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Water status in winter wheat grown under salt stress

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Abstract: Properties of the soil surface layer, the temporal pattern of the microclimate variables as well as crop condition were combined to analyze the characteristics of the evapotranspiration from winter wheat fields in a saline soil area. In order to accomplish this analysis, evapotranspiration was divided into evaporation from the soil and transpiration from wheat. Moreover, the effect of soil salinity on evapotranspiration was evaluated through the relationship between actual evapotranspiration and potential evapotranspiration (Ea/Eo) and the total soil water potential (*) was divided into two components: matric potential (*M) and osmotic potential (*o). Two sites with different salinity levels were chosen for this study, located in Hebei Province, China. Measurements were conducted in April-May 1997 and May 1998. The Bowen ratio method was used to estimate the actual evapotranspiration (Ea), whereas potential evapotranspiration (Eo) was estimated using Penman ˇ s equation. Measurements of soil evaporation (Es) were obtained with micro-lysimeters, and transpiration was calculated from the difference between Ea and Es. The results show that transpiration comprised on average almost 80 % of total evapotranspiration. Evaporation from the soil differed slightly between years, but this variation was dominated by the leaf area index (LAI), which ranged from 4 to 5 during the study period of 1997 and 1998. Soil electric conductivity (EC), which is directly related to osmotic potential, ranged from 1.9 to 3.5 mS cm-1 in 1997 and was negligible in 1998. Our results indicate that lower osmotic potential decreases the total soil water potential, thus affecting plant transpiration. Hence, it is possible to say that soil salinity actually decreases evapotranspiration from winter wheat fields.

Water status in winter wheat grown under salt stress M Larry Lopez C1, WANG Rong2, MAO Xue-sen2, Takahashi Hidenori1 (1. Hokkaido University, Graduate School of Environmental Earth Science, Sapporo, 060-0810 Japan; 2. Shijiazhuang Institute of Agricultural Modernization, CAS, Shijiazhuang 050021, China) 1 Introduction Salinization is one of the major problems in arid and semi-arid regions in relation to land use and in particular to agricultural production[1]. Excessive salinity leads to toxicity in crops and reduction of the availability of water to crops, by reducing the osmotic potential of the soil solution[2]. Movement of soil water induces solute transport, and solutes are transferred towards the ground surface by the upward soil-water movement caused by evaporation, resulting in an accumulation of salts near the surface. Evapotranspiration has been widely studied in recent years, as it has become an important issue regarding irrigation plans, especially in areas where water is not abundant. However, studies conducted in the field under salt stress have been scarce. Evapotranspiration is an important parameter in most agricultural production forecasting models. For example, the widely used Food and Agriculture Organization (FAO) crop monitoring and forecasting model[3] is based on evaporation estimates, which are related to crop growth and yield. By understanding the dynamics of soil-plant-atmosphere interaction in saline soils, it is possible to assess the water status of crops. Furthermore, Sivakumar and Wallace (1991) highlighted the importance of knowing not only total evapotranspiration, but also how the total evapotranspiration is partitioned between its components - crop transpiration and soil evaporation - as only transpiration is related to yield[4]. The objectives of this study are (1) to determine the characteristics of evapotranspiration in saline soils, with especial emphasis on its partition into transpiration and evaporation, and (2) to analyze the effect of soil salinity on the actual evapotranspiration. 2 Methods 2.1 The experimental site The study sites were located at Wangsi and Nanpi Agricultural Ecological Experimental Stations in Hebei Province, China (N38o07ˇ, E116o45ˇ). These two sites, despite being relatively close to each other (around 10 km apart), differ significantly in soil salt concentration due to differences in ground water level. Wangsi is more saline especially duri ng spring, while salinity in Nanpi can be considered mild. The levels of salinity are represented by the electric conductivity (Figure 1). These sites originally comprised a flooded area of the Yellow River and are typically salt affected. The region is semi-arid and mostly plains with an altitude of 20 m. Winter wheat is sown in early October and harvested in early June. Figure 1 The Electric Conductivity (EC), that is strongly related to salt concentration in the soil, in both sites differ significantly from each other. These data correspond to the time when salinity is more severe at both sites 2.2 Measurements 2.2.1 Actual Evapotranspiration (Ea) Measurements were conducted from April 19 to May 3 1997 at Wangsi, and from May 11 to May 23 1998 at Nanpi. In both years the Bowen ratio-Energy balance method (BREB) was used to estimate actual evapotranspiration (Ea). Net Radiation was measured by a radiometer (EKO Inc. Japan, MF-11) and soil heat flux was measured with three soil heat plates buried at