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RESPIRATORY RELEASE OF CO_2 IN ALFALFA AND SOYBEAN UNDER FIELD CONDITIONS*

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ABSTRACT

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Respiration rates under field conditions in the above-ground portions of alfalfa and soybean crops (dark respiration) as well as root and soil respiration rates were measured at night using an open-flow system. Alfalfa was observed in 1978 and soybeans during 1979 and 1980.

Full-crop respiration rates (above-ground, root and soil) of alfalfa ranged from 278 to 855 mg CO_2 m^{-2} h^{-1}, with an overall average of 531 mg CO_2 m^{-2} h^{-1}. Full-crop respiration rates of soybeans ranged from 207 to 984 mg CO_2 m^{-2} h^{-1} in 1979 and 303 to 998 mg CO_2 m^{-2} h^{-1} in 1980. In the period of flowering and pod set, the overall average full-crop soybean respiration rate was 524 mg CO_2 m^{-2} h^{-1} in 1979 and 627 mg CO_2 m^{-2} h^{-1} in 1980. In alfalfa, soil plus roots contributed about 63% of the total CO_2 release. Respiration of aerial parts was between 87 and 93% of the total plant respiration of soybeans (depending on year) with soil plus roots contributing the remainder.

INTRODUCTION

Respiratory release of carbon dioxide from the soil and from the aerial parts of plants must be measured accurately before a complete carbon balance can be established for an agricultural field or an unmanaged ecosystem. Such measurements are also essential in estimating the respiratory contributions of CO_2 from agricultural regions to the global carbon balance.

A wide range of respiration rates has been reported in the literature. Respiration rates in agricultural soils have been variously estimated from 20 to 492 mg CO_2 m^{-2} h^{-1} (Lundegardh, 1927; Moss et al., 1961; Monteith, 1962; Monteith et al., 1964; Brown and Rosenberg, 1971; de Jong and Schappert, 1972; Sale, 1974; Biscoe et al., 1975; Denmead, 1976; Saugier, 1976; Uchijima, 1976; Mogensen, 1977). Only a few measurements of the respiration rates of aerial parts of crops have been made under field conditions. These report a range of respiration rates from 210 to 1340 mg CO_2 m^{-2} h^{-1} (Monteith, 1962; Brown and Rosenberg, 1971; Sale, 1974; Denmead, 1976; Mogensen, 1977).

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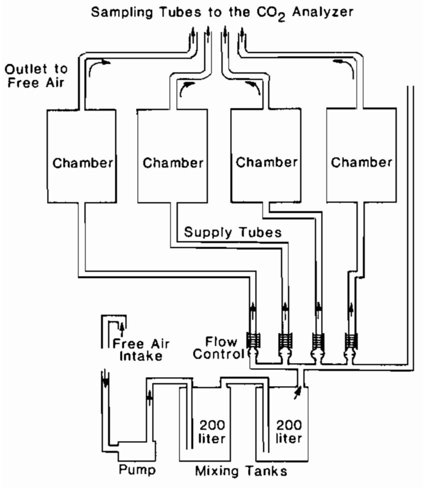


Fig. 1. Air flow and CO_2 concentration sampling system used for study of plant and soil respiration in the field.

The primary objective of the study reported here was to provide information required for the evaluation of the carbon balance of two important agricultural crops. Full-crop respiration rates for alfalfa and soybeans were studied and the relative contributions of their aerial parts and of the soil, including roots, to the total plant respiration were assessed.

MATERIALS AND METHODS

Field and crops

This study was conducted at the University of Nebraska Agricultural Meteorology Laboratory near Mead, Nebraska (41°09′N; 96°30′W; 354 m above mean sea level) during the growing seasons of 1978, 1979 and 1980. Soil in the field is Sharpsburg silty clay loam. The experimental field has an area of 2.21 ha (210 m N—S × 105 m E—W). Measurements of respiration rate were made in the northeast corner of the field. Alfalfa (*Medicago sativa* (L.), cv. Dawson) was grown in 1978. Soybeans were grown in 1979 (cv. Clark) and in 1980 (cv. Harosoy). In both years, soybeans were planted in 0.75-m rows oriented north—south. Alfalfa was irrigated weekly during the period of observation. The soybeans were irrigated once after planting in 1979. The 1980 crop was not irrigated. Additional data on plant growth for both crops are given in Baldocchi (1979 and 1982).

