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MICROCLIMATE IN THE SOYBEAN CANOPY*

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ABSTRACT

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Features of microclimate within different types of soybean canopies were investigated in detail during the growing seasons of 1979 and 1980 at Mead, Nebraska. In 1979, measurements were made in Clark cv. soybeans that were well supplied with water. The canopy of this cultivar is planophile in nature. In 1980, measurements were made in two erectophile canopies of the Harosoy cultivar. These canopies differed isogenically in leaf pubescence and were water-stressed during the period of observation.

In both the Clark and Harosoy cultivars, net radiation was attenuated exponentially with depth into the canopy. Net radiation was more effectively attenuated by the planophile cultivar. In the Harosoy soybeans, greater leaf pubescence, facilitated the penetration of net radiation into the canopy.

Air temperature profiles were affected by water-stress, leaf orientation and leaf pubescence. Within the well-watered, planophile canopy, air temperature increased with depth to a maximum in mid-canopy. Temperature decreased with further depth into the lower canopy. Within the water-stressed, erectophile canopies, the air temperature profile was either lapse or isothermal. Air temperatures were higher in the canopy with dense leaf pubescence, an effect related to the influence of leaf pubescence on the penetration of net radiation.

Vapor pressure profiles were generally lapse throughout the day with a strong gradient in the upper canopy and a weak gradient in the lower canopy. The influence of leaf orientation, pubescence and water-stress on vapor pressure profiles were not discernable.

CO_2 concentration $[CO_2]$ decreased with depth to a minimum at height z_c. Below that height $[CO_2]$ increased with depth. The elevation within the canopy of minimum CO_2 concentration, z_c, was influenced by leaf pubescence and leaf orientation since these affect penetration of radiation into the canopy. Crop moisture status affected the strength of the $[CO_2]$ gradient by influencing photosynthesis.

INTRODUCTION

The microclimate of crop canopies has been the subject of investigation for some time. Within the past two decades, studies have been reported by Brown and Covey (1966), Wright and Brown (1967), Lemon and Wright

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(1969), Gillespie and King (1971) for corn; Penman and Long (1960), Denmead and McIlroy (1971), Legg (1975), Legg and Long (1975) for wheat; Johnson et al. (1976) for barley; Begg et al. (1964) for bulrush millet; Uchijima (1962, 1976a, b), Inoue (1965, 1968) for rice; Saugier (1970, 1976) for sunflower; Goncz and Rose (1972) for Townsville stylo and Sheehy et al. (1977) for forage grasses.

Despite its economic importance the microclimate in soybean canopies has not yet been studied in detail. Such a study can yield valuable information regarding the interaction of a crop with its environment. The only pertinent soybean studies known to us are those of Perrier et al. (1970, 1972), Millington and Peters (1969), Singh et al. (1968) and Sakamoto and Shaw (1967). Perrier et al. (1970, 1972) studied the air flow above and within soybeans. Millington and Peters (1969) examined eddy exchange coefficients within the canopy. Singh et al. (1968) and Sakamoto and Shaw (1967) investigated light distribution within the canopy.

Here we report the results of a detailed investigation of the microclimate within various types of soybean canopies. Data presented in this paper were obtained during the 1979 and 1980 growing seasons. In 1979, experiments were conducted on a well-watered soybean crop, using the planophile Clark cultivar. In 1980, observations were made in two canopies of the erectophile Harosoy cultivar. These canopies differed isogenically in leaf pubescence only. In 1980, the crops were water-stressed during the period of investigation.

The results from these measurements provide an opportunity to examine profiles of meteorological variables within three soybean canopies which have been influenced by a combination of factors such as water stress, leaf orientation and pubescence. Observations of the wind speeds above and within the soybean canopies are presented elsewhere (Baldocchi et al., 1983a).

MATERIALS AND METHODS

Experimental details

The studies described here were conducted at the University of Nebraska Agricultural Meteorology Laboratory at Mead, Nebraska (41° 09′ N 96° 30′ W; altitude 354 m above msl). Soybeans (*Glycine max* L. Merrill, Clark cv.), planophile in nature, were planted in 1979 in an experimental field with dimensions 105 m E—W by 210 m N—S. Border fields to the east, south and west were planted with Woodworth cv. soybeans. In 1980, the Harosoy cultivar was planted in two adjacent experimental fields; this variety is erectophile. The east field (65 m E—W by 210 m N—S) was planted with an isoline with normal pubescence (HN). The west field (85 m E—W by 210 m N—S) was planted with an isoline with dense pubescence (HPD). Pubescence was four times greater on the HPD as on the HN isoline (Bernard and Weiss, 1973). Border fields to the east, south and west of the experimental field were planted with the HN isoline. All fields were planted in 0.75 m wide rows which ran north-south. The soil at the site was Sharpsburg silty clay loam (Typic Argiudoll).

Air temperature and vapor pressure profiles were measured over each field at 1.25, 1.50, 1.75, 2.25, 2.75 and 3.25 m with an automatic, self-checking, multilevel psychrometer (Rosenberg and Brown, 1974). Once each hour the psychrometer assembly rotated automatically into a horizontal position for calibration.

