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Tabulation of N_2, O_2, CO_2, and He Concentrations in Soil Gases Collected on a Regular Basis for 11 Months from a Site at Tucson, Arizona

By

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ABSTRACT

Concentrations of N_2, O_2, CO_2, and He were measured in soil gases collected daily for 11 months from 0.6-m depth at a site at Tucson, Arizona. Soil and air temperatures, percent relative humidity, barometric pressure, and rainfall were also monitored. Sampling and analysis of the soil gases are described and measurements of gas concentrations and meteorological parameters are listed. CO_2 concentrations were higher in the summer than in the winter, whereas O_2 concentrations were higher in winter than in summer. He concentrations were slightly higher in winter than in summer. N_2 concentrations did not appear to be related to any particular meteorology parameter.

INTRODUCTION

Measurements of concentrations of N_2, O_2, CO_2, and He in soil gases and meteorological parameters have been monitored on a long-term basis at several sites in both dry and humid environments (Klusman and Jaacks, 1987; Hinkle, 1988, 1990a, 1990b; Hinkle and Ryder, 1988; Hinkle and Dennen, 1989). The purpose of these studies has been to better understand the effects of environmental conditions on concentrations of soil gas components that are often used for geochemical exploration for mineral and geothermal resources.

Results of these long-term monitoring studies indicate that soil moisture and soil and air temperatures have the greatest impact on soil-gas concentrations. High soil moisture tends to either flush gases from the soil pores or to dissolve the gases; the effect in both cases is decreased concentration of gases in the soil. Increased concentrations of soil-gas CO_2 generally occur with increased soil temperatures, whereas He concentrations generally decline as soil temperatures increase (Hinkle and Ryder, 1987, 1988; Reimer, 1979, 1980). This study was part of a series of soil-gas monitoring studies carried out in different environments to assess the effects of meteorology changes on soil-gas concentrations. The purpose of this study was to compare variations in the concentrations of N_2, O_2, CO_2, and He with variations in meteorological parameters in a hot, dry environment. A depth of 0.6-m was selected for soil-gas sampling, in order to conform to previous studies and because this is the depth most commonly used for soil-gas surveys.

SAMPLE COLLECTION AND ANALYSIS

The site selected for monitoring was located in sandy soil in a sunny, flat area. The hollow probe used in the study was described by Reimer and Bowles (1979) and has been widely used for collecting soil-gas samples. The probe was driven into the ground by means of a sliding hammer attached to the shaft of the probe. After the probe was driven into the ground, it was fitted with an airtight cap and septum for withdrawal of the soil-gas sample. A PVC pipe was placed over the probe and cap, and the pipe was covered with an inverted plastic beaker to protect the probe from the weather.

Before removal of the first sample, 10 mL of air were withdrawn from the probe to remove air introduced when the probe was emplaced in the ground; 10 mL of air were also removed from the probe whenever the rubber septum was changed. All soil-gas samples, except those collected on the first day, had equilibrated for a minimum of 24 h before collection.

Samples were collected from the hollow probe by inserting the needle of the syringe through the septum in the cap and withdrawing 10 mL of the soil gas. The soil-gas samples were transferred to two 5-mL evacuated blood-sampling vials for storage by inserting the needle of the syringe containing the gas sample through the rubber cap of the evacuated vial and allowing the sample in the syringe to be drawn inside. The needle holes were covered with silicone glue. Soil-gas samples can be stored in these evacuated vials for as long as 2 months without leakage (Hinkle and Kilburn, 1979).

Samples were collected and meteorological measurements were made daily, except for weekends and holidays. A total of 175 samples were collected during the period from July 20, 1990, through June 10, 1991.

Soil temperature was measured by a metal dial-type thermometer emplaced 20-cm into the ground next to the probe. Soil moisture was measured indirectly by monitoring rainfall (measured by a rain gauge). Air temperature, relative humidity, and barometric pressure measurements were recorded from National Weather Service measurements read over Tucson radio station KNST (940 AM) at 6:30 or 7:00 every morning. No snow fell during the monitoring period.

For He analysis, gas in the vials was removed by injecting 5 mL of air (equal to the volume of the vial) into the vial and removing the mixture of air and soil gas. The samples were analyzed for He using mass spectrometry (Reimer and Denton, 1978). Standard samples of air containing known concentrations of He were analyzed several times per day to ensure stability of the instrument. Concentrations of He were reported as variations from the concentration of He in air (5,240 ppb) (Glueckhauf, 1946; Oliver and others, 1984). The reproducibility of measurement was +/- 20 ppb. The tubes used for sample storage were approximately 80 percent evacuated. They contained a residual concentration of He, introduced during the manufacturing process, that was the same for all the tubes in each lot produced by the manufacturer. This residual He concentration was measured and subtracted from the raw measurement of He in the soil gas.

Samples were analyzed for N_2, O_2, and CO_2 using gas chromatography; operating conditions for the gas chromatograph are shown in table 1. For gas chromatography analysis, gas in the vials was removed by injecting 5 mL of pure He (equal to the volume of the vial) into the vial and removing the mixture of He and soil gas for the chromatographic analysis. Concentrations of N_2, O_2, and CO_2 were measured compared to standard curves and are reported as volume percents. Standard samples containing known concentrations of the gases diluted with He were analyzed several times per day to ensure stability of the instrument.

DESCRIPTION OF THE DATA TABLES

Data from the analyses were entered into an IBM-compatible personal computer and stored on disks, using the QuattroPro program, which was also used for printing and plotting the data. The data were converted into the U.S. Geological Survey STATPAC format for statistical analyses (Grundy and Miesch, 1987). Table 2 includes data for all measurements: date of sample collection, soil temperature at 20-cm depth (^{0} C), air temperature (^{0} C), relative humidity (%), rainfall (cm), barometric pressure (cm), and volume/volume raw-measurement concentrations of N_2 (%), O_2 (%), CO_2 (%), and He (ppb) in soil gases. A blank space indicates that no measurement was made. In some cases, the sum of N_2 + O_2 concentrations were not approximately 100%. Sums less than 100% probably indicate that

some unanalyzed soil-gas constituent such as water vapor was present. Sums of N_2 + O_2 greater than approximately 100% occurred more frequently in winter and early spring than at other times of the year; the reason for this is not known, but may be related to bacteria in the soil.

Minimum, maximum, and mean values for all the variables are listed in table 3. All values were calculated using only unqualified data, that is, blank spaces in the data set were ignored. There were 174 unqualified values at the site. Correlation coefficients for the unqualified data are shown in table 4.

DISCUSSION OF THE RESULTS

Soil and air temperatures varied seasonally (fig. 1). The ground did not freeze in winter. Rainfall was most frequent in midsummer (fig. 2). Relative humidity generally was highest in late summer and in the winter. Barometric pressure was lower in the spring than at other times of year (fig. 3). Concentrations of He, CO_2, O_2, and N_2 varied seasonally (figs. 4-5).

Concentrations of CO_2 increased and decreased as temperatures rose and fell, and were higher in summer than in winter (fig. 6). The higher CO_2 concentrations are probably related to increased soil bacterial activity or to increased organic decomposition in warm soil.

Although He concentrations often exhibit an inverse relationship with soil and air temperatures, an inverse relationship appeared to exist only during the winter months in this study; concentrations of He were generally higher on cold days than on warm days in winter (fig. 7). This wintertime relationship fits the description of "atmospheric pumping" described by Reimer and Roberts (1985), wherein warm air temperatures dry and heat the upper portions of the soil, thereby creating a local pumping effect with increased dispersal of He into the air and decreased He in the soil gas. Summertime He concentrations did not appear to be related to soil or air temperatures.

Oxygen concentrations were slightly higher in winter than in summer (fig. 8), as has been noticed in other locations (Hinkle and Ryder, 1988; Hinkle, 1990b). Although N_2 concentrations were somewhat higher in winter, their variation was not related to any individual parameter (fig. 9).

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Table 1. Operating conditions for the gas chromatograph

[°C = degrees Celsius; mL = milliliter; in. = inches; % = percent]

Type of gas chromatograph	Carle AGC-100
Detector	thermistor detector
Lower limit of detection	1% N_2 or O_2, 0.03% CO_2
Reproducibility	± 5%
Column	concentric stainless steel, outer column 72 in. x 1/4 in. molecular sieve inner column 72 in. x 1/8 in. porapak mixture (Alltech Associates, Deerfield, IL)
Carrier gas	helium at 60 mL/minute
Temperature	column: 60°C detector: "low" mode

Table 2.