The chambers

Respiration rates from bare soil, soil plus roots and full crop (soil + roots + aerial parts) were measured with an open-flow chamber system originally

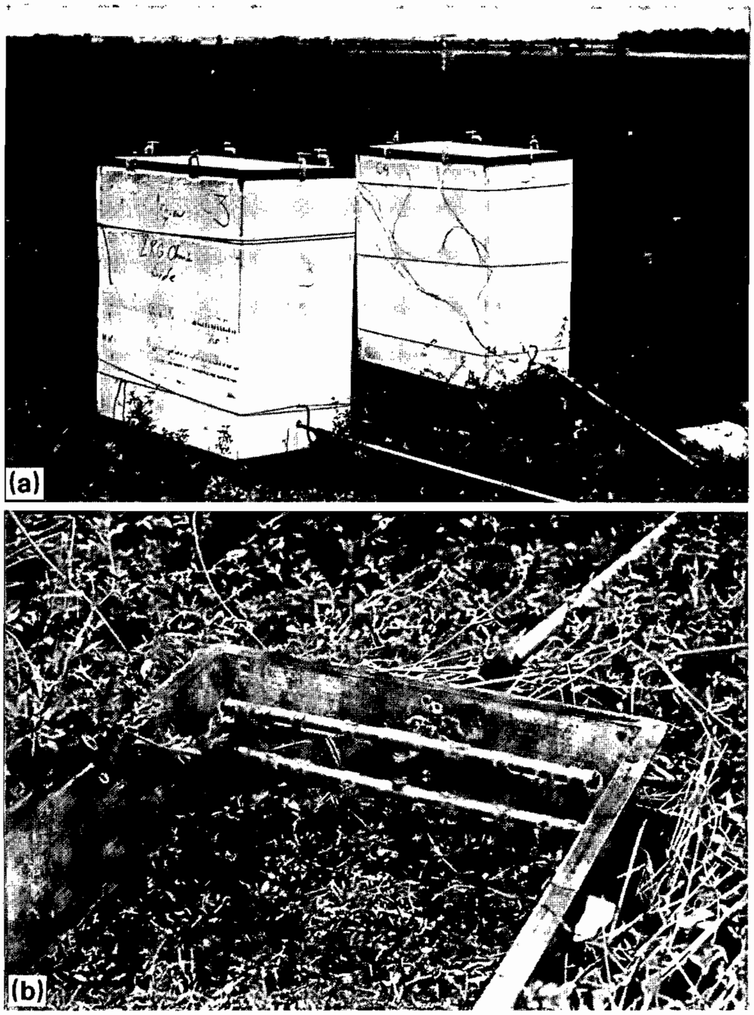


Fig. 2. Large chambers (a) used for measurement of whole crop respiration; a small chamber (b) used for measurement of soil-plus-root respiration, shown shortly after excision of the alfalfa plants and before sealing of the chamber.

designed by Mogensen and Rosenberg (1972). The term "full-crop" respiration includes the dark respiration of the above-ground portions of the canopy, the root respiration and the CO_2 release by decomposition of soil organic matter — all at ambient temperature conditions. Figure 1 is a schematic diagram of the air flow and CO_2 concentration sampling arrangement of the system. The free air intake was set at a height of 2 m. Four large chambers of the type shown in Fig. 2a, which were made of galvanized steel with removable tops and open at the bottom, were used for separate measurement of the full-crop and of soil-plus-root respiration rates.

The large chambers are made of three parts: a cover, a rectangular wall with projecting rims (flanges) open at the top and bottom and a base. The large chambers are 0.91 x 0.51 x 1.02 m high. The base is 0.91 x 0.51 by 0.20 m high. The bottom of the base is sharpened for easy insertion into the soil. A projecting rim with gasket on the base is identical with the bottom rim of the chamber so that they can be bolted together. A sealable port in the base allows insertion of a thermocouple into a chamber. In order to avoid exchange between the air inside and outside the chamber, the edges of the lower part of the chamber were pressed about 0.10 m into the soil. After that, the upper part of the chamber was fitted to the projecting rim and gasket on the lower part and bolted. Soil was spread around the chamber to provide a good seal between the chamber and the soil surface. In operation, the cover was clamped tightly to the gasketed rim on the top of the chamber.

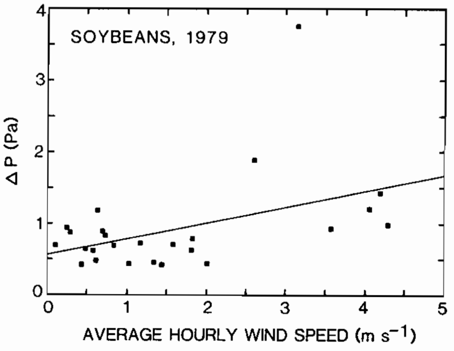
Additionally, four small chambers (0.61 x 0.41 x 0.20 m high) were used to measure respiration rates on soil from which the plants had been cut off at ground level (Fig. 2b) and on soil in which roots had previously been killed. These chambers were comprised essentially of the bases and lids used in the larger chambers. In these configurations the chambers provided information on respiration rates from soil plus roots and from bare soil only.

