The Interactions of Microclimate, Plant Cover and Soil Moisture Content Affecting Evapotranspiration Rates

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INTRODUCTION

The deficiencies and surpluses of water are often the most important of the various factors influencing plant growth. They are, at the same time, the most difficult to control. At present, adequate theory and measuring techniques for predicting the rate of soil water loss by evapotranspiration exist for only a few special combinations of plant and climatic conditions. A better understanding of the factors influencing this process is necessary to help pave the way for the development of methods for increasing the efficiency of water utilization by crops.

The rate of water loss by the processes of evaporation and transpiration is the resultant of five controlling factors, viz:

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* Field data for this study was collected at the U. S. Department of Agriculture Field Station, Marlboro, New Jersey. This paper is a summary of part of a thesis on the same subject by the author in the Soils Department, Rutgers University, New Brunswick, New Jersey.

Evapotranspiration rate determined by
Climate
Soil Moisture
Plant Cover
Soil Texture and Structure
Soil and Crop Management

Of these five factors, the climatic factor has often been used as a first approximation for predicting moisture losses by evapotranspiration, with the remaining four factors either omitted completely or only briefly acknowledged. While it is realized that the climatic factor is of utmost importance since it includes the source of the energy needed for the evapotranspiration processes to operate, the rate of evapotranspiration under specific climatic conditions is often limited by one or more of the remaining four factors. Because these plant and soil factors are so closely interrelated with each other and with the climatic factor, however, much less is known about the individual roles which each play in the overall evapotranspiration process.

In the field study reported in this paper, an attempt was made to obtain further information on the exact relationship of the plant, soil and climate interactions as they affect evapotranspiration rates.

METHOD OF MEASUREMENT

In a previous study (1) the present writer was able to predict the rate of soil moisture loss by evapotranspiration from snap beans with a high degree of accuracy using a modification of Thornthwaite's empirical equations for the water balance (4). These equations were based almost entirely on the climatic factor and were adjusted for varying soil moisture content. From this same field study, a definite relationship between the stage of plant development, as measured by plant cover, and the rate of evapotranspiration was noted (6).

The field experiment reported in this paper was designed to obtain data for the quantitative evaluation of the interaction of soil moisture content, vegetative plant cover and microclimate in terms of rates of moisture loss by evapotranspiration.

This was accomplished in the following manner: Plots of orchard grass were selected with the grass grown in rows of varying width to regulate the amount of grass cover. The following row spacings were used:

Full cover (broadcast), 16 inch (70% cover), 24 inch (50% cover), 32 inch (30% cover) and fallow soil (0% cover).

Grass was chosen over broad leaf plants for the experimental plots because (a) a uniform cover could be maintained by periodic mowing throughout the growing season, and (b) the effect of stage of plant development on the rate of evapotranspiration could be eliminated, the grass being always in the vegetative state. Orchard grass was chosen over other grasses since it does not become dormant during periods of mid-summer high temperatures.

Weekly mowing permitted the percentage of vegetative cover in each plot to be maintained very nearly constant. The grass clippings were removed after each mowing to prevent any effects due to the presence of a mulch. The percentage of plant cover was estimated using a grid overlay photographic technique.

Samples for gravimetric determination of soil moisture were collected on a regular Monday, Wednesday, Friday schedule. From each of the cover treatments, individual samples were obtained on each date at locations within the row, and at six inch increments from the row from two sites in each plot. Similar spacing was used for sampling in the full cover and fallow plots. Duplicate samples were obtained at each location and composited for that location only. Thus for any one measured value of moisture in a particular profile of soil, a total of 32 individual samples were collected. Samples were taken to a depth of 36 inches by increments of three inches in the top foot of the soil profile and six inches for the lower two feet.

Insufficient instrumentation and a lack of electrical power at the site did not permit a continuous record to be made of all the climatic elements known to affect evapotranspiration rates. Instead, spot measurements of air and soil temperatures, solar and terrestrial radiation, atmometer evaporation, and wind velocities were made under different weather conditions over the growing season. Air temperature and relative humidity measurements were made at 1 and 44 inches above the soil surface using a fan psychrometer, soil temperatures at varying increments to a depth of 8 inches using a thermocouple tipped probe, net radiation at 4 feet using the economical net radiometers, and wind velocity profiles from 0 to 44 inches using a hot wire anemometer.

RESULTS AND DISCUSSION

Effect of Interaction of Plant Cover - Microclimate on Evapotranspiration Rates.

