Relative Turgidity as an Indicator of Drouth Stress in Cereal Plants

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In studying a plant's physiological response to drouth, it is essential to know the moisture tension which may exist within the tissue while the process is being measured. Such an index should cover the entire moisture tension range from fully turgid cells to ones at or below the permanent wilting point. Soil moisture determinations give some indication of moisture tension within the plant, although under conditions in which water loss from transpiration exceeds water uptake by the roots the plant may be under much more moisture stress than would be indicated by the soil moisture tension. Also, it is not practical to take soil samples from small-pot experiments. The relative turgidity method of Weatherly (1950) apparently has been successful in measuring water stress in leaf tissue. Only part of one leaf on a plant need be used, and the method is quite simple.

A single factor seldom is responsible for the success of one plant species over another in a dry environment. Plants do not differ in the ability to exploit the water present in a small volume of soil (e.g. in a pot) and, hence, the permanent wilting point for most plants is about 15 atmospheres of soil moisture tension. However, plants do differ in root characteristics, and when unconfined, one plant may penetrate a larger volume of soil and thus have more water available for growth or survival. Some plants appear to conserve water or to use it more efficiently than others. In the xerophytes the protoplasm may be better able to tolerate moisture stress. Thus, one or more of these or other mechanisms may be involved in the drouth hardiness observed in the field.

Sandhu and Laude (1958) and Bayles *et. al.* (1937) have suggested that a correlation exists between drought hardiness and water retention in both winter and spring wheat varieties. Thus, one part of this study was to determine water retention by various cereals growing in the same pot at various moisture levels. In this situation water presumably would be available equally to all plants. Measurements were also made of the water-retaining ability of the leaves of various cereals when placed into atmospheres of known vapor pressure gradients.

METHODS AND MATERIALS

The method of Weatherley (1950) was used for determining relative turgidity. A section of cereal leaf 2 to 3 cm long was cut, immediately weighed and then was floated on distilled water in a staining dish for 24 hours. The dishes were stacked so that evaporation was prevented. The section length was chosen so that when fully turgid, the weight was less than 25 mg. After the turgid weight was obtained, the dry weight was determined by drying for several days at 80°C. Per cent relative turgidity was then calculated as the original water content divided by the turgid water content times 100.

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The methods of Slatyer (1958), with slight modification, were used for determining the relative turgidity of leaves after exposure to known vapor pressure gradients. Three cm sections from primary leaves of cereal plants 2-3 weeks old were suspended for 24 hours over sodium chloride solutions having certain calculated vapor pressures. Relative turgidity was determined as above. Triplicate samples of each cereal variety were exposed at each vapor pressure and all varieties were tested on several different occasions (4 to 8 times).

In the one experiment in which whole plants were dried, the plants were grown in sand and watered with ¼ strength Hoagland's solution and removed for the experiment 3 to 4 weeks after planting. They were washed free of sand, blotted dry, weighed and placed into desiccators over $CaCl_2$ for various lengths of time and then removed and weighed.

Plants were grown in 6-inch pots with 6 of one variety or species on one side and 6 of Balbo rye on the other side allowing all relative turgidity values to be compared with rye as a standard. After the plants had grown for 3 or 4 weeks, water was withheld on one series of pots, then the next week another series received no further water and so on, until the first pots had not received water for about 1 month. At that time relative turgidity measurements were made on all plants, including one series that had not been subjected to drouth. This gave a wide range of moisture stress measurements. Either first or second leaves (from the base) were used for the measurements, although it was found that younger leaves usually gave slightly lower relative turgidity values. The soil was a standard potting mixture of soil, sand and peat moss (ratio 2:2:1).

Cereals used in these studies were as follows: Rye, *Secale cereale*, L., cv. Balbo; barley, *Hordeum vulgare*, L. cv. Rogers (C. I. 9174); oat, *Avena sativa*, L. cvs. Arkwin (C. I. 5850) and Cimarron (C. I. 5106); winter wheat, *Triticum aestivum*, L., cvs. Ponca (C. I. 12128), Pawnee (C. I. 11669), Cheyenne (C. I. 8885) and Red Chief (C. I. 12109).

RESULTS AND DISCUSSION

COMPARISON OF RELATIVE TURGIDITY WITH SOIL MOISTURE CONTENT

In this experiment the plants were grown in 6-inch pots, all competing for the same moisture. From figure 1 it is apparent that there were no differences among the various cereals tested for relative turgidity when the plants were subjected to a given soil moisture content. Soil moisture levels between 8 and 30% caused no significant changes in relative turgidity. However, once the soil moisture dropped below 6% there was a rapid drop in moisture content in the leaves, with relatively small decreases in soil moisture content. This would be expected since the soil moisture tension increases rapidly with a decrease in soil moisture content. The same pattern was obtained regardless of variety or species of cereal used. Similar results were obtained in several other experiments of this type.

