pump filled the bag with gas from in, and around, the receiving chamber in ≈ 2 s. The pump was turned off, the pinch clamp replaced, the twist valve closed, and the bag disconnected. Each bag was placed

in an ice chest and transported to the laboratory and placed in a refrigerator.

During a 45-min period, the bags were removed individually from the refrigerator. Samples chosen at random were measured prior to refrigeration and after the 45-min period of refrigeration. Glass detector tubes (Mine Safety Appliances Company, Pittsburgh), containing thymol blue and diethanolamine-impregnated alumina were used to determine the amount of CO₂ in each sample. The sealed ends of tubes were broken and one end was inserted into a 1.5-inch (3.8-cm-) long piece of tygon tubing, which was connected to the twist valve on the collection bag. The other end of the detector tube was inserted into another piece of tygon tube of equal length, which was connected to a Samplair pump kit model A (Mine Safety Appliances Company) (Fig. 1C). The gas in the sample bag was drawn through the detector tube by pulling one or two pump strokes of 100 s each (100 cm³ of gas volume/stroke) to measure the amount of CO₂, indicated by a change in color from sky blue to white of the material inside the tube. This reaction is due to a change in the structure of thymol blue so that diethanolamine becomes diethanolamine carbonate. The percentage concentration of CO₂ in the sample was determined by dividing the number on the tube at which the color change stopped by the number of pump strokes. The tubes are calibrated for use at temperatures between 40 and 100F (4.4 and 37.8C). Accuracy is not affected by relative humidity.

Soil CO₂ levels in collection bags were not significantly different over the 45-min period of refrigeration. The CO₂ from ≈ 1.3 ft (0.4 m) beneath the surface of treatments fluctuated as much as 2.5-fold for all treatments between 25 May and 13 Aug. (Fig. 2). Levels of CO₂ in all treatments generally increased from late-May to mid-August, reaching highs of $\approx 2.75\%$ in early and late June and from late July on. Levels were slightly lower than those reported by Baron and Gorske (1981) at 6 inches (15 cm) below the surface. This may be due to soil type and environmental conditions at the two locations, or to factors affecting gas accumulation at the different depths.

The accuracy of detector tubes have been questioned (Hopen, 1967).

Fig. 2. Fluctuations in CO₂ levels from ≈ 1.3 ft (0.4 m) beneath the surface of plastic-covered, spray-on mulch-treated or bare soil from 25 May to 13 Aug. 1991.

Levels of CO₂ in samples chosen at random (10% of total number of bags) were measured by the detector tube and compared to levels determined by gas chromatography (Shimadzu GC-14, Japan). Samples from the foil bags were removed with syringes inserted through a self-sealing port built into the bags and inserted into a gas chromatograph. The percent of CO₂ from samples chosen at random measured by detector tubes (mean $1.25\% \pm 0.18\%$ SE) and gas chromatography (mean $1.26\% \pm 0.13\%$ SE) indicate that the detector tube was as equally capable of measuring CO₂ levels as was the chromatograph. The reason for the accuracy of the detector tubes may be that the material used in the tubes used is more sensitive than the detector tubes with gel compounds used by Hopen (1967).

The apparatus can be built with different main tube lengths. A soil gas sample can be obtained from a known

depth and can be analyzed in the field in under 5 min, or transported to another location. The apparatus was used to monitor fluctuations in root-zone soil CO₂ levels for all treatments over time. Although only CO₂ was measured, there was sufficient volume left in the sample collection bag to test for other gasses that may be present in the root zone. When effects of soil gasses on plant development are better understood, the producer can make decisions, including irrigation, cultivation, or fertilization, that affect soil gas levels to possibly improve yield. This apparatus will provide the producer with the ability to accumulate the information on which these decisions could be made.

Literature Cited

Arteca, R.N., B.W. Poovaiah, and O.E. Smith. 1979. Changes in carbon fixation, tuberization, and growth induced by CO₂

applications to the root zone of potato plants. *Science* 205:1279-1280.

Baron, J.J. and S.F. Gorski. 1981. Soil carbon dioxide levels: as affected by plastic mulches. *Proc. Natl. Agr. Plastics Congr.* 16:149-155.

Baron, J.J. and S.F. Gorski. 1986. Response of eggplant to a root environment enriched with CO₂. *HortScience* 21:495-498.

Brown, J.C., O.R. Lunt, R.S. Holmes, and L.O. Tiffin. 1959. The bicarbonate ion as indirect cause of iron chlorosis. *Soil Sci.* 88:260-266.

Hartz, T.K. and D.B. Holt. 1991. Root-zone carbon dioxide enrichment in field does not improve tomato or cucumber yield. *HortScience* 26:1424.

Hopen, H.J. 1967. A simplified method for measuring carbon dioxide content of field air samples. *HortScience* 2:167-168.

Kramer, P.J. and W.T. Jackson. 1954. Causes of injury to flooded tobacco plants. *Plant Physiol.* 29:241-245.

Labanauskas, C.K., L.H. Stolzy, L.J. Klotz, and T.A. De Wolfe. 1971. Soil carbon dioxide and mineral accumulation in citrus seedlings (*Citrus sinensis* var. *bessie*). *Plant & Soil* 35:337-346.

Mauney, J.R. and D.L. Hendrix. 1988. Responses of glasshouse grown cotton to irrigation with carbon dioxide-saturated water. *Crop Sci.* 28:835-838.

Nakayama, F.S. and D.A. Bucks. 1980. Using subsurface trickle system for carbon dioxide enrichment. *Proc. Natl. Agr. Plastics Congr.* 15:13-17.

Overstreet, R., S. Ruben, and T.C. Broyer. 1940. The absorption of bicarbonate ion by barley plants as indicated by studies with radioactive carbon. *Proc. Natl. Acad. Sci. USA* 26:688-695.

Stemmet, M.C., J.A. DeBruyn, and P.B. Zeeman. 1962. The uptake of carbon dioxide by plant roots. *Plant & Soil* 17:357-364.