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Response of Plant Water Potential to the Irrigated Environment of Southern Idaho[1]

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ABSTRACT

Laboratory studies have shown that plant water potential affects a number of key processes involved in growth, but there has been almost no information on what levels of water potential occur under irrigated conditions in the field. Before assessing the practical implication of laboratory results on soil and crop management, this type of information must be available. Consequently, plant water potential in irrigated crops of *Zea mays, Triticum aestivum, Hordeum vulgaris, Phaseolus vulgaris, Pisum sativum, Solanum tuberosum, Beta vulgaris,* and *Medicago sativa,* L. was measured throughout the growing season in southern Idaho. Soil moisture conditions and potential evapotranspiration were monitored. Daily changes in plant water potential varied from less than 5 bars to more than 20 bars, while random sampling of supposedly homogeneous sets of plants showed an average variation of about 2 bars. Changes due to differences in soil moisture were also detected, even though the soil moisture potential was kept high enough for near-optimum crop production. Though the crops differed widely in their response to changes in environment, the plant water potential was strongly affected by microclimatic conditions. Day-to-day changes in plant water potential generally correlated more closely with changes in potential evapotranspiration than with changes in soil moisture content. Many of the daily changes observed in the plants remain unexplained, however. In general, the average water potential levels of all the field-grown plants were lower than levels reported from growth chamber studies. Potentials seldom rose above —8 bars and were never observed above —5 bars.

Additional index words: **Soil water, Soil temperature, Microclimate.**

PLANT water potential influences plant growth in a number of ways, such as cell elongation, certain phases of the plant's biochemistry, and the arrangement and development of some types of cells (17). While basic laboratory and controlled environment studies are increasing the knowledge of water-potential effects on plant growth, little is known about the actual water-energy levels of plants under field conditions. It is known that plant water potential is influenced by available soil water and the evaporative demand of the atmosphere (6, 9, 12, 20). Some data are available showing plant water potential during short periods of time under field conditions (1, 3, 7, 10, 11, 13, 14, and 18); however, there is almost no information on the daily changes of water potential in field crops throughout the growing season. Such information is needed to assess the practical implications of available basic information on plant water potential. The purpose of the study reported here was to obtain some of this type of field data.

METHODS

Throughout the 1969 growing season water potential levels of field crops in south-central Idaho were measured. Included were sweet corn *(Zea mays),* wheat *(Triticum aestivum),* barley *(Hordeum vulgaris),* beans *(Phaseolus vulgaris),* peas *(Pisum sativum),* potatoes *(Solanum tuberosum),* sugarbeets *(Beta vulgaris),* and alfalfa *(Medicago sativa).* The crops were fertilized and irrigated according to local field recommendations for crop production. All plants were grown on Portneuf silt loam soil, and soil moisture at some point in the root zone was, with one exception, always within the tensiometer range.

The measurements on wheat and alfalfa were begun on established plants. The wheat had been planted in the fall of 1968 and by May 7, 1969 was 35 cm tall. It was beginning to head on May 27. The barley was planted about mid-August 1969 and continued to grow vigorously on into the fall. The sugarbeets emerged the last of April, and by June 20 were shading half of the soil surface. The peas were all up by the end of April and were beginning to bloom on June 2. The sweet corn was 10 cm tall on May 27, and was ripe by August 25. The potatoes came up the last of May and completely covered the ground near July 7.

Plant water potential was measured in the field with a portable freezing-point meter similar to that described by Cary and Fisher (4) and Wiebe, et al. (23). Measurements were begun as soon as sufficient top growth for sampling developed, and ended when the plants matured or were frozen on Oct. 4. Daily maximum and minimum leaf water potentials were measured throughout the growing season. In general, measurements for maximum potentials were made before 9:00 AM on samples from leaves that were shaded from direct exposure to the sun. Minimum potentials were taken during the middle of the afternoon on leaves that were fully exposed. In most cases the measurements were made on two leaf samples chosen at random from the field, although care was taken to select leaves from healthy plants and of the same physiological age. Soil moisture status in the field was followed with tensiometers, and in some cases soil temperature was also measured.