Air was sampled to determine CO_2 concentration with a multilevel manifold at 0.30, 0.50, 0.70 and 0.90 m within and at 1.25, 1.50 and 1.75 m above the canopy. The manifold had six intakes at each level. These were spaced equidistantly over a horizontal distance of 2.5 m to obtain spatial averaging. CO_2 concentrations were measured with a system which employed an absolute and a differential infrared gas analyzer (see Rosenberg and Verma, 1976, for details). Once each hour both analyzers were calibrated automatically with standard gases of known concentration.

Net radiation (Rn) was measured above each canopy with a Swissteco net radiometer. Net radiation was measured within each canopy at 0.20, 0.40, 0.60 and 0.80 m using oblong net radiometers (ONR). The ONRs were 350 mm long and 45 mm wide. Impens et al. (1970) report great spatial variation of net radiation within crop canopies. To account for this spatial variation, Rn was measured at six locations within the canopy at both the 0.80 and 0.60 m levels at four locations at 0.40 m and at two locations at 0.20 m.

Air temperature and vapor pressure were measured within the canopy with mini-psychrometers adapted from a design by Stigter and Welgraven (1976). Profiles were measured at three locations within each canopy; in the row, 0.10 m from the row and midway between rows. Profile measurements were made at 0.10, 0.30, 0.50, 0.70 and 0.90 m.

Signals from all micrometeorological sensors were sampled with a computer controlled data acquisition system and were recorded on magnetic tape. CO_2 concentrations were measured and recorded once every seven and one-half minutes. Signals from all other voltage producing sensors were sampled twice per min. Data were later averaged for the first 45 min of each solar hour. The remaining 15 min of each hour were reserved for calibration of psychrometers and infrared gas analyzers.

Leaf water potential (Ψ) was measured with a pressure chamber on an hourly basis. Six to eight sunlit leaves from the upper canopy were selected for this purpose. After excision, each leaf was placed in a plastic bag full of moist air, which was immediately inserted into the pressure chamber.

Profile data presented in this paper were obtained on August 4, 1979, and August 3 and 7, 1980. In 1979, the crop was well supplied with water. The minimum leaf water potential on August 4, 1979, was about -0.6 MPa. The crop was water stressed in 1980. In 1980, the minimum leaf water

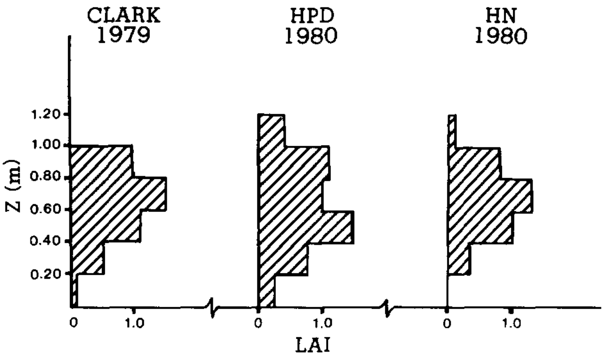

Fig. 1. Vertical profiles of leaf area (by 20 cm increments) for the Clark, HPD and HN canopies.

TABLE 1

Crop height (*h*) and leaf area index (*LAI*) for the soybean cultivars and isolines studied

Cultivar	Date	*h*(m)	*LAI*
Clark	August 4, 1979	0.84	4.1
Harosoy HN	August 3—7, 1980	1.00	3.6
Harosoy HPD	August 3—7, 1980	1.08	4.6

potential on August 3 and 7 was in the order of — 1.5 to — 1.7 MPa. Wind speed at 2 m ranged from 4 to 5 m s^{-1} during the time periods considered here. Vertical profiles of leaf area for the Clark, HN and HPD canopies are presented in Fig. 1. Data on crop height and leaf area index are presented in Table I.

RESULTS AND DISCUSSION

Net radiation profiles

Within-canopy profiles of net radiation (*Rn*) for a well-watered Clark cv. canopy (August 4, 1979) and for water-stressed HN and HPD canopies (August 3, 1980) are shown in Fig. 2a and b, respectively. Both show that *Rn* decreased exponentially with depth during the daylight hours. At night (e.g., 2045 h, Fig. 2b) the shape of the *Rn* profile was slightly lapse in the upper two-thirds of the canopy and relatively constant in the lower third. This results suggests that radiation in the upper two thirds of the canopy was lost at night to the sky, whereas radiation in the lower canopy was trapped by the upper canopy.