The per cent relative turgidity gave some indication as to whether or not the plant would survive upon rewatering. If the value did not fall below 25%, the plants would almost always recover. When the values were below 25%, the plants often did not recover after re-watering, although the correlation between survival and relative turgidity was not good in this range.

In a study dealing with the effect of moisture stress on the translocation of 2,4-D applied to bean leaves (Basler, Todd and Meyer, 1961), relative turgidity of the leaves provided a good index as to whether translocation would occur. Soil moisture content was not nearly as sensitive

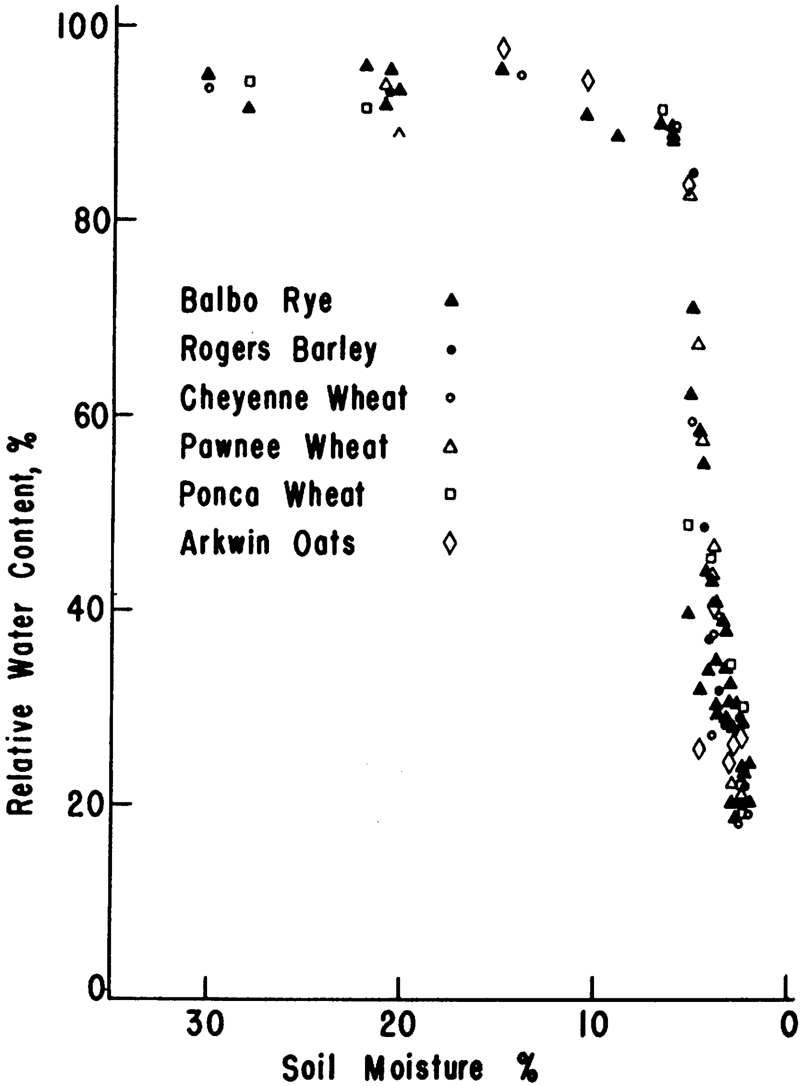

Figure 1. Relative water content of various cereal leaves obtained from plants growing in soil at different moisture levels.

an indicator as relative turgidity. This would be especially true under physiological drouth when water lost through transpiration exceeds water uptake by the roots and internal water stresses result.

DETERMINATION OF WATER RETENTION AGAINST VARIOUS VAPOR PRESSURE GRADIENTS

There are indications that drouth-hardy wheat varieties retain more water when cut and allowed to dry than non-hardy varieties (Sandhu and Laude. 1958, Bayles *et. al.* 1937). In the present experiment, pieces of leaves from various varieties and species of cereals were tested against known vapor pressure gradients. The data presented in Figure 2 represent the averages of from 4 to 6 experients in which triplicate samples were run of each variety. Cimarron oats were used as a comparison standard in all runs. Apparently there were no differences between various cereals tested in relative turgidity at various vapor pressure deficits.

