鹽分 灌漑用水가 土壤의 性質과 作物의 生産量에 미치는 影響

Effects of Salty Irrigation Water on Soil Properties and Crop Yields

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摘 要

美國 Utah州의 Huntington 火力發電所에서 冷却水로 使用하고 버리는 廃水는 鹽分濃度가 4 mmhos/cm정도로 높아 自然河川으로 그대로 放流시킬 수 없으며, 美 環境法에 따라 安全處理後 放流할 수 있다. 따라서 이 鹽分廃水 處理方法의 하나로 보리, 밀, 옥수수, 감자 그리고 알팔파등 사료작물의 灌漑用水로 利用할 수 있는 方法이 長期間 試驗硏究되고 있다. 현재로서는 이 方法이 經濟的인 것으로 評價되고 있으나 長期的으로 이 염분폐수로 인한 土壤의 性質變化, 作物의 生産量 減少등에 미치는 영향을 究明하기 위하여 1977年에 始作하여 8年째 連續 研究事業으로 進行되었다.

本 論文에서는 지난 8年間(1977~1984年)의 觀測·調査資料를 利用하여 염분 관개용수가 長期的으로 토양의 성질과 작물의 生産量에 미치는 영향을 分析하였다. 또한 1984年度의 관측자료로 생산량 推定과 計劃灌漑를 위한 蒸發散과 土壤水分變化를 推定할 수 있는 模型에 대하여 연구한 결과를 要約하면 다음과 같다.

1. EC 4mmhos/cm의 염분 관개용수로 8년간 長期間 灌漑한 결과, 灌漑用水의 量에 關係없이 1977年 3mmhos/cm였던 토양염분농도는 1984年 5mmhos/cm로 增加하였다. 이러한 토양内 염분축적은 예상보다 서서히 進行되었으며, 이 염분축적이 作物의 生産量 減少의 主原因은 아니었다.

2. 지난 2年間의 觀測 結果, 염분 관개용수에 含有된 10ppm정도의 硼素가 作物 특히 보리, 옥수수, 감자등의 생산량 감소의 主原因인 것으로 判斷된다. 염분용수 灌漑區에는 河川水 灌漑區보다 20倍나 많은 硼素가 축적돼 있었으며, 이는 硼素가 토양内에 잘 吸收되며, 토양으로부터 硼素를 溶脫시키려면 염분을 溶脫시킬 때보다 휠씬 더 많은 溶脫用水를 必要로함을 뜻한다. 앞으로 硼素의 土壤内 축적이 長期的으로 작물생산량에 어떠한 영향을 미치며 아울러 各 작물들의 耐硼素性을 구명하기위한 模型개발이 要求된다.

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3. 염분관개용수로 관개할 때, 보리, 옥수수, 감자등의 穀物 생산량과 風乾物 생산량은 현저하게 감소하였다. 보리, 옥수수의 염분용수에 의한 생산량과 河川水에 의한 생산량과의 比는 風乾物의 경우 0.6, 穀物의 경우 0.5였으며 감자의 경우는 0.2以下였다.

4. 염분용수 관개區와 河川水 관개區의 모든작물에서 풍건물 생산량과 蒸散量사이에는 強한 直線的인 關係를 보였다. 보리, 감자의 穀物생산량과 蒸散量사이에도 線型의 관계가 成立되었으나, 밀과 옥수수의 穀物생산량과 蒸散量사이에는 曲線的인 關係를 나타내었다.

Ⅰ. Introduction

Research was conducted during 1984 to evaluate the shared use of cooling water from the Utah Power & Light Company Huntington Power Plant for irrigation. This was the eighth consecutive year of irrigation with this saline waste water. The cooling water is recycled in the cooling process until the salinity increases to a point where it is sent to the waste water pond. The water from the waste water pond is used to irrigate a wide variety of crops such as barley, wheat, corn, potato, and four types of forages. The line source sprinkler system has been used which allows a variable amount of irrigation water from zero to excess, to be applied to all plots. In the normal growth process plants extract nearly pure water from the soil leaving the salt contained in the irrigation water in the soil. Irrigation with the waste water increases the crop yields to much higher levels than would be possible without irrigation. This system of controlled irrigation has been found to be economical but the long time effects on crop production are not known.

There has been no noticeable yield decrease of forage crops caused by irrigating with saline water compared to irrigating with fresh water from the Huntington river. However, decreases in yields were found after the third year in potato, corn, barley, and wheat. In 1984 potato yields in plots irrigated with saline water were only 25 per cent of the yields obtained from plots irrigated with fresh water. Yields of barley and corn irrigated with saline water were about 60 per cent of the yields obtained from plots irrigated with fresh water. Wheat yields decreased from 5 to 20 per cent when irrigating with saline compared to fresh water. The soil salinity has been slowly building up in sites where leaching is limited. However, by the end of the eighth year this build up was not sufficiently high to explain the observed yield decreases. Also, the decreased yields of different crops did not fit the known salinity-yield relationships. Therefore, it is apparent that something other than normal salinity(low osmotic potentials) have influenced yields. Measurements during the past two years of boron levels in soil, irrigation water and plants indicate that boron toxicity may explain this decreased yields. Therefore a major effort was made to evaluate the possibility of boron toxicity.

