Energy Balance as Affected by Height and Maturity of Sudangrass

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SYNOPSIS. Evapotranspiration rates of 75- and 100-cm. crops of sudangrass were similar and considerably larger than that of the 140-cm. height. This difference appeared to be due to the presence of seedheads rather than physiological maturity. It was also shown, for days of similar energy input, that evapotranspiration increased with wind speed. These facts emphasize the point that for well-watered sudangrass, physical rather than physiological factors regulated the evapotranspiration.

A NUMBER of studies have been conducted relating evaporation from a cropped surface to micrometeorological variables such as net radiation, air temperature, vapor pressure, and wind speed (2, 5, 7). These reports indicate that the stage of development of the crop seemed to have an influence on its water loss even after a complete crop cover was developed and while the crop was well supplied with water. A difficulty with these studies is that the microclimate was not completely characterized; thus, direct comparisons with respect to stage of growth may be ambiguous.

The concept of potential evapotranspiration as defined by Penman (4) "as the amount of water transpired by a short green crop, completely shading the ground, of uniform height and never short of water" implies that a tall crop may not transpire at the potential rate, all other factors being similar.

The influence of height and stage of crop development can be determined only by investigating different surfaces simultaneously. More specifically, the crop or plant type should be of the same age, with the same root system, and the same degree of cover. Preferably, all measurements should be made on the same day with the various crop surfaces exposed to identical meteorological conditions. If the physical reason for any differences is to be understood, it is necessary that frequent measurements of both evaporation and associated micrometeorological data be made. This paper contains the result of an experiment in which the height and maturity of sudangrass and their effects upon the components of the surface energy balance equation were studied.

EXPERIMENTAL PROCEDURES

Sudangrass was seeded in an experimental field at the U. S. Water Conservation Laboratory. The field, 73 by 92 m, was divided into 7 borders (13.1 by 73 m, major axis north and south) for irrigation purposes. A sensitive weighing-type lysimeter described by Van Bavel and Myers (8) was located midway in each of the three center borders.

By differential mowing, 3 different heights of sudangrass were obtained for a first series of measurements on 12 and 13 July 1962. On lysimeter 1 the crop was 25 cm high, but the cover was unsatisfactory and the data were not considered as reliable. On lysimeter 2 the grass was 75 cm high, and on lysimeter 3 the grass was 140 cm high and had developed inflorescences.

On 16 July after the first series of measurements, the grass immediately surrounding lysimeter 3 was mowed, leaving the grass on the lysimeter completely exposed.

During a second series of measurements on 20, 21, and 22 July, the sudangrass on lysimeter 2 had grown from 75 to 100 cm, and was beginning to develop inflorescences. On lysimeter 3 the cover had not sufficiently recovered from the mowing of 19 July.

Net radiation was measured 1 m above the surface of the crop over each of the lysimeters with a miniature net radiometer (1). Soil temperatures and soil heat flow were measured at 5 cm. depth and a measurement was made of the "surface" soil temperature. Incident and reflected solar radiation were measured, the latter over the area surrounding lysimeters 1 and 3 during the first run and 2 and 3 during the second run, as well as wind speed at 1 m. over the crop surface adjacent to lysimeter 2. The output from the micrometeorological transducers was automatically recorded at 15-minute intervals on a data-handling system described by

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3 The net radiometers were modified to have a calibration factor in excess of 1.3 mw ly⁻¹ min.
Fritsch and Van Bavel (3). The weights of the lysimeters were recorded on a similar system.

RESULTS AND DISCUSSION

The effect of the difference in height and development of the sudangrass between lysimeters 2 and 3 on 12 July can be seen by comparison of Figures 1 and 2, respectively, each giving the complete energy balance as well as the wind movement on that day. Since the comparison was made on the same day, meteorological variables such as solar radiation, wind speed, air temperature, and air vapor pressure in the air over the field are similar. A comparison of Figures 1 and 2 with regard to hourly and daily values shows that the net radiation over the two surfaces was not significantly different. This finding is somewhat surprising since the visual appearance of the two surfaces was different: lysimeter 3 with its well-developed seedheads giving a much lighter appearance. Direct comparisons of the short-wave reflection over the two surfaces were not available.

