G-2.2 Study on the Establishment of Leaching Technology and Prevention of Secondary Salinization

Contact person Yoshinobu Kitamura
Associate Professor, Arid Land Research Center, Tottori University
1390 Hamasaka, Tottori 680-0001, Japan
Tel : +81-857-23-3411 Fax : +81-857-29-6199
E-mail : ykita@center.tottori-u.ac.jp

Total Budget for FY1996-FY1998 104,194,000 Yen (FY1998 20,735,000 Yen)

Abstract

Based on a series of on-site water and salt balance experiments, it was proved that the ordinary eight-year rotation system and the over-irrigation to the rice fields together with an inappropriate drainage management have accelerated the salt accumulation and concurrently increased abandoned farmlands in the Lower Syr Darya River region. A remarkable finding was obtained on the salt behavior in rice fields, and this denies the hypothesis that rice cultivation practice in arid area is effective for leaching accumulated salts.

In order to overcome problems on secondary salinization, the following remedial measures are recommended:
1) to avoid mixed cropping with rice and upland crops and to unify either upland crops or rice in an irrigation block to control groundwater table, 2) to decrease conveyance and field application losses through improved canal construction and management performance, introduction of canal-lining and improved land-leveling performance, 3) to maintain and operate drainage canals to function, especially installation of drain pipes across dikes for connecting fields and field-drains might enhance subsurface drainage function, 4) to introduce bio-drainage along canals and around farm lots for preventing waterlogging and salinization, 5) to develop design and management technique of evaporation pond for better effluent management at the outfall of each irrigation block, and 6) to conclude international water and/or drainage rights agreements among riparian countries and to enact a basin-basis management regulation to control water withdrawal and drainage.

Key Words Secontary salinization, Irrigation system management, Water balance, Salt balance, Eight-year cropping system

1. Introduction

In the lower river basin of the Syr Darya, which rises in the Tien Shan Range, meanders mainly in lowland deserts with low precipitation (100-200 mm yr^{-1}) and finally flows into the Aral Sea, water withdrawals for irrigation in reclaimed lands along the river have been conducted since 1960s. Irrigated agriculture of rice-based cropping system in the Kzyl-Orda region of the Lower Syr Darya is important to both the national and regional economy. Since rice is the most water consuming crop, water withdrawals have increased sharply with an increase of the area planted to rice. The discharge of sizable drainage from irrigated lands also has sharply increased the level of salinity. This situation increased the salinity in irrigation source of Syr Darya water from 0.4-0.6 g L^{-1} to 1.3-2.0 g L^{-1} for the last three decades$^{1)}$.

Also, due to excessive and inefficient water use, secondary salinization of land exist in irrigated area in the region. Irrigation efficiency for the Aral Basin averaged as low as 60 %$^{2)}$. This indicates that at least 40 % of the water withdrawn was lost before it reached the field, mainly due to seepage from unlined earthen canals. These water losses raise groundwater table and cause waterlogging and land salinization. Salt accumulation in farm lands results in the increase of abandoned lands, and the environmental degradation in the region.

Part of these problems are attributable to the rough water management under large-scaled canal irrigation systems. Thus, proper water management is essential for preventing secondary salinization and sustainable agriculture in the region.

In this study, water and salt behavior was analyzed in an actual irrigation block located in the Kzyl-Orda region of the Lower Syr Darya to make clear the influence of water management on salt accumulation for developing a proper water management technology.

2. Outline of study area

Shamenov kolkhoz (originally collective farm during the ex-USSR era, after independence privatized, hereinafter called kolkhoz) located in the Kzyl-Orda state of Kazakhstan, which is a rice bowl in the Lower Syr Darya basin, was selected as a study area. Though the kolkhoz has a gross area of 19,000 ha, only 1,900 ha or 10 % was reclaimed sporadically for agricultural purposes. The reclamation of land was conducted mainly in water-accessible areas with comparatively low and flat topography. The areas of poor water accessibility with rather undulations were left as wasteland without reclamation. Out of the reclaimed land of 1,900 ha, which have been cultivated in the kolkhoz, the area of 600 ha is abandoned without cropping due to severe salt accumulation. This situation is commonly seen in every kolkhoz in the state.