For most crops, the effect of plant cover on the rate of water loss by evapotranspiration is of primary importance only when the plants are small, i.e., early in the growing season. During this period, rooting depths are generally restricted to the top 12 to 18 inches or less of the soil. For this reason, major emphasis in this paper is placed on water losses from the upper portions of the rooting zone of the grass. Rooting patterns obtained by excavation indicated that the bulk of the roots of the orchard grass, whether grown in rows or broadcast, were located in the top 18 inches of soil with the root density becoming increasingly sparce below that depth.

The most rapid removal of soil moisture by evapotranspiration from all treatments occurred, as expected, from the top few inches of soil. Fig. 1 shows that, on the average over the season, the maximum water use by orchard grass was from the plot having only a fifty percent grass cover. This was particularly evidenced in the top foot of soil. With increasing depth below one foot, the differences in average rates of water loss from plots having 50%, 70%, and complete grass cover were minimized.

From this figure, it may be seen that, in addition to the maximum water loss for all depths occurring from the plot having only 50% plant cover, the effect of rooting depth on the rate of moisture removal was also of greatest importance in this plot. Water losses from the 70% cover plot exceeded that from full grass cover for the three shallower depths while the water losses from the 30% cover averaged well below those from the other grass plots and only slightly above that from fallow soil.

Data from midday measurements over the grass and fallow plots showed that the net radiation over a cropped surface does not decrease linearly as the amount of plant cover decreases. While all treatments received equal amounts of incoming solar radiation, the outgoing terrestrial radiation was such that the net radiant energy over the 30% grass cover was nearly the same as that over bare soil while over the 50% and 70% cover plots it was virtually equal to that measured over the full grass cover (fig. 2).

It is to be noted here that the shape of the curve relating net radiation to plant cover is in close agreement with the curve relating moisture loss rate to plant cover for the 0-12 inch depth. From this, one may conclude that the use of net radiation values measured over a full grass cover to estimate evapotranspiration values from row crops is not seriously in error provided that the plants have matured to the extent that they cover at least 50% of the soil surface and have an effective rooting depth of at least 1 foot.

It has been reported by a number of scientists (2), (3), (5), that the seasonal average evaporation from fallow soil is approximately 40-50 percent of full cover evapotranspiration. The fact that the water loss measurements from the fallow soil reported in this study averaged approximately 75% of that from full grass cover can be explained by the frequency of rainfall occurrance during the sampling period. In fig. 3 it is seen that the water loss rate from the fallow soil was parallel to that from full grass cover for about 5-7 days following a rain. Since the between-rain periods exceeded seven days on only four occasions during the growing season, the above value is not unrealistic.

The apparent large anomalies in moisture loss rates from grass grown in rows to that from full grass cover are the result of a strong interaction between the microclimate and the plants in the row. Differences in soil temperatures measured midway between the rows (table 1) indicate that, whenever the sun's rays are allowed to reach the soil surface, the upper few inches of the soil and, by conduction, the lowest layers of the atmosphere are heated much more strongly than are the same levels of the soil and air when the soil surface is covered with vegetation.

Table 1

Differences in Soil Temperatures

Midway between Rows and under Full Grass Cover (^{o}F)

Depth	16" Rows		24" Rows		32" Rows		Fallow	
inches	A*	B**	A	B	A	B	A	B
1/2	5	14	5	14	7	15	9	20
1	4	11	4	12	6	11	9	20
2	1	7	2	9	2	7	7	15
3	1	6	1	6	1	7	4	13
4	2	5	3	5	1	2	3	9
6	0	3	0	2	-2	2	3	7
8	-1	2	-1	2	-2	1	2	5

* Soil surface damp ** Soil surface dry

At the same time, while almost calm conditions exist within the foliage of the full cover grass plot, this lowest skin of air over the bare areas between the rows, having been warmed and dried by contact with the soil surface, is continually being advected across and between the plants in the row. An example of typical wind profiled over full grass cover and bare soil is shown in fig. 4. The movement of air across and through the row results in a clothesline effect with the row acting as a miniature oasis. As a result, the grass in the row transpires at a much higher rate than does the grass in the full cover plot despite the great difference in plant population (fig. 5).

Data from Livingston atmometer measurements indicated that the evaporating power of the air over the fallow soil was roughly 20% greater than over the complete grass cover. This increase is approximately the same order of magnitude as the maximum increase in evapotranspiration by the grass grown in rows over that from full grass cover.

