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Relationships Between Leaf Water Potential, Canopy Temperature, and Evapotranspiration in Irrigated and NonIrrigated Alfalfa[1]

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ABSTRACT

A prerequisite to exploiting potential production of any crop is to accumulate a knowledge of plant responses, whether the response is to climate, fertilizer, or water. This paper describes a study on a Waukegan silt loam soil (fine-silty over sandy or sandy skeletal, mixed, mesic Typic Hapludolls) where stress differences between irrigated and nonirrigated alfalfa (*Medicago sativa* L.) were evaluated during the daytime in order to expand the limited information available on alfalfa water relations. Canopy temperature (CT), evapotranspiration (ET), and leaf water potential (ψ_l) served as indicators of stress and were measured using an infrared thermometer, portable chamber, and pressure chamber, respectively. Canopy temperature and ET did not differ appreciably between irrigated and nonirrigated alfalfa in early morning, but after 0900 h and throughout the afternoon nonirrigated alfalfa had a higher CT and lower ET. Leaf water potential of nonirrigated alfalfa was consistently lower during the day. The maximum difference in CT, ET, and ψ_l between irrigated and nonirrigated alfalfa occurred at 1500 h where they equalled 2°C, 0.2 mm/h, and 0.7 MPa, respectively. These stress differences reflected the differences in the plant available water of 280 and 60 mm (corresponding to 117 and 25% of extractable water) in the 1.83-m soil profile of the irrigated and nonirrigated plots, respectively. Nonirrigated alfalfa ψ_l declined at a faster rate as the peak stress period (1500 h) was approached; however, after this period a faster rehydration was observed for this treatment, as indicated by the relationship between ψ_l and ET. Despite the faster rehydration of nonirrigated alfalfa, the degree of hysteresis was greater for this treatment than for irrigated alfalfa. The relationship between CT and ET indicated a larger rate of change in CT prior to the peak stress period for nonirrigated as compared to irrigated alfalfa. After this time and until 1700 h, CT remained constant as ET decreased, indicating a decreasing ratio between ET and net radiation and thus greater restrictions on water movement through the plant, a direct cause of the hysteresis observed.

Additional index words: **Infrared thermometry, *Medicago sativa* L., Plant water relations, Water use.**

An integral part of agriculture in the north-central United States involves growing alfalfa (*Medicago sativa* L.) to control soil erosion and to provide high quality feed for cattle. Despite its importance as a forage, little information is available on plant water relations of alfalfa, especially the role that environmental stress plays in altering these relations. Increasing the existing knowledge on water relations will promote higher production potential and more efficient water use in alfalfa through selection and breeding efforts.

Leaf water potential (ψ_l) is a good indicator of soil water stress imposed upon the plant and thereby gives insight into the plant water relationship, providing that good analytical techniques are used (Baughn and Tanner, 1976; Brown and Tanner, 1983). Relationships between ψ_l and visual indications of plant stress have been reported for alfalfa. At first signs of wilting in the field, Brown and Tanner (1983) found ψ_l in alfalfa to be between -1.2 and -1.4 MPa. Peake et al. (1975), using a different cultivar than Brown and Tanner, found that initial visible wilting in the field occurred when ψ_l was between -1.5 and -2.5 MPa, indicating that cultivar difference is negligible in terms of ψ_l. Further stressing of the plant resulted in collapse of small stems and petioles at ψ_l of -2.0 to -4.0 MPa. Death of leaves finally occurred when ψ_l decreased to -4.0 MPa over a 3 to 4-day period.

Hysteresis plays an important role in plant water relations by means of determining the onset of plant stress and also the degree of stress when external forces acting on the plant change. Studies on the diurnal nature of ψ_l in alfalfa are lacking but have been reported for other crops. For example, Ritchie (1973) found that forenoon values of ψ_l in nonirrigated field grown corn decreased proportionally to an increase in evaporative demand. However, in the afternoon at comparable ET demands, ψ_l did not recover to as high a value as the forenoon ψ_l, suggesting hysteresis in corn. Reicosky et al. (1982a) found hysteresis to be more pronounced in nonirrigated than irrigated soybeans. Hysteresis was also observed in initially well-watered avocado trees that went 30 consecutive days without irrigation or rainfall (Sterne et al., 1977). Jones (1978) found hysteresis in one cultivar of winter wheat but not in the second, concluding, however, that the degree of hysteresis was in response to an increasing soil moisture deficit rather than a cultivar difference. Under a controlled and nonlimiting soil moisture environment, Neumann et al. (1973) reported a linear relationship between ψ_l and transpiration rates in corn, soybeans, and sunflowers, indicating no hysteresis.

