The Study on Estimation Model of Return Flow After Irrigation in Paddy Field — Taoyuan Area

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ABSTRACT

Return flow in paddy field is one of important irrigation water resource and has a feature of reusable. Researches of return flow were often used to investigate in fields or experiments formerly owing to many factors exist with influenced interrelationship. This study is combined with a series research as following: observation in fields to investigate return flow after irrigation, calculate and analyze are based on water budget balance theorem, moreover, uses a slope-adjustable sandbox to simulate return flow under different irrigation water and slopes, and then probe into variation of return water with curves which is analyzed by regression methods to establish estimation models of return flow for sandy clay loam, sandy loam, and sand on different slopes. Finally, expecting to build up a general estimation model is which can be used on any soils, slopes, and irrigation water. As a result, we revise return flow on different soils and slopes in order to further estimate regional return flow from investigate in fields and sandbox experiments that had finished.

Key Words: Irrigation Water、Return Flow、Sandbox Experiment、Paddy Field、Water Budget Balance

1. INTRODUCTION

In previous period, water resource was used for providing agricultural irrigation and increasing grain yield in Taiwan, and agricultural water in all is over 70%. Recently, industrial and domestic water is increasing greatly due to society is changing, industry and commerce are developing, population is increasing, and living standard is becoming better etc. changes of water resource use is influenced on agricultural water greatly. Recently, the problem of insufficient irrigating water always exists in drought season or in dry areas. However, it is difficult to develop new water resources, such as building of reservoirs or groundwater. Therefore, alternate water source is a way to solve the problem. Return flow is a reliable and economical alternate water source.

In general, the traditional irrigation for paddy field in Taiwan is from upstream land through ridges to downstream land repeatedly and surplus water finally into the ocean. From above way, it has a meaning of using water resources. In Taiwan, it has higher possibility for using return flow due to steeper slopes. Therefore, if irrigation water after irrigating on upstream can be quantitative and control properly, the rate of available water use can be enhanced.

Moreover, in drought seasons, agricultural water are usually demanded for fallows and transfers irrigation water to other usage, the estimation for damages of irrigation crop is show as transfers irrigation water / unit area. Above estimation method is unreasonable due to the repeated characteristics of return flow is ignored. It should be corrected because of return flow has 2~4 times of reusable, i.e. the estimation of damaged area should include farms which irrigation from return flow. Therefore. As a result, accurate estimation of return flow would be an important rule for estimating agricultural reparation cost.

2. LITERATURE REVIEW

2.1 Summary of Return Water

"Return Flow" is defined as follows(1): part of irrigation water on upstream, appears in canals of downstream and can be reused, includes runoff flow into canals on downstream and leaks into underground and emerges in canals on downstream. Moreover, another definition by Lou(2) is that return flow is composed of rainfall, irrigation water, groundwater drainage and return to rivers or canals. In this study, return flow is defined as follows: water occurred on downstream after irrigation in the period of rice crop, includes drainage, runoff flow into canals and leakage emerges on downstream (excludes rainwater during irrigation).

At present, irrigation water source includes rivers, reservoirs, groundwater, storage ponds, and return flow, and front three items are the main sources for agricultural water in Taiwan. Pools and return flow exist only in certain area which with especial topography. Devices of return flow are used with barrages, storage ponds and wells in Taiwan(3).

Return flow can be classified to visible return flow and invisible return flow by producing. Visible return flow is defined as surface runoff flow through ridges and ridge gaps into canals; on the other hand, invisible return flow is defined as leakage due to ridge gaps or damaged lining canals.

2.2 Related Research Review

The beginning of use and research about return flow is from of La Poundre in the north of Colorado in U.S.A in 1885. Review previous researches of return flow, which is classified as following by theories and methods: experiments in fields[(5), (6), (7)], tank models[(5), (8)], numerical simulation [(9), (10)], data collection method [(2), (3), (11), (12), (13)], and water budget balance theorem[(6), (14)], above all, the summary of each experiment as below:

The experiment in fields: COA[(5)] used water budget balance theorem to investigate return flow in Choshui Ríver irrigation area, and results showed that the return flow of irrigation water is 30.65%. Chien[(6)] used experiment in fields to investigate return flow in Taoyuan main canal irrigation area, and results showed that the return flow of irrigation water is 3.35~89.14%. Kan[(7)] used experiment in fields, water budget balance and tank models to investigate return flow in Kaohsiung Irrigation Association, and results showed as following: 15% of irrigation water flow into drainage canals, 59% of that leaked into aquifer, and 26% were vapor of crop, final ponding depth, and storage of saturated soil.

Tank Model: Liu[(8)] estimated total return flow requirement in Chianan irrigation area based on water budge balance and questionnaire. Results showed that depth percolation of return flow is 70~80%.

Numerical stimulation: Lin[(9)] estimated visible return flow and invisible return flow separately , and estimated based on experiment of constant-head, continuity equation and weir flow formula. Results showed that the total return flow of irrigation is 24% in Yunlin irrigation area. Wu[(10)] classified return flow to be return flow of ridge and return flow of field, and discussed return flow based on the ratio of length and width, width of ridge and effective depth. Results showed that the amount of the irrigation return flow from a rice paddy field is about 28.01% or 26.64% of effective rainfall and irrigation water.

Data collection method: Lou[(2)] estimated return flow based on an axiom, that is return flow equal to consumptive use of irrigation area from irrigation water. Results showed that yearly return flow is approximately $5.27\times10^8 m^3$ in 1960, an average amount of return flow is 1.44x $10^6 m^3$, and equal to 8.36% of irrigation water per day in Changhua irrigation area.

Moreover, Hsu[(3)] estimated return flow based on irrigation plan water, practical irrigation water, and irrigation area. As a result, we got the usage ratio of return flow is over 10% of total irrigation water in Toyuan irrigation area, and the average return flow is 15% in Miaoli.

The return flow estimated by Lin[(12)] were combined with irrigation water and rainfall, and got a result, that the amount of return flow is 5,189,700,000 tons, equal to 63% of irrigation water in Taiwan.

AERC[13] estimated return flow based on previous data of water intake, crop area records, irrigation plan and rainfall records in South main canal irrigation system of Shih-Kang Dam. Result showed that return flow is about 20% of total irrigation water.

Water Conservancy Bureau[14] estimated return flow based on water budget balance and experiment in fields. Result showed that the reuse ratio of return flow is approximately 10% or even 40% in certain regions of Hsinzu and Miaoli.

Comparing above all, each research used different definition, methods to estimated return flow and regions applications. Most methods of previous research still based on experiment in fields or data collected, and the result is only suitable for experiment region. Therefore, this study expects to build up a practical model for estimating return flow and based on the result of observation in fields, influence factors analyze, and sandbox experiments.

3. RESEARCH METHOD AND THEORY ANALYSIS

3.1 Influence Factors of Return Flow

It is necessary and important for realizing producing reasons and factors of return flow before study return flow. The producing reasons are classified as following:

i. Rainfall: Rainfall occurs in irrigation area has two cases. First, if rainfall is less than storage in paddy field, part of rainfall become vapor or absorbed by crop, and others may leaks into canals and gushes on downstream. Second, if rainfall is over than storage of paddy field, besides storage, others through ridges or gaps flow into canals.

ii. Irrigation water source: it includes surplus irrigation water due to over irrigation, ditch seepage, and recession water after stopping irrigation.