The kolkhoz is adjacent to the right bank of the Syr Darya River at around 350 km upstream of the river mouth to the Aral Sea. In order to get enough hydraulic gradient for gravitational irrigation, a water source must be set up at the further upstream point. Water is diverted from the Syr Darya River by gravity through the head race named Aitek Canal of which intake sluice is located at about 50 km upstream of the kolkhoz.

2.1 Climate

Being located very far from the moderating influence of the ocean, the area exhibits the characteristics of extreme continentality. Despite the high latitude (45° N), the summer is extremely hot, with average temperature of 27 ℃ and maximum temperature in excess of 40 ℃. Winter is extremely cold, with average temperature of –5 ℃ and minimum temperature below –25 ℃. The annual precipitation averages 120 mm, which is partial to spring and fall. The area has little rain in summer and suffers severe desiccation. The aridity index is estimated at 0.06, so that the area is classified as arid, however, it is very near to hyper-arid.

Due to the climatic constraint, irrigation is prerequisite for rice-based farming in the region. For the normal growth of rice, temperatures should not fall below 10 ℃. Low temperatures during the early growth stages result in a longer maturation period. Especially, low temperatures during the panicle initiation stage are harmful and may result in sterility of the grains. Thus, from the viewpoint of temperature, the cropping season must be set from the late April to the early September.

2.2 Water quality in the study area

Table 1 shows characteristics of water quality for surface water (irrigation water, ponded water in rice fields and drainage water) and groundwater in the Lower Syr Darya basin in and around the Shamenov kolkhoz, together with a standard range of each parameter for common irrigation water quality not to create soil or crop problems.

2.2.1. Surface water

Judging from EC and TDS, water source for irrigation in this area is almost applicable to direct use without creating significant problems. Only magnesium (Mg^{2+}), and the ratio Mg^{2+} to calcium (Ca^{2+}), i.e. (Mg^{2+}/ Ca^{2+}), exceed the usual range for irrigation water, therefore, the water has a tendency to affect crop growth mainly by reducing calcium uptake and causing calcium deficiency (Gupta, 1990). Though, ponded water in rice fields is worse than water source by some degree in quality due to diffusion of dissolved salts from saturated pore water in paddy soil, still it is out of the range of severe restriction for the most part. Based on the guidelines for interpretations of water quality for irrigation$^{3)}$, both water source and ponded water are classified as restriction degree of slight to moderate range, thus some certain care in selection of crop, variety and management alternatives is required for full-potential production.

Table 1 Characteristics of water quality related to salinity in Lower Syr Darya Basin

Parameter	Units	Water quality in and around Shamenov Kolkhoz				Usual range for irrigation (FAO, etc.)
		Surrface water			Groundwater	
		River & irrigation canal water	Ponded water in rice fields	Drainage water	Cultivated & Abandoned fields	
EC	dS m^{-1}	1.31-2.88 (1.78)	1.84-3.06	2.63-4.40 (3.42)	4.13-73.00 (22.9)	0-3
TDS	mg L^{-1}	955-2151 (1285)	1384-2337	2053-4143 (2620)	2765-86360	0-2000
Ca^{2+}	me L^{-1}	4.6-9.3	6.2-9.1	8.4-19.2	20.3-29.1	0-20
Mg^{2+}	me L^{-1}	5.6-11.3	7.3-12.7	11.6-18.3	20.8-437.0	0-5
Na^{+}	me L^{-1}	5.9-17.0	7.7-15.1	13.1-20.9	17.3-982.6	0-40
CO_3^{2-}	me L^{-1}	-	-	-	-	0-0.1
HCO_3^{-}	me L^{-1}	-	-	-	-	0-10
Cl^{-}	me L^{-1}	4.5-12.2	6.0-13.1	12.6-25.1	26.0-795.9	0-30
SO_4^{2-}	me L^{-1}	11.2-22.4	14.0-24.9	23.7-43.7	13.6-633.5	0-20
K^{+}	me L^{-1}	0.1-0.3	0.2-0.3	0.2-0.5	0.6-3.2	0-2
pH	me L^{-1}	7.6-8.14	7.75-7.94	7.62-8.10	7.42-8.14	6.0-8.5
SAR		2.46-6.08	2.70-5.36	4.13-5.04	3.68-129.36	0-15
Mg^{2+}/ Ca^{2+}		1.05-1.44	1.10-1.72	0.95-1.63	0.90-15.90	0-1

