ASSESSING SENSITIVITY OF PADDY RICE TO CLIMATE CHANGE IN SOUTH KOREA

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Abstract

Paddy rice constitutes a staple crop in Korea. This study conducted a sensitivity analysis to evaluate the vulnerability of paddy rice to future climate change, and compared temporal and regional characteristics to classify regions with unfavorable water balances. The ratio of consumptive use and effective rainfall (REIP) was used as a sensitivity index. Weather data from 1971 to 2010 and future climate change scenarios RCP 4.5 and 8.5 were used to evaluate the sensitivity. The results showed an overall increase in water requirements and consumptive use. The REIP values were small for every period, except the 2040s, 2060s, and 2080s under scenario RCP 4.5, and the 2040s and 2080s under scenario RCP 8.5. Both climate change scenarios showed high sensitivity in the regions Jeollabuk-do, Jeollanam-do, and Gyeongnam-do. However, regions Gyeonggi-do, Gangwon-do, and Chungcheongbuk-do had low sensitivity as compared to other regions. The REIPs were used to categorize sensitivity into four categories: low consumption-water rich, low consumption-water poor, high consumption-water rich and high consumption-water poor. The Gangwon-do region had the highest number of regions that changed from the low consumption-water rich category to the high consumption-water poor category, making it a priority for measures to improve its adaptive capacity for climate change.

KEY WORDS: Climate change, Irrigation, Paddy, Sensitivity, Water vulnerability.

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Introduction

Global warming is a worldwide phenomenon, and the rise in temperature and unpredictable changes in precipitation pose serious risks to agriculture (parry et al., 2007). The average temperature on the Korean Peninsula has risen by 1.5 °C in the past 100 years and, consequently, the crop calendar has changed and the traditional water management practices have being challenged. The slightest change in climate can easily cause changes in crop growing environments and cause serious problems for agricultural water resources in areas with great seasonal and regional deviations.

Rice comprises 90% of staple grain production in Korea and is the staple food source for over 60% of the global human population. Since rice is sensitive to weather conditions, changes in climate can drastically affect its growth and yield. Many studies have examined the changes in growth and irrigation patterns of paddy rice due to climate change. For example (Li et al., 2016) simulated rice yield and growth processes based on RCP 4.5 and 8.5 scenarios and showed that temperature increase would cause earlier vegetative periods and reduced crop yield. In Korea, (Chung. 2009) used the HadCM3 GCM model and data from A2 and B2 to analyze agricultural water demand in the Nakdonggang region; the results predicted a decrease in unit duty of water and irrigation demands. (Yun et al., 2011) used the A1B scenario to analyze changes in reference evapotranspiration and water requirement; results showed an overall increase in both aspects. (Lee et al., 2012) used a crop growth model that implemented various climate change scenarios, and showed a decrease in future consumptive use and increase in crop yield of paddy rice. (Yoo et al., 2012) used a high-resolution climate scenario, RCP 8.5, to analyze the changes in paddy irrigation requirements and unit duty of water for different irrigation districts. The results predicted variation between different irrigation districts and seasons, but on average, the actual crop evapotranspiration would increase and, thus, the paddy water requirement and unit duty of water would increase.

These studies above show that climate change threatens agricultural water security, and that the most immediate threat to future agriculture is climate change. Thus, it is essential to study the potential future risks and vulnerability caused by climate change to prepare for this threat, to promote agricultural production, and help prepare solutions, prioritize policies, and technologies. Vulnerability to climate change is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (McCarthy et al., 2011). This study analyzed the changing trends in agricultural water demands and used a water balance model to evaluate the sensitivity of rice paddy fields. Furthermore, it used an index to compare the temporal and spatial sensitivity of paddy rice cultivation to climate change, and categorized 162 cities and counties throughout the country according to the sensitivity type of paddy.

Materials and methods

Figure 1 shows the procedures for generating a sensitivity index for climate change and conducting daily water balance analyses for 162 cities and counties in 10-year increments.
Daily low/high temperatures, daily rainfall, daylight hours, and relative humidity at weather stations throughout the country over the past 40 years (1971–2010) were collected from the Korea Meteorological Administration (KMA. 2014). The daily rainfall and daily reference evapotranspiration (the Penman-Monteith equation) for the future weather (2011–2100) was calculated using data from Representative Concentration Pathways (RCP) scenarios 4.5 and 8.5.