Evapotranspiration was measured throughout the season with a sensitive weighing lysimeter planted to alfalfa. Weather Bureau Standard pan evaporation measurements were also available from the weather station, which was located in the center of the sampling area encompassing about 50 ha.

RESULTS AND DISCUSSION

Minimum plant water potential generally occurred during the middle of the afternoon, while the maximum occurred early in the morning, as shown in Fig. 1. The data in this figure illustrate the typical variation in plant water potential measured in the field while making duplicate or triplicate measurements on randomly selected plants. These data also illustrate the varying potential patterns that occur between different kinds of plants growing under similar conditions.

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Figure 2 summarizes the bulk of the data collected during the study. Two curves are shown for each crop, the upper being the maximum plant water potential, and the lower, the minimum. The soil temperature curve in Fig. 2 is for the temperature for the 10-cm soil depth reported by the weather station. This standard measurement seemed to most nearly correspond to the average soil temperature measurements under the various crops that were observed intermittently, though in some cases a variation of several degrees did occur. The evaporation points are a combination of Weather Bureau evaporation pan and the lysimeter measurements obtained with alfalfa. The daily values of evaporation that correspond to days in which potential measurements were made on the alfalfa are connected to emphasize any similarity between evapotranspiration and water potential in the alfalfa. The same daily points for soil temperature are connected for consistency. Small arrows on the evaporation chart indicate traces of precipitation, while arrows on the water potential charts indicate irrigations.

Most of the water potential points plotted in Fig. 2 are averages of two random samples. The average difference between random samples was 1.2 bars for beans, 1.9 bars for alfalfa and beets, 2.3 bars for wheat and barley, 1.6 bars for peas, 1.8 bars for corn, and 1.5 bars for potatoes, which is similar to the average variations between duplicate samples when one is measured by freezing point and the other with the psychrometer (4). However, variations between samples were sometimes several bars, as was shown by the individual data points in Fig. 1. In general, agreement between random samples was close when the plants were young, then tended to show greater scatter as the crop matured.

One of the trends in the data presented in Fig. 2 is a correspondence between some of the sharper peaks and dips in the evaporation and the water potential curves for alfalfa during June, July, and early August. This correspondence also developed to some extent with all the crops, particularly during the middle of the summer.

While the potential curves of all crops tended to follow the evapotranspiration curve, the individual crop potential patterns were quite different. Beans and sweet corn are an example. While neither of these crops showed any consistent response to irrigation, the water potential in beans was always higher than in sweet corn. In southern Idaho beans are universally infested with root rot, which became severe in early July and may have been responsible for the lower potential levels at that time. By mid-July the plants had developed secondary root systems. There is some indication (11) that the stomata of beans begin closing at a water potential of —12 bars, and this may be why the potentials never became as low as those commonly observed in sweet corn. Even in bean plants growing in very dry soil well out of the tensiometer range, the water potential never fell below —20 bars. Bean plants are also unique, for as water potential decreases, they tend to turn their leaves edgewise to the sun, reducing the radiation load.

The potential patterns for corn, wheat, and barley were similar in that they exhibited very wide daily

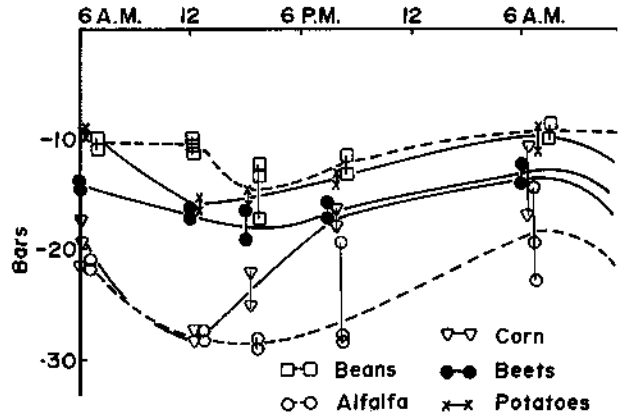

Fig. 1. Individual data points showing the daily variation in plant water potentials for different crops, July 29-30.

swings even though these crops continued to grow well and showed no visible signs of water stress. The potential levels for barley are similar to those reported by Millar, et al. (15). They found that barley stomata may begin closing at about —22 bars, though the afternoon potentials in Fig. 2 suggest that in our study the stomata may have remained open down to several bars below this level.