Soil Gas & Meteorology Variables---Tucson, AZ (1990-1991)

Date	Soil-T(C)	Air-T(C)	RelHumid-%	Rain-cm	BarPress-cm	N2-%	O2-%	CO2-%	He-ppb	Air-Soil-T(C)
07/20/90	24.5	22.0	93.0	1.80	76.25	62.7	17.7	0.30	4830	-2.5
07/23/90	25.0	23.0	64.0	0.50	76.25	68.4	19.1	0.31	5440	-2.0
07/24/90	27.0	29.0	50.0	3.90	76.05	62.0	16.9	0.34	5064	2.0
07/25/90	24.0	23.0	84.0	0.00	76.23	67.4	18.2	0.35	4752	-1.0
07/26/90	25.0	24.0	76.0	0.00	76.33	63.3	17.4	0.32	4986	-1.0
07/27/90	25.0	23.0	66.0	0.00	76.25	68.0	18.9	0.34	4986	-2.0
07/28/90	24.5	26.0	39.0	0.00	76.28	65.0	18.1	0.35	5142	1.5
07/29/90	25.0	28.0	40.0	0.00	76.23	58.4	16.4	0.32	4752	3.0
07/30/90	26.0	24.0	51.0	0.00	76.33	60.5	17.1	0.33	4830	-2.0
08/01/90	24.0	22.0	76.0	0.00	76.20	64.4	18.1	0.40	4752	-2.0
08/13/90	25.0	19.0	97.0	0.50	76.15	67.4	19.3	0.35	5598	-6.0
08/21/90	23.0	20.0	20.0	0.00	76.43	67.0	18.5	0.51	5230	-3.0
08/22/90	23.5	21.0	57.0	0.00	76.33	61.9	17.4	0.48	5690	-2.5
08/23/90	23.5	21.0	45.0	0.00	76.05	70.6	19.9	0.58	5736	-2.5
08/24/90	23.5	19.0	47.0	0.00	76.17	71.1	20.1	0.56	5690	-4.5
08/27/90	26.0	26.0	62.0	0.00	76.50	64.0	18.3	0.41	5736	0.0
08/28/90	26.0	22.0	84.0	0.00	76.43	64.0	18.2	0.36	5736	-4.0
08/29/90	27.0	23.0	69.0	0.00	76.25	65.9	18.8	0.40	5699	-4.0
08/30/90	27.0	22.0	78.0	0.00	76.23	60.9	17.5	0.37	5920	-5.0
08/31/90	26.0	23.0	76.0	0.00	76.20	65.5	18.7	0.37	5506	-3.0
09/01/90	24.5	22.0	87.0	1.30	76.30	54.2	15.4	0.27	5782	-2.5
09/03/90	24.0	22.0	81.0	0.00	76.20	76.5	21.7	0.38	5736	-2.0
09/04/90	23.0	20.0	87.0	0.00	76.28	70.9	20.9	0.42	5874	-3.0
09/05/90	24.0	22.0	81.0	0.00	76.45	69.6	20.1	0.34	5644	-2.0
09/06/90	24.5	22.0	81.0	0.00	76.40	68.5	19.9	0.33	5874	-2.5
09/07/90	25.5	22.0	79.0	0.00	76.23	80.0	23.5	0.43	5044	-3.5
09/08/90	26.0	24.0	66.0	0.00	76.12	68.3	20.3	0.32	4564	-2.0
09/26/90	24.0	18.0	52.0	0.00	76.33	78.7	23.5	0.26	4506	-6.0
10/03/90	18.0	14.0	80.0	1.20	76.15	65.9	19.7	0.20	4854	-4.0
10/17/90	19.5	17.0	84.0	0.00	76.30	78.7	23.4	0.23	5144	-2.5
10/18/90	19.5	17.0	60.0	0.00	76.40	67.9	20.2	0.12	4912	-2.5
10/19/90	20.0	17.0	62.0	0.00	75.95	59.7	17.7	0.13	5318	-3.0
10/22/90	16.5	14.0	33.0	0.00	76.28	65.5	19.4	0.13	5086	-2.5
10/23/90	16.5	11.0	41.0	0.00	76.20	66.4	19.8	0.13	5086	-5.5
10/24/90	17.0	13.0	41.0	0.00	76.48	54.9	16.4	0.09	5028	-4.0
10/26/90	18.0	14.0	39.0	0.00	76.38	75.2	22.5	0.17	4922	-4.0
10/29/90	19.0	18.0	30.0	0.00	76.43	73.2	22.0	0.15	4970	-1.0
10/30/90	18.5	17.0	35.0	0.00	76.61	64.8	19.5	0.13	5492	-1.5
10/31/90	19.0	17.0	42.0	0.00	76.43	55.2	16.6	0.10	5782	-2.0
11/01/90	20.0	18.0	75.0	0.00	76.17	61.1	18.2	0.11	5608	-2.0
11/02/90	19.5	18.0	65.0	0.40	75.67	54.9	16.3	0.10	6420	-1.5
11/05/90	11.0	4.0	64.0	0.00	76.28	64.2	19.5	0.11	5840	-7.0
11/06/90	12.0	8.0	39.0	0.00	75.72	63.4	19.1	0.14	6246	-4.0
11/07/90	13.0	10.0	46.0	0.00	75.95	68.5	20.7	0.16	5840	-3.0
11/08/90	12.0	3.0	73.0	0.00	76.45	73.1	22.4	0.01	6072	-9.0
11/09/90	11.0	5.0	62.0	0.00	76.61	72.6	21.8	0.15	4854	-6.0
11/12/90	13.5	16.0	35.0	0.00	76.71	71.7	21.8	0.11	4440	2.5
11/13/90	15.5	16.0	34.0	0.00	76.45	77.1	23.2	0.14	4674	0.5
11/14/90	15.5	12.0	46.0	0.00	76.30	57.8	17.2	0.08	4596	-3.5
11/15/90	15.0	11.0	39.0	0.00	76.48	75.8	22.7	0.13	4830	-4.0
11/16/90	14.5	11.0	43.0	0.00	76.66	63.5	19.2	0.09	4206	-3.5
11/19/90	15.0	12.0	47.0	0.00	75.95	70.7	21.4	0.15	4050	-3.0
11/21/90	13.0	8.0	80.0	0.10	76.28	69.3	21.0	0.12	4674	-5.0

Table 2.

Soil Gas & Meteorology Variables---Tucson, AZ (1990-1991)