From fig. 1, it was seen that the average rate of evapotranspiration was at a maximum for the 50% cover plot and decreased with both increasing and decreasing plant cover. In the case of the 30% cover plot, while the total wind movement through the row tended to increase with increasing row spacing, the total moisture loss from the plot area was suppressed due to the much reduced plant population. On the other hand, the 70% grass cover plot lost less water than did the 50% cover plot due to reduced air movement. In addition, from measurements of air temperature and relative humidity at the one inch level in the 70% cover plot, there was some evidence of an apparent cooling effect on the air for a short distance out from the row as a result of plant transpiration.

Effect of Interaction of Plant Cover-Soil Moisture Content on Evapotranspiration Rates.

From the above discussion, it has been shown that the interaction of plant cover and microclimate play a most important role in the process of moisture removal by evapotranspiration, and particularly so when the plants are small with only a partial vegetative cover and with shallow rooting depths. Conclusions as to the quantitative relationship of the interactions were based on average evapotranspiration data collected during a growing season with above normal frequency and amounts of precipitation.

The marked influence of the microclimate on the rate of water loss during individual periods when soil moisture was readily available is also evidenced in figures 6, 7, and 8. From fig. 7, for example, it is seen that, when soil moisture was near field capacity in the top 18 inches of the rooting zone, the rate of water loss from plots having 50 and 70% cover was over two times as rapid as from the full cover grass plot during the same period.

When the available soil moisture becomes limited, however, the influcence of the plant cover-microclimate interaction is sharply suppressed and the interaction of plant population-soil moisture content evidences a dominating influence. Due to the frequent rainfall during the period of the field study, insufficient data were obtained to show the exact relationship of this interaction.

SUMMARY AND CONCLUSIONS

In this study, the effect of different amounts of vegetative surface cover on the rate of water loss at different areas of the rooting zone were compared. From the soil moisture data obtained, it was shown that the rate of water loss is not a linear function of the amount of vegetative plant cover over the soil. Rather, when soil moisture is not severely limiting, the relationship is curvilinear with both the 50 and 70 percent grass cover plots losing moisture at a slightly higher rate than did the full cover grass plot. The reason for this phenomenon was shown to be due a clothesline effect. That is, the row itself can be considered to be a micro-oasis with the warmer, drier air from between the rows passing across and between the plants in the row. This results in an increased transpiration rate from these plants over that from plants of the same size in an area fully covered by vegetation. In the case of more widely spaced rows (30% grass cover), the plant density and in turn the total amount of water transpired is reduced to such a point that the overall water loss falls below that from the full cover grass plot.

From the few observations during the periods when the available soil moisture was below 50% of field capacity, it appeared that the shape of the plant cover vs moisture loss rate curve was altered with the plant population - soil moisture content becoming the more dominant interaction.

From results obtained in this study, it is recommended that when values of potential evapotranspiration, based on full cover vegetation, are used in evapotranspiration computations, an adjustment in the procedure for computing the water balance for row crops should be made only during the period from plant emergence until the time at which the plant cover is 40-45% complete. Above this threshold, for adequate soil moisture conditions, the difference between the average rate of water loss from plants grown in rows and that from full cover are not sufficient to warrant further adjustment.

From the standpoint of water efficiency only, and provided that adequate irrigation facilities are readily available, the results of this study would indicate that there would be an actual conservation of soil moisture if the plants were grown in rows of much narrower spacing.

ACKNOWLEDGEMENTS

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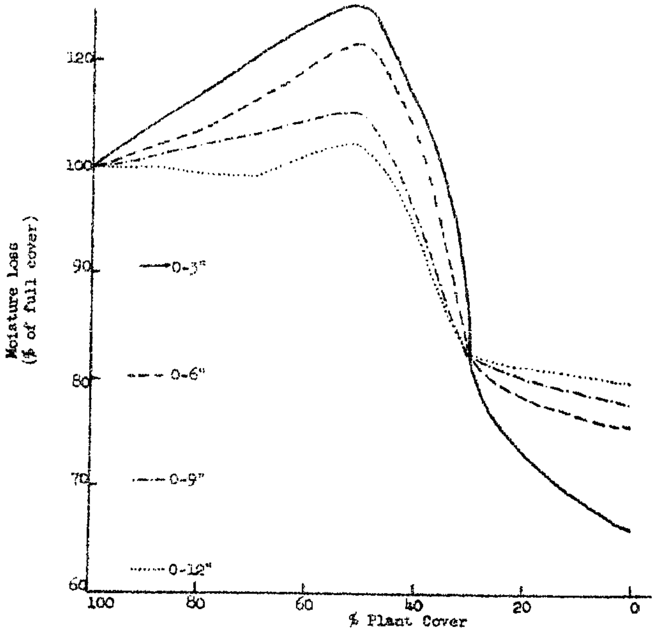

Fig. 1. Effect of plant cover on evapotranspiration rate.

