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Effect of Saline Irrigation Water on Soil Water Potential and Plant Water Stress

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Abstract

Soil water retention considering matric and osmotic potentials is a prerequisite for understanding saline irrigation and water stress in arid and semi-arid regions. The experiment was conducted to study salinity effect on pF, evapotranspiration and plant water stress. It was assumed that soil water potential is the sum of the matric and osmotic potentials.

The experiment of plant water stress using Komatsuna was carried out in a growth chamber (phytotron) at 25℃ temperature and a relative humidity of 70%. The results exhibit that soil salinity increased after each irrigation causing an increase in osmotic potential component of the total soil water potential. The evapotranspiration decreased as salt concentration increased which is due to higher osmotic potential component. Higher salt concentration could increase *pF* so that availability of water to plants decreased. The results of the experiment showed that the osmotic potential was the dominant component of the adjusted *pF* (including osmotic potential component) in saline water treatments. The osmotic potential component value also contributed in the wilting of the plants. The results of the study suggest that the concept of *pF* value including matric and osmotic potential components can be used in applying soil water retention curves of salt affected soils for the development of lands in arid and semi-arid regions.

Key words : Soil water potential, semi-arid region, soil salinity, water stress

I. Introduction

Soil salinity (osmotic potential) and soil water (matric potential) are not separable variables particularly their relation to crop response. Because no salt is transferred to atmosphere by evaporation or transpiration, therefore salts are concentrated in the soil. Letey (1984) pointed out that the presence of dissolved salts in the soil water causes the osmotic component of soil water potential be considered in the basic flow equation. The evaluation of quantitative effect of an osmotic potential gradient on water flow through soil had to established. Kaneki and Tomita (1975) applied the osmotic stress of the medium from pF 3.1 to pF 4.5 for cucumber plants and observed the osmotic stress response.

Nozaka (1993) estimated the effect of soil water potential on transpiration under saline irrigation water. Their result showed that the transpiration ratio (the ratio between the transpiration under saline and fresh water) decreased exponentially with increase in salt concentration in the irrigation water, as the soil water potential decreased. In the field matric and osmotic potential components work in unison ; as evapotranspiration occurs, the soil dries and salts are concentrated in the remaining soil water (Hoffman, 1983). Child and Hanks (1975) demonstrated that under variable salinity (osmotic potential) relative transpiration was related to relative yield in the same manner as water stress (matric potential). Iwata (1995) pointed out that the concept of pF presented by Schofield (1935) had a weakness of neglecting osmotic potential.

An absolute shortage of rain and water resources existing in arid and semiarid zones, makes a necessity of economical water use for sustainable agricultural production. Marginal water in the area may contain large quantities of soluble salts. A knowledge of the amount of water held by the soil at various pF value in relation to salts content is required. Using pF values it facilitates to understand the amount of water that is available to plants, the water that can be taken up by the soil before percolation starts, and the amount of water that must be used for irrigation. Therefore the present research study was conducted to evaluate the effect of soil salinity on pF, evapotranspiration and plant water stress. Moreover, to confirm the hypothesis that soil water potential comprises of the matric and osmotic potentials of the soil solution in arid and semi-arid regions.

II. Experimental Procedure

1. Conditions of the Experiment

Soil samples were prepared with same density and saturated with fresh water and salt solutions. Sandy loam soil was packed in 100 cm columns for the measurement of volumetric water content and its pF values. Water having electrical conductivity (EC) of 0.32, and 2.21, 6.30 and 10.50 dS/m respectively used for the experiment (Table 1). Water contents were measured at different matric heads by pressure plate apparatus and centrifuge machine respectively varying pF from 1-4. Osmotic potential was calculated from the electrical conductivity of saline water. Matric and osmotic components were added to estimate pF values.

Komatsuna (*Brassica Campestris* L. var. Perviridis), a vegetable crop was planted in pots with a depth of 140 mm and diameter of 110 mm. Komatsuna was used because of easy growing and short period of growing. The temperature maintained at 25℃ with relative humidity maintained 70% in the plant growth chamber (phytotron). All the pots were filled with sandy loam soil having a field capacity and bulk density 27% and 1.31 g. cm^{-3} respec-

Table 1 Characteristics of irrigation water

Treament	Concentration		EC of water under	Osmotic pressure*
	NaCl (%)	Sorbitol (Molarity)	NaCl treatment (dS/m)	(cm H_2O)
T1	—	—	0.32	—
T2	0.1	0.053	2.21	1,355
T3	0.3	0.151	6.30	3,856
T4	0.5	0.252	10.50	6,426

