551.586: 631.4

Studies on the Carbon dioxide Factor in the Air and Soil Layers near the ground*

R. K. MISRA.

(*Received August 1946*)

ABSTRACT. The paper deals with the study of CO_2-content of the air layers with which the plants are primarily concerned. It describes variation of the atmospheric and soil air CO_2 with (i) height/depth (ii) time of day and (iii) season. The study was made in the open as well as within crops. The effect of irrigation on CO_2-content of the soil air is also described. Pettenkoffer's method of CO_2-absorption by baryta and subsequent titration by oxalic acid using phenolphthalein as indicator was used for CO_2-estimation. The samples of soil air from within the soil were drawn out for CO_2-estimation through a specially designed steel probe. For the duration of this study the average value of CO_2-concentration in the air layers within the first eight feet above the ground surface was 0.049% and that in the soil air under a bareplot at a depth of 35 cm. was 0.13%.

The study indicates that the amount of CO_2 in the air is more inside a crop than in the open, (ii) it is more during night than during the day—the minimum being in the afternoon and (iii) it is more during winter than during summer, the minimum being in the rainy season. CO_2-content does not appear to vary with height upto the first 35 feet above the ground surface. Soil air CO_2 increases in concentration with depth. It is more under a crop-field than under a bare plot. Its maximum concentration occurs in the rainy season and minimum early in spring and the low values continue throughout the summer months. The effect of irrigation appears to increase the concentration of CO_2 in the soil air.

1. *Introduction* :

Carbon dioxide of the atmosphere and the soil air plays a vitally important role in plant life. Atmospheric carbon dioxide in conjunction with water, is the source of various complicated substances like cellulose, starch, sugars and gums, which constitute the physical structure of all plants and also provide many organic nutrients to them. If the concentration of carbon dioxide in the atmosphere is increased by artificial means up to an optimum value, it results in vigorous plant growth [1—5] Carbon dioxide of the soil air is helpful to plants in various ways. Being an important agency of chemical weathering it helps to disintegrate rock masses to the state of soil which provides mechanical support and inorganic and organic nourishment to the plant. Carbon dioxide of the soil air, when in solution, forms soluble bicarbonates with the alkalies and bases of soils and produces readily available plant food. Further, by combining with certain calcium compounds of the soil it forms calcium carbonate which maintains a slight alkalinity in the soil. The alkalinity thus maintained assists healthy bacterial activity and keeps the land in good tilth[6].

Carbon dioxide represents a very minor constituent of the atmosphere. By volume it is 0.033% and by weight 0.57 gm. per litre of air.[7] Carbon whose only source of supply to the plants is carbon dioxide constitutes, on the other hand, nearly half the dry weight of the plants [1]. In view of this it becomes difficult to believe that the atmosphere alone is the source of supply of this element. Carbon dioxide of the soil air is many times more than that of the atmosphere. It is logical to imagine, therefore, that this will also be playing a part in the general supply of carbon dioxide to the plant kingdom. The carbon dioxide of the soil air may be utilized in two ways. When in solution, it may be translocated into the foliage and utilized in photosynthesis. [1,8,9] Its upward diffusion into the air layers near ground can also assist the atmosphere in keeping pace with the process of photosynthesis. Lundegardh [7] divides the carbon dioxide cycle into a narrower and a wider one, the narrower being between the plants and the soil and the wider between the plants and the atmosphere. According to him, it is the narrower cycle that gives the needed carbon dioxide to plants. Carbon dioxide from the wider cycle is made use of only when the narrower cycle cannot meet the demand.

* This paper summarises some of the results discussed by the present writer in his M.Sc. (Ag.) thesis entitled " Carbon-dioxide in relation to plant growth; its variation with height, time, season and environment in the air layers above and below the ground with which plants are concerned " submitted to the Nagpur University.

The present paper deals exclusively with the study of carbon dioxide in the air and soil layers near the ground with which the plants are primarily concerned. The investigations relating to this study were conducted at the Central Agricultural Meteorological Observatory between the years 1941 and 1943. The times of observation given in this paper refer throughout to the Indian Standard Time which is 5½ hours ahead of G.M.T.

2. *Sampling of the atmospheric and soil air and the method of estimating the concentration of carbon dioxide.*

The air samples were collected in duplicate in three-litre glass jars by aspiration. The jars containing the air samples were closed air-tight with a thin rubber cover. Carbon-dioxide in the air samples was estimated by the Pettenkoffer's method of absorption of the gas by baryta and its subsequent titration with oxalic acid, using phenolphthalein as the indicator. The fractions of carbon dioxide were expressed as percentages by volume of air at normal temperature and pressure. The error involved in the estimation of carbon-dioxide according to this method was of the order of 4% of its mean value. The duplicate estimates of carbon dioxide generally tallied quite closely, differing as they did only in the third decimal place.