Physiological studies of evapotranspiration (ET) on irrigated alfalfa have been limited to a few localities around the world, the majority being conducted in the semiarid climate of Nebraska. Rosenberg (1969) found a maximum ET of 12 and 7.5 mm/day during late spring and mid-summer, respectively. In a similar study, Blad and Rosenberg (1974) reported an average seasonal daily ET of 9 mm with a maximum of 12 mm day^{-1} in late spring. During the 1976 Midwestern drought, Rosenberg and Verma (1978) reported a maximum daily ET of 14 mm with ET exceeding 10 mm day^{-1} for one-third of the days studied. They concluded that regional scale advection of sensible heat caused by the 1976 drought induced the high alfalfa ET rates. For the arid climate of Arizona, van Bavel (1967) reported a maximum alfalfa ET of 12 mm day^{-1}.

Canopy temperature (CT) has been used to qualitatively and quantitatively ascertain the plant water status of alfalfa (Idso et al., 1981). Blad (1980) found moderate to severe plant water stress when CT differences between well-watered and stressed plants developed by mid-morning. He also reported alfalfa as having a lower CT than corn, soybeans, and grass and that CT of well-watered plants was 5 to 7°C lower than stressed plants.

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The purpose of this study was to increase the limited information available in alfalfa water relations. Emphasis was placed on the dynamic nature of the relationship of ET with ψ_l and CT by evaluating the daytime trend of ψ_l, CT, and ET in irrigated and nonirrigated alfalfa.

MATERIALS AND METHODS

Two alfalfa cultivars were grown on adjacent field plots near the Univ. of Minnesota microclimate station located on St. Paul Campus (44°59'N 93°11'W). The soil type on both plots is a Waukegan silt loam (fine-silty over sandy or sandy skeletal, mixed, mesic Typic Hapludolls). The cultivar Blazer was irrigated as required since planting in April 1980 and the cultivar Anchor received no irrigation other than rainfall since its establishment in 1979. The last significant rainfall was 10.7 mm on 19 June 1980. On 1 July 1980, 1 day prior to the start of the experiment, Blazer alfalfa was irrigated with 25 mm of water. Both cultivars had full canopy cover during the 2 consecutive days of the experiment. Because the dormancy response and yield potential are nearly equal (Minnesota Agric. Exp. Stn., 1981), it can be inferred that these cultivars have similar ψ_l responses.

Beginning at predawn on 2 July 1980, ET, ψ_l, and CT measurements were initiated. Evapotranspiration was measured on both plots using the portable chamber technique described by Reicosky and Peters (1977). A precision weighing lysimeter in the irrigated alfalfa plot provided a comparison of ET measured by the portable chamber and indicated acceptable agreement (Reicosky et al., 1982b). Leaf water potential was determined for leaf-stem samples using a pressure chamber (Scholander et al., 1965). Two leaf-stem samples were collected concurrently with each ET measurement. The time interval between cutting of the stem and endpoint of the pressure chamber measurement was approximately 1 min. Errors associated with this sampling procedure would appear minimal as substantiated by Brown and Tanner (1981). Canopy temperature was determined using a Telatemp[3] infrared thermometer (Idso et al., 1981). All measurements were taken at 10-min intervals and collected until shortly after sunset on 2 July and until 1500 h on 3 July. The trends were virtually the same for both days; therefore, only the 2 July data are presented.

Soil water samples were collected on 2 July in both the irrigated and nonirrigated alfalfa plots at 0.15 m depth increments in the top 1.22 m of soil and at 0.30 m depth increments from the 1.22 to 1.83 m depth. Available soil water content was determined on a dry soil weight basis.

Leaf water potential and canopy temperature data analysis included taking the mean of two measurements obtained at 10-min intervals and then smoothing the means using a 1-2-3-2-1 weighted running average. Single ET measurements were smoothed similarly. Two-hour averages of the weighted running averaged were used to describe the general daytime trend in and relationships between CT, ψ_l, and ET for irrigated and nonirrigated alfalfa.