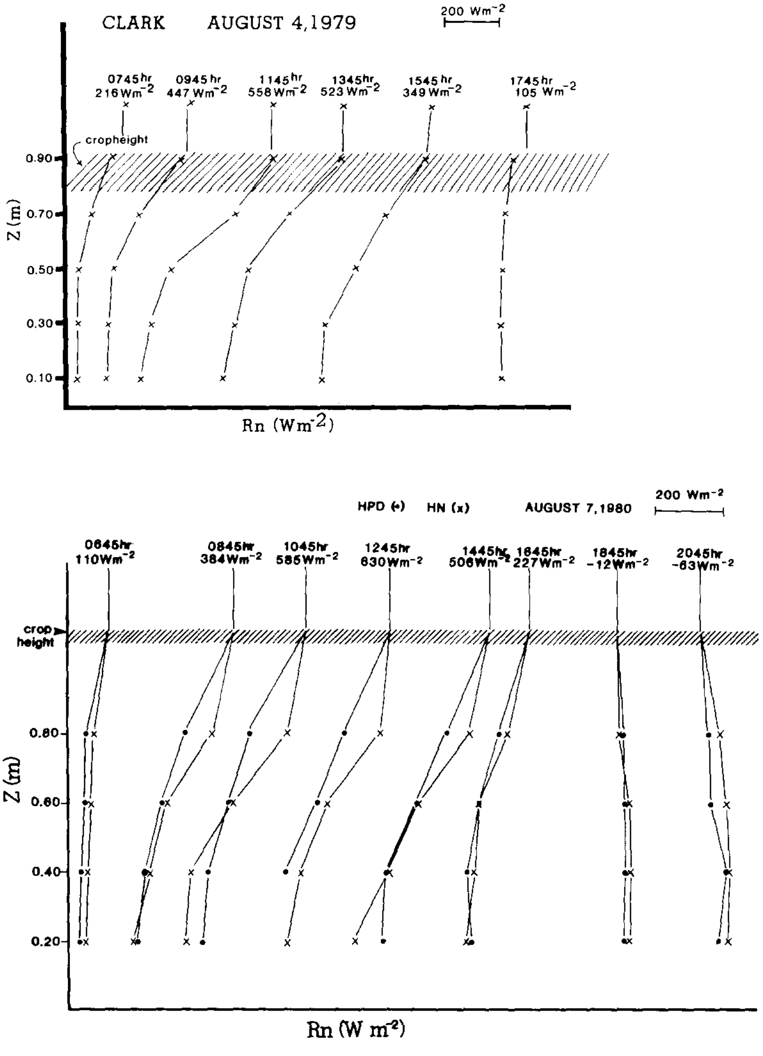

Fig. 2 a and b. Vertical profiles of net radiation (*Rn*) within the canopies of (a) Clark cv. (August 4, 1979) and (b) normal (HN) and densely pubescent (HPD) Harosoy cv. soybeans (August 7, 1980). Values of *Rn* above the canopy (1.85 m above the ground) are also shown.

Net radiation flux densities over the HN and HPD canopies were compared in an adjunct study (Nielsen et al., 1981). No differences in *Rn* were found between the isolines.

Good agreement was observed between *Rn* profiles measured in HN and HPD canopies when the flux density of *Rn* above the canopy (Rn_0) was small (e.g., 0645, 1645 and 1845 h) (Fig. 2b). Profiles of *Rn* did not, however, compare well when flux densities of Rn_0 were large. In general, the HPD isoline absorbed a greater portion of Rn in the upper canopy ($z > 0.6$ m) and allowed a significant amount of Rn to penetrate deep into the canopy ($z < 0.4$ m). This effect is especially noticeable at 1045 and 1445 h. The opposite effect seemed to be true for the HN isoline.

These differences in Rn attenuation were probably due to differences in leaf area distribution and pubescence. Leaf area was greater in the upper portion of the HPD isoline than in the HN isoline (Fig. 1) which may explain the greater absorption of Rn in the upper canopy of the former. This result does not, however, explain the greater penetration of solar radiation deep into the HPD canopy. We speculate that greater pubescence in the HPD isoline affected either the scattering coefficient, the reflectivity of the leaf, or both, and thus facilitated penetration of solar radiation. Our hypothesis is based on the work of Lemeur and Blad (1974) who showed that penetration of radiation into a canopy increases as the scattering coefficient of a leaf increases. Further, Lemeur and Rosenberg (1975) have shown that when the reflectance of a soybean canopy was increased by the application of a reflectant material, the penetration of Rn into the canopy was increased.

It should be noted that the premise on which our hypothesis is based differs from the experimental results of Gausman and Cardenas (1973). They found that pubescent Clark cv. soybean leaves reflected less and absorbed more near-infrared radiation than did normal leaves. No differences between the spectral properties of these leaves were found for the visible portion of the electromagnetic spectrum. We hold our premise to be valid, however, for the following reasons: (1) photographic evidence showed that when light was incident on the leaf at low angles, leaves with densely pubescent leaves reflected more light than did the normal leaves (Fig. 3). Since leaves in a crop canopy are arranged almost spherically, incoming solar radiation, at any given time, is incident at small angles on some portion of the leaves. This effect can account for an increased penetration of radiation into the HPD canopy; (2) Gausman and Cardenas (1973) did not examine the angular response of leaf reflectivity; and (3) our study was performed on Harosoy cv. soybeans. This cultivar has different color pubescence compared to the Clark cv.