* Osmotic pressure calculated by Eq. (3)

Table 2 Some physical characteristics of sandy loam soil

Sand <2.00*	Silt <0.02* (%)	Clay <0.002*	Bulk density g cm^{-3}	Field capacity at pF=1.5 (%)
74.2	16.9	8.9	1.31	27

* Particle size in mm based on International Soil Science Spciety (ISSS).

tively (Table 2). Experiment was conducted in the pots, irrigated with water of four qualities. The control treatment was fresh water (**T 1**) having electrical conductivity (EC) of 0.32 dS/m, and three saline treatments were **T 2**, **T 3**, and **T 4** with EC values of 2.21, 6.30, and 10.50 dS/m, respectively.

2. Evapotranspiration and Soil Salinity Measurement

The saline water was obtained by adding appropriate amount of NaCl and equivalent osmosis solution with electrical conductivity was made by adding Sorbitol to fresh water for avoiding the pathological effect of salts (Table 1). The irrigation interval was three days with depth varied 4 to 12 mm/irrigation to maintain the pots at field capacity (pF=1.5) without drainage. The amount of water loss by evapotranspiration was determined by weighing the pots after the first irrigation and before each of the subsequent irrigation. Calculation was made by considering water added to maintain field capacity.

The sampling of soils were done at 0, 2, 5, and 8 cm depths before each irrigation and at wilting point for monitoring matric and osmotic potentials by measuring soil water content and soil salinity respectively. The value of electrical conductivity ($EC_{1:5}$) is influenced by the temperature of the soil solution, therefore all $EC_{1:5}$ data were calibrated to a temperature of 25℃ for a valid comparison. A temperature correction to 25℃ (EC_{25}) was approximated by the following equation (Tanji, 1990).

$$EC_{25}=EC_t-0.02\ (t-25)\ EC_t \qquad (1)$$

where EC_t=*the electrical conductivity at temper Reports on Engineering Practices No. 71, p. 48.* .mate EC_e by following formula (Landon, 1984).

$$EC_e=6.4\,EC_{1:5} \qquad (2)$$

III. Results and Discussions

The most important water quality parameter from the standpoint of salinity is the total salt concentration. The most important single use of total salt concentration is to estimate the osmotic potential. Electrical conductivity (EC_e) is also a simple index to total concentration of dissolved salts in a given irrigation water and soil solution extract (Bresler, 1982). In this research study the osmotic potential was estimated from the EC_e of the soil by the following formula (Tanji, 1990).

$$\tau_o=40\,EC_e \qquad (3)$$

Where

τ_o=Osmotic potential (*kPa*)

EC_e=Electrical conductivity of saturated extract (dS/m) at 25℃

The pF function defined by Schofield (1935) as the $\log_{10}$ of the numerical value of negative potential of the water expressed in *cm* H_2O, if osmotic potential is negligible. In this study *pF* estimated by adding osmotic and matric potentials. It will be significant in the irrigation planning of dry lands for prevention of water stress and saline effect.

$$pF=\log_{10}\ (Hm+Ho) \qquad (4)$$

Where

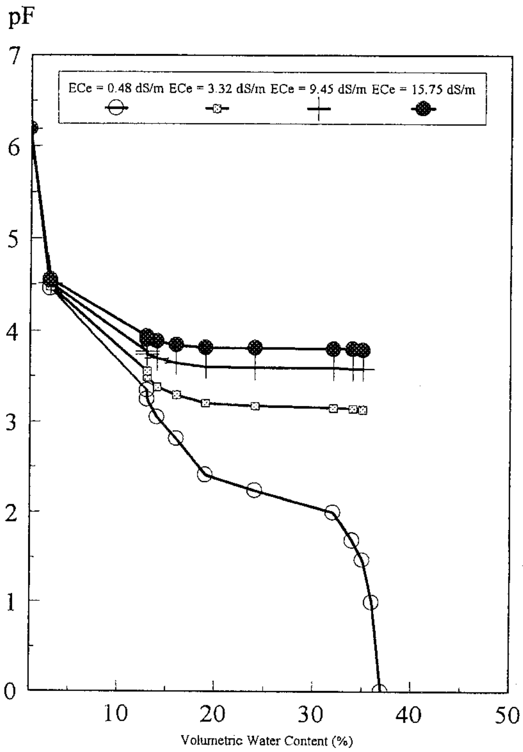

Fig. 1 Water retention curves of sandy loam soil under various salinity treatments.