Date	Soil-T(C)	Air-T(C)	RelHumid-%	Rain-cm	BarPress-cm	N2-%	O2-%	CO2-%	He-ppb	Air-Soil-T(C)
11/23/90	11.0	4.0	79.0	0.00	76.56	70.4	21.3	0.11	4440	-7.0
11/24/90	11.0	7.0	60.0	0.00	76.53	63.8	19.3	0.00	4968	-4.0
11/26/90	16.0	14.0	77.0	0.00	75.59	67.2	20.5	0.01	5506	-2.0
11/27/90	10.0	3.0	79.0	0.60	76.28	66.9	20.2	0.11	5874	-7.0
11/28/90	7.0	-1.0	81.0	0.00	76.76	76.2	23.2	0.00	5920	-8.0
11/29/90	8.0	10.0	21.0	0.00	76.91	58.8	17.7	0.00	5644	2.0
11/30/90	9.0	9.0	40.0	0.00	76.58	72.2	21.9	0.11	5690	0.0
12/06/90	8.0	2.0	48.0	0.00	76.81	78.5	23.6	0.01	5230	-6.0
12/04/90	9.5	9.0	21.0	0.00	76.81	77.6	23.3	0.10	5874	-0.5
12/05/90	9.0	6.0	36.0	0.00	76.58	74.0	22.2	0.00	5736	-3.0
12/06/90	9.0	3.0	50.0	0.00	76.63	77.1	22.6	0.11	6012	-6.0
12/07/90	8.0	4.0	24.0	0.00	76.84	60.7	18.2	0.00	5460	-4.0
12/10/90	9.0	7.0	32.0	0.00	76.66	82.1	24.5	0.10	5514	-2.0
12/12/90	12.0	14.0	64.0	0.00	76.28	68.4	20.4	0.09	5434	2.0
12/13/90	12.0	12.0	96.0	0.50	76.38	72.8	21.8	0.09	5554	0.0
12/14/90	11.0	8.0	80.0	0.30	76.28	76.3	22.7	0.09	4914	-3.0
12/15/90	11.0	11.0	77.0	0.00	76.17	84.7	25.3	0.02	5194	0.0
12/17/90	8.0	2.0	75.0	1.60	76.25	75.3	23.2	0.09	5434	-6.0
12/19/90	4.5	2.0	61.0	0.00	75.74	72.1	22.2	0.10	5514	-2.5
12/20/90	5.5	8.0	68.0	0.84	75.69	68.9	21.2	0.09	5674	2.5
12/21/90				0.51						
12/22/90				0.38						
12/23/90				0.01						
12/24/90				0.00						
12/25/90				0.00						
12/26/90				0.00						
12/27/90				0.38						
12/28/90				0.30						
12/29/90				0.00						
12/30/90				0.00						
12/31/90				0.00						
01/01/91				0.00						
01/02/91	7.0	6.0	86.0	0.00	76.61	72.5	22.1	0.15	5314	-1.0
01/03/91	9.5	11.0	77.0	0.00	76.40	64.0	19.6	0.11	5554	1.5
01/04/91	10.5	13.0	80.0	0.30	76.05	63.7	19.4	0.12	5474	2.5
01/05/91				3.50						
01/06/91				0.10						
01/07/91	9.0	6.0	96.0	0.00	76.73	79.1	24.1	0.02	5794	-3.0
01/08/91	9.0	6.0	93.0	0.00	76.38	74.5	22.8	0.03	5794	-3.0
01/09/91	8.5	6.0	96.0	0.00	76.05	67.1	20.5	0.13	5554	-2.5
01/10/91	8.5	6.0	96.0	0.00	76.48	67.0	20.2	0.01	5714	-2.5
01/11/91	7.0	2.0	92.0	0.00	76.81	71.3	21.5	0.12	5754	-5.0
01/14/91	7.0	4.0	82.0	0.00	76.38	81.1	24.7	0.12	5634	-3.0
01/15/91	6.5	2.0	82.0	0.00	76.56	79.9	24.3	0.13	5754	-4.5
01/16/91	7.0	4.0	73.0	0.00	75.90	77.2	23.4	0.13	5954	-3.0
01/17/91	7.0	8.0	68.0	0.25	76.30	79.8	23.8	0.17	5874	1.0
01/18/91	6.5	3.0	85.0	0.00	76.63	76.8	23.0	0.12	5674	-3.5
01/21/91	7.0	3.0	76.0	0.00	76.28	77.8	22.0	0.00	5834	-4.0
01/22/91	6.5	6.0	65.0	0.00	76.33	71.8	20.8	0.07	5894	-0.5
01/23/91	7.0	6.0	96.0	0.10	76.23	69.8	21.0	0.00	5894	-1.0
01/24/91	6.0	2.0	75.0	0.00	76.68	70.4	21.0	0.15	5794	-4.0
01/25/91	6.0	2.0	67.0	0.00	76.45	64.9	18.9	0.06	5794	-4.0
01/28/91	7.0	3.0	57.0	0.00	75.95	72.8	19.4	0.04	5794	-4.0

Table 2.

Soil Gas & Meteorology Variables---Tucson, AZ (1990-1991)

Date	Soil-T(C)	Air-T(C)	RelHumid-%	Rain-cm	BarPress-cm	N2-%	O2-%	CO2-%	He-ppb	Air-Soil-T(C)
01/29/91	7.0	4.0	79.0	0.00	75.84	74.9	21.2	0.01	5474	-3.0
01/30/91	4.5	-3.0	71.0	0.00	76.76	78.7	22.6	0.01	4954	-7.5
01/31/91	4.5	1.0	28.0	0.00	76.86	67.7	19.7	0.04	5994	-3.5
02/01/91	7.0	11.0	22.0	0.00	76.58	79.9	22.6	0.00	5642	4.0
02/05/91	8.5	6.0	45.0	0.00	76.56	82.0	24.4	0.09	5552	-2.5
02/06/91	10.0	10.0	26.0	0.00	76.35	80.4	24.2	0.09	5874	0.0
02/07/91	12.0	11.0	39.0	0.00	76.45	79.0	23.6	0.00	5736	-1.0
02/08/91	10.5	4.0	48.0	0.00	76.48	80.2	24.1	0.08	5644	-6.5
02/18/91	11.0	7.0	89.0	0.20	76.02	74.6	22.1	0.01	5552	-4.0
02/19/91	8.0	1.0	92.0	0.10	76.68	75.6	22.8	0.09	5322	-7.0
02/20/91	8.5	2.0	76.0	0.00	76.89	68.3	20.4	0.00	5414	-6.5
02/21/91	8.5	6.0	60.0	0.00	76.58	74.9	22.6	0.09	5460	-2.5
02/22/91	9.5	7.0	60.0	0.00	76.43	59.8	17.9	0.05	5368	-2.5
02/25/91	11.0	9.0	50.0	0.00	76.48	65.3	20.1	0.07	5322	-2.0
02/26/91	11.0	9.0	46.0	0.00	76.28	58.4	18.0	0.07	5230	-2.0
02/27/91	11.0	8.0	68.0	0.00	76.10	51.7	15.6	0.04	5276	-3.0
02/28/91	13.5	13.0	77.0	0.02	75.57	71.6	22.1	0.00	5736	-0.5
03/01/91	12.5	12.0	74.0	0.13	75.69	68.0	20.7	0.11	5782	-0.5
03/02/91				0.00						
03/03/91				0.00						
03/04/91	10.5	6.0	79.0	0.00	76.45	66.6	20.1	0.00	5598	-4.5
03/05/91	11.5	9.0	61.0	0.00	76.23	59.4	17.9	0.06	5276	-2.5
03/06/91	14.0	15.0	55.0	0.00	76.02	67.4	20.4	0.10	5876	1.0
03/07/91	11.5	4.0	73.0	0.00	76.07	65.4	19.8	0.09	5782	-7.5
03/11/91	14.0	16.0	28.0	0.00	75.92	57.4	17.4	0.06	5552	2.0
03/12/91	11.5	2.0	54.0	0.00	76.33	60.5	18.3	0.07	5493	-9.5
03/13/91	11.0	4.0	44.0	0.00	76.20	66.5	20.2	0.09	5634	-7.0
03/14/91	10.5	4.0	50.0	0.00	75.59	56.6	17.0	0.07	5354	-6.5
03/15/91	10.0	2.0	52.0	0.00	75.77	59.7	18.2	0.08	5154	-8.0
03/16/91				0.30						
03/17/91				0.00						
03/18/91	9.5	6.0	65.0	0.00	76.23	74.3	22.3	0.11	5474	-3.5
03/19/91	12.0	13.0	32.0	0.00	75.59	68.5	20.7	0.09	5514	1.0
03/20/91	10.0	4.0	79.0	0.00	75.95	72.7	21.9	0.00	5493	-6.0
03/21/91	10.0	4.0	94.0	0.11	75.95	78.1	23.8	0.12	5434	-6.0
03/22/91	8.0	2.0	92.0	0.70	76.48	83.2	24.9	0.02	5114	-6.0
03/25/91	12.0	12.0	39.0	0.00	75.90	70.4	20.9	0.11	5154	0.0
03/26/91	12.0	12.0	57.0	0.00	75.62	54.9	16.3	0.09	5234	0.0
03/27/91	9.5	3.0	76.0	0.10	76.10	69.7	20.7	0.11	5674	-6.5
03/28/91	8.5	3.0	92.0	0.75	76.17	79.4	23.2	0.13	5674	-5.5
03/29/91	8.5	3.0	89.0	0.00	76.35	75.8	22.2	0.00	5674	-5.5
04/01/91	12.5	14.0	29.0	0.00	76.17	70.0	20.4	0.01	5674	1.5
04/04/91	15.0	12.0	59.0	0.00	76.45	70.8	20.9	0.12	5828	-3.0
04/05/91	17.0	15.5	44.0	0.00	76.20	77.5	22.9	0.15	5966	-1.5
04/08/91	17.5	10.5	39.0	0.00	76.05	69.3	20.5	0.12	5920	-7.0
04/09/91	17.0	9.5	52.0	0.00	76.40	77.1	22.7	0.02	5690	-7.5
04/10/91	17.5	10.5	39.0	0.00	76.00	64.6	19.1	0.01	5782	-7.0
04/11/91	18.0	15.5	19.0	0.00	75.46	67.8	20.0	0.14	6104	-2.5
04/12/91	16.0	6.0	21.0	0.00	75.97	72.9	21.4	0.16	6012	-10.0
04/15/91	16.0	8.0	37.0	0.00	75.97	72.8	21.6	0.02	6012	-8.0
04/16/91	17.0	13.0	23.0	0.00	75.92	74.7	21.8	0.15	6196	-4.0
04/17/91	18.0	10.0	33.0	0.00	76.05	82.3	24.2	0.04	6104	-8.0
04/18/91	18.0	9.5	44.0	0.00	75.92	64.6	19.7	0.15	5552	-8.5

