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SOIL WATER UPTAKE BY ALFALFA[1]

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ABSTRACT

Water uptake patterns of alfalfa (*Medicago sativa* L.) assist us in understanding proposed models governing plant water uptake. The data in this paper are presented to elucidate some details of passive water uptake from profiles with nonuniform soil water distributions. Soil water content under an alfalfa seed crop was monitored with a neutron moisture probe. Alfalfa roots withdraw soil water in the lower portion of the root zone (where soil matric potentials were between —7 and —10 bars), while the upper portion of the profile was above —2 bars. This indicates that for passive water uptake to occur, large water potential differences must exist between the root xylem and the soil in the upper, moist portion of the profile. Plant water potential measurements support passive uptake.

Additional index words: **Roots, Water potential.**

THE flow of water into roots is largely passive, because the driving force is the water potential gradient across the root soil interface (2, 7). In this descriptive model, the water potential of an actively growing plant must be lower than that in the soil to maintain a water flow rate into the plant to meet transpirational demand. The present paper describes water uptake patterns by a deep-rooted crop with nonuniform soil water distributions.

PROCEDURES

In a study to develop improved soil water management practices for alfalfa (*Medicago sativa* L.) seed production, soil water profiles were measured with a neutron moisture probe weekly to a 2.3-m depth. Soil water retention curves were determined by the pressure plate method (8) on undisturbed cores collected at 35-cm intervals to a 2.5-m depth. Soil matric potentials (Ψ_m) were calculated from the neutron probe data used in conjunction with the soil water retention curves.

The experimental site was in south central Idaho on Portneuf silt loam, a coarse silty, mixed, mesic Xerollic Calciorthid. This loess soil contains a moderately cemented, nodular calcic horizon with an abrupt upper boundary occurring between 0.4 and 0.5 m below the soil surface and a gradual gradation into noncemented subsoil between the 0.8 and 1 m depth. Figure 1 shows the root system of an excavated alfalfa plant. Rooting was proliferous above the calcic horizon, restricted and distorted through the horizon, and finely branching below it. Not shown in the figure are a large number of fine roots (0.3 mm diam. and smaller) which were lost in removing the plant. These fine roots were especially numerous in the surface 0.4 m, sparse in the next half-meter, and fairly numerous below 1 m. The fine roots continued below 2 m, but were not followed below this depth when the plant was excavated (Fig. 1).

RESULTS AND DISCUSSION

Figure 2 presents soil water content profiles for three dates (8, 15, and 22 July, 1969) on an alfalfa plot seeded 1 year before this study was initiated. On 9 July, when the alfalfa was approaching full bloom, it was irrigated, which accounted for the increased soil water content in the upper meter of the profile as shown on 15 July. Corresponding calculated soil matric potential profiles for several dates are presented in Fig. 3. Three additional proflies are included in Fig. 3 to illustrate the decrease in Ψ_m prior to the period of interest. The first three curves were not extended to the surface due to the effect of rainfall during this period. The only rainfall between 8 and 22 July was a trace on 9 July, the day of irrigation.

Figure 2 and 3 show that the alfalfa consistently withdrew water from the entire measured profile after 9 July, although the Ψ_m in the upper horizons was much higher and the water was more available than in the subsoil. During this period, four-fifths of the water withdrawn from the top 2.3 m of soil came from the first meter, most of which was above —2 bars matric potential, while one-fifth came from the next 1.3 m, much of which was between —7 and —10 bars. If water uptake is passive along a potential gradient, then the plant water potential (Ψ_p) in the roots must have been less than —10 bars for