Sides of the large chambers and the lids of both small and large chambers were insulated with 15-mm styrofoam pads. Before sealing the lids on the chambers, a thin layer of stopcock grease was applied on the rubber gasket of the chamber rims. In the small chambers, thermocouples were installed by inserting the wire between the rim and lid. Twelve C-clamps equally distributed around the lid were used to fasten the lid to the rim. To minimize the effects of wind variations on pressure differences between the inside and outside of the chambers, a 1-m open-ended pipe was connected to the outlet of each chamber.

Ambient air was drawn continuously from a height of 2 m into two 200-l tanks connected in series. There it was mixed to decrease variation in CO_2 concentration before transport under pressure to the chambers. A constant flow rate of $10\,l\,min^{-1}$ was maintained into each chamber. A manifold containing valves and flow meters was installed at the outlet of the second mixing drum to control the flow of air to the four chambers (Fig. 1).

The manifold was connected to the chambers through 15-mm I.D. aluminum pipes. The air entered the chambers and was distributed through a two-level manifold 0.03 and 0.1 m above the soil in the small chambers. In the large chambers, air was distributed by a three-level manifold at 0.3, 0.6 and 0.9 m above soil level. The manifolds, made of copper, were 0.3 m long and 10 mm in diameter with 10 equally spaced horizontal openings of 5 mm diameter on each line.

The difference in the air pressure within and outside of the chamber was measured with a Setra Systems, Inc., Model No. 239 pressure transducer during the 1979 and 1980 growing seasons. These measurements were made sequentially in all chambers each hour during the course of an



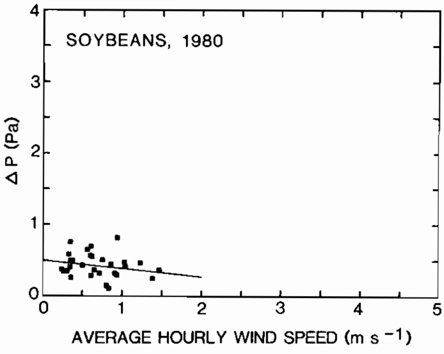


Fig. 3. Effect of wind speed on difference in pressure between the inside of the chamber and the ambient air. Mead, NE, 1979.

Fig. 4. Effect of wind speed on difference in pressure between the inside of the chamber and the ambient air. Mead, NE, 1980.

experimental run. Ten consecutive readings were made hourly in each chamber.

In 1979, the nocturnal average of pressure difference in large chambers covering the plants was 1.19 ± 0.97 Pa. During the same period, the pressure difference in small chambers used for measurement of soil-plus-root respiration was 2.12 ± 1.35 Pa. The pressure difference in large chambers covering the plants during 21 July to 27 August 1980 was 0.41 ± 0.10 Pa — about half of that measured in 1979. Large chambers were also used to measure soil-plus-root respiration from 21 July to 27 August 1980. Then the nocturnal average pressure difference was 0.35 ± 0.12 Pa. Measurements of pressure difference in small chambers over bare soil and over soil plus roots were made four times during the period 18 July—7 September 1980. Pressure difference was 0.48 ± 0.28 Pa, similar to the values found for large chambers in 1980.

The difference noted in ΔP between 1979 and 1980 may have been related to ambient wind speed. The effects of wind on ΔP are illustrated in Figs. 3 and 4. A correlation of $r^2 = 0.18$ was observed in 1979, when averaged hourly wind speed ranged from 0.1 to 4.3 m s^{-1} with a mean of 1.6 m s^{-1}. The correlation between ΔP and wind speed was even worse ($r^2 \approx 0.04$) in 1980, when average hourly wind speed varied from 0.2 to 1.5 m s^{-1}, about half of the wind speed observed in 1979. Figures 3 and 4 appear to indicate that the effect of wind speed on pressure difference is much less noticeable at low wind speeds (< 2.0 m s^{-1}) than at higher wind speeds.