The objective of this study is to identify specific management procedures which will allow continuous use of saline waste water from electrical power plants for irrigation. Evaluation of the effects of irrigation involve monitoring yields, soil salt status, and ground water flow. Predictions will be made of future effects from model computation. The long time trends of effects of salty water on crop yields and soil properties were analysed with eight years data in this paper. Plantgro model was also introduced to estimate the amount of consumptive water and soil moisture contents which is useful for irrigation scheduling and to predict the dry matter production of annual crops with the observed data from Huntington in 1984.

Ⅱ. Research Procedures

This research was primarily field studies conducted at the Utah Power & Light Company holes were installed in four representative crops in the salty and fresh water plots. Evapotranspiration (ET) for the growing season was estimasted using the water balance approach.

$$ET = IRR + R + SWD - DR - RO \cdots\cdots \quad (1)$$

where IRR : total seasonal irrigation
R : amount of precipitation
SWD : difference in the soil water status from planting to harvest
DR : amount of drainage
RO : runoff

4. Soil salinity samples

Soil samples at 48 sites were taken in the spring and fall. Each site was sampled to 150cm at 30cm intervals, resulting in a total of about 240 samples collected. From the saturated extract of each sample, the EC and concentration of Cl^- were determined. Then the extract was diluted (1 : 5) and EC and Cl^- were determined again to check for precipitation of total salts(EC 1 : 5) and chloride salts(Cl 1 : 5). The soil samples were more useful than the solution samplers in that readings of EC were possible in very dry soils. A detailed soil chemistry analysis for concentrations of Ca, Mg, Na, K,Cl, and SO_4 in the saturated extract was made in the spring and fall for the modeling purposes for some of the samples.

5. Crop yield study

Wheat and barley were harvested and samples were weighed in the field for total dry matter. The samples were then brought to a greenhouse for drying and after a few days the grain was removed from the stalk, analyzed for moisture content and weighed. In addition to the weight of 100 kernels from each plot the total and irrigation level were also recorded.

Corn was harvested and weighed for dry matter content (stalk and ears) in the field. Then samples from a representative portion of the plot were dried, the moisture content was determined, and the field data were corrected to a dry weight base.

Both varieties of potatoes (late and early) were harvested at the same time(in October). Only the field weight was recorded.

6. Irrigation and water quality

The amount of irrigation was measured with a can situated at each irrigation level(IL) on each side of line source. Water application varied from zero on irrigation level one (IL-1) to about 70cm on IL-6. The pan evaporation was about 80cm for the year, so fields receiving the most irrigation water were probably over-irrigated. Some leaching probably occurred on plots IL-5 and IL-6.

7. Application of Plantgro model

Plantgro model by Hanks is a computer model to predict dry matter (and grain) production of field crops. Crop production is predicted from the relationship of T (rather than ET) to crop yield since E does not contribute to the growth and development of the plant. Rasmussen and Hanks(1978) indicate that annual changes in the relationship of ET to yield are mainly due to variations in E, with the relation of T to yield(or relative yield) holding steady. The average free water evaporation rate(Eo) is a fuction of the evaporative demand of the climatic environment. It may be obtained from Class-A pan data, a lysimeter, or an appropriate formula. In this model, Eo is split into Ep (potential evaporation) and Tp(potential transpiration) on the basis of crop stage of growth (Childs and Hanks, 1975). This approach involves simplifying assumptions on the relationship of Tp/ Eo (Kt) and Ep / Eo (Ks) to the stage of growth of the plant. Relative potential evaporation, Ks, is computed as (1-Kt) except during the maturity stage. At this stage, Kt decreases due to leaf senescence and Ks is influenced by shading effects. Fig. 3 shows the relationships of Tp

2. Long time effects of salty water on crop yields

The wheat yields (Table-1) show that total dry matter yields with salty irrigation water were less than with fresh water. However, yield difference were less than 5 per cent at the two highest irrigation levels. Production differences were more pronounced for grain yields. The salty irrigation plots outyielded the fresh plots at the two highest irrigation levels.

Both grain and dry matter yields for barley decreased markedly due to irrigation with salty water. The ratios of salty / fresh yields are about 0.6 for dry matter and about 0.5 for grain.

Corn yields also decreased for salty water irrigation. The ratio of salty / fresh yields was about 0.6 for dry matter and about 0.5 for grain.

