551.586 :631.4

Further studies on the Carbon dioxide factor in the Air and soil layers near the ground*

R. K. MISRA

Meteorological office Poona

(*Received* 16 *December* 1950)

ABSTRACT. This paper is in continuation of an earlier one by the author which appeared in this journal. It deals with the study of carbon dioxide content of the soil air of a sugarcane field. It is shown that the carbon dioxide content of the soil air is subject to local variation. An attempt has been made to see whether this local variation of soil air carbon dioxide is in any way associated with the vigour of the sugarcane plants. It is found, as a result, that greater concentration of soil air carbon dioxide is associated with taller plants and larger foliage development.

The paper also describes a pot-culture experiment performed to compare the development of cotton plants when irrigated with carbonated water. Plants grown under irrigation with carbonated water are found to be taller and having greater foliage development.

1. Introduction

The study of the carbon dioxide factor in the air and soil layers with which plants are primarily concerned was undertaken at the Central Agricultural Meteorological Observatory, Poona during the years 1941-43. Some of the results of this study dealing with the variation in the concentration of carbon dioxide of the air and soil layers with height (depth in the case of soil *air*) time of day, season and environment have been discussed in an earlier paper[1]. It has been shown there that the amount of carbon dioxide present in the soil air is many times more than that present in the air layers above ground and that the concentration of carbon dioxide in the soil air of a cropped field is higher than that of a bare plot.

It may be seen from Table 1 that there is a great deal of variation in the carbon dioxide content of the soil air from place to place within the same plot, whether bare or cropped. Then the interesting question that arises is whether such local variations in the carbon dioxide content of the soil air are in any way related to the general stand of the plants as represented by their number, height and leaf area etc. The present paper describes the results of a field experiment conducted to answer this question. The paper also describes the results of a pot-culture experiment where the response of cotton plants to the addition of carbon dioxide in irrigation water was studied.

2. Method

The crop selected for the study was sugarcane. The observations were taken from September 1942 to February 1943. The observations consisted of (a) carbon dioxide content of the soil air, (b) the number of canes in a clump, (c) the height of the tallest cane of the clump, (d) the girth of the tallest cane of the clump, (e) the Brix reading of the tallest cane of the clump and (f) the total area of the fully open green leaves of the clump.

For the estimation of the carbon dioxide content, samples of soil air were aspirated from 35 cm depth into three-litre bottles with the help of the soil air sampling probe which has been described in the earlier paper. The amount of carbon dioxide was estimated according to Pettenkoffer's method of carbon dioxide absorption by baryta and its subsequent titration by oxalic acid using phenolphthalein as indicator.

The spot from where each soil air sample was taken was marked. The sugarcane

*Part of the M.Sc.(Agr.) thesis, which was submitted to the Nagpur University in the year 1943

TABLE 1

Local variation of the soil air CO_2

BARE PLOT		SUGARCANE PLOT			
Date of observation 20.9.42		Date of observation 24.9.42			
Depth of sampling the soil air : 15 cm		Depth of sampling the soil air : 25 cm			
		In different ridges		In the same ridge at different places	
Sub-plot No	CO_2%	Ridge No	CO_2%	Sample No	CO_2%
1	0.18	12	0.66	1	0.84
2	0.32	13	0.68	2	0.70
3	0.19	14	1.03	3	1.26
4	0.85	15	0.71	4	1.42

clump nearest to this spot was then observed for the above mentioned features. The height was measured from the ground surface to the transverse mark of the fully open topmost leaf. The measurements of the girth and Brix readings were taken at 1/4, 1/2 and 3/4 heights of the cane. For working out the leaf area, the length and breadth of the leaves were measured. Length was measured from the collar to the tip and the breadth at the widest point of the leaf. The leaf area was then calculated as half of the product of the length and breadth. Six sets of observations were taken on each day of observation. The observations on the sugarcane clumps were taken a day previous to the date of sampling the soil air for carbon dioxide determination. The data collected are given in appendix 1.

3. **Analysis of the data**

The data contained in appendix 1 are subject to two kinds of variation, namely, the systematic variation due to dates (season) and the random variation of the kind referred to earlier in section 1. It is a comparison of these random variations of carbon dioxide and the developmental features of the sugarcane clumps that can reveal the real relationship which may exist between the carbon dioxide of the soil air and the sugarcane clump. It is, therefore, quite essential to eliminate the systematic variation.