Hm = matric potential in $cm\ H_2O$
Ho = osmotic potential in $cm\ H_2O$

1. Total Water Potential

Soluble salts concentration as well as sodium adsorption ratio are important parameter affecting the plant growth and soil conditions. An important use of total salt concentration is to estimate the osmotic potential. Electrical conductivity (EC_e) is a simple index to total concentration of dissolved salts in a soil solution extract, which was used in this study. Water retention curves of sandy loam soil under three salinity levels were developed and presented in Fig. 1.

pF values were 1.5 and 3.25 at 35 and 13 percent volumetric water content respectively, for no salt concentration. pF varied from 3.14 to 3.50 when EC_e was 3.32 dS/m. When EC_e increased to 9.45 dS/m, pF also increased up to 3.59 and 3.75 at 35 and 13 percent volumetric water content respectively. When EC_e was 15.75 dS/m, pF varied from 3.80 to 3.91 as shown in Fig. 1. The result showed that higher EC_e caused raising pF even though water content remained unchanged at all salinity levels. It showed that availability of water to plants decreased as salt concentration increased under saline conditions.

2. Evapotranspiration

Evapotranspiration (ET) of Komatsuna was measured for 24 days after sowing and presented in Fig. 2. It increased according to the growth and decreased after two weeks. The results showed that under the control treatment (T 1) ET was about 7.00 mm/day. When electrical conductivity of water increased to 2.21 dS/m, there was a little decreased in ET.

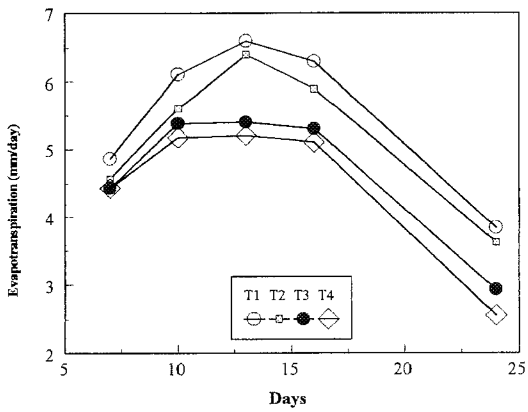

Fig. 2 Evapotranspiration (ET) of Komatsuna under various salinity treatments.

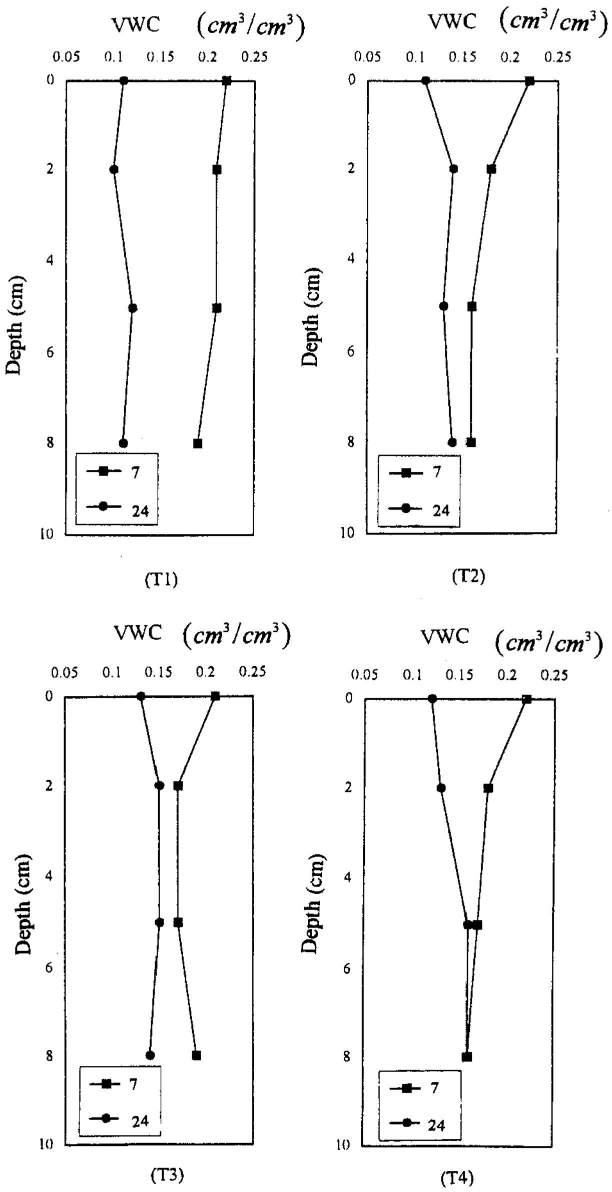

Fig. 3 Volumetric water content (VWC)-depth profile under various salinity treatment after 7 (before irrigation) and 24 (wilting stage) days sowing of Komatsuna.