Potatoes yields were much lower when irrigated with salty water. The ratio of salty / fresh yields was less than 0.2 at the three highest irrigation levels. The potatoes seem to grow reasonably well early in the year, but start to die off before midseason. By the end of the year there were almost no vines left in plots with the highest irrigation level of salty water. Results indicate that potatoes are sensitive to boron.

There was no indication that forage yields were decreased due to irrigating with salty water. The ratio of salty / fresh yields were 0.94, 0.99, 1.12, and 0.99 for alfalfa, grassalfalfa, wheatgrass, and mixed grass, respectively.

The long term trends of dry matter yields of annual crops are shown in Fig.5 as a ratio of salty / fresh yield.

3. Effect of boron on crop yields

The physiological effects on the crops(prima-

Table-1. Average crop yields (kg / ha), Huntington in 1984

Crop	Type	Treatment	Irrigation level 1	2	3	4	5	6
wheat	grain	salty	209	450	1067	2236	3959	4280
		fresh	353	394	1790	3181	3679	3855
		ratio	0.59	1.14	0.60	0.70	1.08	1.11
	dry-matter	salty	1162	1640	2756	5029	8080	9032
		fresh	1321	2677	4271	6424	8497	9179
		ratio	0.89	0.61	0.65	0.78	0.95	0.98
Barley	grain	salty	703	1333	2746	3677	4484	4199
		fresh	592	1964	4271	7552	8684	8419
		ratio	1.19	0.68	0.67	0.49	0.52	0.50
	dry-matter	salty	2258	3095	5886	7560	8856	7993
		fresh	2497	3593	8318	13122	15275	14996
		ratio	0.90	0.86	0.71	0.58	0.58	0.53
Corn	grain	salty	0.0	114	2327	3699	3311	4349
		fresh	0.0	187	1907	6836	8783	7800
		ratio	0.0	0.61	1.22	0.54	0.38	0.55
	dry-matter	salty	756	1759	6479	8873	9856	10575
		fresh	332	1284	7995	15647	17365	16848
		ratio	2.30	1.37	0.81	0.57	0.57	0.63
Potatoes	grain	salty	310	764	2313	4957	6341	7565
		fresh	604	3633	13005	23866	32705	29232
		ratio	0.51	0.21	0.18	0.21	0.19	0.26
Grs.Alf	dry-matter	salty	38	202	1867	4619	6824	7799
		fresh	193	397	1878	5230	6199	7794
		ratio	0.20	0.51	0.99	0.88	1.10	1.00

Table-2. Boron concentration in crops in 1984 at Huntington

Crop	Salty						Fresh					
	1	2	3	4	5	6	1	2	3	4	5	6
	ppm											
Wheat grain	18	20	22	19	21	24	5	4	7	5	8	4
dry matter	13	33	22	33	36	20	10	7	7	7	6	7
Barley grain	9	11	13	20	18	15	6	6	8	6	4	7
dry matter	12	58	75	74	54	49	11	7	7	7	6	8
Corn grain	-	17	24	42	44	36	-	9	10	9	9	9
dry matter	-	71	113	183	139	189	-	16	17	9	10	10
Potatoes dry	29	54	66	53	54	47	13	12	11	14	9	10
field moist	6	9	13	10	9	8	3	2	2	3	2	2
Forages 1st	-	93	104	-	136	135	-	54	49	-	47	45
2nd	-	-	117	112	113	157	-	-	44	30	37	43
3rd	-	-	261	-	239	173	-	-	82	-	62	65
Alfalfa 3rd	-	310	149	325	390	275	-	-	105	62	69	58
Mixed Grass	-	136	177	225	290	265	-	109	-	25	51	20

Alfalfa and mixed grass contained several times as much boron than the other crops. This may be partially due to the type of plant tissue tested. In 1983, corn stover and barley straw contained substantially more boron than the grain, to the degree similar to those found in forage plant tissue. Boron content of each successive cutting increased ; the third cutting contained almost twice as much boron as the first.

Potato tubers contained substantially more boron in 1984 than in 1983, i. e. it increased from 32 ppm to 54 ppm for salty level 5, corresponding to 31 to 19 per cent decrease in relative yield.

In conclusion, an increase in boron content of a crop is critical factor that appears to be related to yield decreases.

4. Analysis of observed data from Huntington in 1984

1) Irrigation water quality

The amount of irrigation, dates of application, electrical conductivity, boron and chloride concentration of the irrigation water in 1984 were shown in Table 3. The EC(genral salinity) of the salty water was higher than in 1983(4.0 compared to 3.7 mmhos / cm) and boron con-concentration also increased (9.4 compared to 8.4 ppm).

2) Application of Plantgro model

a. Results of water balance

The average free water evaporation(Eo) was obtained from Class-A pan data. Eo is divided into Ep(potential soil evaporation) and Tp(-potentail transpiration) on the basis of crop stage of growth, herein 10 days periods.