The general shape for the Rn profiles can be described using an analogy of the Beer-Bouguer law (e.g., Brown and Covey, 1966; McCaughey and Davies, 1974; Denmead, 1976)

$$Rn(z) = Rn_0 \exp[-\gamma f(z)] \tag{1}$$

where Rn_0 is Rn at the top of the canopy, γ is the net radiation extinction coefficient and $f(z)$ is the cumulative leaf area index at a height z. The value of γ increases as the capacity of the canopy to attenuate Rn increases.

Figure 4a and b show the diurnal variation in γ for: (a) the Clark cv. canopy and (b) the HN and HPD canopies. Data shown in both figures were obtained during periods in which the leaf area index was in the order of 4.0. Figure 4a and b show that γ for the Clark cv. was relatively independent

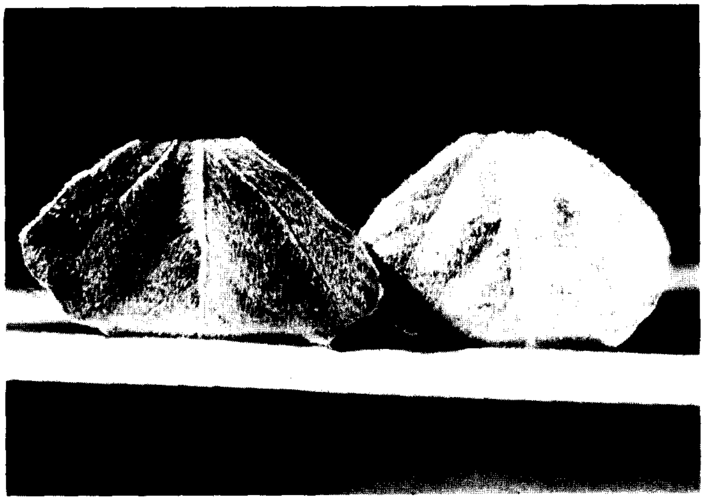

Fig. 3. (Right) normal (HN) and (left) densely pubescent (HPD) leaves of the Harosoy cultivar.

while that for Harosoy cv. was strongly dependent on time of day. This difference is likely due to a difference in the physical features of the Clark and Harosoy canopies; Clark is a planophile cultivar, whereas Harosoy is erectophile. This hypothesis is based on the assumption that effects due to differences in crop water status should be relatively minor compared with the effect leaf orientation has on the penetration of radiation into a crop canopy. These results also support the work of Sheehy et al. (1977) who found that an erectophile forage grass attenuated *Rn* less effectively than a planophile forage grass.

Figure 4b shows that γ decreased with increasing solar elevation. These results suggest that the penetration of *Rn* into the HN and HPD canopies increased with solar elevation. A time dependency of γ has previously been reported in such erectophile crops as corn (Brown and Covey, 1966; McCaughey and Davies, 1974) and wheat (Denmead, 1976).

The values of γ ranged from 0.45 to 0.57 in the Clark cv. and from 0.12 to 0.50 in the Harosoy cv. (Fig. 4a, b) suggesting, as expected, that the planophile Clark cv. attenuated *Rn* more effectively than the erectophile Harosoy cv. The γ values reported here are smaller than those reported for other agricultural crops. For example, γ for rice ranges from 0.45 to 0.65 (Uchijima, 1976a), γ for wheat ranges from 0.50 to 0.75 (Denmead, 1976) and the mean γ for corn is about 0.58 (Brown and Covey, 1966).

Air temperature profile

Within-canopy profiles of air temperature for a well-watered Clark cv. canopy (August 4, 1979) and for water-stressed HN and HPD canopies (August 3, 1980) are shown in Fig. 5a and b, respectively. Generally, the

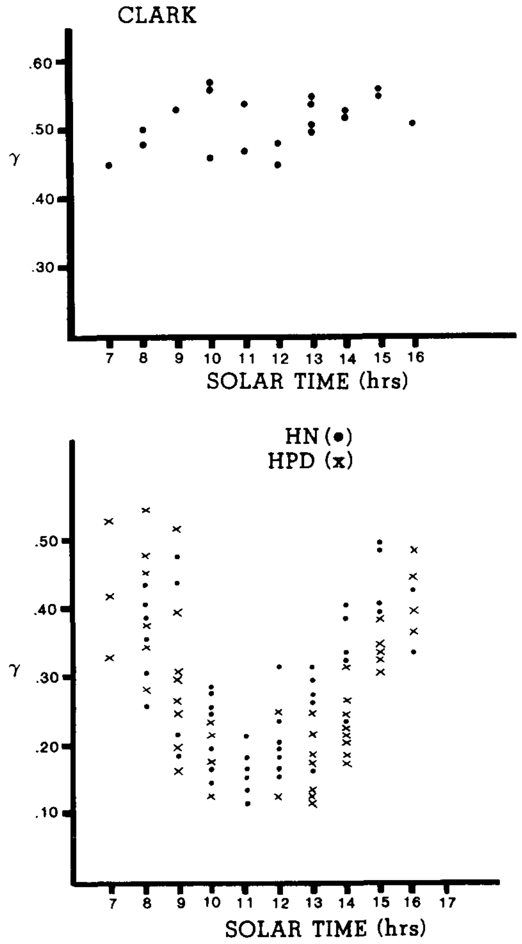

Fig. 4a and b. Diurnal variation in the net radiation attenuation coefficient (γ) for (a) a Clark cv. canopy and (b) for the HN and HPD canopies. These data are for periods when the canopy leaf area index was about four.

daytime air temperatures within the well-watered, planophile canopy increased with depth to a maximum value near mid-canopy and then decreased with further depth. The shape of these air temperature profiles is similar to those reported for other well-watered crop canopies (Brown and Covey, 1966; Biscoe et al., 1975; Johnson et al., 1976; Stigter et al., 1976).