(i). unsuitable irrigation system- includes over irrigation water, lower irrigation technology, low available ratio of irrigation, and ill field management, etc.

(ii). paddy field leakage- owing to ponding in fields for a long period, causes saturated soil and leakage which includes horizontal seepage and deep percolation gushed on canals of downstream.

(iii). leakage of field and canals- leakage from ridge gaps in field, and damaged gaps in lining canals.

All above are the main reasons of that causes return flow after irrigation, some are avoidable and others are unavoidable, such as paddy field seepage, weeding, applies fertilizer, water exchange and drains before reaping. Furthermore, the factors influence the amount of return flow as follows: topography, slopes, soil texture, groundwater table, groundwater flow, and the weather, etc.

3.2 Research Method

Water budget balance theorem is a basic foundation of this study. In order to investigate return flow under conditions of different irrigation, the method that we uses is accurately observation and then chooses a experiment field in Taoyuan. Each items of observation such as input flow, output flow, ponding depth and crops area, which are experiment in details to get better results. Above experiment results are established in certain particular conditions, such as irrigation area, slopes, soil texture, and etc. Therefore, a sandbox model which slope is adjustable designed for establishing a suitable model. Sandbox experiments are proceeding as different soils and slopes to expect establishing estimation of return flow for application in Taoyuan.

3.3 Summary of Water Budget Balance Theorem

The model theorem of study is based on Water Budget Balance, and calculates return flow by the theory, which total amount of input is equal to total amount of output, and the basic equation is showed as equation(1): $P+I+G_I=ET+O+G_o+\Delta S$ (1)

Above parameters are explained as following: P is rainfall; I is input flow of surface runoff; G_I is input flow of groundwater; ET is evapotranspiration; O is output flow of surface runoff, Go is output flow of groundwater, ΔS is storage in fields. The research object of this study is rice paddy, and boundaries of water budget balance system are showed as Fig. 1. Fig. 1. shows that rainfall, irrigation, or gush of groundwater all increase the amount of input flow into rice paddy, on the other hand, drainage, seepage, and evapotranspiration increase the amount of output flow from rice paddy. The mathematic equation of water budget balance in rice paddy also be expressed as equation (1), only that the definition of certain parameters have been revised as following: I is irrigation water; O is return water; ΔS is combined with depth variation of the surface, variation of soil moisture and percolation in paddy field; ET is crops requirement or ET_{crop}.

Owing to percolation in paddy field is the main source of invisible return flow, so it is rational to calculate percolation in paddy field and storage variation in fields separately, i.e. equation (1) can be revised to equation (2). Moreover, paddy field is usually keep ponding in the period of double rice crops, and the growth period of rice crop is approximately 120~150 days in Taiwan. From a long-term view, variation of soil moisture is approach to zero under the condition of saturation status, then equation (2) can be revised to equation (3).

$$P+I+G_I=ET_{crop}+O+G_o \pm \Delta S_1+\Delta S_2 \pm \Delta S_3 \qquad (2)$$

$$P+I+G_I=ET_{crop}+O+G_o \pm \Delta S_1+\Delta S_2 \qquad (3)$$

Above parameters are explained as following: ΔS_1 is variation of ponding depth; ΔS_2 is percolation in paddy field (including vertical and horizontal); ΔS_3 is variation of soil moisture.

Moreover, variation of groundwater table and flow is assumed be balance status during irrigation due to paddy field is keep ponding in a long period. it means G_I is approach to G_o, and equation (3) can be shows as: $P + I = ET_{crop} + O \pm \Delta S_1 + \Delta S_2$ .... (4)

Return flow that this study estimates is includes surface runoff or leakage and all gush on canals of downstream after irrigation. Owing to it's difficult to separate runoff and rainfall, to ensure return flow that we calculate is formed with irrigation water without rainfall, it also means return flow is produced during sunny days, then equation (4) can be revised to equation (5): $I = ET_{crop} + O \pm \Delta S_1 + \Delta S_2$ .... (5)

$O = I - ET_{crop} \pm \Delta S_1 - \Delta S_2$ .... (6)

Equation (6) is transposing the parameters of I and O from equation (5), and be used to estimate return flow which derived from water budget balance theorem. The parameter data such as I, O and ΔS_1 in equation (6) are getting from observation in fields, ΔS_2 is getting from experiment in fields and ET_{crop} can be estimated by experienced formula.

According to a method [15] that FAO recommend and ICID announced, ET_{crop} can be estimated indirectly and classified three steps as following:

Step 1: to estimate the value of ET_0.

Step 2: to decide coefficient of crops Kc from crop growing types, planting time, crops growth period and growth cycle, and ET_{crop} can be calculated from equation (7).

$ET_{crop} = K_c \times ET_0$ .... (7)

Step3: to modulate ET_{crop} with influence factors, that is including region characteristics and irrigation methods.

Four common methods for calculating ET_0 that FAO recommend as following: Blaney – Criddle Method, Radiation Method, Penman Method and Pan Evaporation Method. According to previous researches about above methods in Taiwan, the result shows that Radiation Method and Penman Method are more suitable for Taiwan, but Penman Method is too complicated while applying. Therefore, Radiation Method is used to estimate Et_{crop} in this study.

Radiation Method is a revised experience formula, which announced by Makkink in 1957. The method supposed that temperature, solar irradiation, and sun radiation were main influence factors of ET_{crop}, and the formula as wrote as following:

$ET_0 = C(W \times R_s)$; $R_s = R_a(0.25 + 0.50n/N)$ .... (8)

In equation (8), ET_0 is consult evapotranspiration (mm/day); Rs evaporation requivalent of solar irradiation (mm/day); Ra is is a maximum value of. possible solar radiation; W is weight factors; C is correcting factors; and n/N is the ratio of practical solar period and maximum.

To probe into factors of influence return flow, are based on the view of irrigation management and water budget balance theorem. Such as Irrigation Association had finished different depths of irrigation for distinct soils[16], that is called depth of irrigation plan (d). For example, the depth of irrigation plan (d) in Taoyuan Irrigation Association is 6 and 6.4 mm/day respectively in the period of first and second rice crop, and different slopes and irrigation area also

influence on variation of return flow. The relation between return flow and influence factors are expressed with function, the equation (6) can be simplified as: $O=F_1(I, d, S, A)$........(9)
In above equation, S is slope of irrigation area; A is irrigation area.

In order to express the concept of return flow, the return flow percent of irrigation are being substituted for absolute amount of return flow in this study. Equation (9) can be revised as: $R_r = \frac{O}{I} \times 100\% = F_2(\frac{I}{d})$ .... (10)

In above equation, R_r is return flow percent of irrigation water, and d is depth of irrigation plan.

The multiple of irrigation plan water and irrigation water is used be a variable, which return flow percent of irrigation water in this study. For experiment results that under conditions of different irrigation, are used to establish a estimation model by regression analysis, the mathematic equation of return flow can be supposed as: $Y=AX^3+BX^2+CX+D$ .... (11)
In above equation, Y is return flow percent of irrigation water, X is a multiple between irrigation water and irrigation plan water; and A, B, C, D are coefficient which are decided by experiments.