Kanemasu et al. (1974) reported that positive pressures of the order reported above were sufficient to lower measured CO_2 flux rates from a soil surface by an order of magnitude as compared to those from a soil under suction. We endeavored to maintain as small a positive pressure as possible within the chambers, recognizing that suction might entrain CO_2 from soil outside the chambers. Pressure differences encountered during the 1980 growing season, particularly, should not have influenced our results unduly. This would be particularly true for the respiratory component from the above-ground portions of the crop that contribute the largest share to the total CO_2 flux. Significant errors in the soil emission rate cannot be totally ruled out, however.

Chambers were moved to new locations after no more than two consecutive days of observation.

CO_2 analysis

Air was continuously sampled for CO_2 concentration analysis at the exhaust of the second mixing tank and at the outlet of each chamber. The samples were drawn under vacuum through 6-mm I.D. PVC tubing at a flow rate of $3 \, l \, min^{-1}$ to a point about 40 m distant from the chambers. There the sampling lines were connected to an underground tubing bundle through which the air was pumped into the laboratory. Attempts were made to minimize condensation in the underground tubing bundle by circulating hot water in two unused tubes of the bundle.

Two infra-red gas analyzers (IRGA) (Beckman Instruments, Inc., Fullerton, CA, U.S.A.; Models 315 A and 315 B) were used for determination of CO_2 concentration [CO_2]. Air from each line was mixed continuously in its own tank to provide a time-averaged sample. In order to provide additional protection against interference from water vapor, optical filters that cut off radiation outside the 3.8—5.7 μm wave band were used in the IRGAs. Water vapor is transparent to this waveband, but CO_2 is absorptive. [CO_2] in the chambers was measured differentially according to a technique described by Rosenberg and Verma (1976). The absolute [CO_2] of air drawn from the height of 2 m was measured with one of the IRGAs. The second IRGA measured the difference in [CO_2] between the reference air and a chamber sample. Subsequently, differences between chamber samples were measured sequentially.

The IRGAs used for absolute and differential analyses were automatically calibrated hourly with laboratory standard gases. Our primary laboratory standard gases are calibrated by the National Oceanic and Atmospheric Administration (NOAA) in Boulder, Colorado. Secondary standards used in routine calibration were calibrated against the known CO_2 concentrations of the primary laboratory standards.

Calculation of the respiration rate

The respiration rate is calculated as the product of the flow rate of air passing through the chamber and the [CO_2] enrichment that occurs:

$$R = \frac{(K)(F)\Delta CO_2}{A} \qquad (1)$$

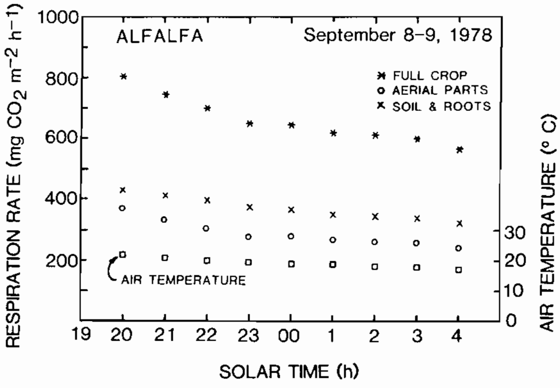


Fig. 5. Hourly mean respiration rate in an alfalfa field (mg CO_2 m^{-2} h^{-1}); full crop, aerial parts and soil plus roots. Hourly mean air temperature within the large chamber is also shown. Mead, NE, 1978.

where R is the respiration rate, K is a factor converting CO_2 from volumetric to mass units, F is the air flow rate through the chamber, ΔCO_2 is the difference in $[CO_2]$ of the air stream before and after passing through the chamber and A is the area of ground surface covered by the chamber. In 1978 and 1979, air streams were analyzed for $[CO_2]$ every 5 min and in 1980 every 7.5 min. The data were merged to produce averages representing the first 45 min of each hour. The last 15 min of each hour were used for calibrations.

measure air temperature at a single height (50 mm in the small chambers and 0.5 m in the large chambers). Soil temperature was measured at depths of 30 and 100 mm. Temperature measurements were made twice hourly and averaged for each hour.