Whereas, drainage water is almost within the range of severe restriction for irrigation purposes, thus, it is not applicable to direct use for irrigation purpose. For reuse of drainage water for irrigation purposes, the mixing with fresh water is required to adjust the salinity to acceptable range. Actually, much drainage water is finally drained off to the river, it causes adverse effect on water quality in the lower reaches including the Aral Sea. For the thorough solution of water quality problems in the Lower Syr Darya region, appropriate measures for drainage treatment ought to be established in future.

Kinds of dissolved salts in surface water are sodium: Na^{+} (39 %), Mg^{2+} (34 %), Ca^{2+} (27 %), and potassium: K^{+} (1 %) for cations, sulphate: SO_4^{2+} (66 %) and chloride: Cl^{-} (34 %) for anions. Occurrence of Mg^{2+} in higher proportion than Ca^{2+} tends to increase the adverse effect due to sodicity$^{4)}$. Therefore, since the high proportion of Mg^{2+} among cations, the sodicity hazard is expected to be high.

Based on a series of water quality data for surface water in and around the kolkhoz observed in 1996 and 1997, distinct linear relationships were obtained between EC and TDS as follows:

$$TDS=753.52EC \qquad (R^2=0.9812) \qquad ----- \qquad (1a)$$

$$TDS=815.99EC-169.97 \qquad (R^2=0.9873) \qquad ----- \qquad (1b)$$

2.2.2 Groundwater

According to **Table 1**, groundwater in this area is almost within the range of severe restriction and thus it does not have any potential to be used for irrigation purposes without creating significant problems.

In case of groundwater, the components of salinity are Na^{+} (67 %), Mg^{2+} (26 %), and Ca^{2+} (7 %) in cations, and SO_4^{2+} (53 %) and Cl^{-} (47 %) in anions. The percentages of Na^{+} and

Cl^- are higher in groundwater than those in surface water.

From the quality data of groundwater in and around the kolkhoz observed in 1996 and 1997, clear linear relationships were also obtained between EC and TDS as follows:

$$TDS=1137.5EC \qquad (R^2=0.9885) \qquad ----- \qquad (2a)$$

$$TDS=1207.7EC-3072.7 \qquad (R^2=0.995) \qquad ----- \qquad (2b)$$

It is obvious from the above equations that the regression coefficient of regression equation with constant term of zero for groundwater is about 1.5 times of that for surface water. EC of groundwater is approximately 8.8 times higher than that of surface water. Dissolved salts such as Mg^{2+}, Ca^{2+}, K^+ and SO_4^{2-} of groundwater are also around 8.8 times higher than those of surface water. However, Na^+ and Cl^- of groundwater are extremely high, i.e. 17 and 21 times higher than those of surface water, respectively. This results in larger regression coefficient for groundwater than that for surface water in the above regression equations between TDS and EC.

2.3 Cropping schedule and its problems

In Kzyl-Orda region, eight-year rotation system (**Fig. 1**) are very popular and has been practiced for some decades. In the eight-year rotation system, the order and frequency of crops is: first and second year, rice; third year, cultivated fallow; fourth and fifth year, rice; sixth year, wheat cover-cropped with alfalfa; seventh and eighth year, alfalfa (with 50 % of cropland being used for rice). Based on the research findings that the soil fertility which was lost during rice planting can be replenished through alfalfa planting as well as the alfalfa fields can be irrigated through seeped water from adjacent rice fields under the system, this system has been recommended by researchers of the USSR Rice Research Institute[5)] and have adopted by farmers in this region. In most rice producing areas in Kazakhstan, this cropping pattern has been the basic for design and construction of new rice land development. Under this rotation program, therefore, approximately half of the irrigated area was allotted for rice cropping and the rest half is kept under upland conditions, for fodder crops or fallow.