However ET decreased down 7.00 to 5.00 mm/day when EC increased from 2.21 to 6.30 dS/m. There was a slight decrease of ET when EC increased up to 10.50 dS/m. This shows that evapotranspiration decreased as salt concentration increased, even the effect was rather small. Which may be due to evaporation of soil was less as compared to transpiration of the plants. The results obtained by Nozaka (1993) showed that the transpiration ratio decreased exponentially with increase in salt concentration in the irrigation water, as the soil water potential decreased. The results of this study are understandable according to the relationship.

3. Irrigation

Water content – depth profiles after 7 and 24 days sowing are shown in Fig. 3 for four treatments. These are initial and last growth stages. The water depletion patterns of soil were about similar in all saline treatments at each growing stage. Evapotranspiration during an irrigation interval results in reduced

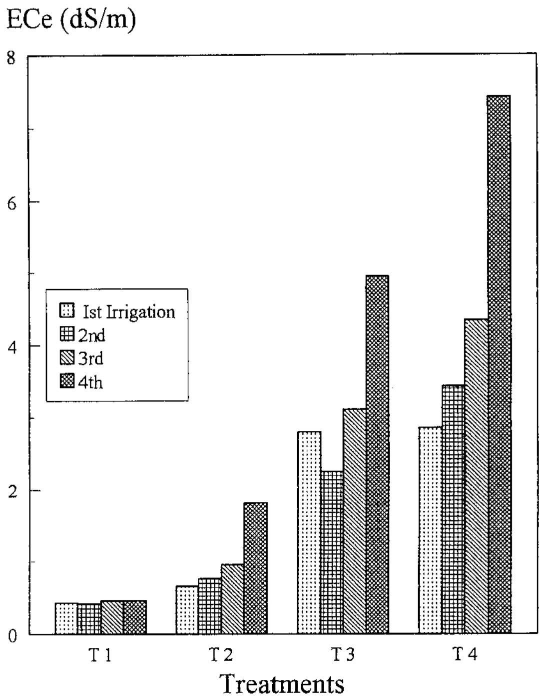

Fig. 4 Average salinity in different treatments after each irrigation.

Table 3 Matric and osmotic potential profile under various saline irrigation water treatments

Treat-ment	Days →	Soil water potential (−kPa) 7		10		13		16		24	
	Depth(cm) ↓	Matric	Osmotic	Matric	Osmotic	Matric	Osmotic	Matric	Osmotic	Matric	Osmotic
T1	0	20.3	44.04	14.34	27.7	13.43	28.72	14.34	31.4	219.5	48.64
	2	21.94	13.2	14.34	14.41	13.43	11.7	14.34	15.6	219.5	15.36
	5	25.2	12.16	14.34	14.18	17.06	12.88	13.43	13.84	219.5	13.57
	8	37.91	11.8	16.15	13.36	14.33	12.26	14.34	12.84	219.5	13.06
T2	0	37.91	42.76	13.43	58.11	15.25	71.94	15.25	94.48	219.5	401.9
	2	20.3	12	16.15	18.23	15.25	22.71	14.34	27.96	153.1	29.18
	5	37.91	12.4	15.25	15	15.15	15.62	15.25	17.76	201.6	16.64
	8	63.3	10.68	17.06	14.69	15.25	12	12.53	14.64	140	14.34
T3	0	21.94	31.2	13.43	215	18.69	279	16.15	381.7	168.4	1,144
	2	50.62	13.16	16.15	23.35	18.69	42.07	16.15	67.08	85.88	103.7
	5	50.62	10.88	16.15	13.47	18.69	23.92	16.15	30.92	84.9	34.3
	8	25.2	10.76	16.15	21.21	16.15	14.77	16.15	17.24	149.5	30.46
T4	0	20.3	31.96	20.31	347.0	17.06	476.2	18.69	568.3	219.5	1,718
	2	63.33	11.56	17.06	34.58	23.57	36.92	18.69	67.84	219.5	148.5
	5	37.91	10.64	20.31	40.06	20.31	19.79	17.06	35.76	63.3	52.99
	8	50.62	11.06	20.31	34.46	18.69	15.87	18.69	22.8	63.3	46.59