The study uses sandbox model experiments to simulate return flow and establish a estimation model by regression analysis from equation(11), which sandbox model experiments are based on three kinds soils including sandy clay loam, sandy loam, and sand under conditions of different slopes (1/100, 1/150, and 1/200).

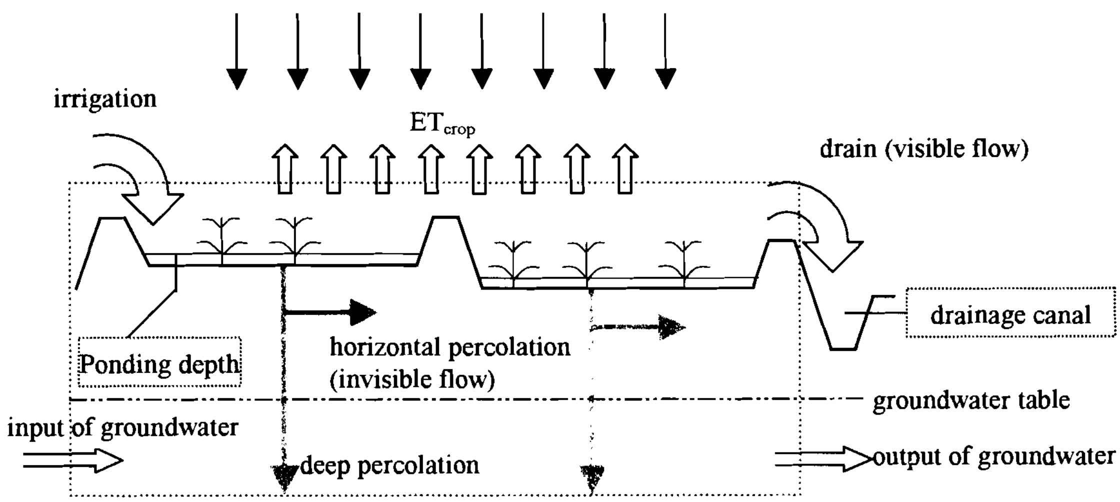

Fig 1. diagram of water budget balance

4. OBSERVATION AND INVESTIGATION IN FIELDS

4.1 Summary of Experiment Area

The study uses Taoyuan main canal irrigation area to be experiment and application area. This area is located in Taoyuan tableland as Fig 2. the most height of altitude is 100 m, and the terrain is higher in south and lower in north as a stairs status . The slopes of tableland between 1/100~1/200 tilts emitting from south to west into Taiwan Strait. The area in Taoyuan main canal irrigation area is about 23.860 ha, and soil texture are combined with clay, sand, sandy clay loam, and sandy loam. Besides, there are 286 ponds in Taoyuan main canal irrigation area.

The method of irrigation in Taoyuan main canal irrigation area is that, outflow from a reservoir and storage on ponds, then inflow canals to irrigation by gravity. The experiment area that this study chooses is located storage pond 4-5 irrigation area of Taoyuan main canal, which is shows as Fig 3, and rice is mainly crop, others are upland crops. The experiment area that crops and buildings area in the period of 1998~2000 is shows as Table 1.

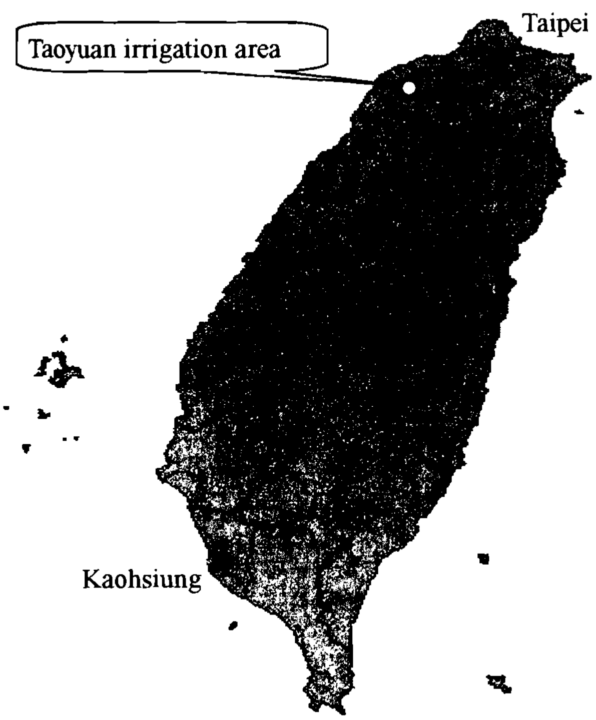

Fig 2. opposite position of Taoyuan area

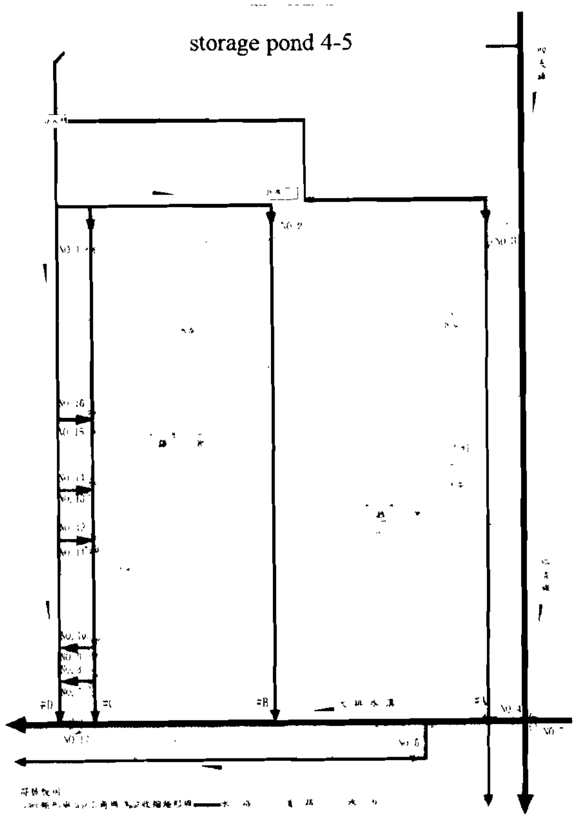

Fig 3. storage pond No.4-5 irrigation area of Taoyuan main canal

Table 1. List of area experiment fields

Area (ha)	the period of second rice crop in 1998	the period of first rice crop in 1999	the period of second rice crop in 1999	the period of first rice crop in 2000	the period of second rice crop in 2000
Paddy field	14.32	12.65	18.97	17.16	18.97
upland	—	1.67	—	1.81	—
building	1.31	1.31	1.65	1.65	1.65
total area	15.63	15.63	20.62	20.62	20.62

4.2 Design of Experiment in Fields

4.2.1 Canals distribution system

the method that we uses is accurately observation in fields to investigate return flow and irrigation water, and then chooses a experiment field in storage pond No.4-5 irrigation area of Taoyuan canal.

4.2.2 Selection of discharge observation station

In order to observe all inflow and outflow in experiment fields, this study setting discharge observation stations as following: inflow point in upstream, outflow point in downstream, and all point which to flow together or outflow to accurate observation irrigation water and return flow after irrigation in irrigation area.