1. Rice
↓
2. Rice
↓
3. Fallow
↓
4. Rice
↓
5. Rice
↓
6. Wheat + Alfalfa (first year)
↓
7. Alfalfa (second year)
↓
8. Alfalfa (third year)

Fig. 1 8-year cropping system

However, there is a possibility that this system has induced waterlogging and salt accumulation in adjacent upland areas to rice field in and/or out of the irrigation block. In this kolkhoz, two irrigation blocks, i.e. Mechet and Saltaban Blocks, in which the eight-year rotation system had been practiced from some decades before, have abandoned farmlands in no small extent due to salt accumulation. In such irrigation blocks, the eight-year rotation system was cancelled and a new cropping pattern tends to be adopted recently. The new cropping pattern is still eight-year rotation system, but that is practiced by introducing same crop in a whole block. Only the Yeltai Block which was developed no long ago is still practicing the ordinary eight-year rotation system. Though Yeltai Block has only limited abandoned farmlands, it is anticipated that the salt accumulation will be accelerated and concurrently abandoned farmlands will increase if this system is practiced continuously.

3. Water balance in Yeltai Block

3.1 Material and method

Among four major irrigation blocks and some minor blocks, Yeltai Block, which was reclaimed in recent years, was selected for the study on water and salt balance. Irrigation water for the block is derived through Yeltai Canal which is diverted from the Communism Canal, main canal in the kolkhoz. Drainage water from farmlands is collected by main drain (Yeltai

Drain) and drained off to the tributary of the Syr Darya River. The irrigation and drainage systems are comparatively simple in this block. By measuring flow discharge both at the head of the Yeltai Canal and the end of the main drain, water balance in the block can be analyzed.

Out of the block area of 827 ha excluding roads, canals and drains, an area of 716 ha is used for cultivation, the rest 111 ha is either not allotted for cultivation due to inappropriateness for the purpose when developed (101 ha) or abandoned after several cropping experiences (10 ha). This block is characterized as well-consolidated one, namely, irrigation canal and drainage systems are set independently, and every individual lot can access to field irrigation canal and field drain through its inlet and outlet, respectively. The lot size of this block varies from 1.5 to 3.5 ha, averages about 2.5 ha. Almost all the farm works are practiced by heavy farm machines. As mentioned above, eight-year rotation system is practiced in the block.

In 1997, an area of 384 ha was under the cultivation of rice, whereas an area of 332 ha was under the cultivation of alfalfa. Irrigation for 1997 cropping was practiced for 122 days from April 21 to August 25 (128 days for considering water balance). However, due to not enough time for preparation, water balance study was conducted for 90 days during May 19 to August 16, 1997. The amount of irrigation inflow was observed at the head of the Yeltai canal, and that of drainage outflow was done at the end of main drain by means of current meter. Though very little amount of water was diverted from the canal for street trees in Jaragash town, it was disregarded in the study. During the study period, no precipitation was observed.

In 1998, the cropping pattern was drastically changed. Out of 716 ha, an area of 537 ha was under the cultivation of rice, whereas an area of 70 ha was under the cultivation of alfalfa and the rest 109 ha was kept as fallow. Irrigation for 1998 cropping was practiced for 112 days from May 1 to August 20. Water balance study was conducted for 123 days during May 1 to August 31, 1998 that outflow from the block stopped.

The results of water balance study in the block for two seasons are summarized as shown in **Table 2**.

Table 2 Water and salt balance in Yeltai Block

Water Balance	Area (ha)	Irrigated (x1,000m3)	Consumed (x1,000m3)	Drained (x1,000m3)	Period
1997	Rice fields: 384	18,062 [24,484] 4704mm(52.3mm/d) [6376mm(50.2mm/d)]	8,942 [12,121] 2329mm(25.9mm/d) [3156mm(24.8mm/d]	9,120 [12,363] 2375mm(26.4mm/d) [3220mm(25.4mm/d)]	5/19-8/16 (90days) [4/26-8/31 (128days)]
1998	Rice fields: 537	21,621 4026mm(32.7mm/d)	12,126 2258mm(18.4mm/d)	9,495 1768mm(14.4mm)	5/1-8/31 (123days)