RESULTS AND DISCUSSION

Alfalfa

Nocturnal patterns

Rates of respiration by alfalfa were measured on 9 nights during the period 8 August—9 September 1978. Typical nocturnal patterns of dark respiration rates for full crop, aerial parts and soil plus roots of alfalfa are presented in Fig. 5 for the night of 8—9 September. Simultaneous measurements of air temperature within the chambers are also shown in this figure. Except for some short-term fluctuations, respiration rates generally decreased with time, in phase with decreasing air temperature. The dependency of respiration rate on temperature is well documented in the literature. The coefficient Q_{10} ranged from 1.4 to 2.2 when the average air temperature varied from 19.1 to 24.4°C. The average Q_{10} was 1.9, corresponding to an average air temperature

TABLE I

Full-crop respiration rates of alfalfa and air temperature in the respiration chamber

Date in 1978	Chamber air temperature (°C)			Mean full-crop respiration rate ($mg\ CO_2\ m^{-2}\ h^{-1}$)
	Min.	Max.	Mean	
Aug. 09	18.5	19.4	18.8	590
Aug. 10[a]	18.7	22.3	20.1	753
Aug. 16	20.4	23.4	21.9	317
Aug. 17	22.8	27.0	24.6	305
Aug. 21	21.2	25.2	23.0	611
Aug. 24	21.1	22.6	21.9	432
Sept. 02	18.4	22.1	19.9	458
Sept. 05	20.0	23.3	22.0	655
Sept. 09	17.1	21.6	19.1	661

[a]Harvest on August 11.

TABLE II

Mean and range of respiration rates for alfalfa (1978)

	Respiration rates ($mg\ CO_2\ m^{-2}\ h^{-1}$)	
	Mean	Range
Full crop	531	278—855
Aerial parts	187	24—415
Soil plus roots	344	145—478
Bare soil	20	12—29
Roots	324	—

of 21.8°C. The average Q_{10} reviewed by Forward (1960) for different plant organs between 15 and 25°C was 1.98. No data for alfalfa were included in Forward's calculation.

Rates of respiration were always greatest when measurement began, usually at around 20 h solar time. At the end of each experimental run (about 4 h solar time), respiration rates were lowest. Maximum respiration rates of 855 and 415 mg CO_2 m^{-2} h^{-1} for full crop and aerial parts, respectively, were observed at 20 h solar time on 10 August.

Influence of harvest

Table I is a listing of mean hourly full-crop respiration rates and air temperature in the chambers during 1978. Respiration rates were much greater at the end of the alfalfa cropping cycle than early in the cycle, especially for full-crop and aerial parts. Respiration rates decreased to a minimum after the alfalfa was harvested on 11 August and increased, thereafter, with regrowth of the crop.

Contribution of soil, roots and aerial parts to the total crop respiration

The mean and range of nocturnal alfalfa respiration rates are given in Table II. Roots contributed about 63% of the total full-crop respiration while the aerial parts contributed about 35%. Thomas and Hill (1937) measured respiration rates of alfalfa and sugar beets during day and night. The aerial parts of alfalfa contributed 52.5% of the total plant respiration. However, when only the nocturnal data were considered, the contribution due to the aerial parts was between 34 and 51% with an average of 43% of the total plant respiration. Based on nocturnal measurements only, Thomas and Hill (1937) found the contribution of the aerial parts of sugar beet to the total plant respiration to be about 50%. However, when respiration data from day and night were included, aerial parts contributed 62% of the total plant respiration.

In laboratory studies with beans, Monteith (1962) found, on one day when the crop was growing vigorously, that root respiration was about 43% of the respiration of aerial parts. One month later when vertical growth had ceased, he found root respiration to be only 10% of the respiration of the aerial parts.

Mogensen (1977), using an open-flow system similar to ours, found root respiration in barley to be about five times less than the respiration rate of the aerial parts. In ryegrass, however, it was 60% as great as the respiration of the aerial parts. Based on changes of root dry weight in a barley crop, Biscoe et al. (1975) concluded that root respiration contributed about 50% of the total CO_2 emitted from the soil.

Considering the relative contribution of bare soil and fresh roots to the overall respiration rate, our results show that alfalfa roots provide the largest share of the CO_2 released from the soil — contributing about 94% of the total of the soil-plus-root respiration. One may properly question whether the roots of excised plants respire at the same rate as if uncut. Certainly, when respiratory substrate has been consumed, this will not be the case. Excision occurred shortly before observations began in the early evening. Observations continued during the night when no additional substrate would be provided the roots by photosynthesis. Since CO_2 release rates did not drop precipitously and since the root component was much greater than the soil component, these "snapshot" observations should provide a reasonable approximation of root respiration. More refined techniques are obviously needed if greater accuracy is to be achieved.