The potential pattern of peas was quite similar to that of beans. The peas were being irrigated every few days after the first part of June. There was no obivous change in the potential pattern due to these frequent irrigations, and the soil moisture potential seldom fell below —0.5 bars.

The water potential pattern of potatoes fell between that of beans and sugarbeets. The potatoes were being sprinkled every night to replace the water transpired the previous day, and so were growing at near-optimum soil moisture conditions.

Sugarbeets and alfalfa developed comparable water potential patterns, particularly in September. Sugarbeets are known to grow relatively well under dry conditions, and their stomata stay open even as the leaves begin to lose turgor (14). It is interesting that the minimum afternoon plant water potential in beets, alfalfa, and barley tended to decrease during September, even though the evaporation curve dropped sharply. This may have been due to the age of the plants and a less active root system, although both crops were growing vigorously. The decrease in potential may have been related to decreasing soil temperatures, which are known to reduce root permeability to water (5, 8, and 16). Disease can also cause decreased water potential in plants (19), although this did not appear to be a factor.

None of the crop water potential patterns showed a consistent response to irrigation with the possible exception of the second irrigation of wheat on May 23, when the soil water in the root zone had moved out of the tensiometer range. The subsequent increase in plant water potential may have resulted from this irrigation.

Variations in the daily maximum plant water potentials (Fig. 2) are difficult to explain. Some of the measurements may reflect the time of sampling. During the middle of the season when the workload