matric and osmotic potentials in the soil solution ; two soil water potential components that influence plant growth. Matric and osmotic potentials as these varied with time under all treatments are shown in Table 3. Matric potential was about same at all depths in saline as well as in non saline treatments. Matric potential decreased after 16 days sowing in upper depths because irrigation stopped. Electrical conductivity of soil solution extract (EC_e) was determined after each irrigation in the pot. Average EC_e in all soil treatments after each irrigation is presented in Fig. 4. EC_e increased after each irrigation in all saline irrigation water treatments.

4. Water Stress

Figure 5 show soil water potential as affected by salinity from 7 to 24 days. In treatment T 1 (control) no osmotic effect, it remained constant with time. The osmotic potential component showed its effect with increasing time. It was the dominant component of total soil water stress in three saline treatments. Total soil water stress decreased in treatment T 1 and even in all other treatments after 16 days because there was no irrigation after 16 days. Wilting of Komatsuna plants was observed apparently in the Phytotron. First leaves become pale and then faded, which could be observed as permanent wilting of plants. At permanent wilting moisture content and salinity in all pots were measured.

Sorbitol was used to see pure effect of osmosis and to avoid the pathological effect due to Na ions on the crop. The molecular weight of Sorbitol is 182 g with formula ; **CH_2OH-$(CHOH)_4$-CH_2OH**. Three treatments of Sorbitol were applied to compare the osmosis effect with NaCl treatments. Table 1 shows that the same amount of osmotic pressure produced by NaCl and Sorbitol. Sorbitol was dissolved in the water and applied to the crop. The permanent wilting was observed at pF 4.25 and pF 4.21 under NaCl and Sorbitol treatments respective-

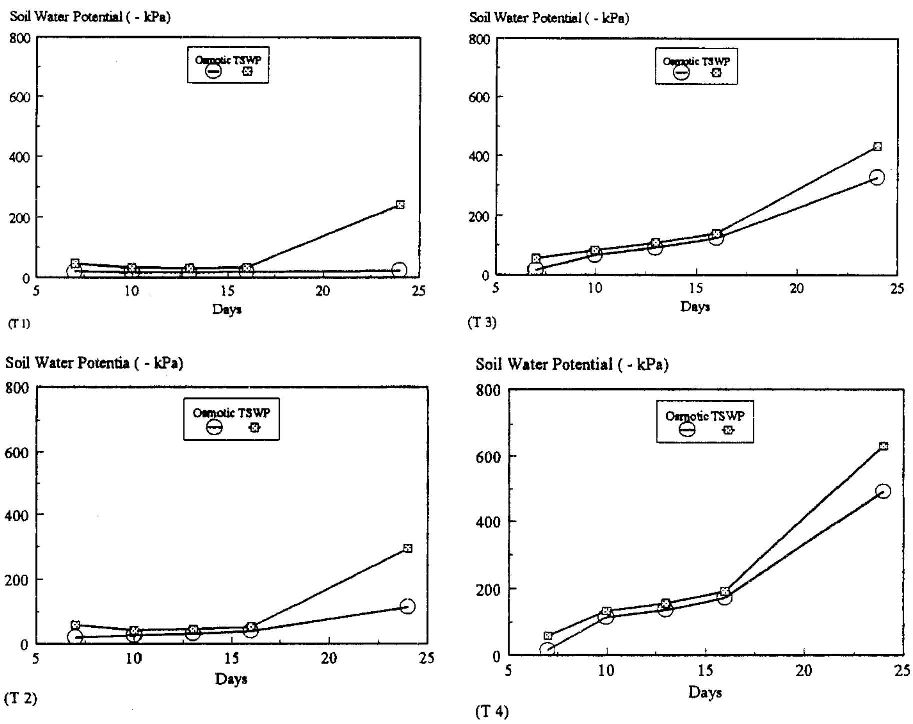

Fig. 5 Variation of total soil water potential (TSWP) and osmotic potential with time, when ECw = 0.32 (T 1), ECw = 2.21 (T 2), ECw = 6.30 (T 3), and ECw = 10.50 dS/m (T 4).