a depth of five millimeters (EKO Inc. Japan, MF-81). To obtain the Bowen ratio, dry-bulb temperature and wet bulb temperature differences (?Td and ?Tw) between two levels were measured with aspirated copper-constantan thermocouples. This widely used technique based on the energy balance equation depends on the measurements of the ratio of sensible heat flux to latent heat flux: where P is air pressure; ? is the air density; Cp is the specific heat of air at constant pressure; ? (PCp/ 0.622?) is the psychrometric constant; ?T is the temperature difference between the two levels and ?e is the vapor pressure difference between the same levels. Therefore, all that is needed to estimate evapotranspiration is knowledge of net radiation and soil heat flux, together with measurements of temperature and vapor pressure at a series of heights within the constant flux layer. ?T and ?e are found by plotting the temperature at each height against vapor pressure at the same height in the boundary layer. Combining Eq. 1 and the energy balance equation, we obtain: where Rn is the net radiation and G is the soil heat flux. 2.2.2 Evaporation and Transpiration Six micro-lysimeters, consisting of a stainless steel cylinder of 100 mm in length, 50 mm in diameter and 2 mm wall thickness, were used to measure daily soil evaporation[5]. An estimate of daily soil evaporation was then calculated from the daily weight loss of the micro-lysimeter. They were inserted centrally between the rows of the crop from 7:00 to 18:00 every day. Subsequently, transpiration was calculated from the difference in weight between the actual evapotranspiration and the soil evaporation, where Es is the soil evaporation. 2.2.3 Potential Evapotranspiration (Eo) Potential evapotranspiration was estimated with Penman˘s equation (1948)[6]: where ??is the slope of the saturation vapor pressure curve; Rn is net radiation; G is soil heat flux; ??is latent heat of vaporization; ??is density of air; k is von Karman constant assumed to be 0.41; P is atmospheric pressure; Uz is wind speed at height z; z is the height of the wind speed sensor; zo is roughness parameter; eoz is saturation vapor pressure of moist air over water at height z; and ez is water vapor pressure at height z. 2.2.4 Soil water potential With Ea and Eo, it was possible to calculate the evapotranspiration efficiency ratio (Ea/Eo). The relation of this ratio with the soil water total potential (*) (the sum of matric (*M) and osmotic potential (*o))[7], is the key to the understanding of the relation of Ea and salinity in the soil. *M was measured directly with tensiometers at 10, 20 and 30 cm depth and *o, in kPa, was obtained from the electric conductivity of soil samples taken daily, using the following equation proposed by the US Salinity Laboratory Staff (1954)[8]: where EC is the soil water electric conductivity (mS cm-1). Since salinity in Nanpi was not significant (low values of electric conductivity), *o was considered negligible for this location in 1998. Therefore, matric potential was the only component of the total soil water potential. 3 Results and discussion 3.1 Evapotranspiration (Transpiration and Evaporation) The comparison of the energy balance for both years shows a slight difference between them. However, even though the available energy (Rn?G) in 1998 was slightly lower than in 1997, the distribution of this energy into latent and sensible heat flux was different, with a larger latent heat value in 1997 (Figure 2). The average value of Ea obtained during the experimental period was not significantly different between years, as it can be obtained from latent heat values for both years. Figure 2 Energy balance partition for Nanpi and Wangsi. The data for Wangsi were taken in 1997 and the data for Nanpi were taken in 1998. The available energy (Rn-G) was almost the same for both years Transpiration in both years was around 80% of the total evapotranspiration, at least partially because of leaf area index (LAI) values that ranged between 4 and 5 for both measurement periods. concurs with Denmead et al (1969) who found the same tendency for wheat[9]. However, soil evaporation in Wangsi was just 14% of the total evapotranspiration, while in Nanpi it was 24%. Osmotic potential data showed that a higher salinity content tends to accumulate on the surface layer, which could also contribute to low soil evaporation. As suggested by Shimojima et al. (1996)[10], evaporation and salinity had a feedback relationship between them: more evaporation brings salt to the soil surface layer through water stream, especially at this plant stage as a good portion of the root system is already long enough to avoid the higher salt concentrations of the upper soil layers. At the same time more accumulation of salt results in a reduction in the soil evaporation. In April-May at the time of measurements, salinity have already affected, soils for several months, and may already have been limiting soil evaporation. Wheat is sown in early October when salinity is not so severe, thus avoiding the possible effect of salinity on early stage of the crop. By April, when salt is visible on the soil surface (accumulated salt), root elongation appears to be unaffected by the higher salt concentration in the soil surface layer. Osmotic potential, as quoted by Kafkafi Uzi (personal communication, Hebrew University, Israel) affects the water uptake of the plant to different degrees. This of course will vary according to plant species and concentration of salts in the soil. The results here indicate that plants uptake water and transpire it, and water movement is not hindered by the salinity present at the study site. However, there is a reduction in the amount of water transpired by the crop when exposed to salinity (Figure 3) caused possibly by the accumulation of salts in the transpiring zone (the leaves). The first consequence of this is the reduction of the stomatal conductance, as suggested by previous studies on wheat[11,12] maize[13] and beans[14]. 