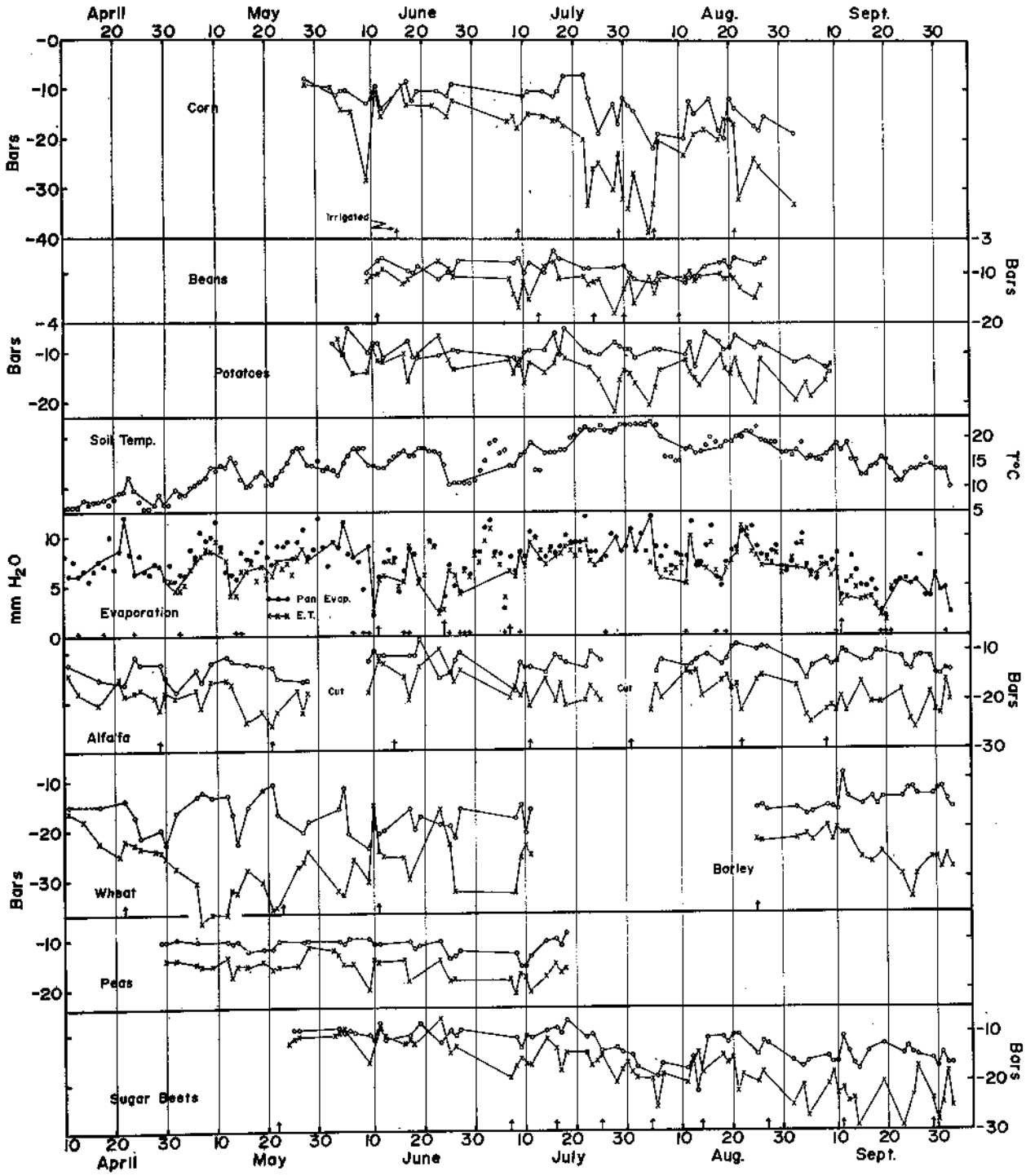

Fig. 2. Summary of the maximum and minimum plant water potentials in field crops during the 1969 growing season. Arrows on evapotranspiration curve indicate rainfall sealed to cm of water, while arrows on crop curves indicate irrigations. Peas and potatoes were irrigated frequently, as explained in the text.

was heavy, the last samples were not collected and tested until about 9 AM. While the samples were always from leaves that were still shaded from the sun, other leaves on the plants had been exposed to the sun for as much as 3 hours, and thus, could have influenced the results. Werner (21), studying the influence of atmospheric and soil moisture conditions on diurnal variations in the relative turgidity of potato leaves, found that the morning turgidity was associated with the accumulative vapor deficit of the atmosphere during the previous night. It is possible that nighttime air and soil temperatures are also important. The occasional reversal in magnitudes of morning and afternoon potentials seemed to be favored by an afternoon of low evapotranspiration following a cool night and a day of high evapotranspiration.

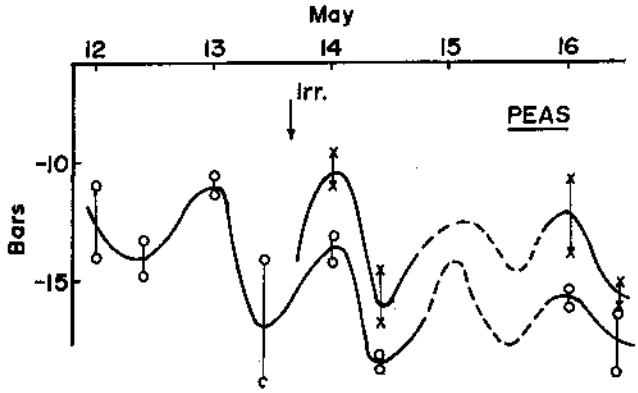

Fig. 3. Influence of irrigation (upper curve) on the water potential in peas.

Although in general the water potential patterns were not greatly influenced by irrigation, it was possible to measure small changes by making careful comparisons after split plot irrigations (Fig. 3). Random measurements of morning and afternoon water potentials were made on peas beginning May 12. On May 14 part of the area was irrigated and part was left with a dry soil surface, although the roots were still in soil holding water in the tensiometer range. Irrigation did increase the potential in the leaves by 2 or 3 bars, and the effect lasted for at least 2 days. While this was a small change in plant water potential compared to the daily swings in potential, it is known that frequent light irrigations may increase plant growth in some cases.

Another specific example of the effect of irrigation is shown in Table 1. The column headed "wet" refers to seedlings that had just been irrigated so that the soil surface was still damp. The column headed "dry" represents seedlings that had not been irrigated for several days, and the soil surface was dry. Six random measurements of plant water potential were made on each treatment as shown. Even though the soil moisture potential was only about 0.2 bar greater on the wet plot, the moisture potential in the beet seedlings was increased by 2 or 3 bars.