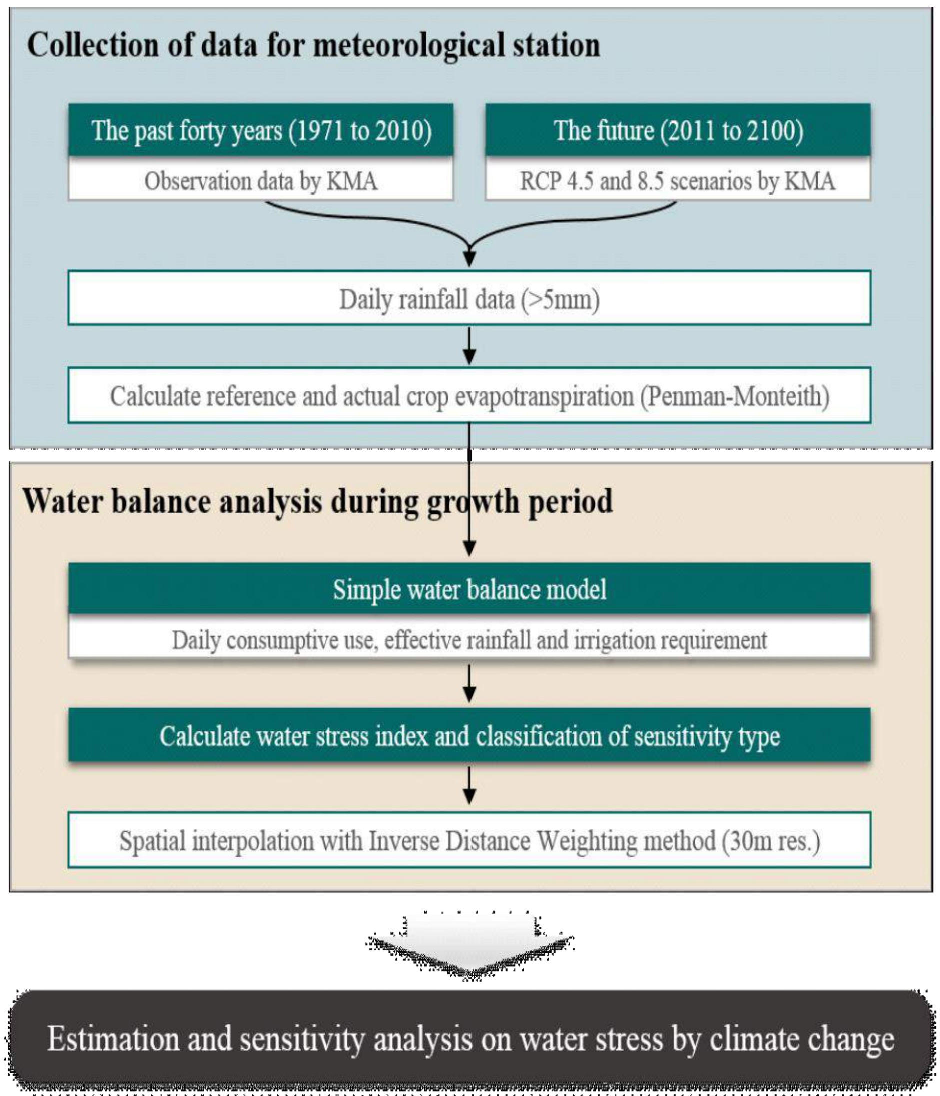


Figure 1. Procedures for evaluating sensitivity of paddy rice to climate change

Future climate change scenarios

The KMA provides climate change scenarios for South Korea based on RCP, using global and regional climate models. The dynamic downscaling technique is applied to the regional climate model (HadGEM3-RA) to generate climate change scenarios for the Korean Peninsula at a spatial resolution of 12.5 km. The study periods for the climate change scenarios are shown in Table 1. Periods were distinguished by the past (observed between 1971 and 2010) and the future (climate change scenarios, 2011–2100) and were divided into 10-year increments.