In the case of samples of soil air a portable sampling probe (Fig.1) was designed to aspirate the soil air into the sampling jars. The probe was similar to that used by earlier workers (Russell and Lundegardh)[10]. The probe consists of a steel tube of about 0.8 cm. external and 0.4 cm. internal diameter. It is one metre long, the lower end "P" being sharp and tapering to facilitate insertion into the soil. When not in use the entire length of the tube is filled inside by the insertion of a well-fitting steel rod "R" which can be operated by a handle. The probe is inserted into the ground, down to the desired depth, the steel rod "R"

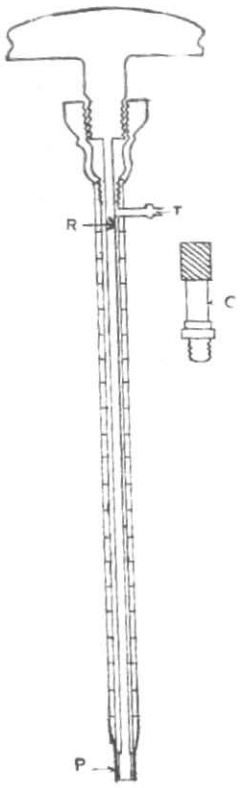

FIG. 1.
The Portable Soil air Sampling Probe.

pulled out, and the upper end of the tube closed with an air-tight screw cap "C". A side tube "T" is provided in the probe near its upper end. At the time of sampling, this tube is connected to the sampling bottle filled with water. The entrapped air of the sampling probe is removed before collecting the actual sample.

3. *Carbon dioxide in the air layers above bare ground.*

The results of a preliminary experiment are given in table 1. The table indicates that there is no significant variation with height of carbon dioxide content in the air layers up to 35′ above ground surface. It is found, however that the carbon dioxide content of the air varies greatly with time of the day.

TABLE I.

CO_2 percentages at 3′, 18½′ and 34′ above ground and at five different times of the day.

Dates.	Time in hours.	Mean percentages at the heights of		
		3′	18½′	34
14-12-41	06	0.052	0.063	0.087
	10	0.031	0.030	0.037
	14	0.034	0.034	0.030
	18	0.030	0.033	0.033
	22	0.042	0.045	0.048
15-12-41	06	0.051	0.051	0.047
	10	0.040	0.037	0.040
	14	0.047	0.042	0.034
	18	0.038	0.045	0.037
	22	0.049	0.045	0.048
16-12-41	06	0.053	0.053	0.043
	10	0.034	0.041	0.037
	14	0.031	0.035	0.038
	18	0.037	0.037	0.040
	22	0.038	0.045	0.044
17-12-41	06	0.047	0.051	0.051
	10	0.033	0.037	0.040
	14	0.035	0.035	0.031
	18	0.034	0.041	0.034
	22	0.038	0.038	0.037
18-12-41	06	0.042	0.053	0.049
	10	0.034	0.033	0.037
	14	0.039	0.042	0.034
	18	0.044	0.045	0.040
	22	0.060	0.041	0.037

TABLE I (a)

Analysis of variance of the data in Table I.

Factors.	Degrees of freedom.	Variance.	"F" calculated.
Height ..	2	0·000015	
Time of day ..	4	0·000772	9.191**
Days ..	4	0·000046	
Height × Day ..	8	0·000042	
Height × Time ..	8	0·000030	
Day × Time ..	16	0·000094	
Second order interaction or error	32	0·000084	
Total ..	74		

**means significant at P = 0.01.

(a) Diurnal variation.

A reference to table 1 will indicate that early morning values of carbon dioxide are generally higher than at other times. The values recorded at 10 and 18 hours are generally lower than those recorded at 22 hours. The results of a detailed study of the diurnal variation in the concentration of carbon dioxide in the air layers at 4′ above ground are given in table 2. It is seen from table 2 that the carbon dioxide in the air is maximum sometime after midnight and minimum at about mid-day. Thus, on the whole, the concentration of carbon dioxide in the air is lower during the day than during the night. During nights respiration associated with biological processes results, in the absence if photosynthesis, in an increased amount of carbon dioxide. The carbon dioxide thus produced concentrates in the stratifying lower layers of the atmosphere. During the day carbon dioxide can be added to the air layers by the diffusion of soil air and also by its liberation from the increased microbial and chemical activities in the top layers of the soil which are warmer by day than during night. But there are two depleting factors which are also in operation during the day, *viz.* photosynthesis and turbulence. The former would consume a part of the carbon dioxide present and the latter would cause dilution of the remainder by mixing up to a considerable height. The combined effect of these two processes is, therefore, to reduce the carbon dioxide concentration in the air layers near the ground.

TABLE 2.

Mean percentage of the atmospheric carbon dioxide indicating its diurnal variation.