RESULTS AND DISCUSSIONS

Soil water content was greater in the irrigated than in the nonirrigated alfalfa plot, as illustrated in Fig. 1. Available water in the 1.83 m soil profile for the irrigated and nonirrigated plot was 280 and 60 mm, respectively. The available water corresponds to 117 and 25% of extractable water in the profile. Also apparent from Fig. 1 is that most of the soil water depletion by alfalfa occurred in the top 0.91 m of the profile, where 90% of the difference in irrigated and nonirrigated available soil water content can be accounted for.

Daytime trends in CT, ET, and ψ_l for 2 July are illustrated in Fig. 2. A difference in ψ_l between irrigated and nonirrigated alfalfa was found throughout the day with irrigated alfalfa at the higher (less negative) ψ_l. The smallest difference in ψ_l during the day was 0.5 MPa near sunrise and the largest was 0.7 MPa while for nonirrigated alfalfa it was −1.7 MPa. Evapotranspiration differed between irrigated and nonirrigated alfalfa over the course of the day; the smallest (0.03 mm h^{-1}) and largest (0.20 mm h^{-1}) differences were near sunrise and 1500 h, respectively. Maximum ET for irrigated and nonirrigated alfalfa was 0.78 and 0.58 mm h^{-1}, respectively. Canopy temperature differences were less than 0.5°C until 0900 h. The nonirrigated alfalfa CT remained higher for the rest of the day with a maximum difference of 2°C at 1500 h. Differences in ψ_l, ET, and CT between irrigated and nonirrigated alfalfa were related to the availability of soil water as the higher ET and ψ_l and lower CT were associated with the higher soil water content in the irrigated plot.

The relationship between ψ_l and ET is shown in Fig. 3. As ET increased from 0700 h, ψ_l decreased. The rate of decline in ψ_l, from 0700 to 0900 h was nearly equal for both irrigated and nonirrigated alfalfa where the slopes of the relationship are 1.2 and 1.3 MPa mm^{-1} h^{-2}, respectively. After 0900 h, the rate of decline in ψ_l increased for both treatments, with the fastest rate in nonirrigated alfalfa. The increasing rate of decline in ψ_l persisted until the peak stress period was reached at 1500 h. This suggests water stress became critical in nonirrigated alfalfa at 0900 h, the time at which the slopes of the irrigated and nonirrigated relationship in Fig. 3 begin to diverge. Between 0900 and 1500 h the rate of decline in ψ_l was three times

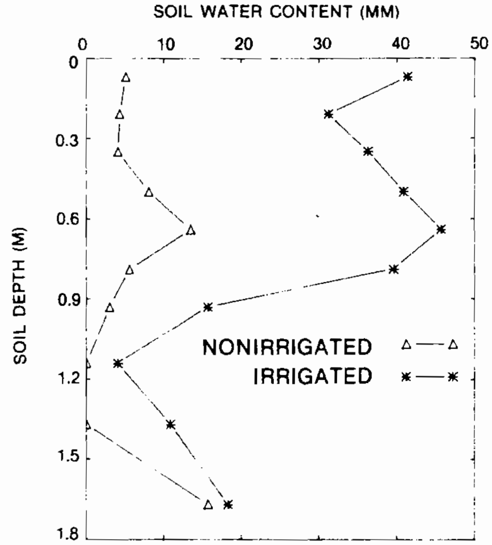

Fig. 1. Available soil water content at various depths in the soil profile for irrigated and nonirrigated alfalfa on 2 July 1980.

[3] Name of a company or product does not imply approval or recommendation by the USDA or Univ. of Minnesota to the exclusion of others which are suitable.

faster for nonirrigated alfalfa. The fastest rate of decline in irrigated and nonirrigated alfalfa ψ_l during the daytime period occurred at 1300 to 1500 h where the slopes of the relationship are 3.6 and 25 MPa/mm^{-1} h^{-2}, respectively. After peak stress and to the end of the measurement period, nonirrigated alfalfa rehydrated faster with a rate of recovery in ψ_l twice as large as that of the irrigated alfalfa.