Salt Balance	Area (ha)	Salt Inflow (ton)	Salt Remained (ton)	Salt Outflow (ton)	Period
1997	Culti-vated: 716	24,719 34.5 t/ha 384 kg/ha/d	3,259 4.6 t/ha 51 kg/ha/d	21,460 30.0 t/ha 333 kg/ha/d	5/19 - 8/16 (90 days)
1998	Culti-vated: 716	24,923 34.8 t/ha 283 kg/ha/d	409 0.6 t/ha 5 kg/ha/d	24,514 34.2 t/ha 278 kg/ha/d	5/1 - 8/31 (123 days)

* [ ] for 1997 water balance : estimated values for whole season based on extrapolation using observed data

3.2 Relationship between cropping pattern and water balance

3.2.1 Cropped area and irrigated amount

In 1998, allotted area for rice was increased to 1.4 times of that in 1997. Since the irrigation for alfalfa is done only once at the beginning of each season, amount of irrigation water for the block ought to be decided by cultivated area of rice. According to the simplified calculation, irrigated amount in 1997 ought to be 1.4 times of that in 1998. However, the seasonal average of irrigated amount for 1997 was almost the same as that for 1998, i.e. 2.32 m^3s^{-1} and 2.23 m^3s^{-1}, respectively. The observed water profile in irrigation canal was almost the upper limit throughout the season in each year. Namely, it can be judged that the supplied amount at the head of canal was as much as its conveyance capacity regardless of crop water requirement in the command area. There are several causes to derive such a canal operation as follows:

a. to secure hydraulic head required for gravity irrigation in flat topography,
b. to maintain deep water in rice fields,
c. to supplement canal losses, and
d. not enough efforts to save water attributed to extremely low water charge, i.e. about 0.704 US$ per $1000m^3$.

Thus, the smaller the cultivation area of rice is, the larger the unit water discharged at the canal head becomes. The total water discharged per rice fields at the canal head was 4026 mm in 1998, whereas that for 1997 was extremely high rate as estimated at 6276 mm. Generally, the water withdrawal for rice fields is exceedingly high. This is due to the above-mentioned causes.

3.2.2 Consumed and drained amounts of water

The consumed amount shown in **Table 2** includes canal losses as well as evapotranspiration (ET) from rice fields and groundwater outflow to adjacent upland fields. Since the total canal losses in the block were estimated at 27.7% as mentioned below, more detailed components can be given as **Table 3** by separating canal losses from consumed amount shown in **Table 2**. In this calculation, canal losses were assumed not to flow into the main drain in the block. Field consumption, i.e. ④ in **Table 3**, is the sum of ET and groundwater outflow in rice fields. Thus the daily field consumption is estimated at about 9.3 (9.1-9.5) mm d^{-1}. Though ET in rice fields was not observed throughout the season, estimating ET at approximately 7 mm d^{-1}, groundwater outflow is obtained at around 2.5 mm d^{-1}.

The amount of drained water from the block was completely different from each year. The difference in the amount of intake water to rice lots between two years is almost equivalent to that in drained amount. Namely, the remainder subtracted the amount of practically used in a rice lot (9.3 mm d^{-1}) from the amount of water supplied through a inlet of each lot is composed of surface drainage and subsurface drainage. Based on the on-site situation, it can be understood that surface drainage occupies overwhelmingly large portion of total drained amount.

Table 3 Components of water consumption for rice in Yeltai Block (mm)

Year	Period of water balance	Withdrawal at canal head ①	Canal losses ②=①x0.277	Field intake ③=①-②	Field consumption ④ (mm d^{-1})	Drained ⑤ (mm d^{-1})
1997	128 days	6136	1700	4436 (34.7)	1216 (9.5)	3220 (25.2)
1998	123 days	3990	1105	2885 (23.5)	1117 (9.1)	1768 (14.4)

4. Salt balance in Yeltai Block

4.1 Material and method

The salt balance in a irrigated area for a certain period is expressed by the following equation:-

$$\begin{aligned} \Delta Sa &= WrSr + WiSi + Wg_1Sg_1 - WdSd - Wg_2Sg_2 - P_s \\ &= WrSr + WiSi - WdSd - WpSp - P_s \qquad \text{--- (3)} \end{aligned}$$

Where,

Δ Sa= changes in salt amount in the area,

W = amount of water (in terms of depth of water spread uniformly over the soil surface),
S = salt concentration,
$\mathbf{P_s}$ = amount of salt removed in harvested plant,
WpSp = amount of salt outflow from the area by percolated water originated from irrigation water ($\mathbf{WpSp = Wg_2Sg_2 - Wg_1Sg_1}$),

Suffixes are:
r = rain water,
i = irrigation water,
d = drainage water,
$\mathbf{g_1}$ = groundwater inflow,
$\mathbf{g_2}$ = groundwater outflow,
p = percolated water.