The shape of the daytime air temperature profile within the water-stressed erectophile canopy was quite different. In general, these air temperature profiles were either lapse or isothermal (Fig. 5b); no mid-canopy temperature maxima were observed. These daytime air temperature profiles were similar in shape to those reported by Begg et al. (1964) and Saugier (1970) for water-stressed crops. Water stress, in combination with the

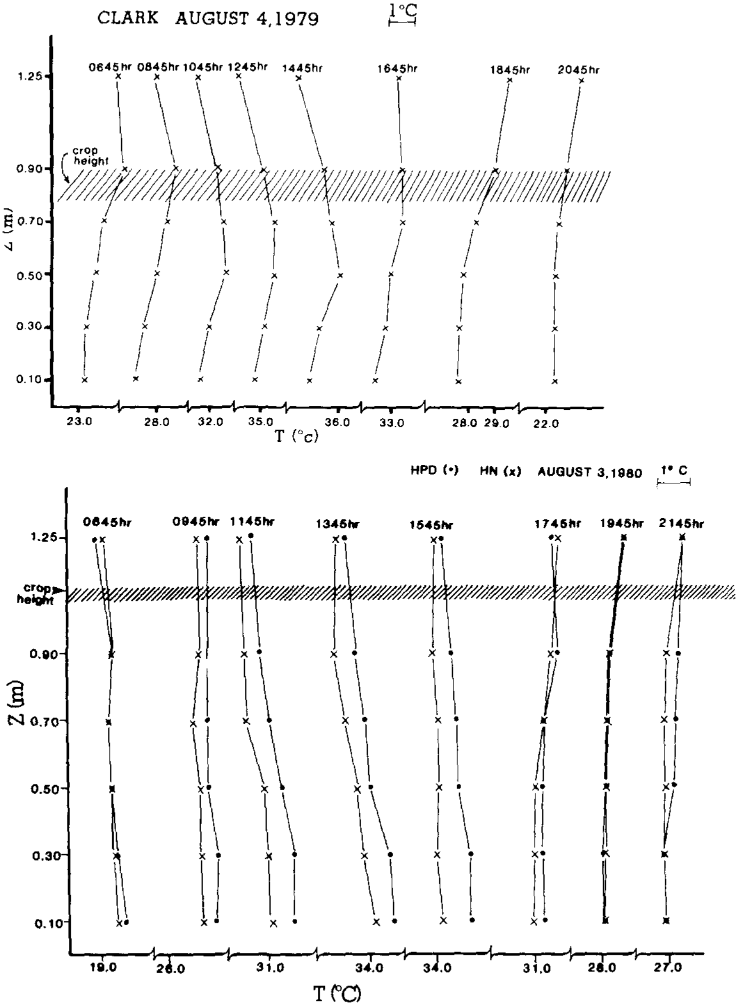

Fig. 5a and b. Diurnal variation in the vertical profiles of air temperature within (a) a well-watered Clark cv. canopy an (b) water-stressed Harosoy canopies differing in degree of pubescence.

erectophile Harosoy cv. canopy structure, eliminated the daytime mid-canopy temperature maxima. Water stress reduced transpirational cooling, thus, causing a substantial amount of sensible heat to be generated throughout the canopy. The erectophile nature of the crop facilitated the penetration of solar radiation deep into the canopy. This solar radiation was then mainly consumed by heating the soil and the adjacent air layer.

The nocturnal air temperature profiles within the canopy are similar in shape in Fig. 5a and b. In the upper half of the canopy, the air temperature profile was inverted. In the lower half of the canopy, the air temperature profile was either inverted or isothermal. Temperature profiles in the lower levels of the canopy were relatively isothermal at night since the upper canopy trapped a substantial portion of the outgoing terrestrial radiation. Temperature profiles were inverted in the upper canopy because of the unimpeded radiation to the sky from there.

Air temperature was similar within the HN and HPD canopies during morning and evening periods when insolation was weak or absent. As the day progressed, temperatures were higher in the HPD canopy. Differences in air temperature within the two isolines during the daytime period (e.g., 0945, 1145, 1345 and 1545 h in Fig. 5b) probably resulted from the differential attenuation of solar radiation. As shown in the previous section, the HPD isoline absorbed more *Rn* in the upper canopy while allowing more to penetrate deep into the canopy (Fig. 2b). Since the crop was water-stressed, a substantial amount of the additional *Rn* in the upper canopy of the HPD isoline was converted to sensible heat. In the lower canopy of the HPD isoline, the additional *Rn* would have heated the soil and adjacent air because there were few transpiring leaves in this zone.