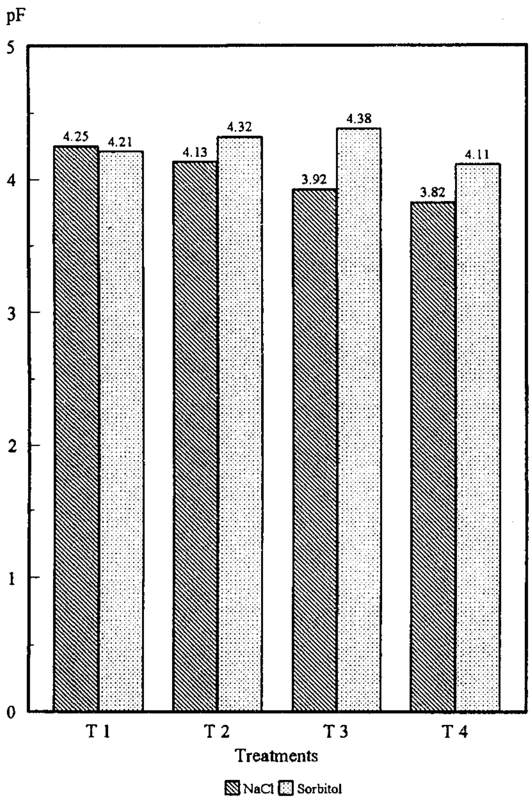

Fig. 6 pF at wilting of Komatsuna including osmotic and matric potentials.

ly, when no salts in irrigation water. When electrical conductivity of irrigation water was 2.21 dS/m, the permanent wilting was observed at *pF* 4.13 including osmotic potential. The permanent wilting was observed at *pF* 3.92 and 3.82 when *EC* of water was 6.30 and 10.50 dS/m respectively including osmotic potential component under NaCl treatment. The permanent wilting was observed at *pF* 4.32, 4.38, and 4.11 at same osmotic potentials in T 2, T 3, and T 4 treatments respectively under Sorbitol application (Fig. 6). The osmotic potential component was a dominant component of the total soil water stress in saline irrigation water treatments. The osmotic component also contributed in the wilting of the plants. The *pF* values at permanent wilting point obtained under NaCl treatment were smaller than Sorbitol treatment. There may be some ions effect on crop due to which it wilt at lower *pF* under NaCl treatment.

Ⅳ. Conclusions

Increasing salinity lead to increase pF without changing water content in all salinity levels. It showed that availability of water to plants under saline condition decreased by higher salt concentration. Evapotranspiration decreased down 7.00 to 5.00 mm/day when EC of water increased from 2.21 to 6.30 dS/m. Accumulation of salts effected osmotic potential component after each irrigation. The osmotic potential was a dominant component of total soil water potential in saline water treatments. It also contributed in wilting of plants.

In salt affected regions electrical conductivity is an important parameter for salinity measurement which may be used to estimate osmotic potential. pF including both matric and osmotic potential components can be used for irrigation planning to develop the salt affected soils in arid and semiarid regions. Detailed studies are needed of saline soils to further validate the effect of osmotic potential on plant growth, reclamation of salt-affected soils and water resources planning.

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塩分を含んだ灌漑水が土壌水分保持特性，土壌乾燥ストレスに与える影響

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要 約

土壌の水分ポテンシャル特性曲線は土壌の作物に対する有効水分量を知るために重要である。実験はpF 値が毛管と浸透圧ポテンシャルの和で表されると考え，塩分水を含ませた砂壌土の pF 曲線を描いた。実験作物には水分ストレスを見るためにコマツナを用いた。コマツナ作物に対する土壌乾燥の実験には塩水処理した浸透圧を含む砂質土の標準水分保持曲線を描いた後に，温度 25℃，湿度 70％の成育栽培用のファイトトロンを利用した。灌漑の都度，土壌塩分量は増大して土壌内水分浸透圧成分の増大を招く。塩分濃度が増大するに従い，浸透圧成分が増大し，蒸発散速度は低下する。灌漑水の塩分濃度が増せば pF も増大するが，これは作物細胞が有する水分ポテンシャルと土壌水分ポテンシャルとの差が少なくなり吸水量も減少するためである。塩水灌漑における灌漑水の浸透圧ポテンシャルは全土壌水負圧増加の大部分を占め，作物のしおれ点にも関係している。

実験の結果，次のことが分かった。pF による土壌の水分管理には土壌・水分・作物系としての新しい見方が必要であり，乾燥地および半乾燥地の塩性土壌の開発には毛管ポテンシャルと浸透ポテンシャルを考慮した pF 値の概念の導入が望ましいことを示した。

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