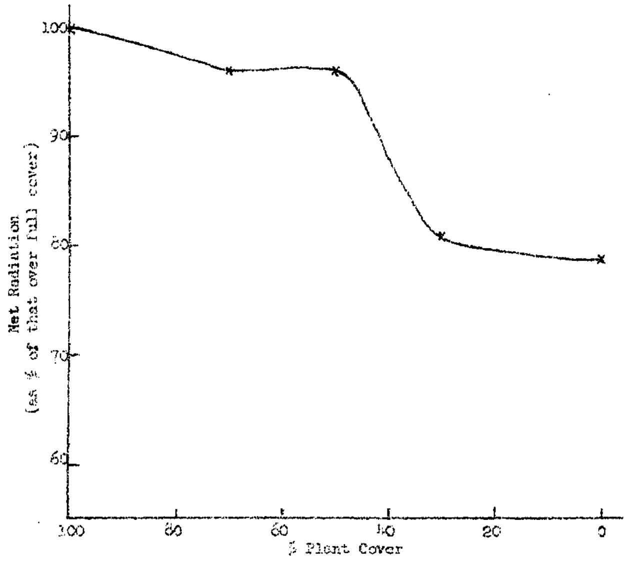

Fig. 2. Effect of plant cover on net radiation (ave. of 35 midday observations).

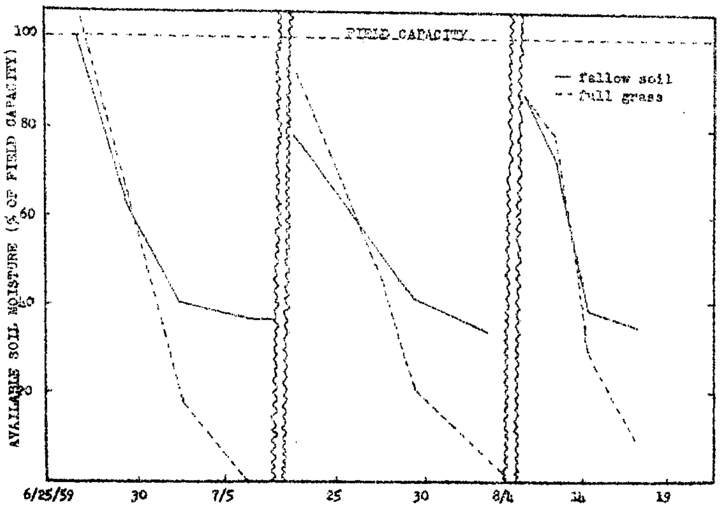

Fig. 3. Soil moisture storage change (0 - 3" depth) during three drying periods for full grass cover and fallow soil.

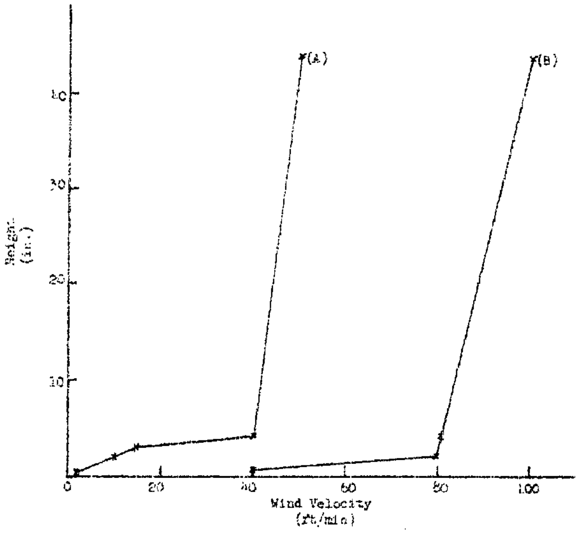

Fig. 4. Wind profiles over (A) grass and (B) bare soil.

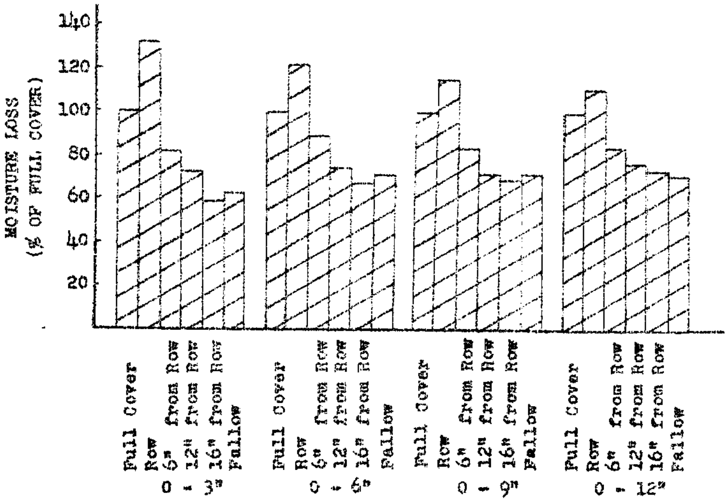

Fig. 5. Average soil moisture loss from orchard grass.