In many of the tests it did appear that there was a slightly better water retention by Cimarron oats as compared to the other cereals, although it seems doubtful whether this difference was real. Slatyer (1958) found that privet leaves retained more water than did tomato leaves (Fig. 2), although both of these species lost much more water than did our cereals. Part of this difference might be attributed to exposed edges, although this seems doubtful since the cereal leaf edges exposed were between 8 and 20 mm/section while in his experiments the exposed edges were about 16 mm/section.

A few experiments were performed where whole plants (with intact root systems) were dried in the presence of $CaCl_2$ desiccant. Using this method, differences in water retention between wheat cultivars did occur.

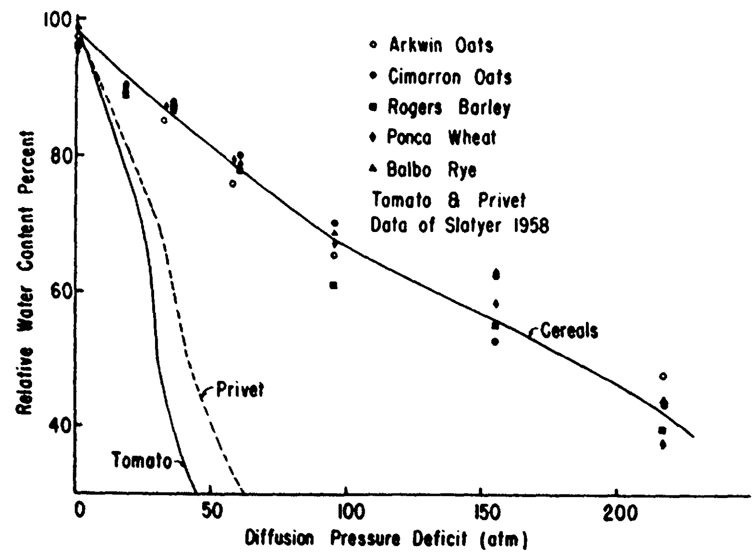

Figure 2. Water loss from detached cereal leaves after exposure to moisture stress.

Water retention was greatest in those known to be most drouth hardy (Red Chief and Cheyenne) and least in the rather non-hardy Ponca (Table I). The two oat cultivars lost water at a faster rate than any of the wheat cultivars (Table I). The drouth hardiness of oats is known to be much less than for wheat which would correlate with these findings. Previously Sandhu and Laude (1958) showed an inverse correlation between the rate of drying of wheat shoots and their relative drouth hardiness.

These results appear contrary to the experiments with water retention in different cultivars and species growing in the same pot (Fig. 1). This inconsistency could be explained in the following manner. In the pot experiments an equilibrium would probably be reached between the moisture in the plants and the soil moisture, since the moisture stresses develop over a period of days or weeks. In the desiccator the plants were exposed for periods up to 17 hours and they were not at equilibrium with the desiccant. The only time differences in water retention between plants might be found would be under non-equilibrium conditions. A decrease in rate of water loss by some of the plants in the direct desiccation tests, could have considerable survival value where the plant was not competing in the same volume with a plant having a greater rate of water loss. Other experiments have indicated that this may be the case. Cheyenne wheat plants growing in one pot have remained in good condition while Ponca wheat growing in another pot, which was treated identically, have almost died from drouth. Cheyenne wheat plants lost water at a slower rate in the desiccation tests and this variety is also known to be more drouth hardy in field tests.

TABLE I. WATER RETENTION OF INTACT 4-WEEKS-OLD CEREAL PLANTS AFTER DESICCATION FOR VARIOUS TIME PERIODS OVER $CaCl_2$ DESICCANT.

Plant	Hours of Desiccation	% water retained
Red Chief wheat	17	37
Cheyenne wheat	17	28
Ponca wheat	17	14
Wintok oats	9	31
Wintok oats	14	13
Arkwin oats	9	36
Arkin oats	14	14

SUMMARY

The relative turgidity method of Weatherley is an excellent indicator of degree of moisture stress in cereal plants and is more senstitive than soil moisture determinations. No significant differences were obtained in relative turgidity between plants (regardless of cereal species) growing in the same pot.

The water retention of small pieces of cereal leaves was measured against a series of known vapor pressure gradients. They retained a remarkably high water content compared to plants such as tomato and privet, although no differences were found among the various cereals tested.

The water retention of intact wheat plants desiccated over $CaCl_2$ was found to correspond to the known drouth hardiness in the field. Oat plants were found to be inferior to all the wheat plants tested in water retaining ability.

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