Soybeans

Nocturnal patterns

Soybean respiration rates were measured on 12 nights during the period 6 August—16 September 1979 and on 11 nights between 21 July and 4 September 1980. Summaries of the data on air temperature, wind speed, pressure difference between the interior of the chamber and the ambient air,

TABLE III

Nocturnal mean hourly full-crop respiration rate in soybean and concurrent environmental conditions, 1979

Date	Full-crop respiration rate ($mg\ CO_2\ m^{-2}\ h^{-1}$)	Chamber air temperature (°C)			Mean wind speed at 2 m ($m\ s^{-1}$)	Pressure difference (Pa)	Soil water content (% by vol.)
		Min.	Max.	Mean			
Aug. 06	588	23.5	26.2	24.8	2.89	—	20.2
Aug. 08	582	24.5	28.8	26.0	3.42	1.14	19.7
Aug. 10	444	11.5	19.8	14.1	0.49	0.59	20.0
Aug. 13	318	15.9	18.9	16.8	1.61	0.72	18.4
Aug. 15	397	14.2	14.9	14.4	1.67	0.44	16.9
Aug. 17	399	18.8	21.9	20.6	0.65	0.71	15.4
Aug. 20	493	18.2	22.4	20.0	1.17	0.67	14.2
Aug. 23	308	9.8	16.0	12.3	0.28	0.97	15.3
Aug. 31	905	20.2	23.8	21.4	2.79	2.81	24.5
Sept. 03	821	18.6	21.8	20.1	—	0.95	22.9
Sept. 08	631	15.0	18.8	16.7	—	3.37	19.3
Sept. 15	399	7.7	11.8	9.4	—	0.74	16.2

TABLE IV

Nocturnal mean hourly full-crop respiration rate in soybean and concurrent environmental conditions, 1980

Date	Full-crop respiration rate (mg CO_2 m^{-2} h^{-1})	Chamber air temperature (°C)			Mean wind speed at 2 m ($m\ s^{-1}$)	Pressure difference (Pa)	Soil water content (% by vol.)
		Min.	Max.	Mean			
July 21	362	13.7	18.4	15.6	0.97	0.34	16.6
July 23	479	17.1	22.8	19.2	0.79	0.33	16.3
July 29	645	23.8	26.7	25.0	—	0.51	16.7
July 31	448	18.3	21.2	20.0	—	0.58	16.6
Aug. 06	670	23.8	27.5	25.2	—	0.52	18.6
Aug. 11	588	16.3	19.0	17.4	0.37	0.49	30.5
Aug. 13	928	21.0	22.3	21.6	—	1.64	31.4
Aug. 18	878	21.4	24.1	22.8	1.29	0.51	32.5
Aug. 20	650	14.7	17.8	16.0	—	0.53	33.3
Aug. 27	753	18.0	18.4	18.2	1.01	0.28	29.4
Sept. 04	496	15.9	20.6	18.2	0.74	0.50	22.4

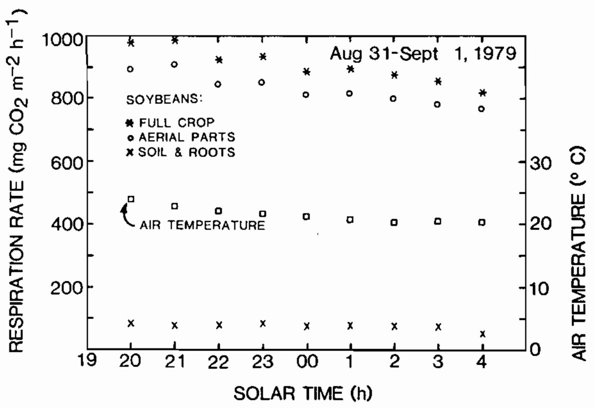


Fig. 6. Hourly mean respiration rate in a soybean field (mg CO_2 m^{-2} h^{-1}); full crop, aerial parts and soil plus roots. Hourly mean air temperature within the large chamber is also shown. Mead, NE, 1979.

soil water content, and hourly mean full-crop respiration rate are presented in Tables III and IV for 1979 and 1980, respectively.

Representative nocturnal patterns of dark respiration rate for full crop, aerial parts and soil plus roots of soybeans are shown in Fig. 6. As with alfalfa, the respiration rate of soybeans also decreased with decreasing temperature. Nocturnal mean hourly full-crop respiration rates are shown in Tables III and IV for 1979 and 1980, respectively. The actual maximum hourly rates were 984 and 998 mg CO_2 m^{-2} h^{-1} in 1979 and 1980 (not shown in the tables). These maxima were observed at the corresponding hourly mean air temperatures of 22.8 and 24.1°C. In 1979, the coefficient Q_{10} ranged from 1.7 to 3.4 within the air temperature interval 9.7 and 26.3°C. The average Q_{10} was 2.4, corresponding to an average air temperature of 19.1°C. In 1980, Q_{10} varied from 1.7 to 2.4 within the range of average air temperature of 15.6—25.6°C. The average Q_{10} was 2.0 at an average air temperature of 20.6°C. These Q_{10} values are in good agreement with the values reported by Buchanan and Fulmer (1930) and Forward (1960).