4.2.3 Setting water measuring equipment and observation

It needed to set water equipment after decided the location of discharge observation station. This study chooses measuring weirs to observe discharge is base on considers of accuracy and convenient setting. As a result of different size, cross-section shapes in each canal, standard 90-degree-V-north triangular weir, standard contract rectangular weir, and standard suppressed rectangular weir shows as Fig 4, which are used to observe return flow and irrigation water. After setting water measuring equipment, above weirs are used to observe during the period of 1998 ~ 2000, and counts 5 periods crops.

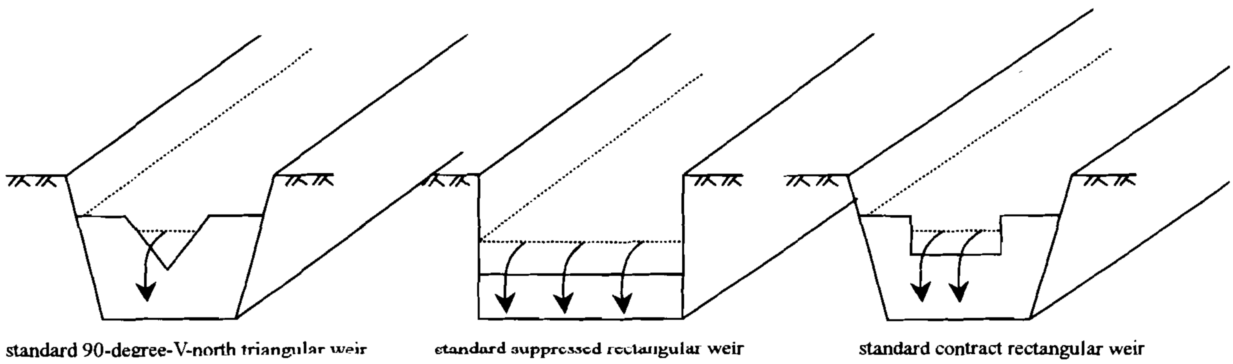

Fig 4. diagram of measuring weirs

4.2.4 Observation frequency and discharge calculation

The data of overflow depth has to observe everyday and calculates discharge with experiment formulas as equation (12)~(13), that application for different weirs.

(i).Zhao-zhi formula: $Q = Kh^{5/2}$(standard 90-degree-V-north triangular weir) .... (12)

(ii).Shi-yuan formula: $Q = CBh^{3/2}$(standard suppressed rectangular weir) .... (13)

(iii).Ban-shou formula: $Q=Cbh^{3/2}$(standard contract rectangular weir) .... (14)

In above formulas, K and C are flow coefficient; h is overflow depth; B is width of weir; b is width of weir crest gap.

In this study, the decision of observation frequency for observing discharge and ponding depth is based on irrigation water isn't supply steady from storage pond 4-5, if the data that observation one time per day which be average value on the day, the result may be prejudiced. For above, there are three times of observation per day in this study.

Moreover, in above, this study uses three data of observation results in Nth day and one data of observation result in the next morning (N+1th day) to be an average value in Nth day, and shows as Fig 5.

	the (N − 1)th day	the Nth day	the (N + 1)th day
8:00	12:00 16:00	8:00 12:00 16:00	8:00 12:00 16:00
observation –value of irrigation		← 24hrs →	
observation –value of return flow		← 24hrs →	
ET_{crop}		← 24hrs →	
leakage		← 24hrs →	
ponding depth		← 24hrs →	
calculation –value of return flow		← 24hrs →	

Fig 5. observation frequency of parameters of water budget balance

5. SANDBOX EXPERIMENT OF RETURN FLOW PARAMETERS

This study designs a sandbox model and experiments under conditions of three kinds soils and slopes. It's expecting getting nine different curves of return flow, and based on above curves of return flow to establish estimation Model.

5.1 Analysis Items of Indoor Experiments

5.1.1Classified Experiment of Soil Texture

In order to realize basic physical texture of above three soils, and experiments are proceeded in this study such as sieve analysis and hydrometer analysis with soils which are for sandbox experiments. Besides, the classified standard of soil texture which this studies use is based on soil texture triangle made by USDA to distinguish soil texture.

5.1.2 Hydraulic Conductivity Experiment

In order to realize the hydraulic conductivity of soils, Seepage meter is used for experiment in this study and drawing as Fig 7. In seepage meter experiment, some initial conditions and operations are designed as following: the height of soil pillar is 50 cm, water head is keep constant with 10 cm, and observes one time per day. Finally, hydraulic conductivity K is calculated with equation (15).

$$K = \frac{Q}{A \cdot \Delta h / \Delta L} \quad \cdots\cdots (15)$$

In above equation, K is hydraulic conductivity (mm/day); Q is discharge flow (ml/sec); A is section area of soil pillar (cm); Δh is difference of water head; and ΔL is the thickness of soil pillar (cm).

5.2 Establish and Design of Sandbox Model

The sandbox model is established in this study, material which size is with length of 4m, width of 0.8m, and depth of 1.5m as Fig 8. The sandbox is welded by iron plate with the corner iron of thickness is 3 and 4 mm. The sandbox model is combined with a water meter, a check valve, a water tower, water intake in the upstream, horizontal collecting pans in the downstream and vertical outlet pipe, which all drawing as Fig 8.