In order to eliminate the systematic variation from the data, an analysis of the sum of squares and the sum of products was performed. This analysis has helped to bring out, in a simple manner, the unbiased estimates of the elements constituting the above mentioned relationship.

The detailed analysis is given in Table 2 where the degrees of freedom, the sum of squares and the sum of products, which can be attributed to error, are mentioned. It is this error which gives a reliable estimate of the random variation and hence it has been used here to determine the coefficients of correlation between the carbon dioxide of the soil air and the various observed developmental features of the sugarcane clumps. The correlation coefficients have been worked out according to the following formula—

$$\text{Correlation coefficient} = \frac{\text{Sum of products}}{(\text{Sum of squares of } CO_2 \times \text{sum of squares of other variate})^{\frac{1}{2}}}$$

where, the sums given on the right hand side are taken from the error column of the analysis table.

The significance of the correlation coefficients thus worked out was tested by applying the " t " test. The " ts " were calculated by the formula

$$t = \frac{r}{(1-r^2/(n-1)^{\frac{1}{2}}}$$

where, " r " is the correlation coefficient and " n—1 " represents the degrees of freedom. The degrees of freedom due to error were substituted for " n—1 ". The correlation coefficients and their " ts " are given in Table 3. At the bottom of this table are given the values of " t " which are necessary if the correlation coefficients are to be significant.

TABLE 2

Analysis of the sum of squares and the sum of products for the following variates

(a) CO_2 and the number of canes in the clump

Factors	Degrees of Freedom	Sum of squares for CO_2	Sum of squares for No of canes	Sum of products
Total	89	3.04	420	−2.25
Date	14	2.04	175	−3.62
Error	75	1.00	245	+1.37

(b) CO_2 and the height of the tallest cane of the clump

Factors	Degrees of Freedom	Sum of squares for CO_2	Sum of squares for Height	Sum of Products
Total	89	3.04	8.90	+0.27
Date	14	2.04	3.59	−0.43
Error	75	1.00	5.31	+0.70

(c) CO_2 and the girth of the tallest cane of the clump

Factors	Degrees of Freedom	Sum of squares for CO_2	Sum of squares for Girth	Sum of products
Total	89	3.04	74.4	−0.8
Date	14	2.04	18.7	−0.5
Error	75	1.00	55.7	−0.3

(d) CO_2 and Brix readings of the tallest cane of the clump

Factors	Degrees of Freedom	Sum of squares for CO_2	Sum of squares for Brix	Sum of Products
Total	65	2.48	665.6	−8.6
Date	10	1.82	502.4	−9.1
Error	55	0.66	163.2	+0.5

(e) CO_2 and leaf area of all the fully open green leaves of the clump

Factors	Degrees of Freedom	Sum of squares for CO_2	Sum of squares for Leaf area	Sum of Products
Total	89	3.04	1917.6	−3.7
Date	14	2.04	414.6	−8.8
Error	75	1.00	1503.0	+5.1

TABLE 3

Correlation coefficients

Correlation between CO_2 and the following developmental characters of the sugarcane crop	Correlation coefficients	Calculated values of "t"
Number of canes in the clump	+0.09	0.79
Height of the tallest cane	+0.30	2.85
Girth of the tallest cane	—0.04	0.35
Brix reading of the tallest cane	+0.05	0.37
Leaf area of the clump	+0.13	1.15

Values of "t" for 75 degrees of freedom as obtained from Fisher's Table are 1.99 for $P=0.05$ and 2.64 for $P=0.01$

It will be seen from the table that a significant positive correlation exists between the carbon dioxide of the soil air and the height of the sugarcane plants. The leaf area also shows a fair amount of correlation with the soil air carbon dioxide, but it falls short of the 5 per cent level of significance. Other characters, however, do not show any marked correlation with carbon dioxide.

It will be clear, therefore, that the greater amounts of carbon dioxide in the soil air are associated with taller plants. A tendency for greater amounts of carbon dioxide to be associated with greater foliage development is also suggested by the present study.