Table 1. Past climate data and future climate change scenarios used in this study

Period	No. of meteorological stations	Climate data	Source
1970s (1971–1980)	62	Observed	KMA
1980s (1981–1990)	68	Observed	KMA
1990s (1991–2000)	72	Observed	KMA
2000s (2001–2010)	81	Observed	KMA
2010s (2011–2020) to 2090s (2091–2100)	60	Climatic change scenarios (RCP 4.5 and 8.5)	KMA

Sensitivity index of vulnerability of paddy rice to climate change

Water balance analysis was used to predict paddy water requirements. Increase in crop evapotranspiration and decreases in effective rainfall are direct consequences of climate change that increase agricultural water demands (Jang et al., 2004). Equation 3 defines the Rainfall Effectiveness Index for paddy fields (REIP). A higher REIP indicates favorable water balance conditions with an adequate environment for cultivating paddy rice. A lower REIP indicates unfavorable conditions for growing paddy rice, and higher sensitivity to climate change.

$$REIP = \frac{\sum ER}{\sum CU} \qquad (3)$$

where CU is the crop consumptive use which is defined as the sum of actual crop evapotranspiration and deep percolation, and ER is effective rainfall.

Categorizing climate change sensitivity of paddy rice

The REIP was calculated for all fields. The sensitivity to climate change may be different for two cases that have the same REIP value. Hence, this study categorized climate change sensitivity into four types, according to the magnitudes of REIP relative to a baseline, and analyzed regional characteristics. In this study, the baseline was limited to an average during 1971 to 2010. Regions where the future consumptive use was lower than the baseline consumptive use were categorized as Low Consumption (L), those where it was higher as regions of High Consumption (H). Regions where the future effective rainfall was lower than the baseline effective rainfall were categorized as Water Poor (P), those where it was higher as Water Rich (R). Second, categorization of consumptive use and effective rainfall were combined to analyze different regions according to the four sensitivity types: low consumption-water rich (LR), high consumption-water rich (HR), low consumption-water poor (LP), and high consumption-water poor (HP) (Figure 2).

Results and discussion

Temporal changes in paddy water requirements

Table 2 shows the irrigation requirement calculations throughout the paddy rice growth period for future climate change scenarios. The effective rainfall was highest in the 2000s, while consumptive use was lowest. The net water requirement was highest in the 1970s, when consumptive use was also the highest, but was the lowest in the 2000s, when effective rainfall was highest.

Temporal changes for each climate change scenario were assessed relative to the average values over the last 40 years (1971–2010). The average consumptive use for the baseline period was 536 mm, and the predicted future values for RCP were about 576 mm on average. For RCP 8.5, the average simulated value was almost 595 mm (11% increase). The annual precipitation during the cultivation period increased in all periods, relative to the baseline, except in the 2010s and 2030s.. The average effective rainfall for the baseline period was 493 mm. The predicted values for the 2030s, 2060s, and 2090s, were 492 mm (0.2% increase), 578 mm (17.2% increase), and 489 mm (0.8% decrease), respectively, for RCP 4.5, and 470 mm (4.6% decrease), 499 mm (1.2% increase), and 570 mm (15.7% increase), respectively.

The average net water requirement for the baseline period was 556 mm. The predicted values for the 2030s, 2060s, and 2090s were 602 mm (8.3% increase), 496 mm (10.9% decrease), and 620 mm (11.5% increase), respectively, for RCP 4.5, and 626 mm (12.6% increase), 616 mm (10.8% increase), and 590 mm (6.2% increase), respectively, for RCP 8.5. Specific trends were not identified due to complex effects involving increased actual crop evapotranspiration and effective rainfall.

Table 2. Results of annual precipitation, consumptive use, effective rainfall, and net water requirements for paddy fields under RCP scenarios in South Korea.

Period	PR (mm)		CU (mm)		ER (mm)		IR (mm)	
Period	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
1970s	748		547		472		583	
1980s	876		539		498		559	
1990s	890		536		488		562	
2000s	954		522		515		521	
2010s	**851** (-1.8%)	918 (5.9%)	576 (7.4%)	549 (2.4%)	**473** (-4.1%)	492 (-0.3%)	605 (8.7%)	571 (2.6%)
2020s	939 (8.3%)	893 (3.0%)	555 (3.5%)	575 (7.2%)	485 (-1.6%)	**467** (-5.2%)	584 (4.9%)	623 (11.9%)
2030s	865 (-0.2%)	**848** (-2.2%)	594 (10.7%)	579 (7.9%)	492 (-0.2%)	470 (-4.6%)	602 (8.3%)	**626** (12.6%)
2040s	1,066 (22.9%)	1,057 (21.9%)	550 (2.6%)	581 (8.4%)	541 (9.7%)	549 (11.4%)	534 (-4.0%)	548 (-1.6%)
2050s	990 (14.2%)	996 (14.9%)	573 (6.9%)	600 (11.9%)	518 (5.1%)	508 (3.0%)	569 (2.3%)	602 (8.3%)
2060s	1,235 (42.5%)	869 (0.2%)	564 (5.1%)	627 (16.9%)	578 (17.2%)	499 (1.2%)	496 (-10.9%)	616 (10.8%)
2070s	1,018 (17.4%)	1,093 (26.1%)	600 (11.8%)	605 (12.9%)	506 (2.7%)	532 (7.9%)	609 (9.4%)	594 (6.8%)
2080s	1,062 (22.5%)	1,150 (32.7%)	566 (5.5%)	597 (11.4%)	533 (8.2%)	551 (11.7%)	538 (-3.2%)	571 (2.6%)
2090s	886 (2.2%)	1,127 (30.0%)	**611** (13.9%)	**641** (19.5%)	489 (-0.8%)	570 (15.7%)	**620** (11.5%)	590 (6.2%)