Table 2.
Soil Gas & Meteorology Variables---Tucson, AZ (1990-1991)

Date	Soil-T(C)	Air-T(C)	RelHumid-%	Rain-cm	BarPress-cm	N2-%	O2-%	CO2-%	He-ppb	Air-Soil-T(C)
04/19/91	18.0	9.5	46.0	0.00	76.05	78.7	23.9	0.21	6150	-8.5
04/22/91	18.0	9.0	40.0	0.00	76.02	73.5	22.5	0.17	5782	-9.0
04/23/91	18.5	9.5	48.0	0.00	75.90	81.3	25.1	0.24	6012	-9.0
04/24/91	18.5	9.0	51.0	0.00	76.07	76.8	23.5	0.20	5710	-9.5
04/25/91	19.0	10.5	52.0	0.00	75.95	76.5	21.5	0.14	5434	-8.5
04/26/91	19.0	10.0	47.0	0.00	75.82	69.8	19.6	0.27	5664	-9.0
04/29/91	17.0	5.5	29.0	0.00	76.17	82.9	23.5	0.31	5572	-11.5
04/30/91	18.0	10.0	33.0	0.00	76.15	65.0	18.3	0.24	5664	-8.0
05/01/91	19.0	13.0	27.0	0.00	75.95	67.2	19.0	0.13	5526	-6.0
05/02/91	19.5	12.8	28.0	0.00	75.77	65.0	18.3	0.25	5258	-6.7
05/03/91	18.0	8.9	29.0	0.00	75.97	68.3	19.3	0.14	5402	-9.1
05/06/91	19.5	15.0	24.0	0.00	76.15	74.2	21.1	0.20	5258	-4.5
05/07/91	20.5	15.0	22.0	0.00	75.95	63.9	18.0	0.13	5258	-5.5
05/08/91	22.0	16.7	32.0	0.00	76.15				5078	-5.3
05/09/91	23.0	18.9	30.0	0.00	75.79	76.5	21.7	0.31	5330	-4.1
05/10/91	22.5	18.3	28.0	0.00	75.57	67.0	19.0	0.28	5150	-4.2
05/11/91	21.0	11.7	30.0	0.00	76.23	71.0	20.1	0.24	5294	-9.3
05/13/91	21.0	13.3	27.0	0.00	76.07	63.7	18.3	0.20	5150	-7.7
05/14/91	22.0	14.4	20.0	0.00	75.84	60.3	17.0	0.12	5402	-7.6
05/21/91	24.0	15.0	31.0	0.00	75.79	64.7	18.2	0.27	5366	-9.0
05/22/91	24.0	14.4	49.0	0.00	75.95	67.7	19.2	0.29	5006	-9.6
05/23/91	23.5	13.9	37.0	0.00	76.20	74.9	21.2	0.15	5402	-9.6
05/24/91	24.0	16.7	33.0	0.00	76.23	67.1	19.1	0.24	5330	-7.3
05/27/91	25.5	16.1	35.0	0.00	76.00	75.2	21.1	0.33	5438	-9.4
05/28/91	25.0	15.6	26.0	0.00	76.07	71.0	20.1	0.27	5474	-9.4
05/29/91	25.0	13.9	31.0	0.00	76.00	72.6	20.7	0.28	5150	-11.1
05/30/91	25.0	16.1	25.0	0.00	75.72	68.6	19.5	0.28	5150	-8.9
05/31/91	25.0	20.0	31.0	0.00	75.29	72.0	20.2	0.34	5366	-5.0
06/03/91	23.0	14.4	43.0	0.00	76.07	74.6	21.3	0.29	5114	-8.6
06/04/91	24.5	17.2	38.0	0.00	75.97	69.5	19.6	0.27	5452	-7.3
06/05/91	25.5	17.8	28.0	0.00	76.00	65.3	18.3	0.26	5600	-7.7
06/06/91	24.0	17.2	26.0	0.00	76.17	70.9	20.0	0.27	5600	-6.8
06/07/91	25.0	18.3	17.0	0.00	76.17	65.2	18.4	0.24	5390	-6.7
06/10/91	28.0	20.6	26.0	0.00	76.00	65.1	18.3	0.29	5474	-7.4

Table 3. Summary data for variables

VARIABLE	MINIMUM	MAXIMUM	MEAN
Soil Temperature (C)	4.5	28.0	15.7
Air Temperature (C)	-3.0	29.0	11.6
Relative Humidity (%)	17.0	97.0	55.6
Rainfall (cm)	0.0	3.9	0.1
Barometric Pressure (cm)	75.29	76.91	76.21
N2 (%)	51.7	84.7	69.7
O2 (%)	15.4	25.3	20.5
CO2 (%)	0.00	0.58	0.16
He (ppb)	4050	6420	5460

Table 4. Correlations of variables. Significant vlaues (90% confidence level) are underlined.

	Soil-T	Air-T	RelHumid	Rain	BarPress	N2	O2	CO2	He	Air-Soil-Dif.
Soil-T		0.88	-0.28	0.09	-0.32	-0.27	-0.43	0.80	-0.22	-0.18
Air-T			-0.19	0.16	-0.24	-0.33	-0.47	0.74	-0.25	0.30
RelHumid				0.21	0.19	0.09	0.17	-0.09	0.04	0.16
Rain					-0.05	-0.10	-0.12	0.10	-0.08	0.15
BarPres						0.19	0.23	-0.19	-0.10	0.15
N2							0.96	-0.11	0.14	-0.15
O2								-0.28	0.16	-0.10
CO2									-0.15	-0.07
He										-0.08
Air-Soil-Dif.										