4. The results of a pot-culture experiment conducted to study the response of cotton plants to additional supply of carbon dioxide through irrigation water

The experiment for the above study was in progress during the period of April to September 1943. The experiment was done on cotton plants. Plants were grown in glass vessels containing about six pounds of the local black cotton soil. The soil in the vessels rested on a two-inch layer of pebbles. Glass tubes running through the soil and resting over the pebbles used to provide water at the bottom of the vessels from where it could rise into the soil through capillarity. Seeds were directly sown in the vessels. The seedlings were thinned to one in each vessel a few weeks after germination.

Carbon dioxide dissoved in water was supplied to the soil by irrigation. To minimise the escape of the gas supplied the soil surface was kept completely covered by means of rubber cloth allowing only the glass tubes and the plant to come out. The top ends of the glass tubes were corked. The experiment consisted of two treatments—(1) The soil was irrigated with plain water, (2) Water fully saturated with carbon dioxide, *i.e.*, with as much carbon dioxide as it could hold in solution at the prevailing temperature was used for irrigation. The quantity of water supplied to the soil was the same in both the treatments.

The observations on plants consisted of the measurements of height and leaf area. The height was measured from the surface of the rubber cloth to the tip of the topmost bud. For finding out the leaf area, a factor was first worked out. The length from the point of attachment of the petiole to the tip of the topmost lobe and the breadth between the tips of the two opposing lowest lobes were measured. The area was then calculated as half the product of the length and the breadth, assuming the leaf to be a triangle. The area of the same leaf was also directly found out by using squared paper. The ratio between this and the former evaluation gave a factor which could be used to obtain the leaf area from the length and the breadth measurements.

There were seven pots per treatment. Each pot had a single cotton plant. Plants were sown in the pots on 25 March 1943 and the supply of carbonated water was started from 24 April 1943. In all, the plants were irrigated eight times (during the period May to September) and the total amount of carbon dioxide administered was 1500 cc.

The mean height and leaf area, recorded periodically before and after the treatment, are given in Table 4. Table 4 also contains the critical differences at $P=0.05$ for both the features observed. The height and leaf area of the control and treated plants are also shown graphically in Figs. 1 and 2 respectively. The figures clearly show that

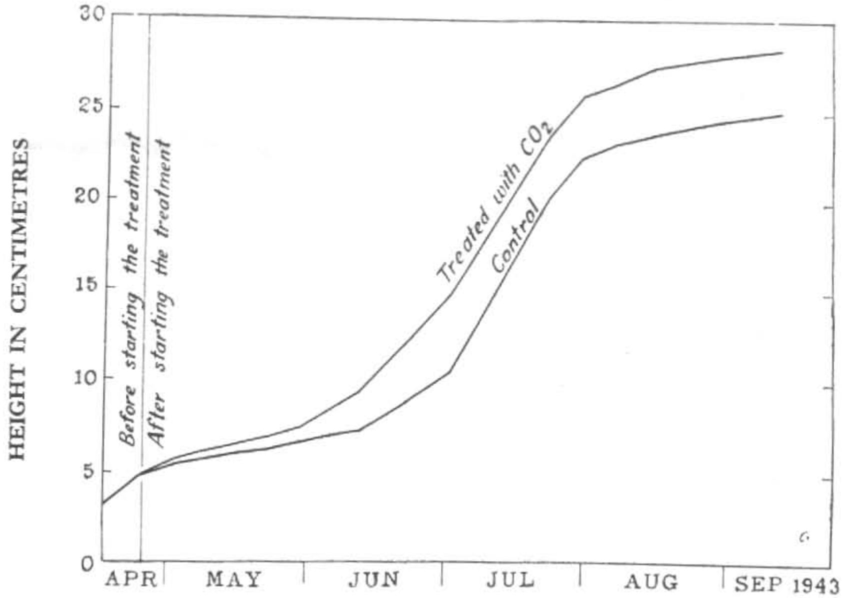

Fig. 1. Height of cotton plants as affected by carbon dioxide administered through irrigation water