※PR: Precipitation, CU: Consumptive use, ER: Effective rainfall, IR: Net water requirement

※ Percentage to the baseline (the average of 1971–2010) in parentheses

Regional changes in the sensitivity index of paddy rice

This study categorized 162 cities and counties throughout South Korea, including Jeju Island, into 9 regions (U1, U2, M1, M2, M3, L1, L2, L3, and L4) to observe regional changes in the sensitivity index (Figure 3)

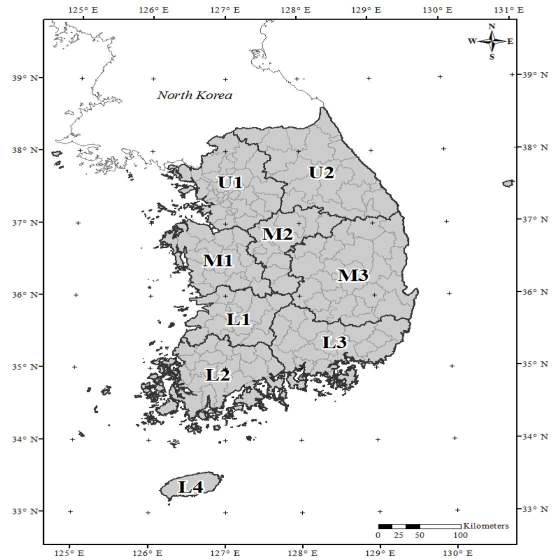


Figure 2. The 9 regions corresponding to provinces (U1: Gyeonggi, U2: Gangwon, M1: Chungcheongnam, M2: Chungcheongbuk, M3: Gyeongsangbuk, L1: Jeollabuk, L2: Jeollanam, L3: Gyeongsangnam, and L4: Jeju).

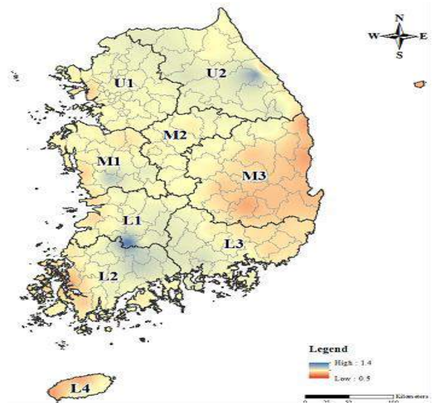
The temporal distribution of climate change scenarios RCP 4.5 and RCP 8.5 did not show significant statistical differences (Table 3). However, categorization of regional REIPs for all periods showed larger deviation for RCP 4.5 than RCP 8.5. Thus, regionally, it was predicted that RCP 4.5 has a larger deviation for sensitivity to climate change, compared to RCP 8.5.

Table 3. Temporal and regional averages and standard deviations of Rainfall Effectiveness Index for Paddy fields.