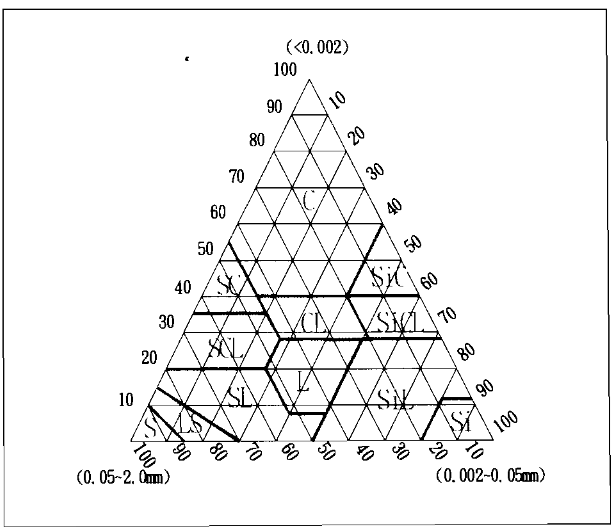

Fig 6. soil texture triangle

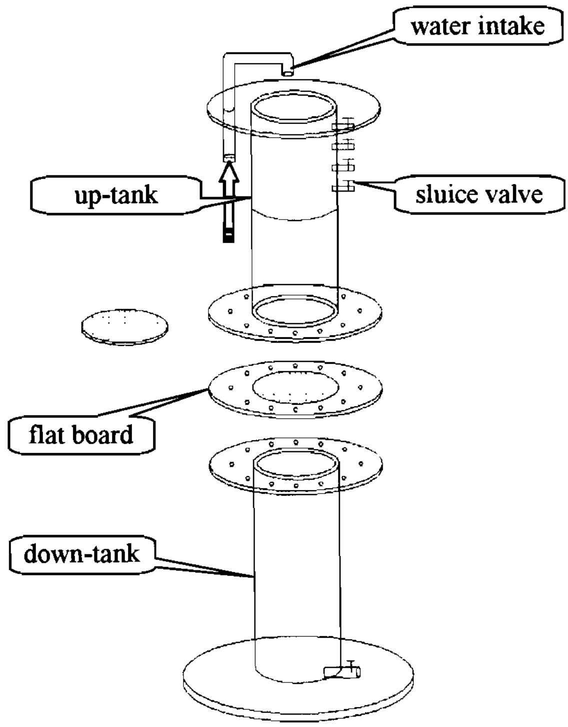

Fig 7. diagram of seepage meter

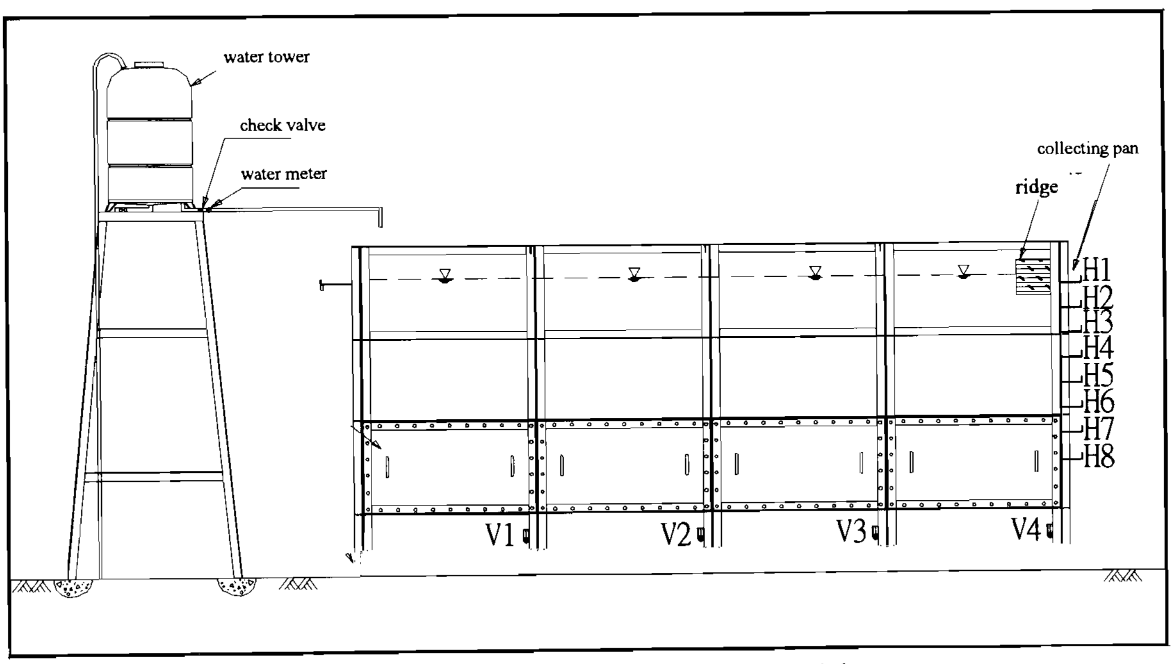

Fig 8. diagram of sand box model

5.3 Experiment Items of Sandbox experiment

5.3.1 Experiment of hydraulic conductivity

This study uses sandbox experiments which under the condition of constant-head to estimate soil hydraulic conductivity. Owing to verify with experiment of seepage meter, the water head is also keep in 10 cm, and calculates hydraulic conductivity by equation (15).

5.3.2 Experiment of Return Flow

After finishing prearrangement of sandbox model experiment, it's proceeding as following: first, the depth of irrigation plan that is the first period of crop (6 mm/day) in Taoyuan irrigation water for the basic multiple. Furthermore, experiments based on different three slopes (1/100, 1/150, 1/200) in Taoyuan irrigation area, and irrigation depth is used be 6, 3, and 1 multiple of 6 mm/day to observe return flow.

6. RESULT OF SANDBOX EXPERIMENT AND INVESTIGATION IN FIELDS

6.1. Soil Texture and hydraulic conductivity

The sieve analysis and hydrometer analysis is used for realize basic physical texture of soils that we use in this steady, and results show that three experiments soil are sand, sandy clay loam, and sand loam.

Regarding hydraulic conductivity of soils, at first in 1998, we observed the hydraulic conductivity by one-ring lysimeter in storage pond 4-5 irrigation area of Taoyuan main canal. Besides, The constant-head experiments of sandbox model and seepage are also used. Above all, all results show as Table 2. As a result, hydraulic conductivity from experiment of seepage meter is bigger than that by sandbox model. The hydraulic conductivity for sandy clay loam got from constant-head experiment by using sandbox models is only 0.266 mm/day, which is much smaller than experiment in fields and constant-head experiment by using seepage meter, but another result shows that 4.69 mm/day is close to 4.71 mm/day, which by seepage meter experiment and observation in fields respectively.

Table 2. hydraulic conductivity results of experiment soils

soil texture	hydraulic conductivity K_1 (mm/day)	hydraulic conductivity K_2 (mm/day)	hydraulic conductivity K_3 (mm/day)
Sand (S)	10.70	17.40	–
Sandclay loam (SCL)	0.266	4.69	4.71
sand loam(SL)	6.40	9.00	–

PS: K_1 constant-head experiment of sandbox; K_2 is constant-head experiment of seepage meter; K_3 is experiment in fields.

6.2 Result of Return Flow in Fields

Th investigate of return flow in this study is excluding rainfall. The items of investigation, which including irrigation water, return flow and ponding depth were observed only during the period of sunny. It means that experiments in fields are observed concentrated in sunny day or observed in 5~7 days after rain.

This study used the method of experiment in fields to realize the behavior of return flow under different irrigation water, and observed in the second period of crop in 1998 and the first period of crop in 1999. Result show that, the range of return flow is 7.44~22.46 mm/day from irrigation water requirement is 12.2~34.75 mm/day, and the return flow ratio is 34.52~77.27% of irrigation water. Three types of expressions were used in this study to express the relations between return flow and irrigation water: i. (irrigation water) and (return flow), ii. (irrigation water) and (the return flow ratio of irrigation water), iii.(irrigation water / depth of irrigation plan)and (the return flow ratio of irrigation water). The method of regression analysis us used for comparing above three types of expressions, and results show that correlation coefficient is 0.6286, 0.1407 and 0.7287 respectively. It means the type of (irrigation water / depth of irrigation plan) and (the return flow ratio of irrigation water) is more proper to express the relation of return flow and irrigation water.

The experiment in fields of return flow is observed from the secondary period of crop in 1998 until the secondary period of crop in 2000. According to the result, if irrigation water is between 11~30 mm/day in the first period of crop in 2000, it can cause 4~22 mm/day of return flow; moreover, during two periods of crop in 1999~2000, if irrigation water is between 3~32 mm/day, it can cause 0.4~25 mm/day of return flow.