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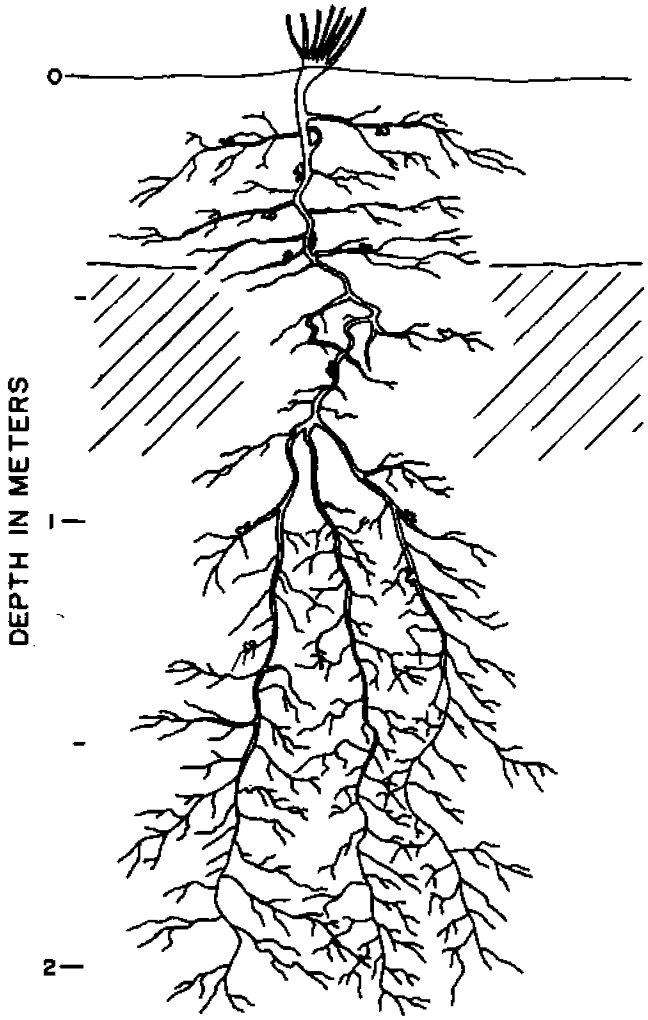

Fig. 1. Sketch of the root system of an excavated alfalfa plant grown in Portneuf silt loam. Roots smaller than 0.3 mm diam. were lost in excavating and are not shown. Root growth was restricted and distored in the moderately cemented subsoil horizon, but was extensive below this region.

uptake to occur below 1 m. When plant water potentials (Ψ_p) in the tops were measured with a portable freezing-point meter (1) at 1500 hours in early July, it was found to be between —13 and —15 bars on recently irrigated plots similar to that shown in Fig. 3. Plant water potential measurements made with a Peltier-type vapor pressure psychrometer (14) yielded similar values.

The passive uptake theory (3, 5, 7) requires (a) that the water potential in the xylem of the plant be highest at the root tips and decrease in the direction of the stem, and (b) that Ψ_p be less than Ψ_m for water uptake to occur. From Fig. 3, the Ψ_m in the subsoil between 15 and 22 July was between —7 and —10 bars. Since Ψ_p had to be less than Ψ_m for uptake to occur, there had to be a large difference between Ψ_m and Ψ_p in the upper root zone. The soil water potential gradients near the plant roots would have been small (12) with a Ψ_m of more than

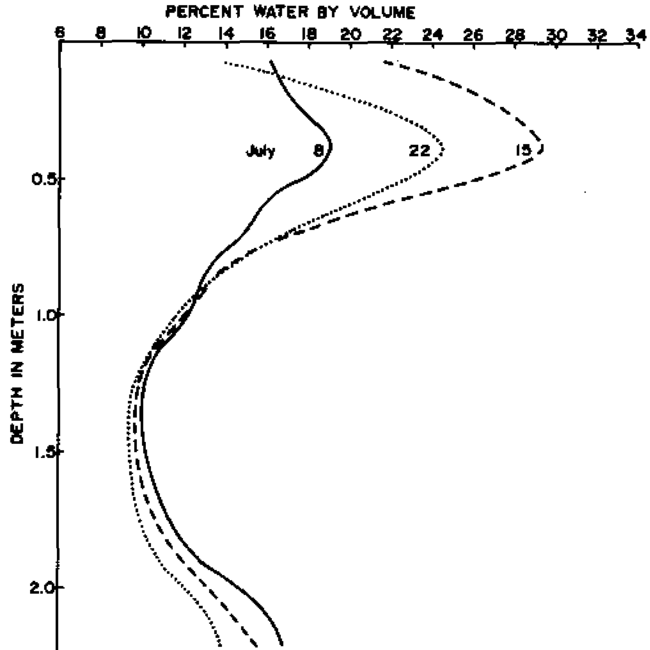

Fig. 2. Soil water on an alfalfa plot on three dates illustrating the pattern of water use after an irrigation.

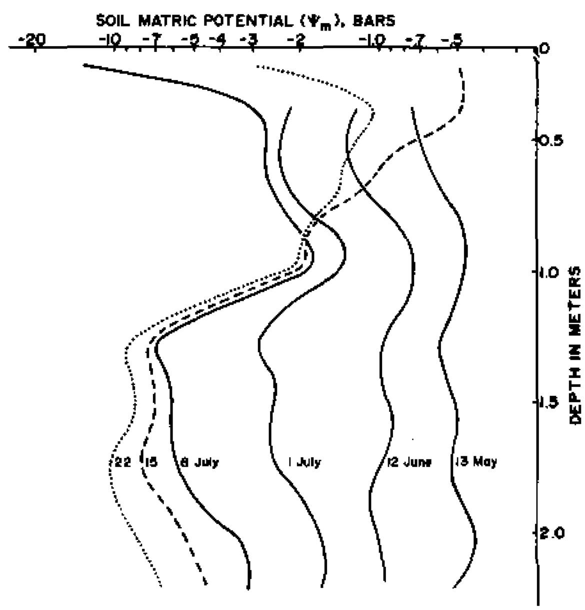

Fig. 3. Soil matric potential on the alfalfa plot of Fig. 2 on six dates illustrating the pattern of matric potential increase with time.