By regarding **Wr and** $\mathbf{P_s}$ as zero, Δ **Sa** can be simplified as follows:

$$\Delta \mathbf{Sa} \fallingdotseq \mathbf{WiSi - WdSd - WpSp} \qquad \text{--- } \mathbf{(4)}$$

Thus, by grasping **Wi**, **Si**, **Wd and Sd**, the sum of Δ **Sa** and **WpSp** (Δ **Sa+WpSp)** can be calculated. (Δ **Sa+WpSp)** is regarded as the changes of salt amount in the area together with those in the adjacent area including groundwater caused by irrigation and drainage practice in the area. Using the relationship between TDS and EC for surface water, i.e. Eqs. (1a) or (1b), **Si** and **Sd** can be estimated from the observed EC value.

4.2 Salt balance

The amounts of salt inflow and outflow can be calculated by multiplying the estimated TDS and the observed flow discharge together. **Table 2** shows results of salt balance in total volume for two years. For 90 days in 1997 from May 19 to August 16, total salt inflow to the block amounted to 24719 tons (34.5 t ha^{-1} or 384 kg ha^{-1} d^{-1}), whereas total salt outflow was 21460 tons (30.0 t ha^{-1} or 333 kg ha^{-1} d^{-1}). Thus, the balance amounting to 3259 tons (4.6 t ha^{-1} or 51 kg ha^{-1} d^{-1}) remained in the block in 1997. On the other hand, for the whole crop season in 1998, salt inflow by irrigation water amounted to 24923 tons (34.8 t ha^{-1} or 283 kg ha^{-1} d^{-1}), salt outflow by drainage was 24514 tons (34.2 t ha^{-1} or 278 kg ha^{-1} d^{-1}) and the remained salt was 409 tons (0.6 t ha^{-1} or 5 kg ha^{-1} d^{-1}). These can be regarded as the amount of annual accumulation of salt. The places where salt accumulation occur are not rice fields, but adjacent areas out of the block and upland fields such as alfalfa and fallow fields where seeped water is supplied from rice fields. Especially, salt accumulates in soil layers where water is supplied by capillary rise from the groundwater.

As shown in **Table 2**, the salt balance situation was drastically changed in 1998 as compared with that in 1997. This was seemed to be due to the significant increase of rice fields converted from upland fields in 1998. The change of salt accumulation rate was dependent upon the scale of annual change from forage crop (or fallow) to rice under the eight year cropping system. Namely, the larger the rate of area converted from upland fields into rice fields to the area of total rice fields becomes, the more salts can be drained from the block.

5. Impact of cropping system on water and salt behavior in an irrigation block

Soil water salinity in a rice field displayed a very interesting variation throughout the irrigated period as shown in **Fig. 2**. At the beginning of irrigation period, the soil water salinity at 61 cm in depth showed high EC value (around 18 dS m^{-1}) and then it sharply decreased to the same level as that of ponded water (about 2.5 dS m^{-1}). However, it increased gradually and leveled off after reached the certain salinity (15-16 dS m^{-1}). Though accumulated salts in the shallow soil layer are leached under unsaturated flow condition at the initial stage of irrigation, salts from the deeper layer diffuse upward in percolated water and thus increase soil water salinity in the shallow layer after subsoil is saturated. Namely an upward diffusive transport of salts surpasses a downward percolation flow. This result denies the hypothesis that rice cultivation practice in arid area is effective for leaching accumulated salts.