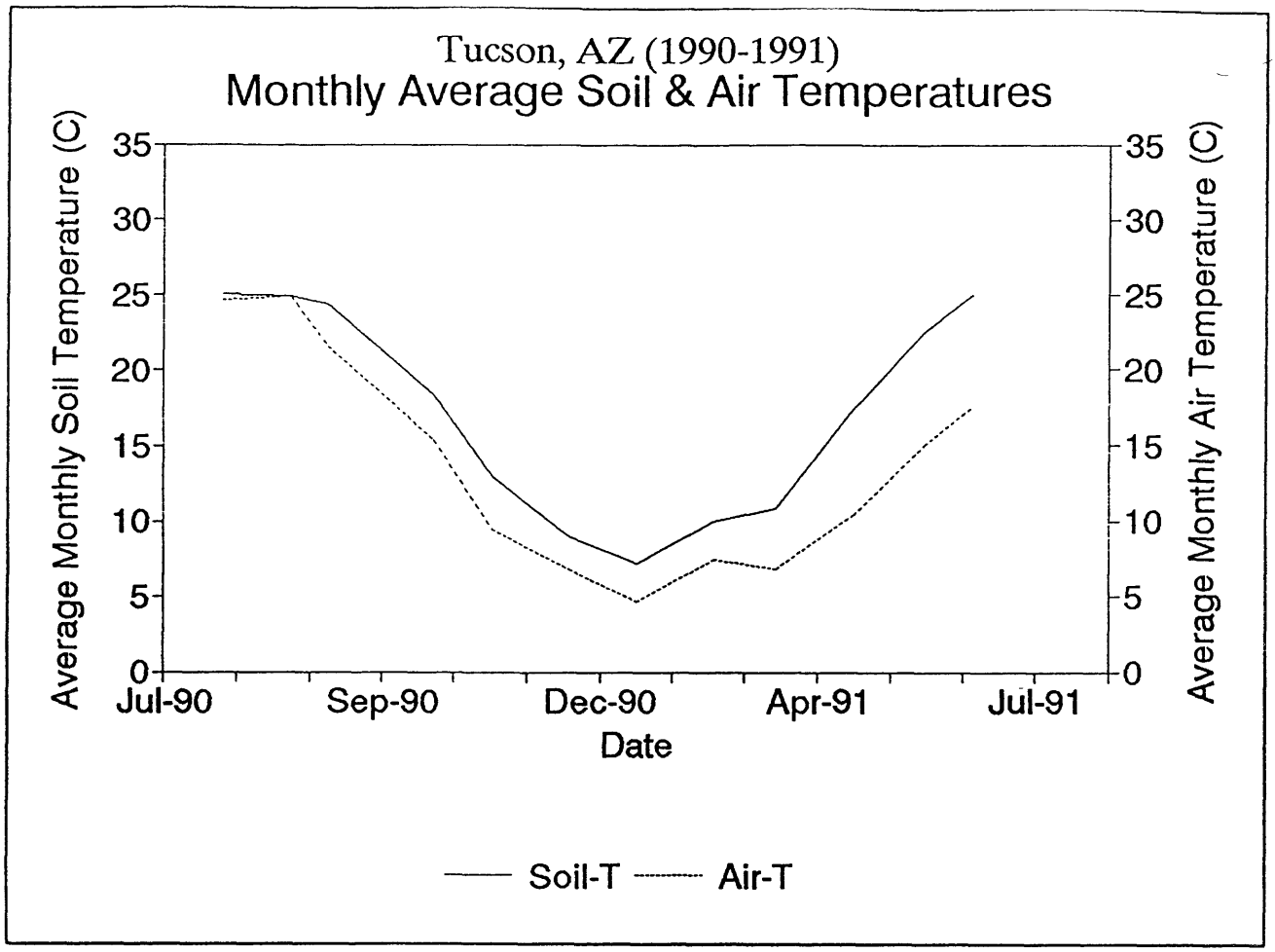


Figure 1.

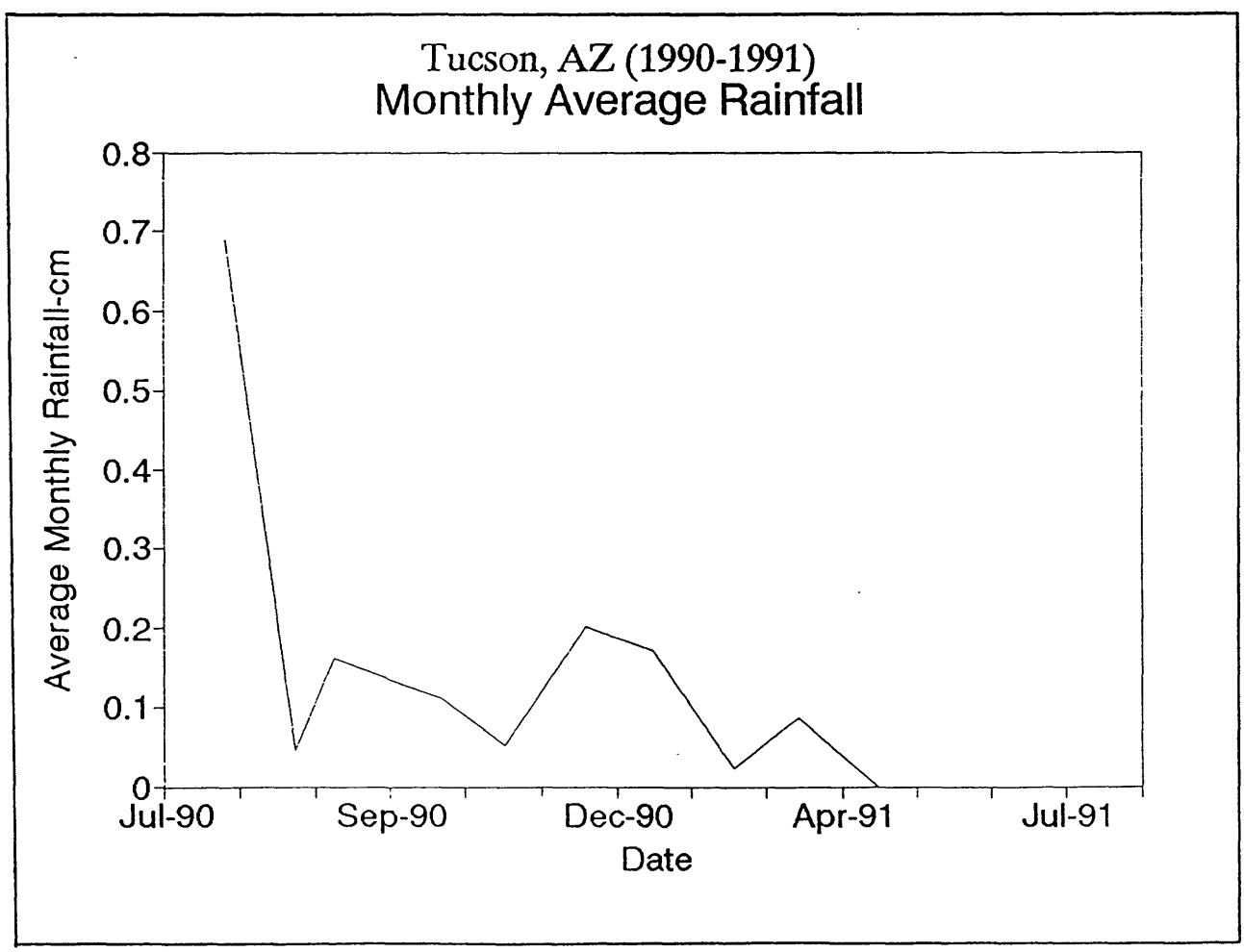


Figure 2.