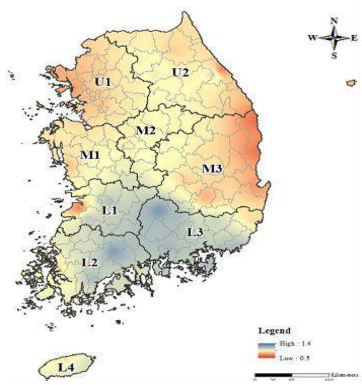
Period	RCP 4.5		RCP 8.5		Region	RCP 4.5		RCP 8.5	
Period	Avg	Std	Avg	Std	Region	Avg	Std	Avg	Std
2010s	0.91	0.078	0.97	0.087	U1	0.85	0.093	0.84	0.049
2020s	0.96	0.117	0.90	0.050	U2	0.91	0.091	0.89	0.042
2030s	0.90	0.092	0.88	0.056	M1	0.91	0.080	0.89	0.076
2040s	1.06	0.073	1.02	0.088	M2	0.98	0.089	0.95	0.069
2050s	0.98	0.061	0.93	0.083	M3	0.99	0.089	0.96	0.041
2060s	1.11	0.090	0.88	0.081	L1	1.04	0.089	0.97	0.062
2070s	0.93	0.072	0.95	0.059	L2	1.02	0.094	0.97	0.092
2080s	1.03	0.063	1.00	0.071	L3	1.09	0.081	1.05	0.070
2090s	0.88	0.083	0.97	0.091	L4	0.97	0.094	0.97	0.086
Avg	0.97	0.081	0.95	0.074	Avg	0.97	0.089	0.95	0.065

※ Avg: Average, Std: Standard deviation, bold: the minimum REIP

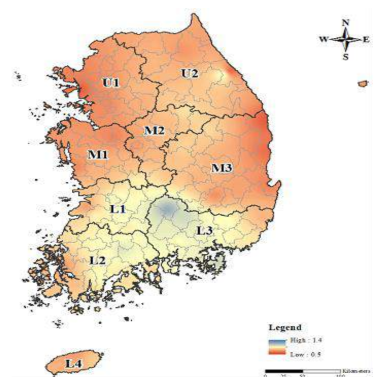
As shown in Figure 4, the L3 region was considered to have overall favorable water balance conditions in both future climate change scenarios. Regions L1 and L2, which are both major rice producing areas in South Korea, also showed less vulnerable to climate change, more than other regions. Conversely, U1, U2, and M1 had the lowest REIP for both RCP 4.5 and RCP 8.5, which indicated a need to improve the adaptive capacity for climate change in these regions.



(a) Baseline (1971-2010)



(d) 2040s under RCP 8.5 scenario



(e) 2060s under RCP 8.5 scenario

Figure 3. Spatial distribution of the REIP under different RCP Scenarios: (a) distribution of average REIP during the baseline period (1971–2010); (b) the 2060s with the most favorable REIP under the RCP 4.5 scenario; (c) the 2090s with the least favorable REIP under the RCP 4.5 scenario; (d) the 2040s with the most favorable REIP under the RCP 8.5 scenario; and (e) the 2060s with the least favorable REIP under the RCP 8.5 scenario.

Categorization of climate change sensitivity types

Climate change scenario RCP 8.5 showed an increase in the number of cities and counties classified as water poor regions during all periods (Figure 5). The average number of cities and counties classified as LP and HP in the future was 42 and 42, respectively. The 2010s and 2030s had the highest number of cities and counties classified as either LP or HP. Of most concern, was the 2040s and 2090s, where the numbers of HP cities and counties was highest, even when compared to scenario RCP 4.5. The lowest number of LR regions was during the 2060s and highest during the 2040s. For scenario RCP 8.5, the average number of cities and counties of each type were in the order of HR (26.3%) > LP (25.8%) > HP (25.7%) > LR (22.2%), showing HR with the highest weight, unlike the baseline, and showing LR with the least weight. Scenario RCP 8.5 had the highest percentage of cities and counties categorized as HR at 25.3%, contradicting the results of RCP 4.5. However, the number of cities and countries for each sensitivity type did not show a big difference between RCP 8.5 and RCP 4.5.

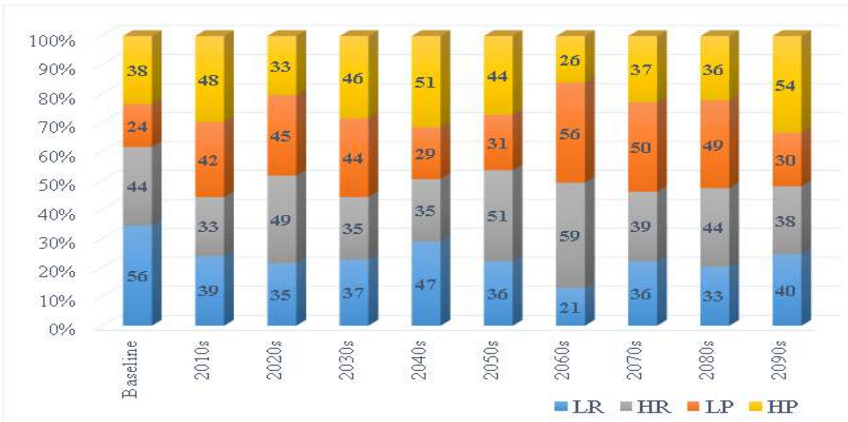


Figure 4. Regional distribution of sensitivity types for scenario RCP 8.5. The 2030s had the highest number of water poor regions and the 2010s and 2030s had the highest number of LR regions.