To probe into the relative relation of irrigation water and return flow by periods of crop, the results of observation in the first period of crop in 2000 and the secondary period of crop in 1999~2000 are used for drafting ,which the horizontal and vertical axles are (irrigation water / designed irrigation water) and (return flow / irrigation water)×100% respectively. Furthermore, two boundaries conditions are supposed as followings: i. Return flow is zero while irrigation water is zero in theory. ii. The return flow ratio is 95% of irrigation water while irrigation water is 6.5 multiples of irrigation plan water; it also means that the return flow ratio of irrigation water should be 95% while irrigation is approach infinitely great. Above all, curves of return flow by results of investigate drafting as Fig 9 ~11.

According to the results of regression analysis from Fig 9~11, the equation of return flow in the period of first crop can be estimated as equation (16); and the period of second crop can be estimated as equation (17); and periods of all crop are as equation (18).

$Y=0.5652X^3-6.1774X^2+30.8920X-0.0260$; $R^2=0.9956$; $X \geqq 0.0009$......................(16)

$Y=0.8005X^3-7.2932X^2+28.2080X-0.3117$; $R^2=0.9917$; $X \geqq 0.0111$......................(17)

$Y=0.7166X^3-7.1066X^2+30.5380X-0.4089$; $R^2=0.9847$; $X \geqq 0.0135$......................(18)

In above equations, Y: is the return flow ratio of irrigation water, it means that (return flow /

irrigation water) × 100%. X: is the multiple of irrigation water / depth of irrigation water; R^2: is called R-Square value or correlation coefficient.

Above all, equations (16)~(18) can be applied for the region that base on the slope is 1/150, and the soil is sandy clay loam in theory.

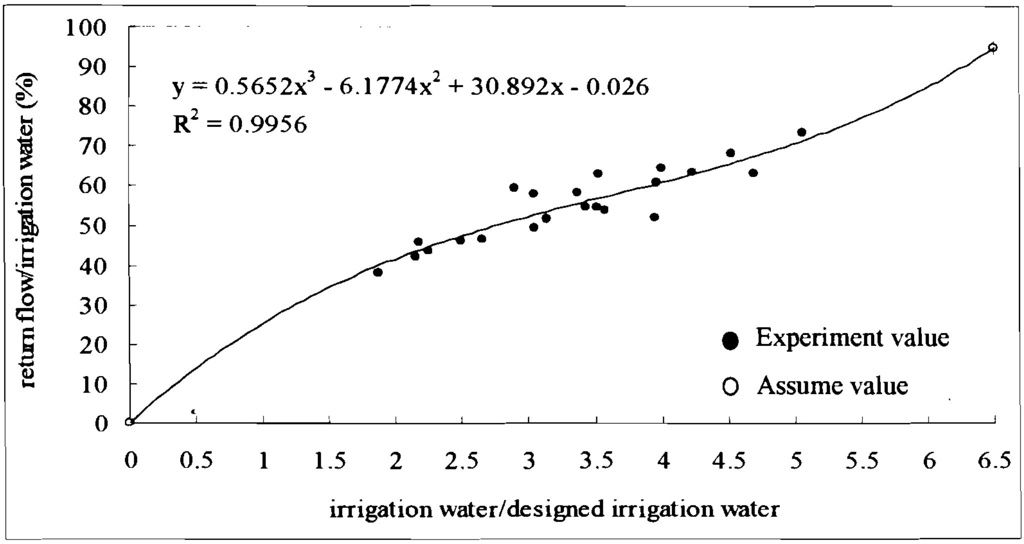

Fig 9. relation between return flow and irrigation in the period of first crop, 2000

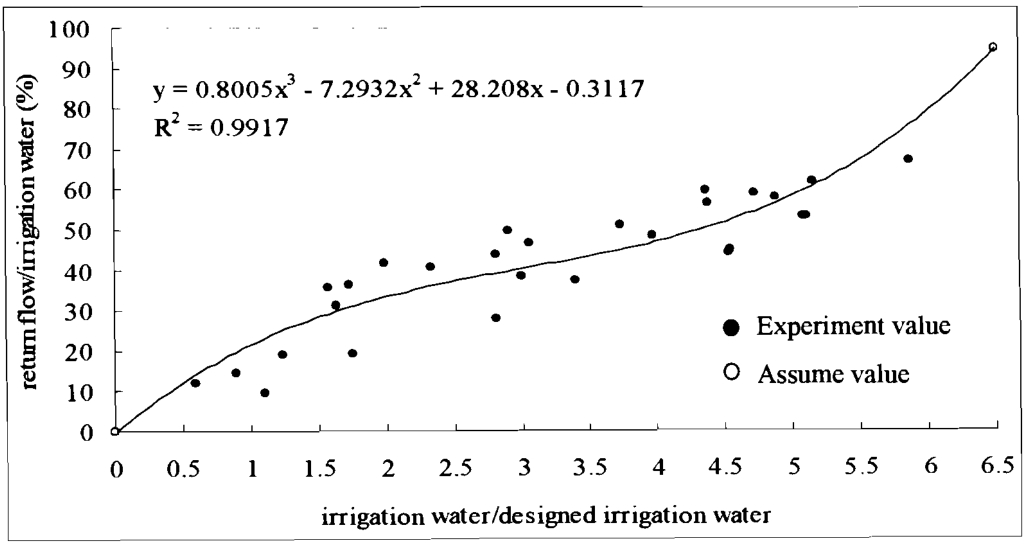

Fig 10. relation between return flow and irrigation in the period of second crop, 1999~2000

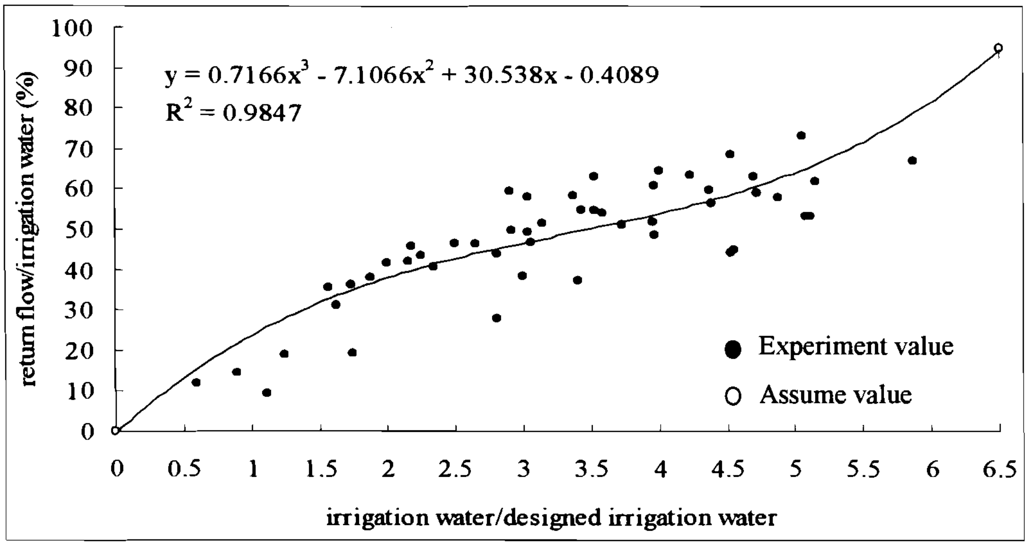

Fig 11. relation between return flow and irrigation in periods of double crop, 1999~2000

6.3 Results of Sandbox Experiment

In 2001~2002, this research focus on sandy clay loam, sand, and sand loam by sandbox models to hold experiment of return flow and probe into the ratio of return flow in different irrigation water. The experiment of sandbox return flow is taking the depth of irrigation plan 6 mm/day in Taoyuan irrigation area for the basic irrigation water, providing multiple depth of irrigation plan (6, 3, 1 multiple) to the sandbox, and estimating return flow of the downstream collecting pan on three different slopes as 1/100, 1/150, and 1/200, and the result is shown as Table 3~5.