Crop transpiration coefficients(Kt) and soil evaporation coefficients(Ks) corresponding to crop stage of growth for wheat, for instance, were adapted from Hill et al.(1984) as shown in Fig. 3.

The value of Kt is essentially zero during its early stage of 20 days from planting. After full effective cover, Ks increase from 0.1 to 0.5, rather than to 1.0 because of crop shading.

The results of water balance approach for wheat and potatoes by Plantgro model was shown in Table 4 and 5. Water added during growing season was from 125mm in IL-1 to 815mm in IL-6 for both wheat and potatoes. Some drainage occurred only in IL-6 for wheat, but considerable drainage occurred on potatoes plots IL-5 and IL-6.

b. Estimation of soil moisture content

It is very important to estimate the soil moisture content for irrigation scheduling to

Table-5. Water balance results for potatoes by Plantgro model

Level	IL-1		IL-2		IL-3		IL-4		IL-5		IL-6	
Plot	S	F	S	F	S	F	S	F	S	F	S	F
	cm											
Trans.	7.4	10.4	8.6	11.5	23.4	25.2	38.1	45.4	50.6	53.4	51.4	54.6
Evapo.	19.0	20.5	26.2	26.6	27.3	28.1	28.4	29.1	28.4	29.8	28.4	29.8
Total ET	26.4	30.9	34.8	38.1	50.7	53.3	66.5	74.5	79.0	83.2	79.8	84.4
Depletion	13.6	18.1	12.9	17.3	12.4	16.8	11.7	15.8	4.0	6.5	-1.6	2.6
Drainage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	6.1	5.5	10.8	8.9
Rainfall	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Irrigation	0.0	0.0	9.0	7.9	25.5	23.7	42.0	45.8	62.1	63.9	68.5	69.0
Wateradded	12.5	12.5	21.5	20.4	38.0	36.2	54.5	58.3	74.6	76.4	81.0	81.5
Dry matter	%											
predicted	12.6	17.8	14.7	19.6	40.1	43.2	65.2	77.6	86.5	91.3	87.8	93.4
measured	4.0	2.0	10.0	11.0	31.0	40.0	66.0	73.0	84.0	100.	100.	89.0

city was 28 per cent. Soil water content of wilting point was assumed to 12 per cent for the salty plot and 10 per cent for the fresh plot, respectively.

c. Estimation of crop yields

From the judgement of comparing the measured crop yields to the predicted ones, it was proved that strong linear relationship exist between dry matter yields and estimated amount of transpiration for all crops in both salty and fresh plot as shown in Fig. 7. Strong linear relation was still available for the grain yields of barley and potatoes (Table-1), but irregular curvilinear relation was found for the grain yield of wheat and corn. So it is possible to predict the dry matter yield of all crops and grain yield of barley and potatoes from the linear equation (5). The comparison of predicted relative yield to measured one was shown in Table 4 and 5.

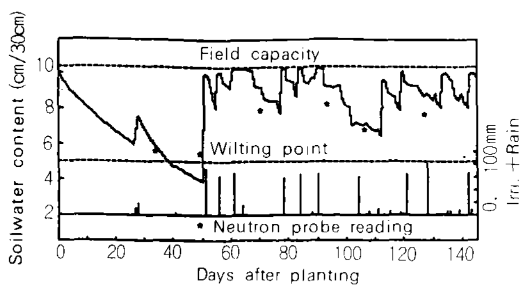

Fig. 6. Model estimated soil water of the first 30cm layer versus Neutron probe measurements for wheat field

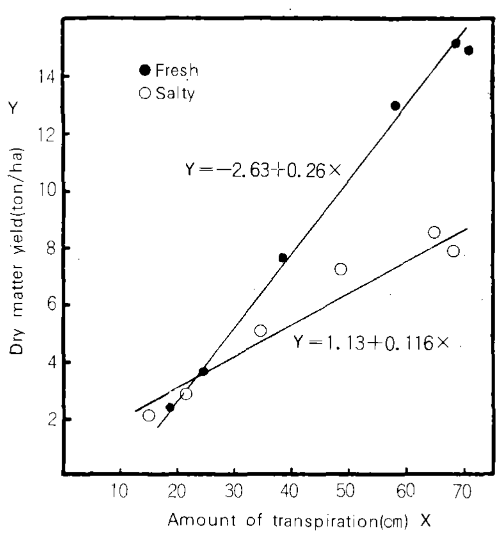

Fig. 7. Relation of dry matter yield of barley in salty and fresh plot as related to transpiration

Ⅳ. Conclusions

Research was conducted during 1984 to evaluate the shared use of cooling water from the Utah Power & Light Company Huntington Power plant for irrigation. This was the eighth consecutive year of irrigation condueted with