Regions that change from LR (the most favorable) to HP (the most sensitive type) in the future are a priority for measures to adapt to climate change. Conversely, regions that change from HP to LP are predicted to experience the least adverse effects of climate change. Figure 6 shows that regions that changed from LR to HP in the climate change scenario RCP 4.5 occurred most often during the 2030s with 27 cities and counties, and the least often during the 2060s, with only 7 cities and counties. Furthermore, from 2011 to 2100, there were 34 cities and counties that changed from LR to HP, and there were 22 for U1, 4 for U2, and 4 for M1 (Figure 10). RCP 8.5 had the most cities and counties in the 2010s (29), followed by the 2090s (27). However, the 2020s and the 2080s had 5 and 6 cities and counties, respectively, which changed from LR to HP, indicating that these periods are predicted to experience the least adverse effects of climate change. In all scenarios, U1 was the most sensitive to future climate change and is a priority for efforts to adapt to climate change. Twenty-two cities and counties improved from HP to LR for scenario RCP 4.5, and 34 cities and counties for scenario RCP 8.5. The M3 region is known as the driest region with the least rainfall and highest temperatures in South Korea.

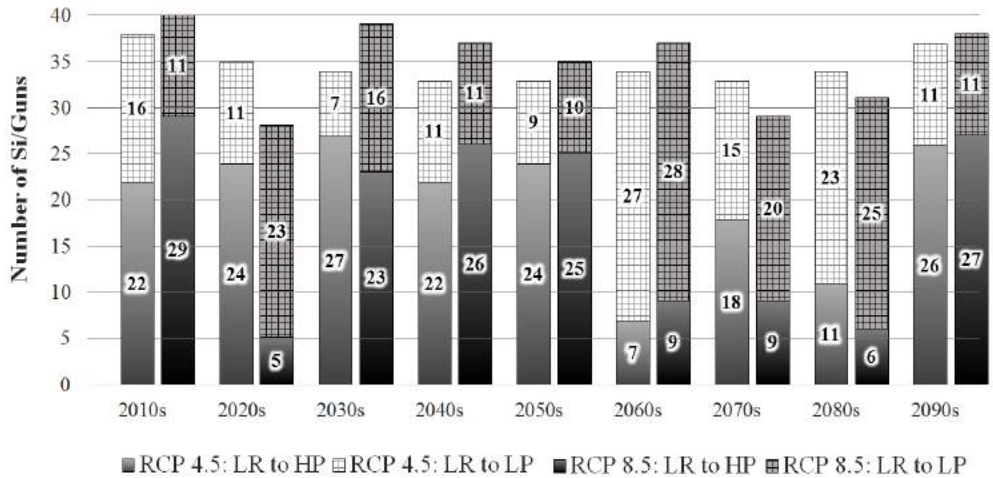
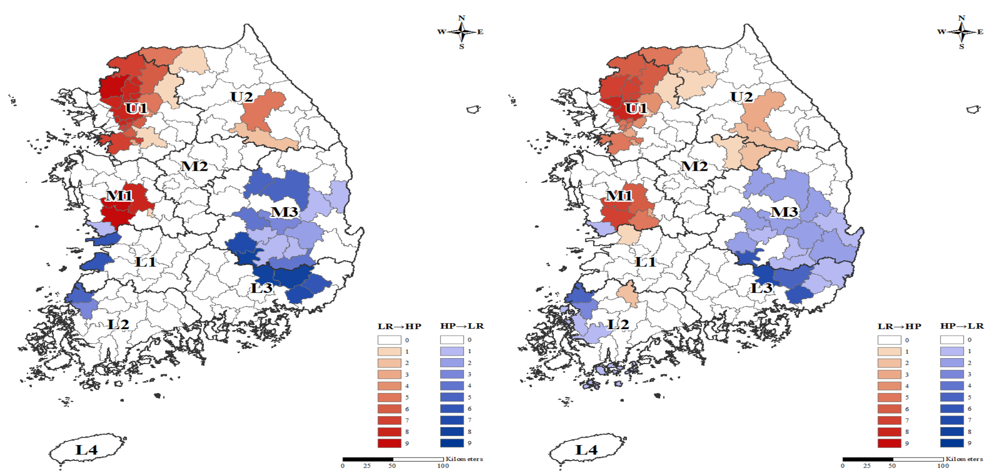


Figure 5. Comparison of changes in sensitivity types (LR to HP, HP to LR) with future climate change scenarios.