The experiment results show that, sandy clay loam on the slope of 1/100, while irrigation water is 1~6 multiples of the depth of irrigation plan, return flow is 23.40~87.85% of irrigation water; when the slope is 1/150, the ratio of return flow is between 18.22~78.55%; and when the slope is 1/200, the ratio of return flow is between 13.12~52.45%. If sandy loam on the slope of 1/100, while the irrigation water is 1~6 multiples the depth of irrigation plan, return flow is between 23.8~61.78% of irrigation water; slope of 1/150 can get return flow is 18.23~54.26% of irrigation water; and slope of 1/200 can get the ratio between 13.13~43.93% of return flow. For sand on the slope of 1/100, 1~6 multiples irrigation water can cause the ratio of return flow between 14.09~24.20%; the slope of 1/150 can cause the ratio of return flow between 12.52~24.80%; and the slope 1/200 can get the ratio of return flow is between 12.38~21.26%.

The function is similar that used by sandbox experiment and field experiment, which means that Y is for the return flow ratio of irrigation water; X is for the multiple of irrigation plan, and the function of return flow can be expressed as: $Y=AX^3+BX^2+CX+D$(A, B, C, and D are coefficients). The results of sandbox experiment about return flow for sandy clay loam, sandy clam, and sand can shown in curves of return flow in accord with above functions, and the estimation function is show as Table 6, and the curve of return flow is as Fig 12~14.

Table 3. Sandbox experiment of return flow — sandy clay loam

water / slope	irrigation (L)	return flow (L)	irrigation / designed irrigation water	Percent of return flow (%)
S=1/100	115.2	101.20	6	87.85
	57.6	40.84	3	70.89
	19.2	4.49	1	23.40
S=1/150	115.2	90.49	6	78.55
	57.6	36.82	3	63.93
	19.2	3.50	1	18.22
S=1/200	115.2	60.42	6	52.45
	57.6	26.18	3	45.44
	19.2	2.52	1	13.12

Table 4. Sandbox experiment of return flow — sand loam

slope \ water	irrigation (L)	return flow (L)	irrigation / designed irrigation water	Percent of return flow (%)
S=1/100	115.2	71.17	6	61.78
	57.6	31.86	3	55.31
	19.2	4.57	1	23.80
S=1/150	115.2	62.51	6	54.26
	57.6	27.56	3	47.85
	19.2	3.50	1	18.22
S=1/200	115.2	50.61	6	43.93
	57.6	21.45	3	37.24
	19.2	2.52	1	13.12

Table 5. Sandbox experiment of return flow — sand

slope \ water	irrigation (L)	return flow (L)	irrigation / designed irrigation water	Percent of return flow (%)
S=1/100	115.2	27.88	6	24.20
	57.6	12.33	3	21.41
	19.2	2.71	1	14.11
S=1/150	115.2	28.57	6	24.80
	57.6	11.08	3	19.24
	19.2	2.4	1	12.50
S=1/200	115.2	24.49	6	21.26
	57.6	10.55	3	18.32
	19.2	2.38	1	12.40

Table 6. Functions of return flow from sandbox experiment

Soil texture	slope	Function of return flow	R^2 value	Limit for use
sandy clay loam	1/100	$Y = 0.0971X^3 - 3.1600X^2 + 31.0260X - 0.1870$	0.9988	$X \geqq 0.0061$
	1/150	$Y = 0.1606X^3 - 3.1790X^2 + 27.6890X - 0.2644$	0.9973	$X \geqq 0.0096$
	1/200	$Y = 0.1170X^3 - 2.4509X^2 + 20.1910X - 0.1940$	0.9967	$X \geqq 0.0097$
sand loam	1/100	$Y = 0.2648X^3 - 4.8969X^2 + 30.5520X - 0.6771$	0.9972	$X \geqq 0.0223$
	1/150	$Y = 0.2091X^3 - 3.8583X^2 + 25.3270X - 1.1027$	0.9912	$X \geqq 0.0439$
	1/200	$Y = 0.0811X^3 - 2.1694X^2 + 17.9420X - 0.8726$	0.9916	$X \geqq 0.0499$
sand	1/100	$Y = 0.3570X^3 - 4.3461X^2 + 17.0560X + 0.3349$	0.9950	$X \geqq -0.019$
	1/150	$Y = 0.2780X^3 - 3.3933X^2 + 14.2180X + 0.4469$	0.9912	$X \geqq -0.031$
	1/200	$Y = 0.3223X^3 - 3.8630X^2 + 14.8810X + 0.3371$	0.9934	$X \geqq -0.022$