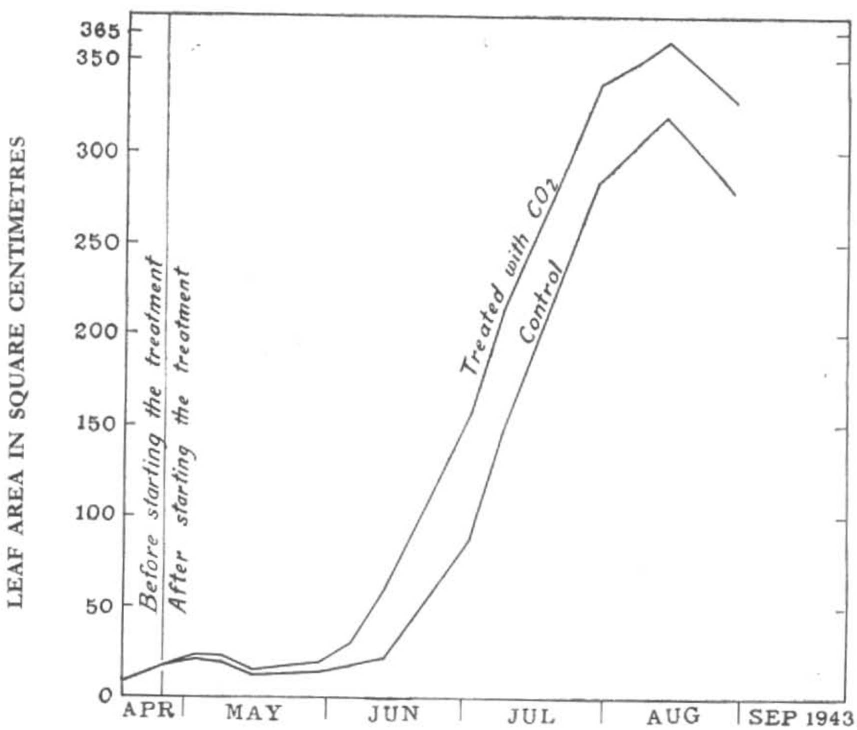

Fig. 2. Leaf area of cotton plants as affected by carbon dioxide administered through irrigation water

the plants which had received carbon dioxide in irrigation water have been taller and have developed more foliage than those which did not receive any such treatment. A reference to Table 4 would further show that the differences between the control and treated plants have been statistically significant between 5 June 1943 and 16 July 1943 as far as height is concerned and between 1 and 16 July 1943 as far as the leaf area is concerned.

Carbon dioxide supplied to the plants in the above manner can be helpful to them only in two ways. It can be made available for photosynthesis by being transported into the foliage through the transpiration stream [2-4]. It can also render many of the otherwise insoluble ingredients of soil into soluble forms and thus make more food available to the plants. To what extent the carbon dioxide can be helpful to plants by rendering more food available to them can be seen from the following simple experiment.

5. The solvent action of carbon dioxide

The main requirements of the plants are nitrogen, potassium and phosphorus. An experiment was performed to compare the solvent effects of plain water and water fully saturated with carbon dioxide on the black cotton soil of Poona. Weighed quantities of air-dry soil were shaken for half an hour with ordinary water and with water saturated with carbon dioxide. The soil extracts thus obtained were chemically analysed in duplicate for nitrogen, phosphorus (P_2O_5) and potash (K_2O). Nitrogen was estimated by the Kjeldahl's process, while P_2O_5 and K_2O by colorimetric method[5]. The results obtained are given in Table 5. It will be

TABLE 4

The effect of carbon dioxide on the growth of cotton plants

Date	Mean height of cotton plants (cm) Irrigated with: Plain water 1	Water saturated with CO_2 2	Difference (2—1)	Critical difference at P=0.05	Mean leaf area of cotton plants (sq cm) Irrigated with: Plain water 1	Water saturated with CO_2 2	Difference (2—1)	Critical difference at P=0.05
			Before starting the treatment					
16-4-43	3.1	3.1	0.0	0.3	8.2	9.3	1.1	2.6
24-4-43	4.6	4.7	0.1	0.6	16.1	17.2	1.1	4.3
			After starting the treatment					
1-5-43	5.4	5.6	0.2	0.7	20.6	21.9	1.3	6.4
8-5-43	5.6	6.1	0.5	0.7	19.0	21.6	2.6	9.1
15-5-43	5.9	6.5	0.6	0.7	11.7	14.1	2.4	4.3
22-5-43	6.2	6.9	0.7	0.8	13.9	16.1	2.2	3.3
29-5-43	6.7	7.5	0.8	0.9	14.4	17.9	3.5	6.5
5-6-43	7.1	8.5	1.4*	1.2	16.2	29.6	13.4	14.4
12-6-43	7.4	9.6	2.2*	1.9	20.3	58.1	37.8	38.1
1-7-43	10.6	14.8	4.2*	3.3	89.5	156.8	67.3*	66.5
8-7-43	13.5	18.1	4.6*	3.8	144.2	216.3	72.1*	69.9
16-7-43	17.1	21.9	4.8*	4.1	196.8	277.7	80.9*	78.5
23-7-43	20.1	23.6	3.5	4.2	240.7	299.0	58.3	82.9
30-7-43	22.5	25.8	3.3	4.9	285.6	338.4	52.8	88.8
6-8-43	23.1	26.5	3.4	5.0	305.6	351.1	45.5	86.7
14-8-43	23.7	27.4	3.7	5.6	321.4	362.7	41.3	91.3
29-8-43	24.5	28.0	3.5	6.8	277.7	329.4	51.7	69.8
12-9-43	25.0	28.4	3.4	6.4	—	—	—	—