No difference was measured in the soil heat flow. This result is to be expected since in both cases the soil was well shaded and moist.

Marked differences were found in evapotranspiration. The 24-hour total for the 75-cm. crop was 598 ly (about 10 mm) compared to 355 ly (about 6 mm) for the 140-cm. crop. Thus, a sharp contrast emerges between the two conditions in that the 75-cm. crop extracted 190 ly of sensible heat from the air, whereas the 140-cm. crop lost 50 ly of sensible heat to the air. This difference is more clearly portrayed in Figure 3, where the hourly values of the sensible heat term are plotted. Figure 3 shows that during the period of net radiative loss (0000 to 0600 and 1800 to 2400) the values of A were quite similar between lysimeters 2 and 3. However, during the period of radiative gain, specifically between 0900 and 1300, the 75-cm. crop extracted approximately 0.1 ly min. \(^{-1}\) from the air, giving a Bowen ratio of roughly \(-0.1\). To the contrary, the 140-cm. crop yielded approximately 0.25 ly min. \(^{-1}\) to the air, implying a Bowen ratio of roughly \(+0.4\). Both curves show a maximum around 0700, which is not associated with any change in either wind speed or wind direction. It could be explained by heat storage in the crop. The maxima in both curves observed around 1800 are associated with the maximum wind speed on the day of observation (See Figure 1 or 2).

It is of interest to note that the tall grass on lysimeter 3 transpired at a rate equal to the shorter grass on lysimeter 2 during the period of negative net radiation after 1800. In both instances the transpiration was considerably more than prior to 0600 on the same day, clearly associated with greater wind speed prevailing during the period. The difference in behavior during periods of negative and of positive net radiation suggests that the effect on the energy balance between the two stands is somehow associated with the exchange of short-wave radiation. The difference may be caused by the difference in height or the maturity.

In order to examine the effect of height, the data obtained on 20 July over lysimeter 2, which had reached a height of 100 cm., can be compared with those of 12 July (75-cm. height). These days, 12 and 20 July, were similar, as may be seen in Figures 1 and 4. Owing to a slight degree of cloudiness, solar radiation and net radiation were somewhat less on the 20th. The soil heat flow was negligible, and air temperature and vapor pressure were similar on

\(^*\) All times are true solar times.
both days. The wind-speed pattern was also comparable, though the winds were lighter on the 20th. Evapotranspiration of the crop on the 12th and 20th was also quite similar; in fact, the daily total differed by only 1 ly. In both cases the crop extracted a large amount of sensible heat from the air, the daily distribution of A being given in Figure 5. From a study of Figures 1, 4, and 5 we conclude that a 25-cm. difference in height did not cause a significant difference in evapotranspiration, radiant or sensible heat exchange. This result, to a large extent, eliminated the effect of crop height itself as a pertinent factor.

It could be argued that in the case of the maturing crop on lysimeter 3 of 12 July, the plant itself was limiting the availability of water for evaporation, thus causing part of the radiant heat to be converted into sensible heat. This notion was clearly disproved by the mowing of the grass around the lysimeter on 16 July. Even though the mowing took place early in the morning and the lysimeter was not completely exposed for the entire day, the evapotranspiration from lysimeter 3 increased from values of 6.13, 6.10, 5.65, and 6.43 mm. on 12, 13, 14, and 15 July, respectively, to 10.05 mm. on 16 July. On the same day, lysimeter 2 evaporated 9.01 mm. Thus, removing the surrounding crop increased evapotranspiration on the mature grass by almost 90%, which was greater than the transpiration from lysimeter 2. This finding is conclusive evidence that the sudangrass at this particular stage of maturity had the ability to transpire, provided the energy was made available to the transpiring surfaces. Additional evidence along similar lines has been published elsewhere (6).