Vapor pressure profiles

Vertical profiles of vapor pressure for a well-watered Clark cv. canopy (August 4, 1979) and for a water-stressed HN canopy (August 3, 1980) are shown over the course of a day in Figure 6a and b, respectively.

Vapor pressure profiles exhibit two distinct segments during the sunlit hours: (a) an upper segment (above ~ 0.50 m) where the gradient is strong because a considerable portion of net radiation is consumed by transpiration and (b) a lower segment (below 0.50 m) where the vapor pressure gradient is weak since both the amount of *Rn* penetrating and the amount of transpiring leaf area available in the lower canopy are small. The data shown in Fig. 6a and b do not permit us to discern the influence of crop moisture status, leaf orientation or pubescence on the shape of the daytime vapor pressure profile. However, greater vapor pressure values were observed in the well-watered canopy. The vapor pressure profiles presented in Fig. 6a and b are similar to those observed by Begg et al. (1964) in a water-stressed, erectophile canopy of bulrush millet, by Saugier (1976) in a water-stressed planophile canopy of sunflower and by Brown and Covey (1966) and Johnson et al. (1976) in well-watered, erectophile canopies of corn and barley, respectively.

Vapor pressure gradients were weak during the mornings, as expected, since insolation was weak. It is, however, interesting to note that in the evening (e.g., as late as 1945 h; Fig. 6b) vapor pressure profiles remained lapse. Evapotranspiration continued in the evening since sensible heat was directed towards the canopy from above.

Instrument failures did not allow comparison of vapor pressure profiles between the HN and HPD isolines during the course of a day. Profiles for

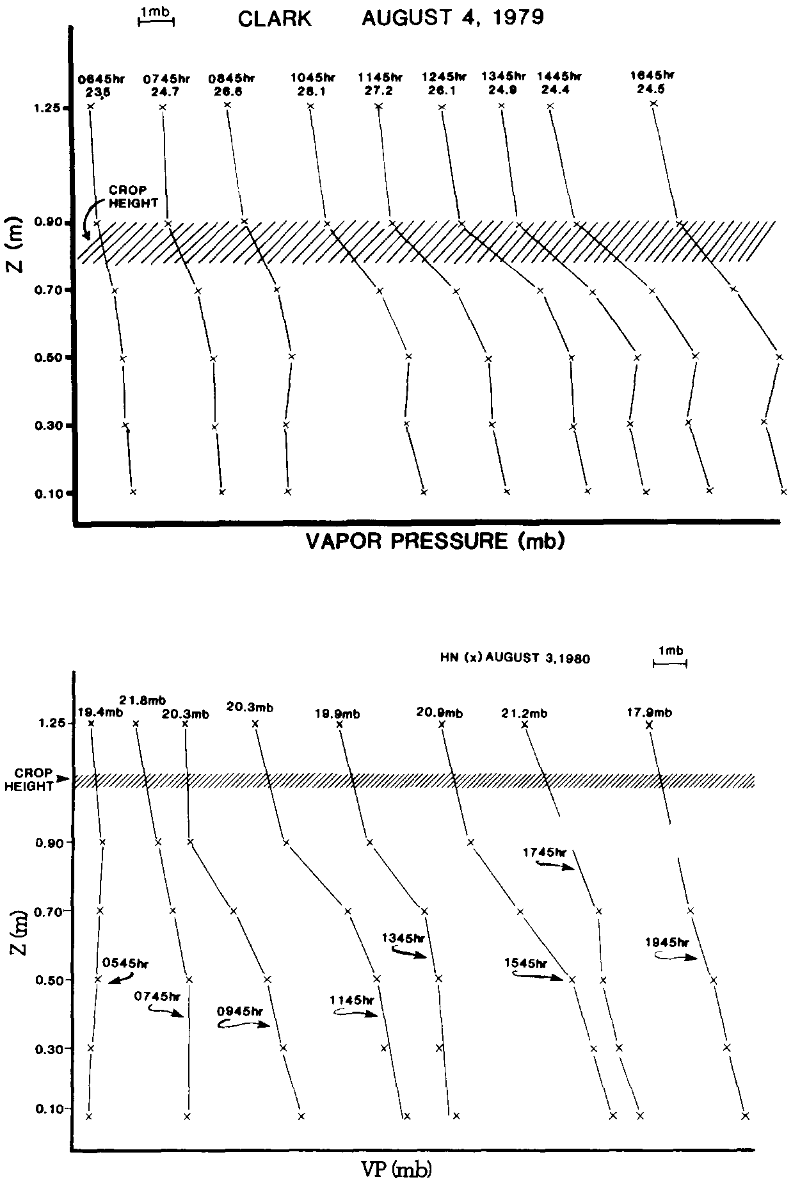

Fig. 6 a and b. Diurnal variation in vapor pressure (VP) within (a) a well-watered Clark cv. canopy and (b) a water-stressed Harosoy cv. canopy.