Dates.	Hours of observation.												
	06	08	10	12	14	16	18	20	22	00	02	04	06
13-3-43	0.056	0.054	0.049	0.047	0.049	0.051	0.051	0.053	0.060	0.058	0.058	0.051	0.050
13-5-43	0.049	0.046	0.044	0.039	0.034	0.036	0.040	0.039	0.041	0.045	0.049	0.046	0.048
14-7-43	0.047	0.043	0.036	0.036	0.037	0.038	0.040	0.038	0.046	0.045	0.051	0.048	0.047
15-9-43	0.050	0.045	0.039	0.037	0.038	0.039	0.039	0.042	0.045	0.046	0.045	0.042	0.042

(b) Seasonal Variation.

The data regarding the seasonal fluctuations of the atmospheric carbon dioxide were collected from the 15th october 1942 to the 24th November 1943 on a few selected days during each month at 06, 13 and 17 hrs. at 0 (surface), 4′ and 8′ above ground. The mean percentages of carbon dioxide irrespective of time and height are graphically represented in Fig. 2 together with the rainfall and the daily wind velocity at 6′ above ground. A reference to Fig. 2 would indicate the following main features in the fluctuations of the atmospheric carbon dioxide:—

(1) High values during winter (November to January).

(2) Steady decrease from winter to summer, *i.e.*, January to June.

(3) Persistence of low values throughout the monsoon season.

(4) Increase during the post-monsoon period (October-November).

The factors which would normally tend to increase the amount of carbon dioxide in the air layers near the ground are (i) plant respiration, (ii) micro-biological and chemical processes which go on in the soil layers and (iii) the diffusion of the soil air carbon dioxide from the top most layers of the soil. The factors which would decrease the amount of carbon dioxide in the air layers are (i) photo-synthesis, (ii) rainfall which washes down part of the atmospheric carbon dioxide to the soil and (iii) turbulence in the atmosphere which would prevent any accumulation of carbon dioxide in the lower strata of the atmosphere. In winter, when most of the fields are under crops and there is enough moisture in the soil to permit microbial and chemical activities and when there are greater possibilities of diffusion from the soil due to increased pore-space as compared to the rainy season, all the three factors which tend to increase the amount of carbon dioxide are operative while the only factor on the depletion side is the process of photosynthesis. The net result of all these