Despite the faster rehydration in nonirrigated alfalfa, the degree of hysteresis was greater for this treatment. For example, at an ET of 0.4 mm h^{-1}, the ψ_l of irrigated and nonirrigated alfalfa was −0.3 and −0.9 MPa in the morning, and in the late afternoon, the ψ_l at the same ET rate was −0.6 and −1.4 MPa, respectively. The difference between the morning and late afternoon ψ_l at the same ET rate is therefore 0.3 and 0.5 MPa for irrigated and nonirrigated alfalfa, respectively. The faster rehydration of the nonirrigated alfalfa suggests that water stress recovery is dependent largely on the magnitude of the rate of decline in ψ_l between 0900 and 1500 h.

The relationship between CT and ET is shown in Fig. 4. As ET increased from 0700 h, CT increased. The ET increase was in response to increasing radiant energy and air temperature during this time, with CT increases due to the inability of alfalfa to dissipate all available energy via ET. The rate of CT increase from 0700 to 0900 h was nearly equal for both irrigated and nonirrigated alfalfa where the slopes of the relationship are 21 and 23°C mm^{-1} h^{-2}, respectively. After 0900 and until 1100 h, the slope of the curve for nonirrigated was about double that of the irrigated alfalfa. This suggests that the water stress in nonirrigated alfalfa became critical at 0900 h when the slopes begin to diverge. As the peak stress period was approached, differences between the slopes of the irrigated and nonirrigated relationship were enhanced. Thus from 0900 to 1500 h the rate of increase in nonirrigated alfalfa CT tripled that of irrigated alfalfa. After 1500 and until

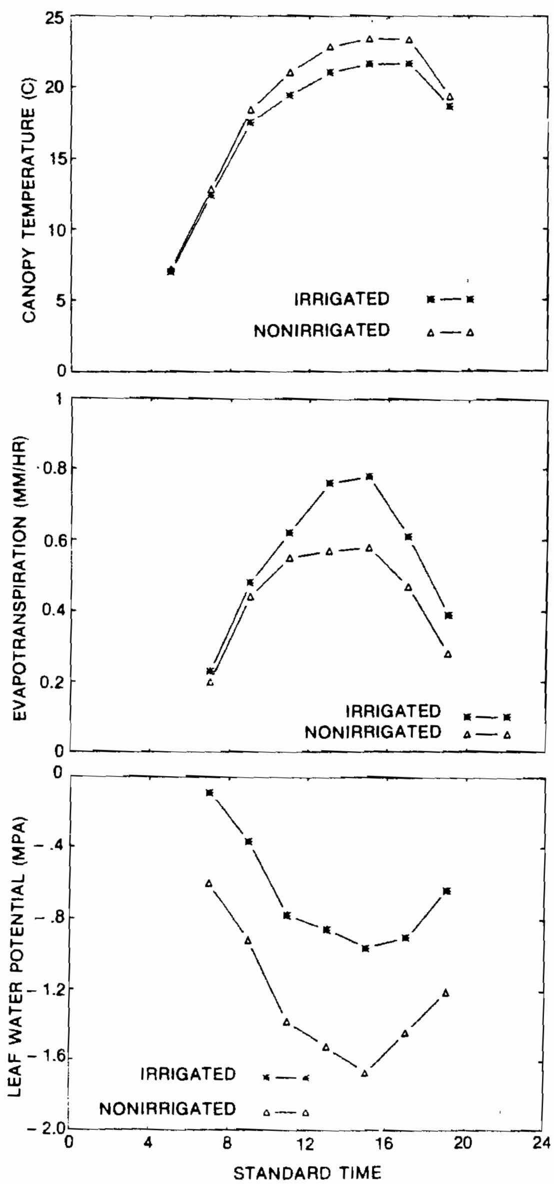

Fig. 2. Daytime trend in canopy temperature, ET, and leaf water potential of irrigated and nonirrigated alfalfa on 2 July 1980.