Irrigation occasionally caused a decrease in plant water potential (Table 2). Potential measurements shown under the "wet" heading were made on plants that had just been irrigated. These measurements are compared to random measurements taken from adjacent rows of plants that had not been irrigated for several days, but which were growing in a soil with moisture potential of approximately —0.5 bar. It is apparent that irrigation initially decreased the water potential in these plants, possibly because of lower root permeability resulting from lower soil temperature or lower soil oxygen. A similar response to irrigation was also observed with corn and alfalfa. The decrease in potential did not last more than 24 hours, and did not develop after each irrigation.

In general, the water potentials shown in Fig. 2 are lower than one might have expected from values reported for similar plants grown in controlled-environment chambers. For example, Boyer (2), growing corn and soybeans in a chamber, found that elongation stopped at potentials less than —8 bars, and photosynthesis decreased sharply at potentials less than —12 bars. On the other hand, the plants studied here were growing well at potentials 10 bars below these limits. Furthermore, the potentials shown in Fig. 2 are reasonable when compared to other available field observations (10, 11, 13, 14, 18). Apparently the water relations of field-grown plants may be significantly different from those of plants grown under artificial conditions. As in the case of glasshouse nutrition studies, caution must be exercised in extrapolating growth chamber results to predict plant water potentials under field conditions.

Table 1. Random measurements of plant water potential of sugarbeet seedlings May 19, 2 PM.

	Wet		Dry	
Soil temperature at 10 cm, C	22.1	22.1	25.0	24.8
Soil water potentials at 15 cm, bars	-0.33	-0.29	-0.52	-0.45
Seedling water potentials, bars	-7.8	-10.7	-12.0	-14.6
	-10.4	-10.4	-14.0	-12.3
	-11.6	-9.8	-13.5	-12.1
Avg	-10.0		-13.0	

Table 2. Maximum and minimum plant water potentials in beans and peas on June 12.

	Wet		Dry	
	bars		bars	
Beans, a. m.	- 9.8	- 9.4	- 6.8	- 7.4
p. m.	- 9.2	- 9.1	-10.4	- 7.3
Peas, a. m.	-14.0		-11.0	
p. m.	-18.0	-17.8	-14.0	-14.1

It should also be noted that potentials measured on crop plants in the field with the pressure bomb may be higher than potentials measured with the psychrometer or freezing point methods (3, 22). The pressure bomb tends to measure pressure potentials in the conductive tissue, while the psychrometer and freezing point meter tend to measure total potentials in and around the cellular tissue. Under field conditions, a total potential difference of 5 bars or more may exist between cell tissue and conducting vessels, even in roots growing in moist soil (1, 3, 7).

SUMMARY

On the Portneuf silt loam soil of southern Idaho plant water potential is influenced more by the evaporative demand of the atmosphere than by soil water potential, so long as the soil water is within the tensiometer range. This is particularly true during midsummer. In the spring and fall there is less correspondence between maximum plant water potential and high evaporative demand. This may result in part from lower soil temperatures.

The average sampling variation between plants is about 2 bars. The variation is less when the plants are small and increases as the plants mature. The general level of stress may also increase as the plants become larger. Nevertheless, by making careful and repeated comparisons between plants, it was generally possible to measure a change of 2 or 3 bars in plant water stress following irrigation, even though the soil moisture was still in the tensiometer range before irrigation.

There are large differences between water potential levels in different kinds of plants growing under identical conditions. The potential seldom rises above —8 bars, and was never observed above —5 bars under field conditions. On hot dry days the water potentials in corn and wheat fell more than 20 bars, while an 8- to 10-bar drop was more common in

plants such as potatoes and peas. The significance of these differences remains to be studied. In general, water potentials of field-grown plants are lower than those of plants grown in controlled-environment chambers. Thus, simultaneous measurements of water potentials, growth responses, and environmental conditions will have to be made in the field before the system can be quantitatively described.

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