—2 bars. Therefore this large difference between Ψ_m and Ψ_p lends support to the theory that the major resistance to water flow is between the root surface and the xylem (6, p. 292).

The alfalfa plant moisture potentials decreased through the growing season, perhaps as a combined result of moisture stress and maturity (4). Soil matric potential profiles for two additional plots on 24 and

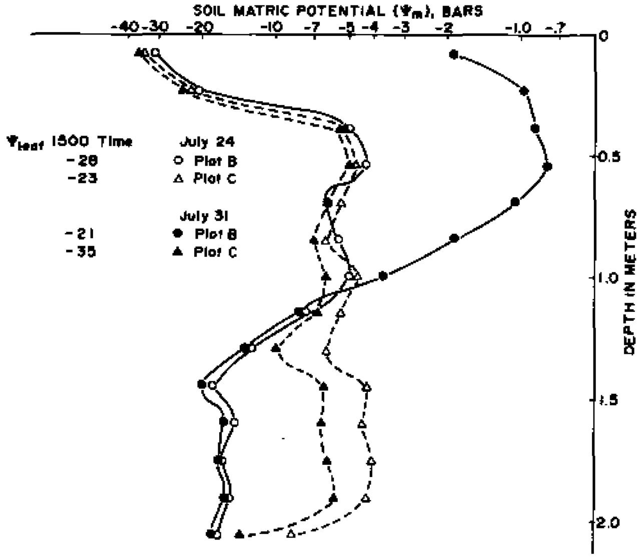

Fig. 4. Soil matric potential on two alfalfa plots on 24 and 31 July and measured afternoon plant water potential. Plot B was irrigated 25 July.

31 July, together with their afternoon Ψ_p, are presented in Fig. 4. The plots were now setting seed. By 24 July, the plants on plot B had with-drawn most of the available soil water except through the cemented horizon with its sparse root density and had a Ψ_p of —28 bars. This plot received an irrigation on 25 July which wetted the soil to a 1-m depth. The alfalfa on plot B (with soil water available at less than —1 bar on 31 July) now had a Ψ_p of —21 bars, while the plants on plot C (where the Ψ_m was generally below —5 or —6 bars) now had an afternoon Ψ_p of —35 bars. These water potential values are consistent with passive water uptake.

After the 9 July irrigation (Fig. 3), the alfalfa crop should have been transpiring near its maximum rate (10), which, according to Wright and Jensen (13), would remove 58 mm of water from the plot between 15 and 22 July. However, only 44 mm were removed from the upper 2.3 m of the profile. While upward flow could supply some water, it could not account for 2 mm/day under our conditions. Therefore, assuming that the withdrawal rate in the 2.0 to 2.3 m zone continued below 2.3 m, an additional meter of root zone would be required to meet this demand. This indicates that the alfalfa probably was well rooted to 3.3 m, or more. Thus, the fine roots in the lower part of the profile are probably very effective for water uptake, pointing to the need for more definitive studies on the value of these lower profile roots in supplying plant water requirements.

The effectiveness with which the alfalfa crop utilized subsoil moisture is supported by the yield data. Plots irrigated once in May to fill the root zone had enough water to satisfy the crop and produce the largest seed yields of the irrigation treatments imposed, 2,020 kg/ha vs. 1,640 kg/ha for the next largest yielding plots which were irrigated when the mean Ψ_m reached —6 bars[3].

CONCLUSIONS

The data presented here support the recent hypothesis (11) and data (9) that root water uptake is a function of (a) the difference between the plant water potential and the soil water potential of a given soil layer and (b) the root density of that layer, and that (c) the major resistance to water flow is between the root periphery and xylem. In addition, our data emphasize that while water is preferentially taken up from soil layers where the soil water potential is high, it continues to be withdrawn from layers of lower potential. Since the plant water potential is a determining factor of the potential gradient for water flow from soil to plant xylem, the wilting or 15-bar percentage is not a lower limit of availability. Root location, whether shallow or deep, does not appear to affect water uptake.

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