(a) RCP 4.5 Scenario (b) RCP 8.5 Scenario

Figure 6. Results of regional sensitivity changes according to RCP scenarios (Red: LR to HP, Blue: HP to LR)

Conclusion

This study predicted changes in the water balance of paddy fields using climate change scenarios RCP 4.5 and 8.5. Furthermore, an index was used to quantitatively express the sensitivity to climate change of paddy rice fields and categorize 162 cities and counties in South Korea into four types.

Scenarios RCP 4.5 and 8.5 both showed an increase in consumptive use. The increase for RCP 8.5 (average 10.9%) was higher than for RCP 4.5 (average 7.5%). The annual precipitation during the cultivation period increased compared to the present in all periods, except for the 2010s and 2030s. However, effective rainfall varied according to climate change scenarios and periods due to effects of rainfall days, rainfall intensities, and freshwater conditions of the field.

Sensitivity of paddy rice to climate change was evaluated using the ratio of consumptive use to effective rainfall (REIP). Higher REIP values indicated favorable water balance conditions, and low sensitivity to climate change, and vice versa. Compared to the REIP values over the past 40 years, sensitivity improved only during the 2040s, 2060s, and 2080s for RCP 4.5, and during the 2040s and 2080s for RCP 8.5. In the regional analysis, both climate change scenarios showed high REIP values for L3 regions, but U1 regions generally showed the lowest REIP values overall, which predicted an increase in sensitivity to climate change.

Cities and counties were categorized into four sensitivity types using the REIP: low consumption-water rich (LR), low consumption-water poor (LP), high consumption-water poor (HP), and high consumption-water rich (HR). In both RCP scenarios, the number of water poor regions (LP and HP) increased overall compared to the present. The number of cities and counties that changed from LR to HP over an extended period was highest in the U1 region, which indicated that this region should be a priority for measures to adapt to climate change. However, the M3 region showed a high number of changes from HP to LR, and was predicted to experience the least adverse effects of climate change.

This study predicted changes in agricultural water requirements from climate change and provided an index to quantitatively represent the water sensitivity of paddy rice.However, climate change scenarios include some degree of uncertainty and different information can be provided depending on the downscaling techniques or spatial resolution used (Chen et al., 2011and Oh et al., 2016). Therefore, sensitivity analysis can produce different results. In addition, since the changes in other factors, such as cultivation area or cropping system, from climate change were not considered (Li et al., 2009) future studies should address these aspects.

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MODELING THE IMPACT OF DRAINAGE DESIGN PARAMETERS ON THE AMOUNT OF NITROGEN LOSSES IN TILE-DRAINAGE SYSTEMS: A CASE STUDY FROM SOUTHWEST IRAN

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Abstract

Excessive soil nitrogen losses as a result of the inappropriate design of subsurface drainage systems have given rise to different environmental problems. The drain spacing and depth play a substantial role in the quality and quantity of the drain outflow into the environment. In this research, a simple but comprehensive simulation model using a system dynamic approach for the water and nitrogen cycle was used to simulate the impact of drain depth and spacing on nitrate and ammonium losses in sugarcane farmland at Imam Khomeini agro-industrial Company. Sixteen scenarios were modeled including the combination of four drain spacing (60, 70, 80 and 90 m) and four different drain depths (1.1, 1.4, 1.7 and 2.0 m) to compare the effect of drain spacing and depth on the amount of ammonium losses through runoff, nitrate and ammonium losses through drainage water, nitrogen losses via the denitrification process and nitrogen uptake by the plant. The results indicated that through the increasing of drain spacing and the reducing of drain depth nitrogen losses in the form of denitrification and runoff would increase; and the nitrate and ammonium losses through the drainage water would decrease. Furthermore, the amount of applied urea fertilizer has a significant impact on the amount of nitrogen losses. So, based on the results the optimal tile-drainage system density in this region would be a drain spacing of 80 m and depth of 1m, in as such that the total drainage and runoff losses would be reduced up to an acceptable level. Therefore, the optimum design of subsurface drainage systems based on environmental criteria could aid in the control of nitrogen pollution on the farm-level.