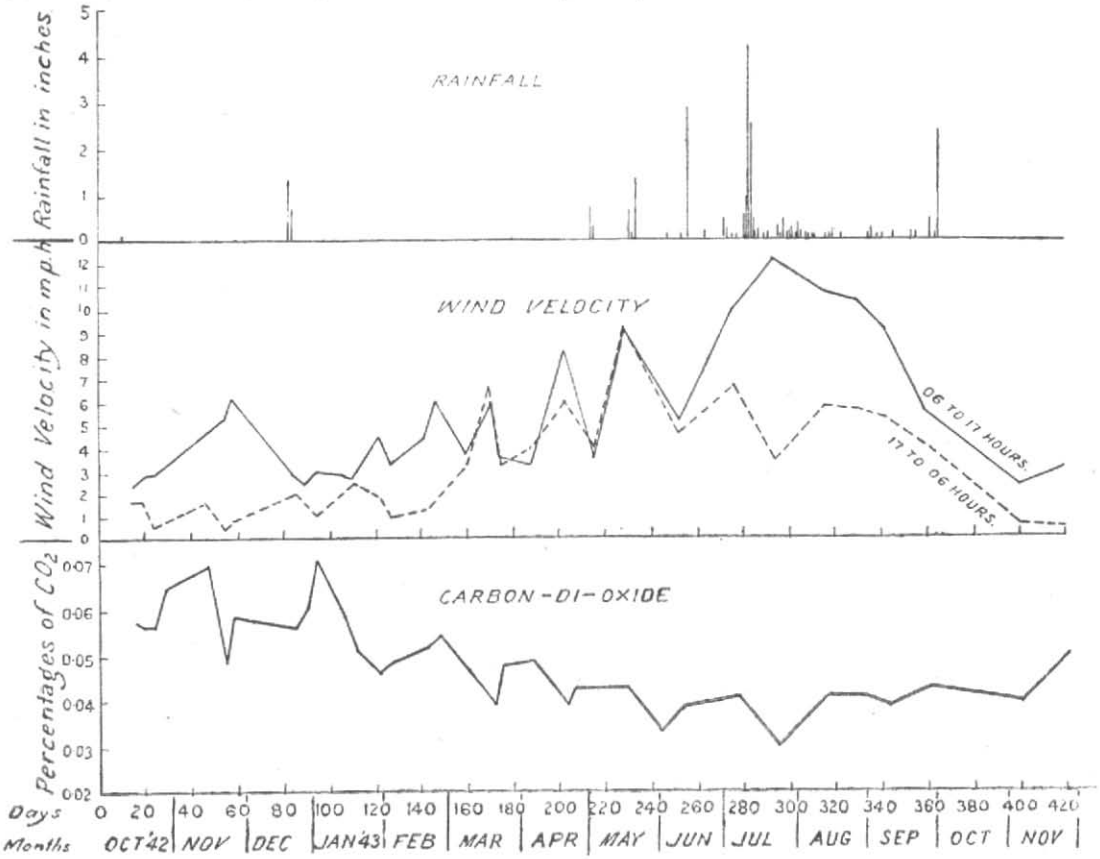

FIG. 2

factors of production and depletion is an increase in the concentration of carbon dioxide in the air layers above the ground during winter season. In summer, when most of the fields are bare and there is little moisture in the top layers of the soil to permit the microbial activity, there is only one source of carbon dioxide production, *viz.* the chemical activity going on in the soil. Thus the production being comparatively lower and the turbulence being fully operative, the concentration of carbon dioxide in the air layers above ground falls down considerably. In the rainy season, in addition to the effect of high winds, the continuous rains over a long period bring down much of the carbon dioxide of the atmosphere to the soil. As a result of this the percentage of carbon dioxide in the atmosphere decreases to a minimum value. Later in the post-monsoon months, the weather is dry, air movements are weaker, the fields are full of crops and in the presence of sufficient moisture the microbial activity is also possible on the surface soil so that the concentration of carbon dioxide in the air layers above ground begins to increase.

4. *Carbon dioxide content of the air layers above ground inside cropped fields.*

The difference between the concentration of carbon dioxide of the crop atmosphere and that in the "open" was studied in jowar, sugarcane and betel-vine crops. The results are given in table 3. It will be seen that the average concentration of carbon dioxide in the open is less than that inside the crops.

TABLE 3.

Mean percentages of CO_2 in (a) open, jowar and sugarcane ; (b) open and sugarcane ; (c) open and betel vine.

	(a)				(b)			(c)	
Dates.	Open.	Jowar.	Sugar-cane.	Dates.	Open.	Sugar-cane.	Dates.	Open.	Betel-vine.
27-12-41	0.043	0.045	0.051	9-1-42	0.044	0.048	23-1-42	0.036	0.053
28-12-41	0.033	0.040	0.049	10-1-42	0.041	0.052	24-1-42	0.041	0.049
1- 1-42	0.037	0.041	0.051	11-1-42	0.037	0.048	25-1-42	0.041	0.057
2- 1-42	0.041	0.045	0.049	15-1-42	0.037	0.045	26-1-42	0.041	0.048
3- 1-42	0.040	0.051	0.055	16-1-42	0.037	0.043	27-1-42	0.040	0.055
4- 1-42	0.039	0.041	0.049	17-1-42	0.047	0.050	28-1-42	0.043	0.059
5- 1-42	0.041	0.039	0.049	18-1-42	0.040	0.047	29-1-42	0.040	0.059

Analysis of variance of the above data.

Due to	(a) D.F.	Variance	"F" Calculated	(b) D.F.	Variance	"F" Calculated	(c) D.F.	Variance	"F" Calculated
Environment	2	0.000230	38.333**	1	0.000179	35.800**	1	0.000566	43.538*
Days	6	0.000021	3.500*	6	0.000019	3.800*	6	0.000009	0.692
Residue	12	0.000006	—	6	0.000005	—	6	0.000013	—
Total	20	—	—	13	—	—	13	—	—

D.F. means Degrees of Freedom. * means significant at P=0.05. ** means significant at P=0.01.

5. *Variation of carbon dioxide content of the air layers above ground inside the sugarcane crop with height, time of day and season.*

The crop selected for this study was sugarcane, variety CO 419. Estimations of carbon dioxide were made periodically at 0′ (surface), 4′ and 8′ above ground three times a day at 06, 13 and 17 hours. The observations were started in October 1942 when the crop had a well developed canopy and continued until the harvest of the crop in February 1943. The observations were started again in April 1943 in the new crop and continued until September 1943 when the over-all height of the crop was just over 8′. Table 4 contains the mean percentages of carbon dioxide at different heights (irrespective of time of day) and at different times of the day (irrespective of height above ground). The table also gives the mean percentages of carbon dioxide for the days of observations irrespective of height and time. The data have been arranged according to the age of the crop for the sake of convenience.

A reference to table 4 will indicate that there is no considerable variation of carbon dioxide with height upto about 250 days after planting the crop. Later, when the crop has developed an effective canopy of green leaves from a height of about 8′, the percentages of carbon dioxide at this height remain higher than at the other two heights.

Table 4 will further indicate that the course of diurnal variation of carbon dioxide content of the crop atmosphere is similar to that found in the open. The maximum concentration is reached during the night, as represented by the morning values, gradually decreasing during the day until the minimum has occurred at about mid-day.

The mean values of carbon dioxide irrespective of height and time have been shown graphically in Fig.3 together with the corresponding values in the open. The carbon dioxide curve for the sugarcane crop runs more or less parallel to that for the open. The concentration of carbon dioxide in the air of the crop atmosphere is also higher during the winter months. Later, the concentration decreases reaching a minimum sometime during the rainy months.