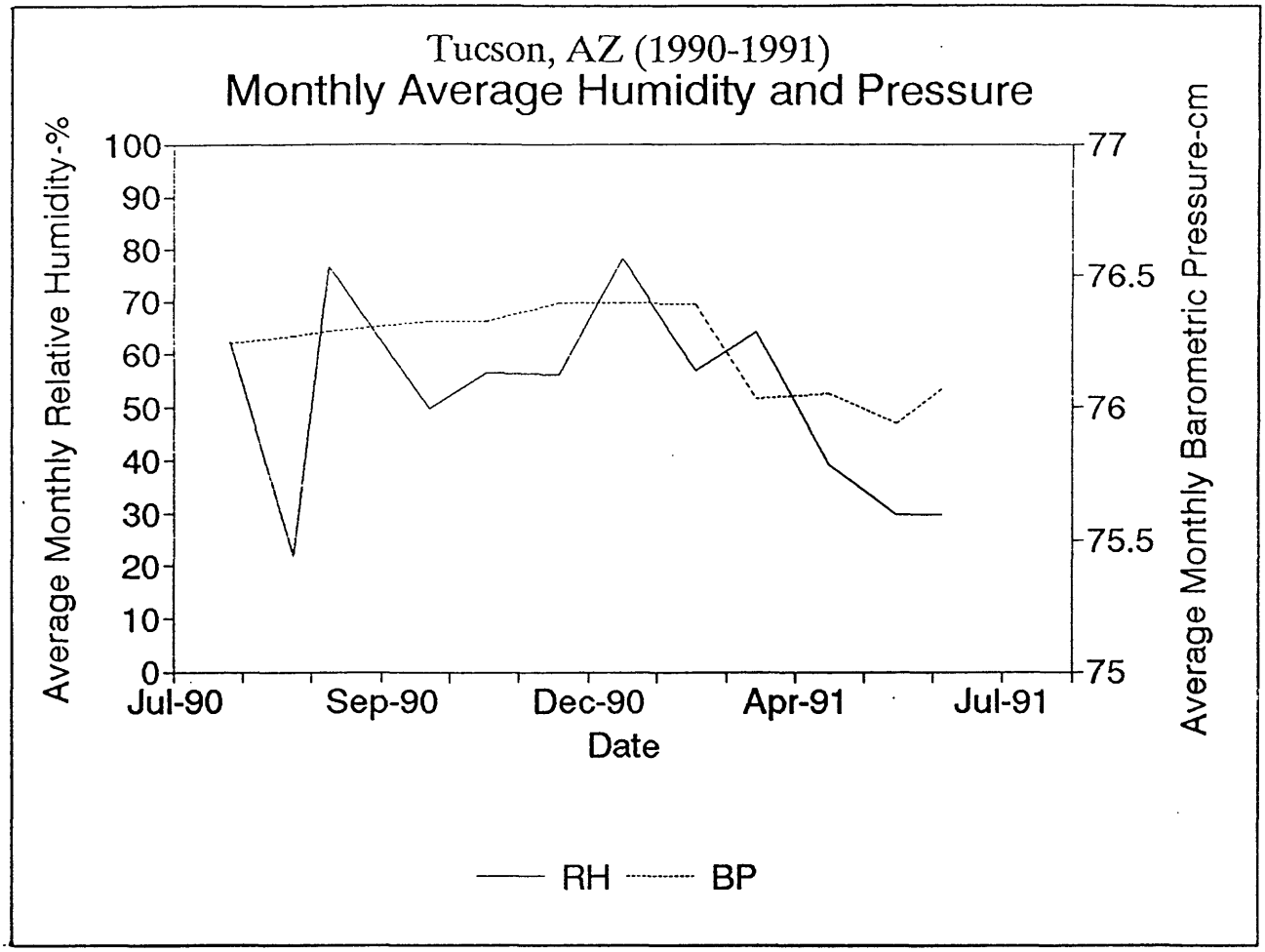


Figure 3.

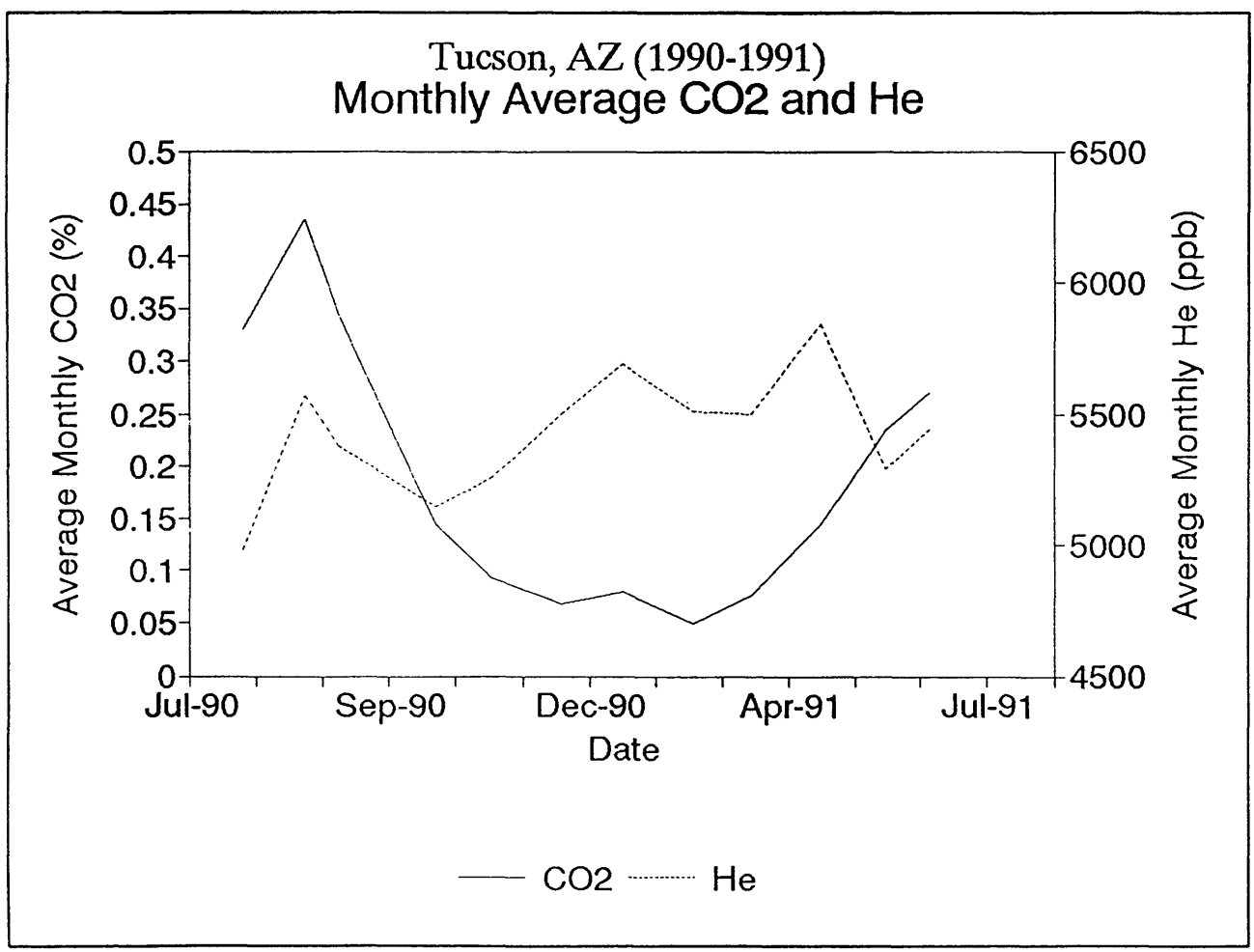
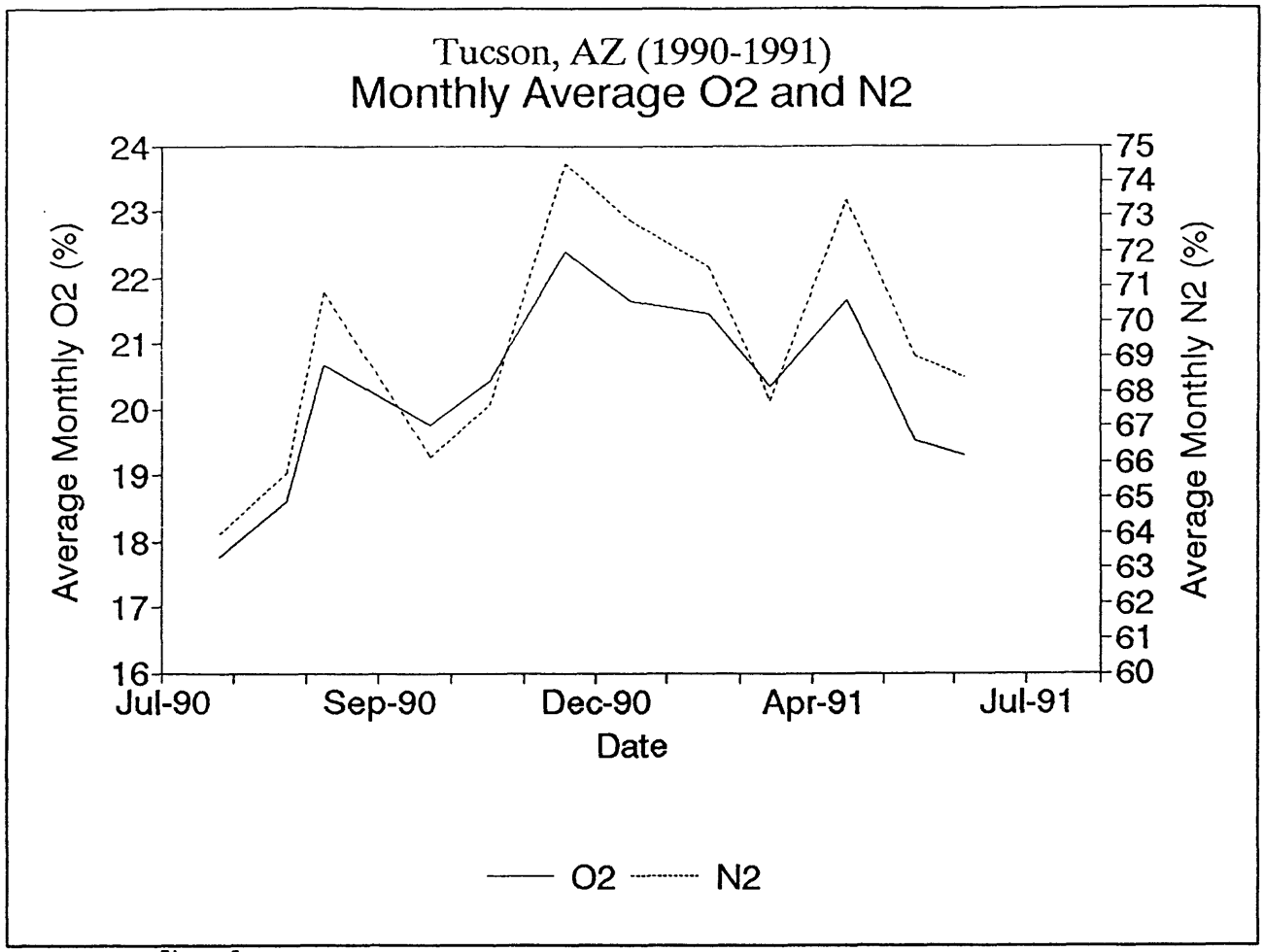


Figure 4.