selected hours, however, are shown in Fig. 7. Vapor pressure was greater within the HN than within the HPD canopy. These data are supported by the results of Ghorashy et al. (1971) and Baldocchi et al. (1983b). These workers show that soybeans with normal pubescence transpire more than

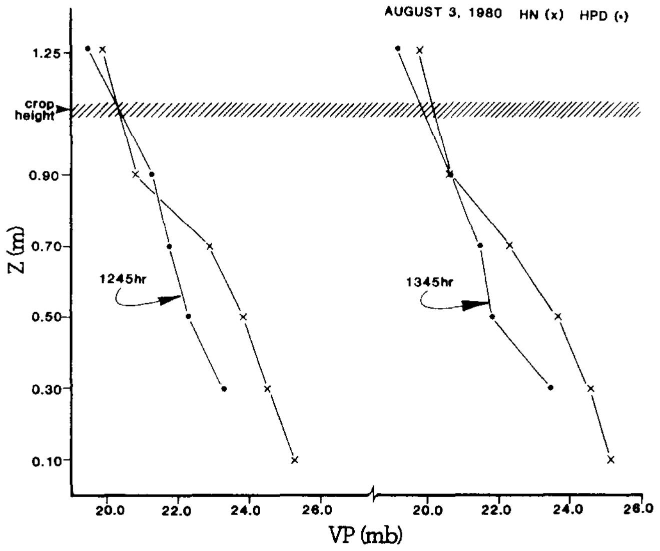

Fig. 7. Influence of leaf pubescence on vapor pressure profiles within the canopy of water stressed Harosoy cv. soybeans.

their densely pubescent isogenic pair; hence, a greater humidity should be expected within the canopy of the normal isoline.

CO_2 concentration [CO_2] profiles

Figure 8 presents vertical profiles of CO_2 concentration ([CO_2]) (August 4, 1979) from within the well-watered, planophile (Clark cv.) soybean crop. Early in the morning (0445 h) the [CO_2] profile was lapse because of the respiratory release of CO_2 by the crop and rhizosphere. Since no photosynthesis takes place then, a considerable buildup of [CO_2] occurs within the canopy. At this time, CO_2 at 0.30 m reached about 370 ppm, approximately 20 ppm greater than that in the ambient air at 1.25 m above ground. Brown and Rosenberg (1970) have noted similar values of nocturnal CO_2 concentrations in a sugar beet field. Nocturnal concentrations as high as approximately 500 ppm, however, have been reported in agricultural fields, by Pearman and Garratt (1973) and Verma and Rosenberg (1976).

During the hours of sunlight, the crop was photosynthesizing and the crop and rhizosphere were respiring. These processes caused the [CO_2] profiles to be inverted in the upper portion of the canopy and to be lapse in the lower portion. The minimum daytime within-canopy [CO_2] was about 313 ppm and occurred at about 0.90 m. This value was in the order of 2–4 ppm less than the concentration in the ambient air (at 1.25 m above ground). A similar 'drawdown' has been observed in other C_3 species (Monteith, 1962;

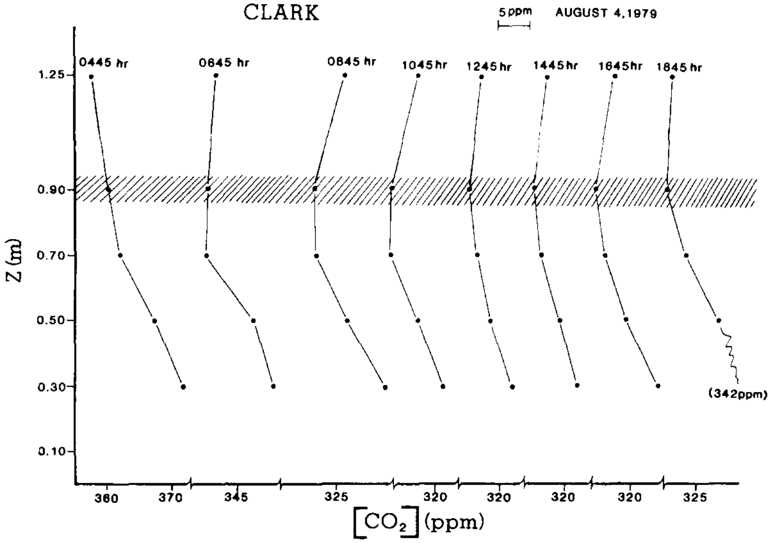

Fig. 8. Diurnal variation in [CO_2] within a well-watered Clark cv. canopy.

Inoue, 1965, 1968; Denmead, 1966; Denmead and McIlroy, 1971; Saugier, 1970, 1976; Biscoe et al., 1975; Uchijima, 1976a, b; Johnson et al., 1976). A greater 'drawdown' has been observed in C_4 species (for example, corn; Lemon, 1960; Uchijima, 1976a; Uchijima and Udagawa, 1978), however.