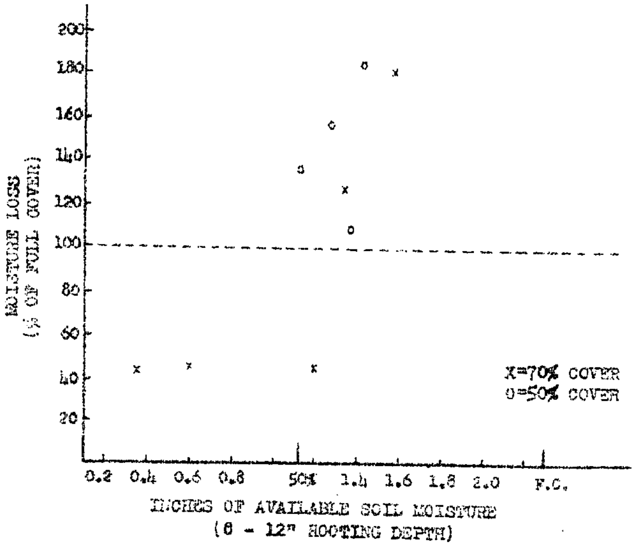

Fig. 6. Effect of available soil moisture content on rate of moisture loss from various amounts of grass cover.

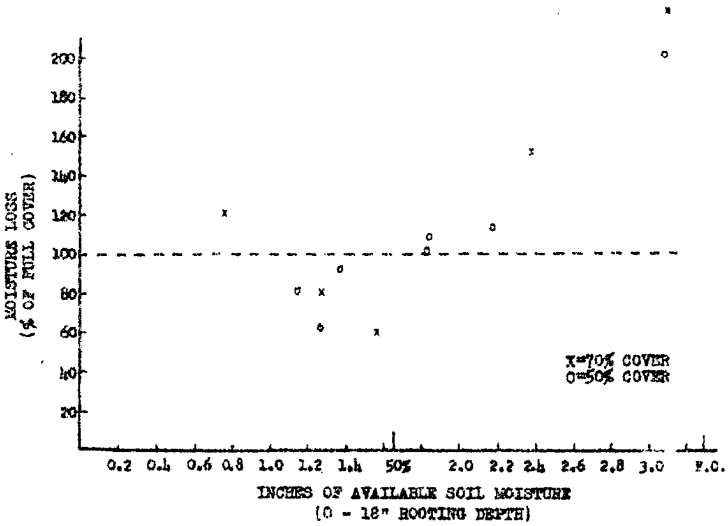

Fig. 7. Effect of available soil moisture content on rate of moisture loss from various amounts of grass cover.

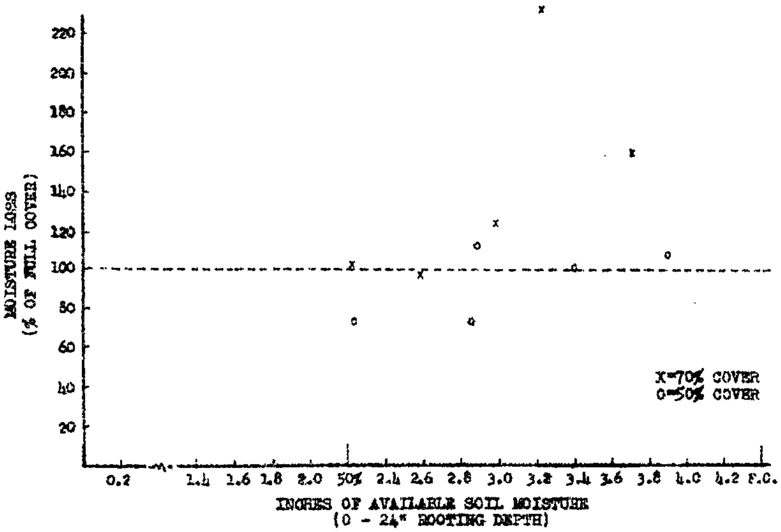

Fig. 8. Effect of available soil moisture content on rate of moisture loss from various amounts of grass cover.