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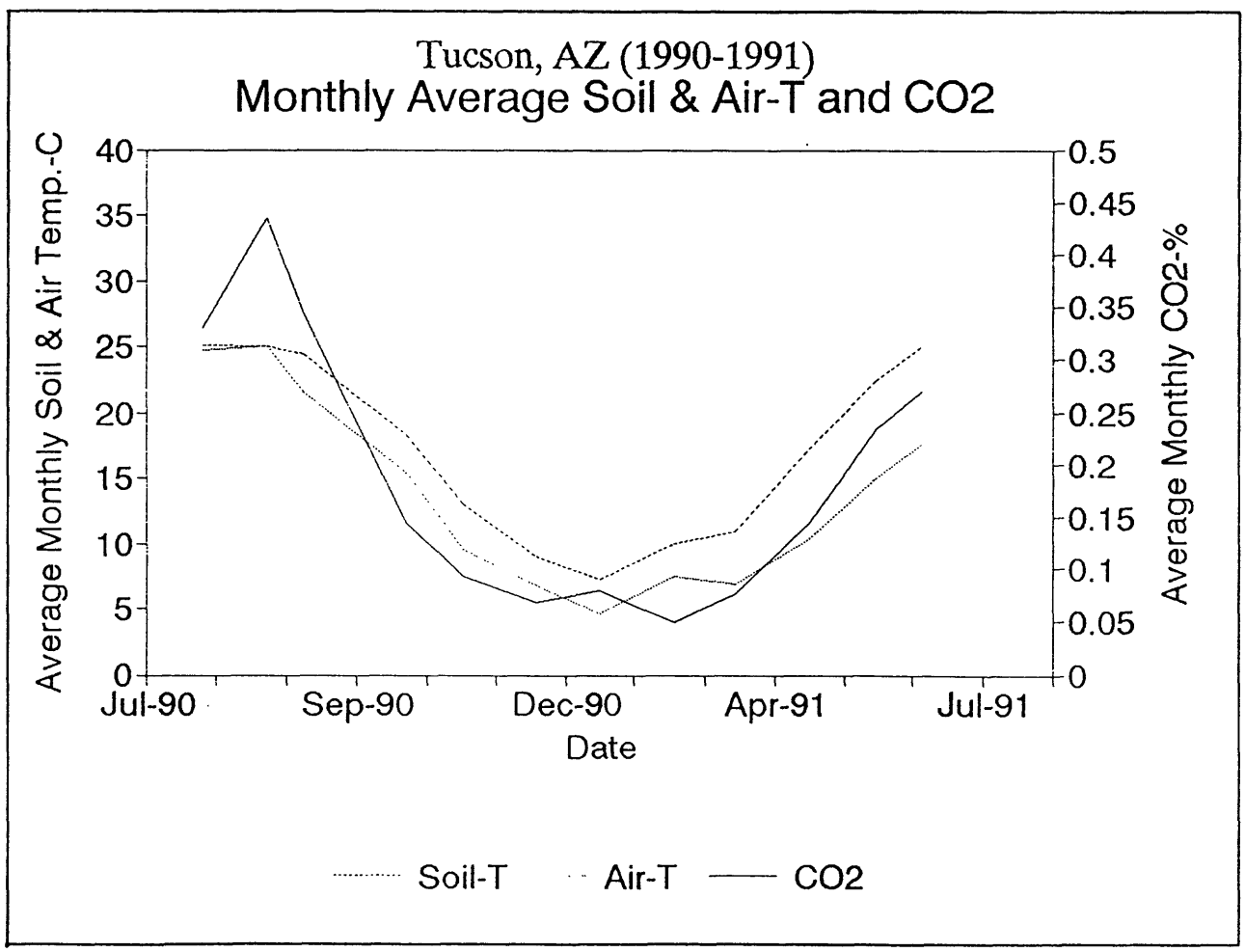

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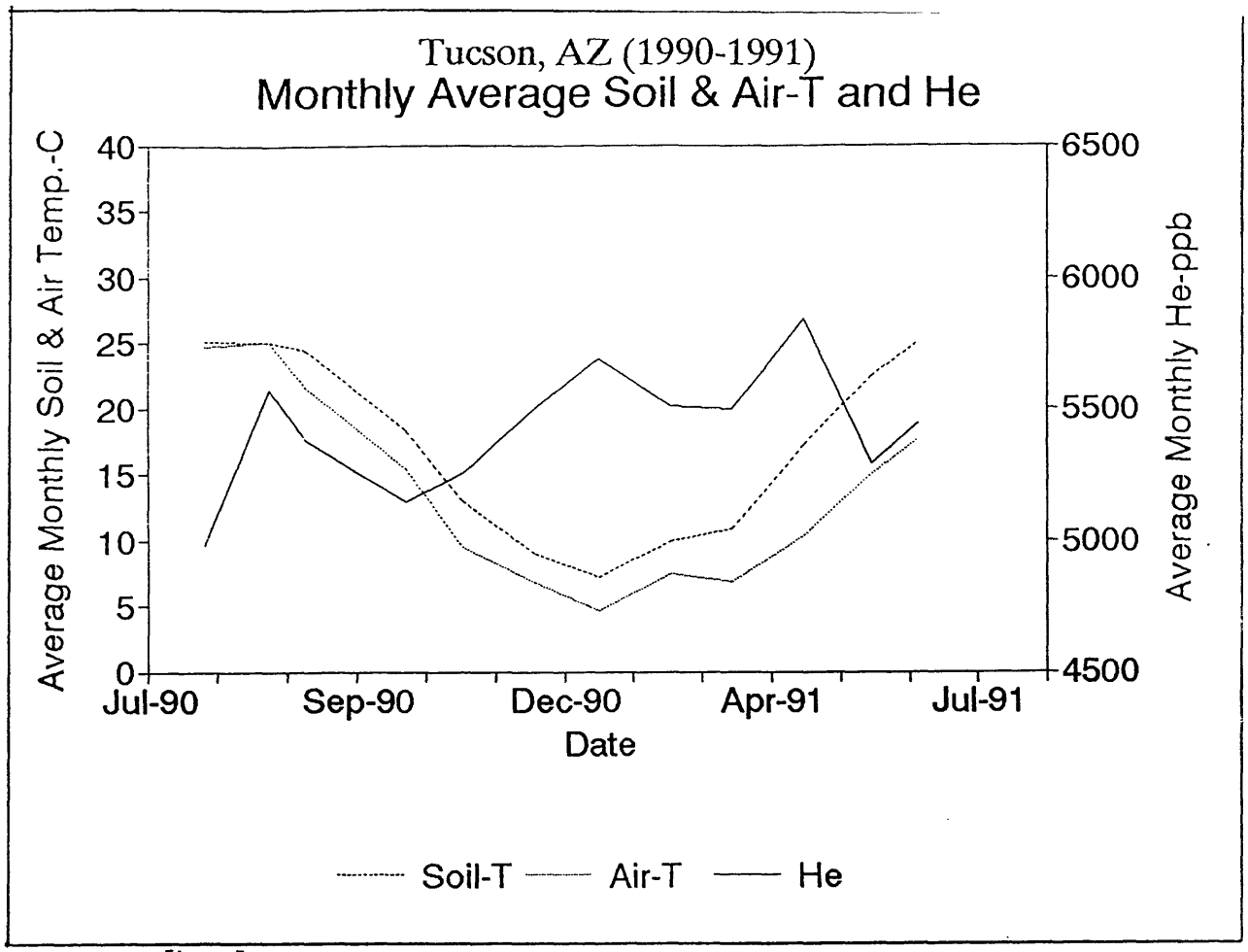