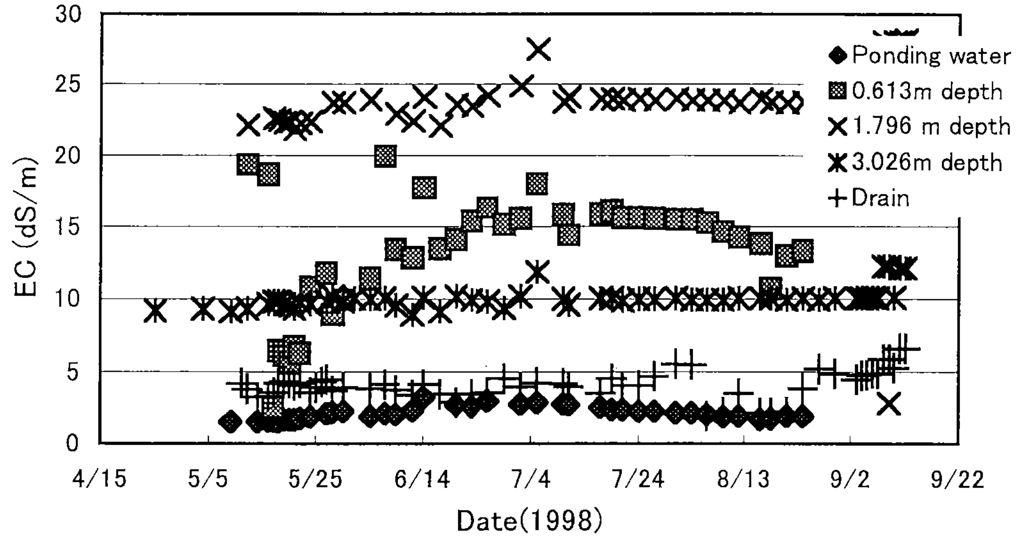

Fig. 2 Change in EC of groundwater in rice field

Though field-drains are constructed to mitigate hydraulic continuity between rice fields and upland fields, subsurface drainage function of them was not demonstrated and groundwater level in upland fields showed sensitive reaction to the ponded water level in rice fields (**Fig. 3**). This implies that seeped water from rice fields flows underneath the drain bed, raises groundwater table and leads salt accumulation in the upland fields. The loss of subsurface drainage function in drain seems to be due to mechanical compaction of drain dikes used as farm roads by heavy machinery. This situation also eliminates the leaching effect of rice cultivation.

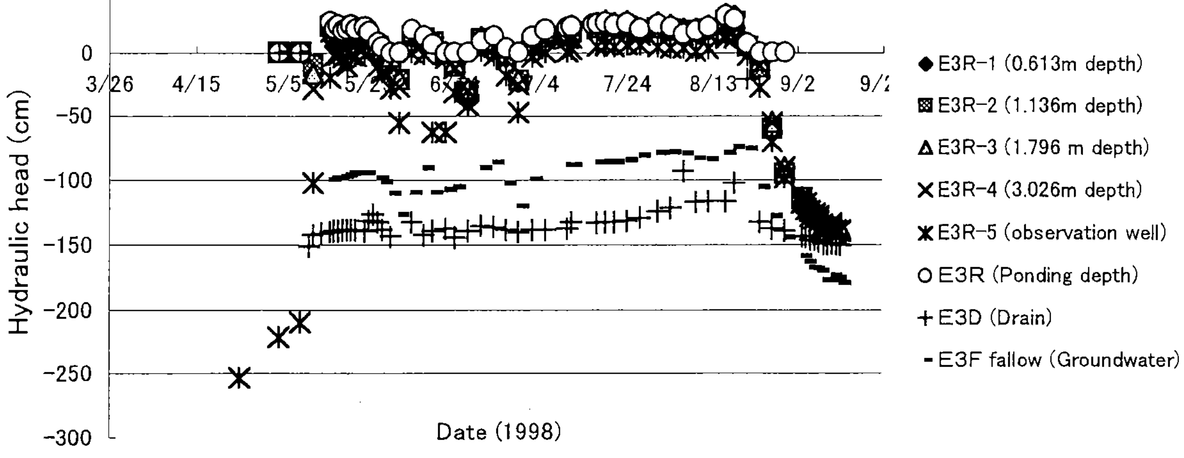

Fig. 3 Change of hydraulic pressure in E3R and E3F plo

6. Land leveling and its impact on water management

It was revealed that the performance of land-leveling was extremely low in rice plots. In the 2.4 ha plot, undulation varies from –15.4 to 14.9 cm with standard deviation of 6.5 cm. Since ponded depth is managed based on the highest portion of a lot, this brings about deep water condition which leads wastage of irrigation water and salt accumulation.