The concurrent soil water contents — 24.5 and 32.5% by volume — were among the highest observed in each year. The lowest nocturnal mean hourly full-crop respiration rates were 207 and 303 mg CO_2 m^{-2} h^{-1} in 1979 and 1980, respectively. Both rates were observed at 04 h solar time when air temperatures were low (9.8°C in 1979 and 13.7°C in 1980).

Soil water content by volume was also quite low on these nights (15.3% in 1979 and 16.6% in 1980).

Contribution of soil, roots and aerial parts to the total crop respiration

The range of nocturnal respiration rates for soybeans in 1979 and 1980 is summarized in Tables III, IV and V. As shown in another contribution (DaCosta et al., 1986), low respiration rates occurred in soybeans when air

TABLE V

Mean and range of respiration rates for soybean (1979 and 1980)

	Respiration rates (mg CO_2 m^{-2} h^{-1})			
	Mean		Range	
	1979	1980	1979	1980
Full crop	524	627	207—984	303—998
Aerial parts	466	494	155—905	291—673
Soil plus roots	58	122	13—90	12—356
Bare soil	23	45	13—34	9—96
Roots	35	77	—	—

temperature and soil water content were low and high respiration rates occurred when air temperature and soil water content were high. This was especially true for respiration rates of the full crop and its aerial parts and less noticeable for soil plus roots and bare soil. The magnitudes of the respiration rates for full crop and aerial parts agreed well between years. Soil and root respiration rates varied more widely.

Respiration rate on bare soil was measured only once in 1979 and 1980. Respiration rates of soil plus roots and respiration rates of bare soil in 1979 were about half those observed in 1980. Roots contributed most of the CO_2 evolved from the soil in the 1980 studies — 60 and 63% of the total soil-plus-root respiration in 1979 and 1980, respectively.

Monteith et al. (1964) obtained 15-day averages of bare-soil respiration during a 1-year study. They found a seasonal variation of 63—279 mg CO_2 m^{-2} h^{-1}. Respiration rates of roots, which amounted to 83—125 mg CO_2 m^{-2} h^{-1}, were estimated by comparing respiration rates measured on adjacent areas of bare and cropped soil. Measurements of root respiration rates of several species growing in sterile sand were reported by Newton (1924). These varied from about 54 to 108 mg CO_2 m^{-2} h^{-1}.

Estimates of the proportion of the total soil respiration attributable to root respiration vary greatly, e.g., negligible (Witkamp, 1966) to about 70% (Chapman, 1979). Chapman (1979) pointed out the need to know whether root respiration is stimulated by tissue damage and disturbance. The magnitudes of soil and root respiration show the importance of these measurements in the carbon balance of plants.

Most of the total respiration of the soybean crop is attributable to the aerial parts (87—93%) with the soil and roots contributing the remainder. Similarly, high contributions of aerial parts to the total plant respiration have been reported for other crops — ryegrass, 60%; barley, 83% (Mogensen, 1977) and beans, 86% (Monteith, 1962).

The rates observed are in reasonably good agreement with others reported in the literature. Denmead (1976) found a mean value of 700 mg CO_2 m^{-2}

h^{-1} for aerial parts of wheat and Mogensen (1977) observed a mean value of 844 mg CO_2 m^{-2} h^{-1} for barley.

Comparison between respiration rates of alfalfa and soybean

Full-crop respiration rates were of about the same magnitude in alfalfa and soybean. Full-crop respiration rates averaged 531 mg CO_2 m^{-2} h^{-1} for alfalfa and 524 and 627 mg CO_2 m^{-2} h^{-1} for soybeans in 1979 and 1980, respectively.

Respiration rate of the aerial parts of the soybean crop were more than double those of alfalfa, however. Soil-plus-root respiration rates were much greater in alfalfa than in soybean. Bare-soil respiration rates were approximately equal while the root contribution was much greater for alfalfa than for soybean.

SUMMARY AND CONCLUSIONS

The greatest share of the CO_2 released by an alfalfa crop was contributed by the soil and roots (about 63%). Most of the CO_2 released by soybean during the flowering and pod set stages was from the aerial parts (between 87 and 93%, depending on year). Although no data on soybean respiration in the field was found in the literature, comparably high contributions of aerial parts have been reported for other crops.