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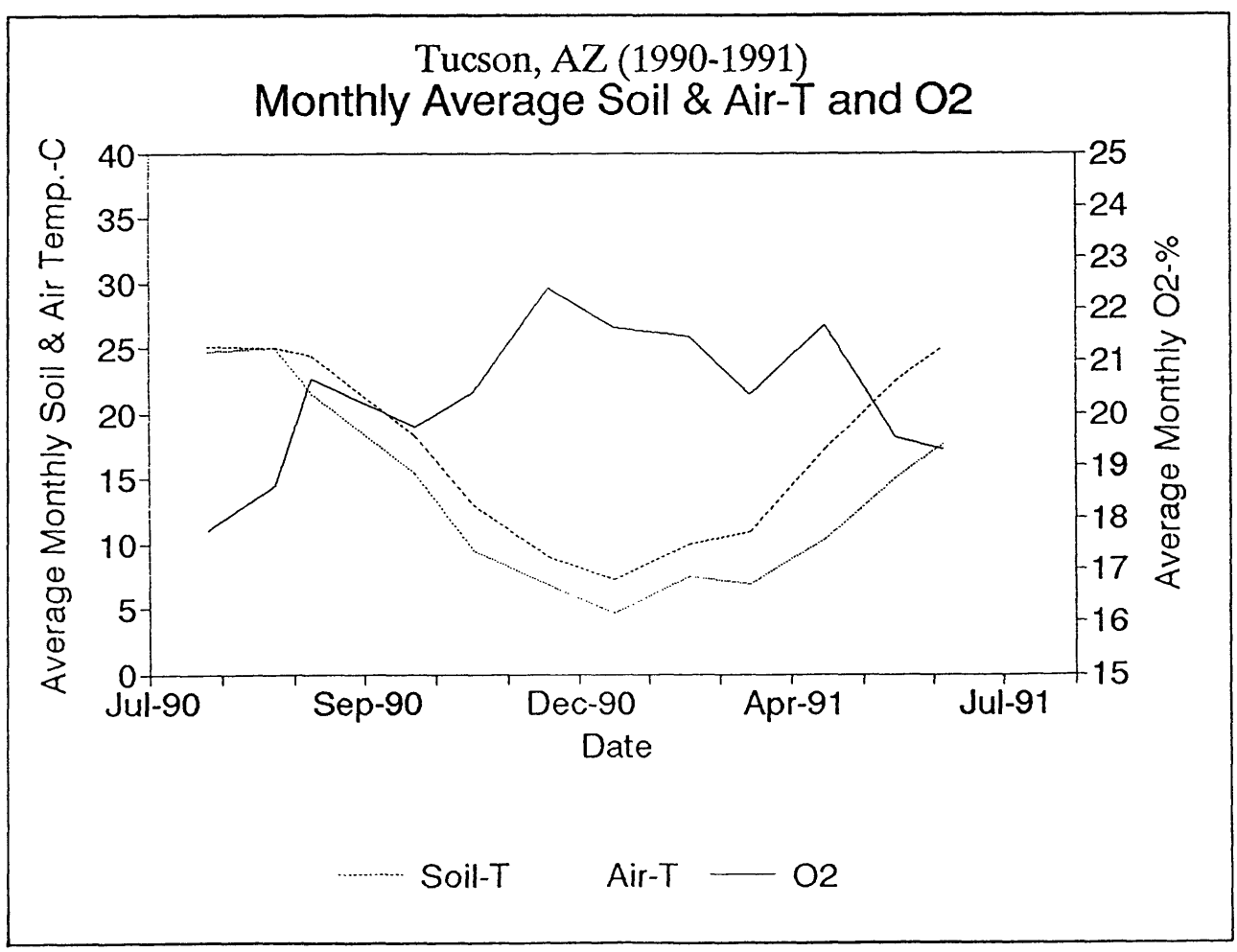

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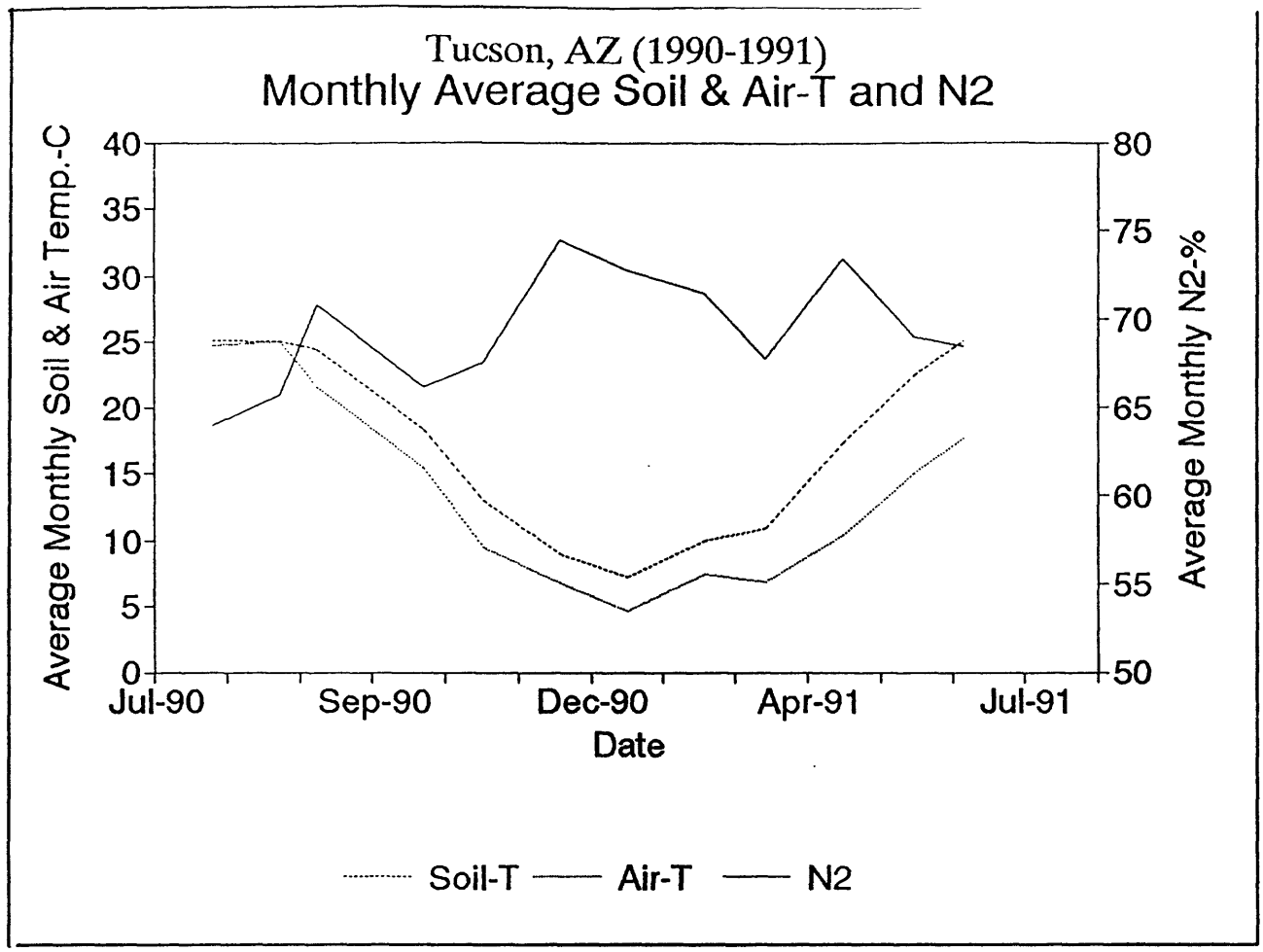
Tucson, AZ (1990-1991)
Monthly Average Soil & Air-T and N2
Average Monthly Soil & Air Temp.-C
Average Monthly N2-%
40
35
30
25
20
15
10
5
0
80
75
70
65
60
55
50
Jul-90
Sep-90
Dec-90
Apr-91
Jul-91
Date
Soil-T
Air-T
N2

Figure 9.