Accordingly, the conclusion is drawn that the difference in the energy balance over the green stand and the mature stand on lysimeters 2 and 3, respectively, on 12 July must be attributed to the fact that the inflorescences, themselves not capable of transpiration, absorbed a greater part of the incident radiation, converting it into sensible heat. Due to the greater turbulent exchange above the inflorescences than below them, more sensible heat was communicated to the air than to the transpiring surfaces below. These findings also imply that the temperature of the crop surface on lysimeter 3, as seen from the sky, would have to be greater than the air temperature, which was about 34° C. The crop on lysimeter 2 presented a surface to the air that was lower in temperature, thus enabling the downward flux of sensible heat.

Additional data obtained during this experiment gave further evidence that the transpiration from the crop is controlled by physical factors, although some of these are associated with the nature and morphology of the crop. The effect of wind speed and the intensity of sensible heat exchange resulting therefrom may be found by comparing the energy balance data obtained on 12 and 13 July, shown in Figures 1 and 6, respectively. On the latter day, wind speeds during the afternoon and early evening were considerably less than on 12 July. Thus, in spite of virtually identical incident solar and net radiation, the evapotranspiration was 86 ly, or 1.4 mm., less on 13 July. Soil heat flux being about the same, we find only 120-ly sensible heat derived from the air on the 13th, as contrasted with 190-ly
on 12 July. The hourly distribution of A on the 2 days is shown in Figure 7. Referring again to a comparison of the wind speeds on the 2 days, shown in Figures 1 and 6, we see from Figure 7 that during the period of approximately equal wind speeds (0000 to 0700 and 1200 to 1400), the extraction of heat from the air was approximately equal (0.05 to 0.10 Ly min⁻¹). However, later in the day when a contrast in wind speed developed, the crop extracted only half as much sensible heat from the air on the 13th as it did on the 12th. This again is evidence to show that transpiration follows the sensible energy input as well as the radiative energy input. The source of the sensible energy in this case is the air that flows over the irrigated areas, having been heated during the day over the surrounding desert. Sometimes this situation is referred to as advection. Data given here make it clear that advection is not a simple phenomenon, but is related to wind speed and time of day, and also, that the nature of the crop may well determine whether a site will be importing or exporting sensible heat from or to other surrounding areas.

A final argument against the effective influence of any physiological factor is the observation that none of the evapotranspiration curves in Figures 1, 2, 4, or 6 show any sign of a so-called midday depression, even though the evaporative conditions were probably as severe as may be found anywhere.

**SUMMARY AND CONCLUSIONS**

The evapotranspiration, net radiation, soil heat flow, and sensible heat-flow components to the air were very similar for 75- and 100-cm. crops of sudangrass. Differences in evapotranspiration occurred during the period when the sudangrass grew from 100 to 140 cm., developing seedheads. The decreased evapotranspiration, other components of the energy balance being similar, indicated that energy was used in heating the air. The lower evapotranspiration rate was not caused by physiological maturity, as demonstrated by mowing the sudangrass surrounding the lysimeter, but appeared to be due to the fact that the seedheads absorbed the radiant energy, converted it into sensible heat, and also provided a very effective aerodynamic barrier against the transfer of sensible heat to the transpiring surfaces. Evapotranspiration from the sudangrass was increased with increased wind speed, notably during periods of darkness. Thus, we conclude that for well-watered sudangrass, meteorological factors regulated the evapotranspiration rather than physiological factors.

Facts and conclusions presented pertain only to sudangrass in the particular climate where it was observed. There is no reason to assume that similar results would be obtained with other crops. Our data do suggest, however, that even after a closed stand is obtained, many factors associated with the management and development of the crop may influence its use of water because of the resultant changes in the physics of the crop surface and the air layer intimately associated with it. Accordingly, the concept of potential transpiration loses much of its generality, but not its usefulness.

**LITERATURE CITED**