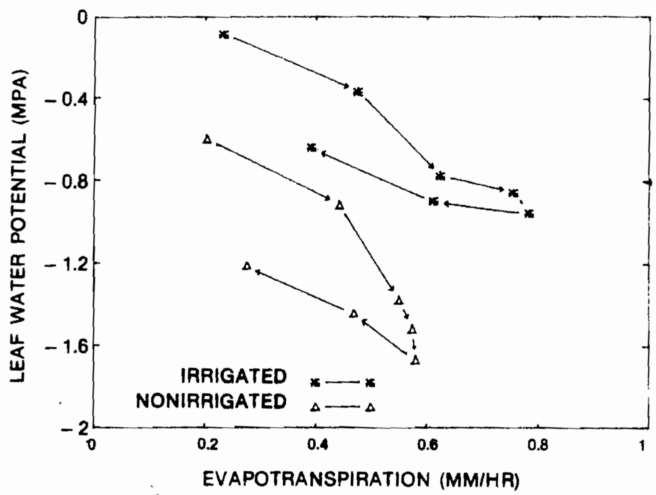

Fig. 3. Relationship between leaf water potential and ET for irrigated and nonirrigated alfalfa. Data points plotted at 2-h intervals beginning 0700 and ending 1900 CST.

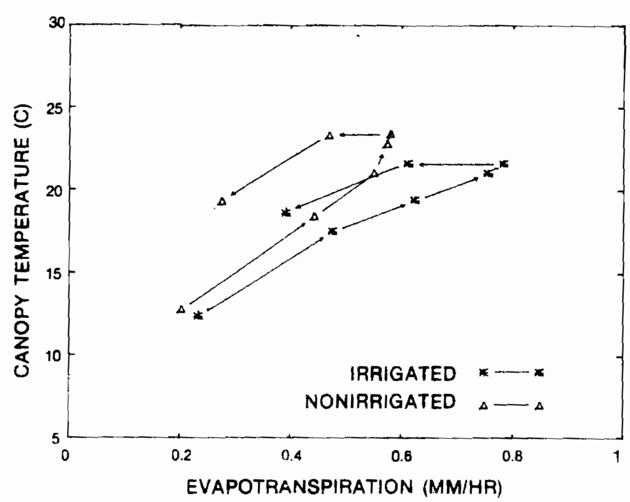

Fig. 4. Relationship between canopy temperature and ET for irrigated and nonirrigated alfalfa. Data points plotted at 2-h intervals beginning 0700 and ending 1900 CST.

1700 h CT remained constant for both treatments as ET decreased. During this time a lower amount of available energy would be partitioned into ET, thereby allowing greater sensible heating with a nearly constant CT. Lowering of the ratio between ET and net radiation from 1500 to 1700 h indicates restrictions were placed on water movement through both the irrigated and nonirrigated alfalfa. This restriction to water movement is another measure of hysteresis. The return to a lower CT for nonirrigated alfalfa from 1700 to 1900 h when the radiation load was reduced was faster, possibly because of the higher CT attained during the daytime period.

Major features in Fig. 3 and 4 are verified by the 3 July data. These features include the nearly equal slopes of the relationship of ET with ψ_1 and CT between 0700 and 0900 h for irrigated and nonirrigated alfalfa. They also verify the divergence in the slopes after 0900 h which increased as the peak stress period was approached. Further verification was halted due to appearance of clouds shortly after 1500 h, brining to termination the experiment.

CONCLUSIONS

Stress was evident in nonirrigated alfalfa as established by CT, ET, and ψ_1 differences between irrigated and nonirrigated alfalfa. Lower availability of soil water in the 1.83 m profile on the nonirrigated (25% extractable) as compared with the irrigated plot (117% extractable) resulted in a lower ψ_1 in nonirrigated alfalfa, thereby reducing ET with a subsequent rise in CT during the daytime.

Nonirrigated alfalfa ψ_1 declined at a faster rate as the peak stress period (1500 h) was approached; however, after this period a faster rehydration was observed for this treatment, as indicated by the relationship between ψ_1 and ET. This suggests that the period prior to peak stress is the most critical in terms of water stress recovery, as the degree of hysteresis was greater for nonirrigated than for irrigated alfalfa. The relationship between CT and ET indicated a larger CT rise as ET increased in nonirrigated alfalfa. This signifies a greater fraction of available energy was consumed in sensible heating for nonirrigated alfalfa. As ET decreased in late afternoon from 1500 to 1700 h, CT of irrigated and nonirrigated remained constant. In order to maintain this constant CT the ratio between ET and net radiation must decrease, thereby indicating restrictions to water movement through irrigated and nonirrigated alfalfa and a cause of the hysteresis observed.

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