* significant at 5% level

noted that the water saturated with carbon dioxide extracts nearly 4 times more P_2O_5 and 2 times more K_2O than plain water. Thus the increase noticed in height and leaf area of the plants may partly be due to more plant food being liberated as a result of the action of carbon dioxide on soil particles in the presence of the soil moisture.

TABLE 5

A comparison of the solvent action of plain and carbonated water

Extracted by	Quantity extracted out from 100 gm of air-dry Poona soil (mgm)		
	N	P_2O_5	K_2O
Water	54.6	2.36	0.50
Water with CO_2	55.3	9.30	1.09

6. Conclusion

The paper discusses the results of a study on carbon dioxide content of the soil air carried out in a sugarcane field. It also discusses the results of a pot-culture experiment where the effect of carbon dioxide, supplied through irrigation water, on the height and leaf area of cotton plants was studied.

It was shown in the beginning that there was a good deal of variation in the carbon dioxide content of the soil air from place to place in the same field. The question then raised was whether such variations in the carbon dioxide concentration were in any way related to the general stand of the sugarcane plants. During the course of the foregoing discussions it has been shown that the carbon dioxide of the soil air is correlated with the height of the sugarcane plants—the greater the amount of carbon dioxide in the soil, the greater is the height of plants. There also exists a tendency of greater amounts of carbon dioxide being associated with larger foliage development.

The pot-culture experiment was performed on cotton plants. The results of this experiment have shown that the administration of carbon dioxide through irrigation water stimulates plant growth. Plants receiving the carbon dioxide in the said manner tend to be higher and develop more foliage. This has been shown to be at least partly due to the liberation of more available nutrients in the soil by the solvent action of carbon dioxide.

7. Acknowledgement

The author expresses his deep sense of gratitude to Dr. L.A. Ramdas under whose guidance the work had progressed. The author is also thankful to Director General of Observatories for permission to work in the Agricultural Meteorology Section of the India Meteorological Department. The author's thanks are due also to Mr. V. K. Ramabhadran of the Agricultural Meteorology Section for his assistance and interest in the statistical portion of the work and to the Principal, Professor and the Agricultural Chemist of the local Agricultural College for affording facilities for work.

REFERENCES

1. Misra, R.K., *Ind. J. Met. Geophys.*, **1**, 4, pp. 275-86 (1950).

2. Miller, E.C., *Plant Physiology*, 454-55 (1931).

3. Bergamschi, Maria. Atti Bot. " Grovanni Briosi " e Lab. Crittogam, Ital. Univ. Pavia 1 :117-149 (Biol. Abstr. **6**, 8—9, para 18387).

4. Hartel, Otto. Jahrb. Wiss, Bot. 87 (2/3) : 173-210 (Biol. Abstr. **13**, 7, para 12083).

5. Second Int. Congr. Soil Sci. Leningrad —Moscow, USSR, 194-5, 198-200.

APPENDIX I

Data collected in the 1942-43 sugarcane crop to study the relationship between the soil air CO_2 and the developmental features of the sugarcane plants