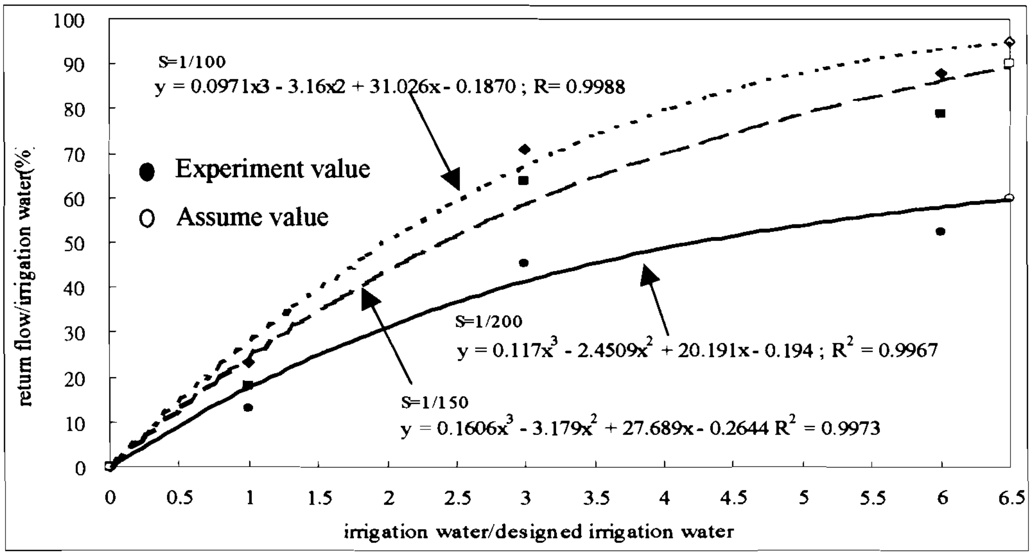

Fig 12. Curves of return flow from sandbox experiment — sandy clay loam

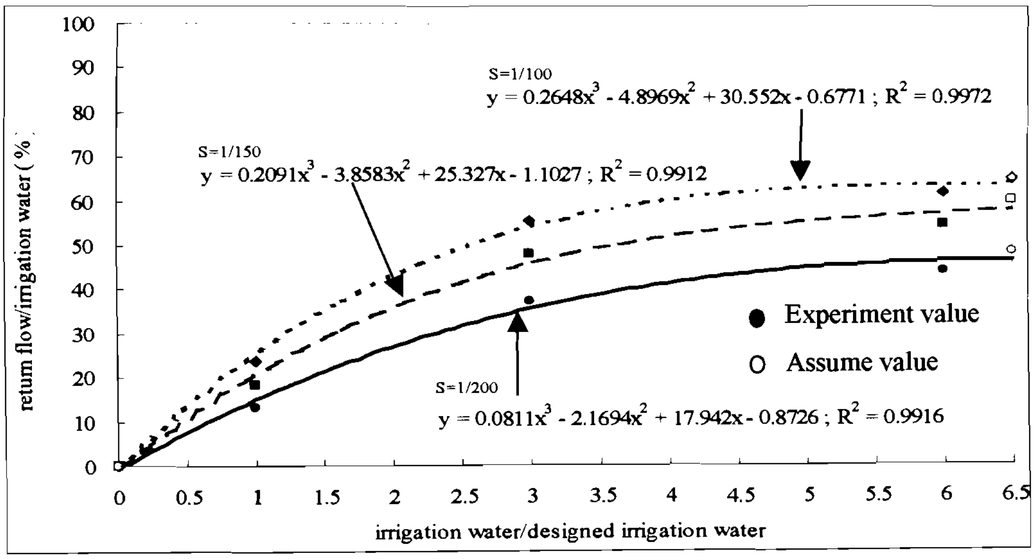

Fig 13. Curves of return flow from sandbox experiment — sand loam

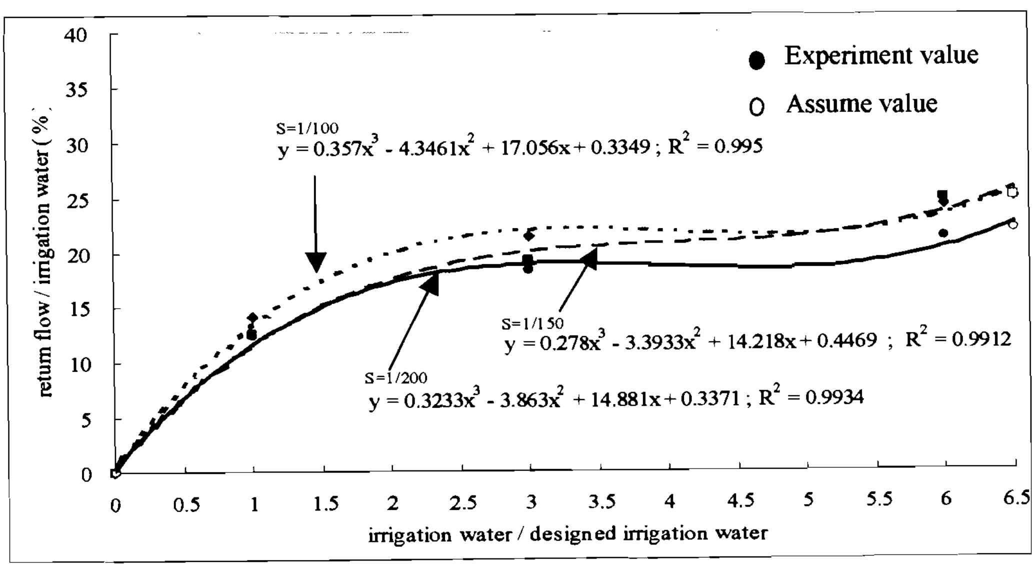

Fig 14. Curves of return flow from sandbox experiment — sand

6.4 Discussion of Experiment Results

According to the results of experiment in fields (Fig 9~11) and sandbox experiment (Fig 12), to compare both functions of return flow, the results show that, on the items (sandy clay loam and the slope of 1/150), and also one multiple of the depth of irrigation plan, the ratio of return flow for experiment in fields and sandbox experiment are 23.74% and 24.41%; when the depth of irrigation plan is three multiples, the ratio for experiment in fields and sandbox experiment are 37.97% and 43.68%; and when depth of irrigation plan is six multiples, the ratio are 46.59% and 58.53%; and when the depth of irrigation plan is 0.76 multiples, the both ratio are 19.01%.

To compare above experiment results, when irrigation water is 0.76, 1, 3, and 6 multiples of the depth of irrigation plan, the ratio of return flow in sandbox experiment are all higher than that in fields, and the difference are 0%, 0.67%, 5.71%, and 11.93%, which the difference and irrigation water be direct'proportion. The difference is still <1% while the depth is equal to irrigation plan; on the other hand, if over irrigation is 6 multiples of the depth of irrigation plan, the difference will be 11.93%.

The reasons about above results about that the ratio of return flow for sandbox experiment is higher than observation in fields, and specification as following: 0.266 mm/day, the hydraulic conductivity of sandbox experiment, is smaller than 4.71 mm/day, that of site experiment results; during sandbox experiment, the surface soil in the sandbox is uncovered land, so ET_{crop} is smaller than that of experiment covered by paddy; and from water budget balance (equation 6), the ET_{crop}, percolation, and return flow are being an negative relation, which means consumptive use(ET_{crop} and percolation) in irrigation area is bigger, and return flow is smaller. Therefore, return flow of sandbox experiment is bigger than that experiment in fields, which tallies with water budge balance theorem. From above, the results of return flow from the estimation of sandbox experiment and experiment in fields are similar. In the future, sandbox experiment can be used for application in an irrigation area with same soil, hydraulic conductivity, and slopes to estimate return flow on different soil, hydraulic conductivity, and slopes.

7. CONCLUSION AND SUGGESTION

7.1 Conclusion

i. This study uses sandbox for the experiment of return flow that base on three different slopes as 1/100, 1/150, and 1/200. The result of sandbox model experiment is similar with experiment in fields, which is base on conditions of. sandy clay loam, the hydraulic conductivity is 4.69 mm/day and the slope is 1/150. The estimation model should been used for application in other regions which is established from sandbox model experiments and finish the experiments that the condition is as the same as fields.

ii. From the result of sandbox experiment, return flow increases in the condition of constant irrigation water and slope becomes steeper, Owing to slopes is a important factor that influences return flow either high depth or low from irrigation. Therefore, it is feasible to use sandbox model for estimating return flow on different slopes.

iii. Above results show that, the estimation model is established by sandbox experiment and experiment in fields, which is base on the condition of slopes are 1/100, 1/150, and 1/200, soils are sand, sand loam and sandy clay loam. Therefore, at present, the model is only suitable for irrigation area with above conditions. To expect build up a general model, the experiment need keeping on different slopes and soils to be suitable for use in more region.

7.2 Suggestion

i. To use better materials to be inner medium between soil and sandbox, and let soil and box walls can be closed completely, and also reduce unusual leakage i to increase the accuracy of sandbox experiment.

ii. The return flow ratio of irrigation is 12.38~87.85 % by sandbox experiment and experiment in fields which according irrigation plan. Above values are not used for the deduction in irrigation water while irrigation, further, it is used for irrigation managers make a more available irrigation system.

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