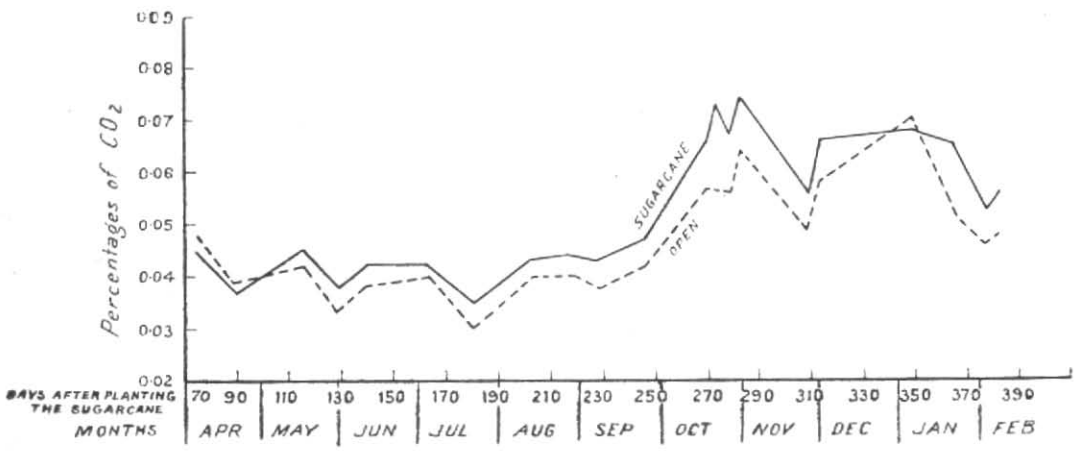

FIG. 3.

TABLE 4.

Mean percentages of CO_2 indicating the variation of carbon dioxide of the crop-atmosphere (sugarcane) with height, time of day and season.

Date.	Days after planting the cane.	Heights in ft.			Time of day in hours			Mean CO_2 % irrespective of height and time.
		0	4	8	06	13	17	
6- 4-43	74	0.044	0.046	..	0.048	0.043	0.045	0.045
21- 4-43	89	0.036	0.038	..	0.043	0.033	0.034	0.037
17- 5-43	115	0.046	0.043	..	0.052	0.037	0.044	0.045
31- 5-43	129	0.042	0.034	..	0.040	0.033	0.042	0.038
10- 6-43	139	0.040	0.043	..	0.047	0.035	0.042	0.042
4- 7-43	163	0.044	0.043	0.040	0.048	0.038	0.041	0.042
21- 7-43	180	0.035	0.036	0.033	0.036	0.030	0.038	0.035
12- 8-43	202	0.044	0.043	0.043	0.047	0.039	0.044	0.043
27- 8-43	217	0.044	0.043	0.045	0.050	0.041	0.042	0.044
7- 9-43	228	0.041	0.045	0.043	0.045	0.039	0.044	0.043
25- 9-43	246	0.045	0.047	0.050	0.053	0.044	0.045	0.047
(Data below refer to the previous sugarcane crop which had a well developed canopy.)								
15-10-42	270	0.061	0.064	0.074	0.076	0.059	0.065	0.066
28-10-42	283	0.070	0.070	0.082	0.087	0.066	0.069	0.074
27-11-42	313	0.063	0.066	0.069	0.074	0.060	0.064	0.066
2- 1-43	349	0.063	0.070	0.073	0.074	0.065	0.066	0.068
30- 1-43	377	0.051	0.049	0.060	0.062	0.045	0.053	0.053

6. *Carbon dioxide content of the soil air of a bare plot.*

The study of the carbon dioxide content of the soil air was made in the observatory plot, which had been lying fallow for more than ten years. Table 5 would give an idea of the amount of carbon dioxide present in the soil air. It is many times more than in the air layers above ground.

(a) **Variation with depth.**

Table 5 also indicates the variation of carbon dioxide in the soil air with depth. It will be seen that from 5 cm. to 15 cm. depth the concentration of carbon dioxide does not vary considerably. Below 15 cm. a marked regular increase is noticed up to 165 cm. Beyond this the concentration remains again more or less constant up to 205 cm. which was the maximum depth studied.

TABLE 5.

Mean percentages of Co_2. of the soil air at various depths (mean of 4 estimations at each depth).

Depth in cm.	%	Depth in cm.	%	Depth in cm.	%	Depth in cm.	%
5	0.15	20	0.19	65	0.79	165	1.50
10	0.14	25	0.23	85	1.04	185	1.61
15	0.14	45	0.50	145	1.37	205	1.60

(b) Diurnal variation.

The three hourly mean values of carbon-dioxide at three depths, *viz.*, 15, 25, and 35 cm. recorded on the 17th September 1942 are presented in Table 6. The statistical analysis of this data shows that there is no significant variation with time at any of the three depths. Probably the slight increase in production due to increased microbial and chemical activities under favourable temperature conditions during the day is counter balanced by the increased diffusion due to greater turbulence during the same period.

TABLE 6.

Mean percentages of CO_2 of the soil air.