Figure 8 shows the height of the minimum CO_2 concentration (z_c) remained at about 0.90 m throughout the period of photosynthetic activity (0745—1845 h). Uchijima (1976a), on the other hand, reports that z_c, in corn, decreases with increasing solar elevation. The value of z_c, in this study, did not change with increasing solar elevation probably because the planophile leaves of the Clark cv. prevented deeper penetration of solar radiation with increasing solar angle (Fig. 4a).

Water stress affected the shape of the [CO_2] profiles by inhibiting photosynthesis. Figure 9 shows [CO_2] profiles when the HN and HPD isolines experienced water-stress. Again, [CO_2] profiles were lapse in the absence of sunlight because of respiration by the crop-rhizosphere system (e.g., 0445, 1945 and 2145 h). During the period of photosynthetic activity, [CO_2] gradients were much weaker than those observed in the well-watered Clark cv. canopy (Fig. 8). For example, the [CO_2] differences between 1.25 and 0.70 m were ~ 1—2 ppm when the HN and HPD crops were water stressed as compared to 2—4 ppm when the Clark cv. was well-watered.

The influence of additional pubescence on the shape of the [CO_2] profile can also be observed in Fig. 9. The height (z_c) of the minimum CO_2 concentration was at ~ 0.70 m in the HN isoline and at ~ 0.90 m in the HPD isoline. The height z_c was lower in the HN isoline than in the HPD isoline,

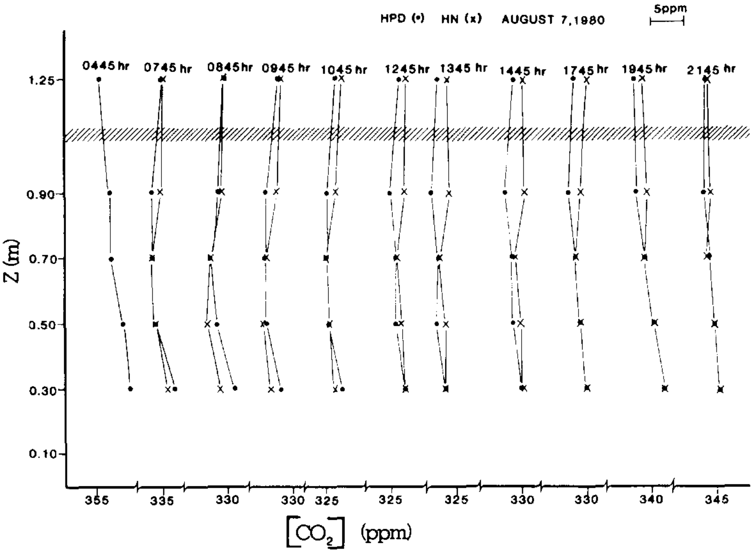

Fig. 9. Diurnal variation in [CO_2] within two water stressed Harosoy cv. canopies differing in leaf pubescence.

probably because light was absorbed differently by the canopies. For example, Fig. 2b shows that the HN isoline attenuated a smaller portion of *Rn* between 0.60 and 0.80 m than did the HPD isoline. Leaf orientation may also have affected the relative location of z_c. The ratio z_c/h (where h is canopy height) was greater in the planophile Clark cv. than in both erectophile Harosoy canopies. This effect was due to differences in the penetration of solar radiation into these canopies. Water stress probably did not affect z_c, since stress did not seem to influence the penetration of radiation into the canopy.

CONCLUSIONS

Profiles of net radiation, air temperature, vapor pressure and CO_2 concentration measured within soybean canopies have been examined in detail. Net radiation (*Rn*) was attenuated by the canopy in accordance with the Beer-Bouguer Law. The attenuation of *Rn* by the canopy was a function of solar elevation in the erectophile (Harosoy) cultivar; it was independent of solar elevation in the planophile (Clark) cultivar. Leaf pubescence also affected *Rn* penetration. Net radiation penetrated deeper into the soybean isoline with dense pubescence.

Air temperature profiles were influenced by crop water status, leaf orientation and leaf pubescence. Air temperature within a well-watered, planophile canopy increased with depth during the daytime, to a maximum value at mid-canopy. Below the mid-canopy level, temperature decreased with depth. In the water-stressed erectophile canopy, the temperature profile was either lapse or inverted and no temperature maximum was observed in mid-canopy. In the canopy with greater pubescence, air temperatures were higher. This effect was likely due to greater pubescence facilitating the penetration of radiation deeper into the canopy.

The shape of the vapor pressure profile appeared independent of crop water status. In general, daytime profiles were lapse, with a strong vapor pressure gradient in the upper canopy and a weak gradient in the lower canopy.

CO_2 concentration decreased with depth until a minimum was reached at a height z_c. Below that height $[CO_2]$ increased with depth. Moisture status affected the shape of the $[CO_2]$ profile. Stronger gradients were measured within the well-watered canopy than in the water-stressed canopies. This effect was due to inhibition of photosynthesis by water stress. Leaf orientation appears to influence the location of z_c which was found lower in the erectophile than in the planophile canopy.

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