ACKNOWLEDGMENTS

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REFERENCES

Baldocchi, D.D., 1979. Environmental and physiological effects on the carbon exchange rate and water use efficiency of alfalfa. M.S. Thesis. CAMaC Progress Report 79-1, University of Nebraska, Lincoln, NE, 110 pp.

Baldocchi, D.D., 1982. Mass and energy exchanges of soybeans: Microclimate—plant architectural interactions. Ph.D. Dissertation. CAMaC Progress Report 82-3, University of Nebraska, Lincoln, NE, 265 pp.

Biscoe, P.V., Scott, R.K. and Monteith, J.L., 1975. Barley and its environment. III. Carbon budget of the stand. J. Appl. Ecol., 12: 289—293.

Brown, K.W. and Rosenberg, N.J., 1971. Energy and CO_2 balance of an irrigated sugar beet (*Beta vulgaris*) field in the Great Plains. Agron. J., 63: 207—213.

Buchanan, R.E. and Fulmer, E.I., 1930. Physiology and Biochemistry of Bacteria. Vol. II. Williams and Wilkings Co., Baltimore, MD, 709 pp.

Chapman, S.B., 1979. Some interrelationships between soil and root respiration in lowland Calluna heathland in southern England. J. Ecol., 67: 1—20.

DaCosta, J.M.N., Rosenberg, N.J. and Verma, S.B., 1986. Joint influence of air temperature and soil moisture on CO_2 release by a soybean crop. Agric. For. Meteorol., in press (AGMET 1416).

De Jong, E. and Schappert, H.J.V., 1972. Calculation of soil respiration and activity from CO_2 profiles in the soil. Soil Sci., 113: 328—333.

Denmead, O.T., 1976. Temperate cereals. In: J.L. Monteith (Editor), Vegetation and The Atmosphere, Vol. 2. Academic Press, New York, pp. 1—31.

Forward, D.F., 1960. Effect of temperature on respiration. In: W. Ruhland (Editor), Encyclopedia of Plant Physiology, XII/2. Springer-Verlag, Berlin, pp. 234—258.

Kanemasu, E.T., Powers, W.L. and Sij, V.W., 1974. Field chamber measurements of CO_2 flux from soil surface. Soil Sci., 118: 233—237.

Lundegardh, H., 1927. Carbon dioxide evolution of soil and crop growth. Soil Sci., 23: 417—453.

Mogensen, V.O., 1977. Field measurements of dark respiration rates of roots and aerial parts in Italian ryegrass and barley. J. Appl. Ecol., 14: 243—252.

Mogensen, V.O. and Rosenberg, N.J., 1972. An improved method for measuring soil and root respiration. In: Simultaneous Determination of Short-period Photosynthesis and Evapotranspiration. Final Report to NOAA on Grant No. E-293-68(G) pp. 52—58.

Monteith, J.L., 1962. Measurement and interpretation of carbon dioxide fluxes in the field. Neth. J. Agric. Sci., 10: 334—346.

Monteith, J.L., Szeicz, G. and Yabuki, K., 1964. Crop photosynthesis and flux of carbon dioxide below the canopy. J. Appl. Ecol., 1: 321—337.

Moss, D.N., Musgrave, R.B. and Lemon, E.R., 1961. Photosynthesis under field conditions. III. Some effects of light, carbon dioxide, temperature and soil moisture on photosynthesis, respiration and transpiration of corn. Crop Sci., 1: 83—87.

Newton, J.D., 1924. Measurements of carbon dioxide evolved from the roots of various crop plants. Sci. Agric., 4: 268—274.

Rosenberg, N.J. and Verma, S.B., 1976. A system and program for monitoring CO_2 concentration, gradient and flux in an agricultural region. Agron. J., 68: 414—418.

Sale, P.J.M., 1974. Productivity of vegetable crops in a region of high solar input. III. Carbon balance of potato crops. Aust. J. Plant Physiol., 1: 283—296.

Saugier, B., 1976. Sunflower. In: J.L. Monteith (Editor), Vegetation and the Atmosphere, Vol. 2. Academic Press, New York, pp. 87—119.

Thomas, M.D. and Hill, G.R., 1937. The continuous measurement of photosynthesis, respiration and transpiration of alfalfa and wheat growing under field conditions. Plant Physiol., 12: 285—307.

Uchijima, Z., 1976. Maize and rice. In: J.L. Monteith (Editor), Vegetation and the Atmosphere, Vol. 2. Academic Press, New York, pp. 33—64.

Witkamp, M., 1966. Rates of carbon dioxide evolution from the forest floor. Ecology, 47: 492—494.