Time in hours	Depth in cm.		
	15	25	35
06	0.23	0.31	0.32
09	0.19	0.29	0.27
12	0.26	0.29	0.26
15	0.24	0.28	0.26
18	0.26	0.28	0.26
21	0.21	0.29	0.28
00	0.24	0.28	0.28
04	0.19	0.27	0.28
06	0.21	0.24	0.25

Analysis of variance of data in Table. 6.

Factors.	Degrees of Freedom.	Variance	"F" Calculated
Time of day ..	8	0.0007	1.75
Depth ..	2	0.0081	20.25**
Residue ..	16	0.0004	—
Total ..	26	—	—

**means significant at P=0.01.

(c) Seasonal variation.

The estimations of carbon dioxide in the soil air for this purpose were made on a few selected days during every month from October 1942 to September 1943 at 0830 and 1430 hours. The soil air was always drawn from 35 cm. depth. The daily mean percentages of carbon dioxide of the soil air are represented graphically in Fig.4 along with the soil moisture and temperature at 12" depth and rainfall for the same period. It will be seen from Fig.4 that,

(i) the concentration of carbon dioxide in the soil air is maximum from June to September which is the rainy season, at Poona,

(ii) the concentration of carbon dioxide generally goes on decreasing throughout the post-monsoon and winter months and

(iii) the minimum value is reached sometime in early spring and continues more or less constant till the onset of the monsoon, when the carbon dioxide begins to increase in its concentration in the soil air.

The high concentration of carbon dioxide in the rainy season, besides being due to the rain water bringing down in solution some of the atmospheric carbon dioxide, may also be due to increased bacterial activity. Leather[11] has shown that in a fallow soil the first monsoon showers accelerate the activities of some bacteria, which also leads to the greater production of carbon dioxide in the soil. Further, the black cotton soil of Poona swells up considerably on becoming wet so that all the pore space is considerably reduced. As a direct result of this the diffusion of carbon dioxide from the soil into the air layers above ground is rendered more difficult.

With the onset of clear weather the soil starts drying slowly and thus the diffusion of carbon dioxide from the soil increases, though rather slowly, so that the concentration of carbon dioxide shows a slow decrease as the season advances. By about March the soil becomes sufficiently dry and porous and with the increase in wind velocity the greater quantity of the carbon dioxide starts diffusing into the air layers above ground. As a result, the concentration of carbon dioxide of the soil air falls to the minimum value.

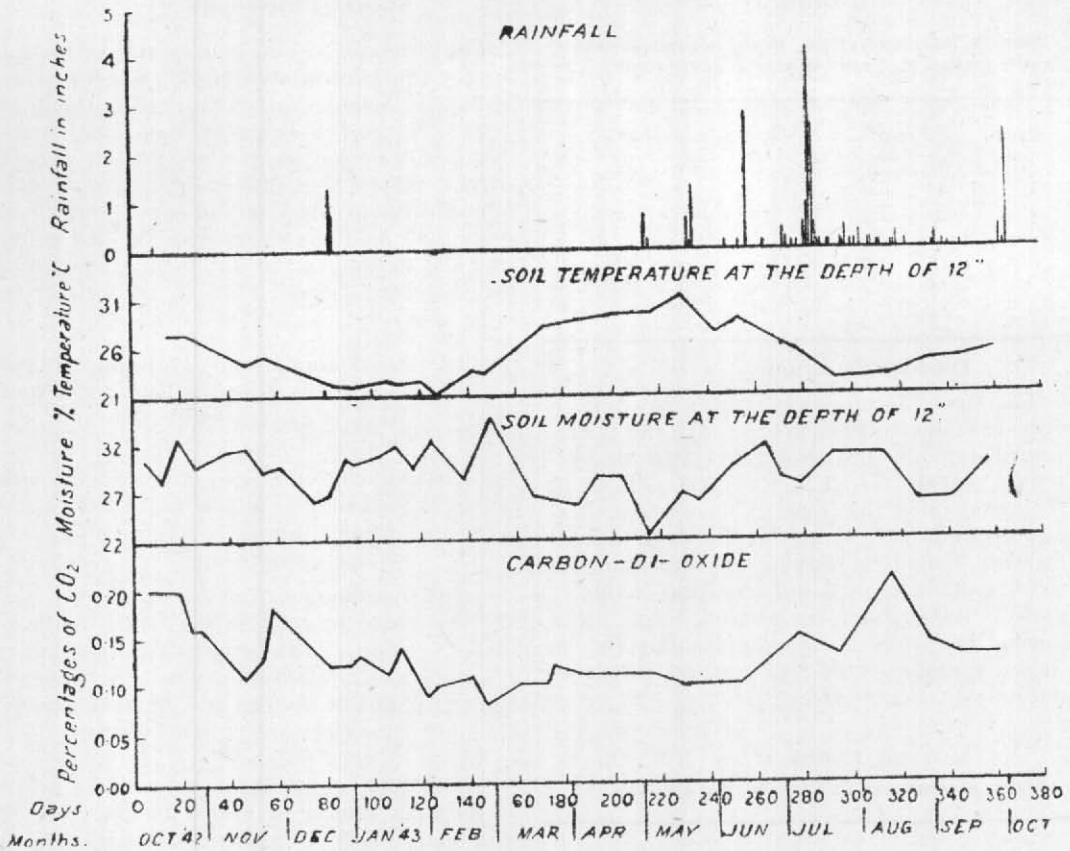

Fig. 4. Seasonal variation of Carbon dioxide of the soil air of the bare plot.