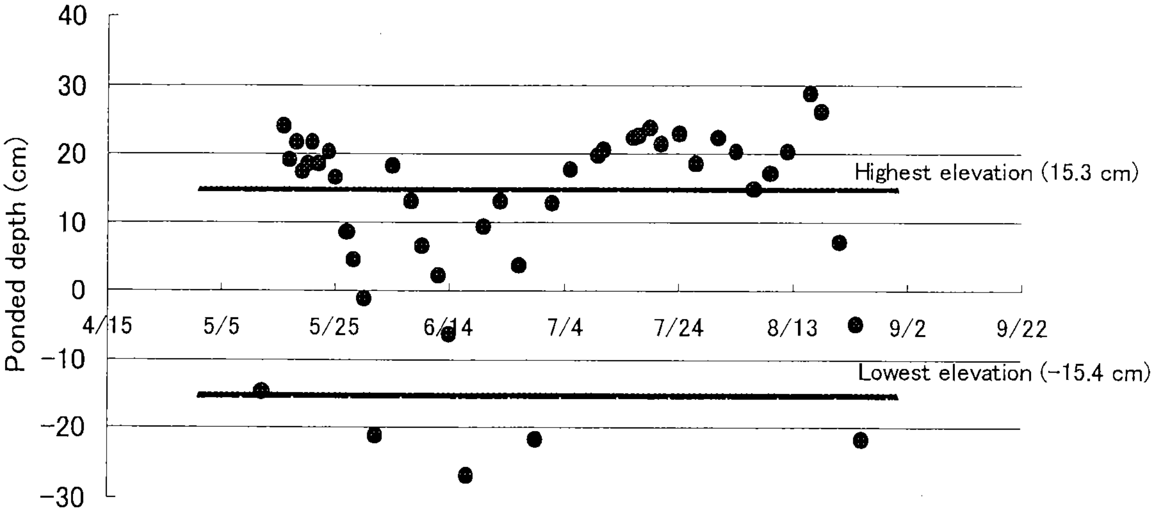

Fig. 4 Change of ponded depth in a paddy field (Yeltai Block, 1998)

7. Quantitative assessment of canal losses

Based on the field measurement, the conveyance losses in a distribution canal were estimated at around 5.8 % km^{-1}, and total losses of distribution system in the block were equivalent to 28 % of distributed amount. Conveyance losses also cause waterlogging and salt accumulation in the adjacent area.

8. Some proposals related to water management to prevent secondary salinization

In order to overcome the above problems the following remedial measures are recommended:

a. to avoid mixed cropping with rice and upland crops and to unify either upland crops or rice in an irrigation block to control groundwater table,

b. to decrease conveyance and field application losses through improved canal construction and management performance, introduction of canal-lining and improved land-leveling performance,

c. to maintain and operate drainage canals to function, especially installation of drain pipes across dikes for connecting fields and field-drains might enhance subsurface drainage function,

d. to introduce bio-drainage along canals and around farm lots for preventing waterlogging and salinization,

e. to develop design and management technique of evaporation pond for better effluent management at the outfall of each irrigation block, and

f. to conclude international water and/or drainage rights agreements among riparian countries and to enact a basin-basis management regulation to control water withdrawal and drainage.

9. Conclusions

Based on a series of on-site water and salt balance experiments, it was proved that the ordinary eight-year rotation system and the over-irrigation to the rice fields together with an inappropriate drainage management have accelerated the salt accumulation and concurrently increased abandoned farmlands in the Lower Syr Darya River region. A remarkable finding was obtained on the salt behavior in rice fields, and this denies the hypothesis that rice cultivation practice in arid area is effective for leaching accumulated salts. To overcome problems on secondary salinization, some remedial measures are recommended.

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