Date	Mean CO_2 %	No. of canes in the clump	Height of the tallest cane of the clump in hundred cm	Mean girth of the tallest cane of the clump in cm	Mean Brix reading of the tallest cane of the clump	Total area of all the fully open green leaves of the clump in thousand sq cm
7-10-42	0.6	9	2.7	10	—	20
	0.5	8	2.7	10	—	17
	0.4	6	1.5	9	—	7
	0.5	7	2.8	10	—	11
	0.6	9	2.8	9	—	14
11-10-42	0.5	6	2.8	11	—	10
	0.5	6	2.7	8	—	8
	0.5	6	2.5	9	—	10
	0.5	5	2.6	10	—	14
	0.4	4	2.8	8	—	7
	0.5	8	2.8	9	—	18
15-10-42	0.9	4	2.7	8	—	7
	0.4	10	2.4	9	—	13
	0.9	6	2.5	9	—	10
	0.8	1	2.7	8	—	4
	0.8	9	2.7	8	—	13
	0.5	4	2.3	9	—	8
19-10-42	0.7	5	2.5	9	—	10
	0.6	7	2.8	8	—	13
	0.6	4	2.8	9	—	8
	0.5	4	2.5	10	—	5
	0.5	5	2.5	9	—	10
	0.8	8	2.6	9	—	20
24-10-42	0.9	7	2.9	10	13	15
	0.9	4	2.7	10	10	10
	0.7	5	2.7	8	11	8
	0.9	3	2.8	9	12	5
	0.9	3	2.3	9	8	4
	0.9	4	2.5	8	11	6
28-10-42	0.8	3	3.1	9	12	7
	0.5	2	2.4	8	10	5
	0.7	2	2.6	8	9	3
	0.9	3	2.8	8	13	6
	0.8	8	2.7	7	12	12
	0.8	4	2.8	7	13	9
16-11-42	0.6	3	3.2	8	13	9
	0.4	6	2.9	8	13	17
	0.6	5	3.1	8	14	13
	0.6	4	2.8	9	12	9
	0.3	4	2.3	7	11	8
	0.4	3	2.6	9	13	4

APPENDIX I—(Contd.)

Date	Mean CO_2%	No. of canes in the clump	Height of the tallest cane of the clump in hundred cm	Mean girth of the tallest cane of the clump in cm	Mean Brix reading of the tallest cane of the clump	Total area of all the fully open green leaves of the clump in thousand sq cm
23-11-42	0.8	2	3.0	9	11	7
	0.5	2	3.0	9	13	7
	0.5	3	3.0	8	14	8
	0.5	1	2.6	8	12	2
	0.5	3	2.5	8	12	6
	0.5	2	3.0	8	12	4
27-11-42	0.7	5	3.4	8	15	12
	0.8	3	2.3	7	10	5
	0.5	1	2.5	8	10	3
	0.5	5	2.7	9	13	12
	0.5	5	3.1	9	12	14
	0.5	4	3.1	8	13	8
29-12-42	1.0	4	3.0	8	15	10
	0.9	2	2.8	7	15	6
	0.9	1	2.9	9	15	2
	0.9	3	2.9	9	16	7
	1.0	2	2.5	7	12	3
	0.7	2	2.8	9	18	6
2-1-43	0.9	3	3.3	8	19	9
	0.9	3	3.1	9	16	8
	0.9	4	3.0	7	19	7
	0.6	3	3.3	9	19	7
	0.8	2	3.0	8	19	5
	0.7	7	3.3	9	17	22
14-1-43	0.5	6	3.2	8	18	18
	0.7	4	3.4	10	18	10
	0.7	3	2.9	8	19	6
	0.6	2	3.1	8	18	5
	0.5	2	2.6	6	14	3
	0.7	8	3.2	9	17	22
19-1-43	0.5	8	3.2	9	18	15
	0.6	7	3.2	8	17	15
	0.4	3	2.6	8	17	7
	0.4	2	3.0	8	16	5
	0.5	2	2.8	8	19	5
	0.5	3	3.1	8	18	8
30-1-43	0.7	4	3.2	8	19	7
	0.5	5	3.2	8	17	14
	0.5	2	2.9	6	13	2
	0.4	2	2.9	8	17	4
	0.5	2	2.9	10	17	5
	0.4	2	3.0	9	18	5
4-2-43	0.4	4	3.1	9	18	8
	0.4	2	2.6	8	13	4
	0.3	4	3.0	8	19	9
	0.4	5	3.1	9	18	12
	0.4	3	3.5	9	21	10
	0.4	3	3.1	7	19	6