7. *Carbon dioxide content of the soil air of the sugarcane field.*

The mean percentages of carbon dioxide in the soil air of the bare observatory plot and the sugarcane field are given in table 7. It will be seen from the table that the sugarcane field gives very high percentages of carbon dioxide as compared to the bare field.

TABLE 7.

Mean percentages of CO_2 of the soil air at 35 cm. depth.

Dates	Bare plot of the observatory	Sugarcane field
7-10-42	0.20	0.49
19-10-42	0.20	0.61
24-10-42	0.16	0.86
28-10-42	0.16	0.75

Seasonal variation.

Observations for this study were also started in October 1942. These were continued in the next year's crop until September 1943. Estimations of carbon dioxide were made at 0830 and 1430 hours. The soil air was always drawn from 35 cm. depth. The mean percentages of carbon dioxide, based on six observations on each day, are given in table 8 and are arranged according to the age of the crop.

It can be seen from table 8 that during the summer months the percentages of carbon-dioxide go on increasing in contrast to those below the bare soil (Fig. 4) where the concentration remains more or less quite low during this period. This difference, in the march of the seasonal curve of carbon dioxide of the soil air, between the bare and sugarcane plots may be due to (i) the latter getting plenty of organic manure at the time of plantation and also later on and (ii) the frequent irrigation of the sugarcane field during this period. Table 9 would give an idea of the amount of manure which the sugarcane field under discussion got during the first 157 days after the planting of the

TABLE 8.

Mean CO_2% indicating the seasonal variation of carbon dioxide of the soil air of sugarcane field.

Dates.	Days after planting the cane.	CO_2%
6-4-43	74	0.73
17-5-43	115	1.10
31-5-43	129	1.50
10-6-43	139	1.41
4-7-43	163	1.51
21-7-43	180	2.81
12-8-43	202	2.78
7-9-43	228	0.80
25-9-43	246	0.78

Previous year's sugarcane crop which was grown in a different field.

7-10-42	262	0.49
28-10-42	283	0.75
16-11-42	302	0.50
27-11-42	313	0.59
2-1-43	349	0.78
14-1-43	361	0.61
30-1-43	377	0.49

sugarcane crop. In the presence of sufficient moisture the decay of organic matter goes on in the soil. The carbon dioxide is thus generated as one of the products of this decay.

TABLE 9.

The type and quantity of manure applied to sugarcane field under study.

Age of the crop in days.	Type of manure.	Quantity of the manure
Before planting	Farm yard	22½ cart loads
56	Ground nut cake	402 lbs.
91	do	804 lbs.
129	do.	402 lbs.
157	do.	268 lbs.

The carbon dioxide content of the soil air of the sugarcane field reaches a maximum value during rainy months just like that of the bare plot. Similarly in the post-monsoon months the value of carbon dioxide falls down considerably. During the winter months the value is maintained quite low.

Thus it will be seen that the seasonal changes in the concentration of carbon dioxide in the soil air of the sugarcane field are similar to of the bare plot, except during the summer months, when probably the seasonal changes in the sugarcane field are masked by the cultural factors.

8. *The influence of irrigation on carbon dioxide of the soil air of the sugarcane field.*

The day to day variation in the concentration of carbon dioxide of the soil air of the sugarcane field was studied between two irrigations, *viz.*, from the 12th September to 1st October 1943. Soil air samples from 35 cm. depth were drawn from a selected spot in the field. The carbon dioxide content of the atmospheric air at surface level near the sampling spot was also estimated. The field was irrigated on the evening of the 12th September. Sampling of soil air was tried on the 13th, but no air could be drawn out as the field was saturated with water. This happened also on the 1st October, when the sampling was attempted just after the next irrigation. From the 14th September onwards it was possible to draw out soil air, though the rate of flow was slow for a few days in the beginning. The data from the 14th to 30th September are presented in table 10.

TABLE 10.

The effect of irrigation on soil air CO_2 of the sugarcane field. Date of irrigation 12-9-43.