3.2 Soil water potential (?) On the surface layer EC (1:5, HORIBA B-173) measured in situ varied from 1.9 to 3.5 mS cm-1 while at 30-cm depth it varied from 1.7 to 2.5 mS cm-1. The pH values (HORIBA B-212) also measured on the surface ranged between 8.0 and 8.4. According to Noguchi (1977), wheat root profile extends to around 20 cm to the sides of the plant (horizontally), and to a depth of 20-cm [15]. Under conditions of soil hardness, possibly caused by salt content (but not proven in this study) the gross of the root profile is found in the surface soil layer. In order to calculate the total soil water potential, osmotic potential was calculated with Eq. (5) using values of EC (0-30 cm soil surface layer) and thus a single daily value is obtained. The daily values of osmotic potential (Figure 4) obtained did not actually represent the every day variation but rather represented the difference in osmotic potential resulting from differences in sample areas within the study site. Therefore, daily osmotic potential values calculated for different sample areas were averaged, and that average was used as the daily osmotic potential value of the study site. Finally, for the estimation of the total soil water potential, daily values of soil water matric potential (obtained with tensiometers) and theaveraged soil water osmotic potentials were added. The result was the total soil water potential for every single day. It is important to mention here that the water used for irrigation already has an electric conductivity of 2 mS cm-1. Therefore, irrigation does not necessarily mean that salts will be leached since the water used for irrigation contains salt itself. Water used for irrigation at both sites is ground water obtained from different water table levels. In Wangsi the water table ranges between 1 to 3 m, whereas the water table in Nanpi ranges between 6 to 8 m. Hence, the same evaporative demand brings more salts to the soil surface layer in Wangsi than in Nanpi. 3.3 Relation between Ea /Eo and ?o Since *o was the average value of the total measurement period in 1997, the variation of Ea /Eo was basically dependent on soil water content variation. As is shown in Figure 3, if only *M is considered in 1997, it would not be possible to explain the low Ea / Eo values. After the inclusion of *o, in agreement with Shainberg and Oster (1978)[16], it is clearly seen that * is lower, representing the actual values that must be used in order to understand the decrease in evapotranspiration. In 1998, *o is close to zero (representing the absence of salinity) and * is comprised of only *M. As it can be observed in Figure 6, the values of Ea / Eo for Nanpi are consistently above those for Wangsi. Since Ea /Eo represents the ratio of actual transpiration over the potential evapotranspiration, it is possible to compare the data obtained for these two years regardless of the time and place where they were measured. Figure 4 The distribution of osmotic potential (salt concentration) with depth (a) and the average daily variation of osmotic potential on the soil surface layer (b) sampled at six plots within the wheat field. The daily variation is attributed to a high spatial variation in salt concentration rather than daily variation In 1997, Ea / Eo drops sharply within a short variation of *M. This short variation can not be explained easily, rather than there is a possibility that the data taken by the tensiometers were not accurate. Therefore, in 1998, *M was obtained from the *M vs. soil moisture curve developed by Takeuchi (1996) for Nanpi[17]. The result was a wider range of Ea /Eo in relation to *M.. This suggests that the values for 1997 might have followed the same trend. Nevertheless, the important aspect of this figure is that it describes a reduction in evapotranspiration in Wangsi, which is more salt-affected than Nanpi. 4 Conclusions Studies of plant water movement in saline soils must take into account osmotic potential, as salt concentration decreases the total soil water potential and can affect plant - soil water movement. At the crop stage, at which the experiment was conducted, transpiration was almost 86 % of the total evapotranspiration in Wangsi. Comparisons of evaporation with mild salt-affected soils reveal that soil surface salt accumulation could be limiting evaporation as evaporation was proportionally lower in severe salt-affected soils. Transpiration, though reduced, is not impeded completely by salinity. This depends on different factors, such as planting date, plant species resistance and agricultural practices (e.g. fertilizers). Transpiration rate information is a very useful parameter for crop yield models for saline soils. References

关键词： evapotranspiration; potential evapotranspiration; soil salinity; water potential; wheat