Dates. after irrigation	Soil air CO_2 (%)	CO_2 over ground surface (%)
14-9-43	0.66	0.048
15-9-43	0.71	0.057
17-9-43	0.81	0.042
18-9-43	0.97	0.044
19-9-43	1.00	0.044
21-9-43	1.08	0.056
22-9-43	1.10	0.061
23-9-43	1.17	0.056
24-9-43	0.93	0.057
26-9-43	0.95	0.046
27-9-43	0.77	0.041
30-9-43	0.66	0.050

Table 10 indicates that in the beginning there is a progressive increase in the concentration of carbon dioxide in the soil air lasting till about the 11th day after irrigation, probably due to the existence of a layer of wet impervious soil at the top preventing upward diffusion. Later on the carbon dioxide content of the soil air falls down because conditions become more favourable for upward diffusion as the top layer of the soil dries up and becomes permeable. The upward diffusion of carbon dioxide from the soil is mainly dependent on the permeability of the soil and the gradient of carbon dioxide concentration from the soil to the atmosphere. For sometime after irrigation the soil contains much free water.

When this water has disappeared, both the above conditions for the escape of carbon dioxide become favourable. Between the 9th and 12th days after irrigation the rise in the values of carbon dioxide of the air above ground surface gives an evidence of some upward diffusion. Later on, the gradient from the soil to the atmosphere is less steep and, therefore, further escape of carbon dioxide is not so much favoured. Thus it will be seen that the effect of irrigation is to increase the concentration of carbon dioxide in the soil air.

9. *Conclusion.*

The important features of the foregoing discussion are summarised below.

A. Carbon dioxide in the air layers above ground.

(1) The average concentration of CO_2 in the air layers up to 8′ in the open during the period of the present investigations at Poona is found to be 0.049% by volume. The concentration of CO_2 inside the crops is higher than that in the open.

(2) There is found to be no variation of CO_2 in the air layers up to 35′ in the open and 8′ inside the sugarcane crop—the heights up to which the investigations were made. The higher percentages of CO_2 inside the sugarcane crop at 8′ in the later stage of growth is due to the formation of a well developed canopy at and above that height.

(3) The CO_2 concentration in the air layers in the open as well as inside the sugarcane crop is more during the night than during the day.

(4) The main features of the seasonal changes in the concentration of CO_2 in the air layers in the open and inside the sugarcane crop are more or less similar; they are briefly:—

(i) high values during winter,

(ii) steady decrease from winter to summer,

(iii) persistence of low values throughout the monsoon season and

(iv) increase during the post-monsoon period.

B. Carbon dioxide in the soil air.

(1) The average CO_2 content of the soil air of the bare observatory plot during the years 1942-43 may be taken as 0.13% by volume at a depth of 35 cm. It is about 3 times more than the amount of CO_2 present in the air layers above ground. The concentration of CO_2 in the soil air of the sugarcane field is much higher than that of the bare plot.

(2) The CO_2 in the soil air of the bare plot as well as in the sugarcane plot goes on increasing with depth.

(3) No marked diurnal variation is noticed in the concentration of CO_2 in the soil air of the bare plot at depths of 15cm. or more.

(4) The outstanding points in the seasonal variation of the CO_2 in the soil air of the bare plot are:—

(i) maximum in the rainy season,

(ii) decreasing tendency throughout the post-monsoon and winter months and

(iii) minimum early in spring with the continuation of low values throughout the summer months.

The course of seasonal changes in the CO_2 content of the soil air of the sugarcane field is more or less similar to that described above except for the summer months when the crop is in its initial stage of growth. During this period the CO_2 percentages increase probably due to the addition of manures and frequent irrigations.

(5) The effect of irrigation is to increase the concentration of carbon dioxide in the soil air.

10. *Acknowledgements.*

Sincere thanks are expressed to Dr. L.A. Ramdas for guidance, to Mr. A.K. Mallik for his help and advice during the progress of the work, to Director General of Observatories for permission to work at the Central Agricultural Meteorological Observatory and to the Principal and Professor of Agriculture of the local Agricultural College for permission to work in the fields of the Agricultural College Farm. Thanks are also due to Messrs. Ramabhadran and Nayar for their suggestions and help in the statistical portion of the work.

REFERENCES :

1. Miller, E.C., *Plant Physiology* (Mc. Graw Hill), 458, 454 (1931).
2. White, H.L., *Biol. Abs.* 6 (4), 9327 (1932).
3. Bomber, A and Rintelen P., *Biol. Abs.* 7 (9), 20659 (1933).
4. Johnston, E.S., *Biol. Abs.*, 10 (5), 10385 (1936).
5. Richter, A.A., *Biol. Abs.*, 14 (5), 9256 (1940).
6. Lyon, T.L., Fippin, E.O. and Buckman, H.O., *Soils, their properties and management* (Mc. Millan), 481-82 (1938).
7. Lundegardh, H., *Environment and plant development-translated* by Eric Ashby (Edward Arnold), 264, 267-68 (1931).
8. Bergamschi, Maria, *Biol. Abs.*, 6 (8-9), 18387 (1932).
9. Hartel, Otto, *Biol. Abs.* 13 (7), 12085 (1939).
10. Lundegardh, H., *Soil Science*, 23 (6), 417 (1927).
11. Leather, J.W., *Mem. Dept. Agri. in India, Chemical Series*, 4 (3), (1915).