KEY WORDS: Drain depth, Drain spacing, Nitrogen losses, Drainage water, Sugarcane, Imam Khomeini agro-industrial Company.

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Introduction

Artificial field drainage as a means to remove excess water in the root zone is now about 200 years old (Smedema et al. 2004), but estimating optimal drain spacing remains a challenging part of any drainage-scheme design (Shokri and Bardsley 2015). The environmental impacts of agricultural drainage have led to serious problems (Alibakhshi et al. 2013). Nitrate pollution is one of the main pollution for surface and ground water in agricultural areas. (Piccini et al. 2012; Shah and Singh 2016). The subsurface drain spacing and depth are two important parameters in designing drainage systems that play a determining role in the amount and quality of the drain outflow (Kalita et al. 2006). The inappropriate design of subsurface drainage systems would lead to the excessive loss of the soil nitrogen through drainage and runoff losses that cause environmental problems. The nitrate and ammonium pollutions in the agricultural watersheds with tile-drainage systems can be controlled by appropriate subsurface drainage systems designing to decrease the volume of drainage water and nitrate and ammonium concentrations in the drain outflow.

Nitrogen dynamics in Soil-Water-Plant-Drainage system is a complex process due to contribution of many interactions of the chemical, physical and biological processes. Thus, in order to model this complex relations in such a system we need a new tool. One of the most effective techniques for modeling complex systems is the System Dynamics approach.

The System Dynamics approach (SD) was first developed by Forrester (1961) for understanding of strategic issues in complex systems. Every SD is determined by interaction, information, interdependency, feedback, stock and flow diagram. In SD, the relation between behavior and structure of every dynamic system is based on the concept of information feedback and interaction of stock and flow variables (Simonovic 2000; Sahin et al. 2014; Neuwirth et al. 2015).

Today many simulation models have been developed for simulating nitrogen leaching and transformation in the plant root zone, the most important of them including LEACHN (Wagenet and Hutson 1989), ANIMO (Rijtema and Kroes 1991) and HYDRUS (Simunek et al. 1999). The problem of these models is number of input parameters and measuring some of them at the field-scale are really difficult or sometimes it is not possible. Moreover they cannot be used in artificial-drained farmlands for modeling of the drainage rate and the nitrate and ammonium losses from the drain pipes. This may be related to this fact that the hydraulics flow toward drains has not been taken into consideration.

The review of literature indicates that there is no study on modelling the effect of drain spacing and depth on nitrogen losses at sugarcane farmlands under subsurface drainage systems. The optimal designing of tile-drainage systems according to environmental criteria is the procedure that desirable economic and environmental results due to the ability to control pollution at the farm-level. It would be difficult and time-consuming to implement different drain depth and spacing at the farmland in other to investigate nitrogen losses from tile-drainage system. It can be achieved by simulating of different scenarios of drain spacing and depth. Therefore, the main objective of this research is the investigation of the impact of drain spacing and depth on the amount of nitrogen losses in subsurface drainage systems using a simple water and nitrogen dynamic developed model by the system dynamic approach and selecting optimal drain spacing and depth (optimal tile-drainage system density) based on environmental criteria (minimizing the nitrate and ammonium drainage and runoff losses into the environment) in a sugarcane farmland at Imam Khomeini agro-industrial Company.

Materials and methods

Description of developed model using system dynamics approach:

In order to simulate the scenarios of the impact of different drain spacing and depth on the amount of ammonium losses through runoff, nitrate and ammonium losses through drainage water, nitrogen losses by denitrification process and nitrogen uptake by plant we used the developed modeled by Matinzadeh et al. (2016). Briefly, this model has two essential sub models of hydrological and nitrogen cycle. Output of hydrologic sub model include simulation of soil water content in different layers, upward flux, water table fluctuations and drainage rate from subsurface drainage system. On the other hand, output of nitrogen cycle sub model include simulation of fertilizer dissolution, nitrification process, denitrification process, ammonium volatilization, mineralization, immobilization, nitrogen uptake by the plant, soil particles adsorption, upward flux, nitrate and ammonium losses from surface runoff and subsurface drainage. The time scale of these hydrological and nitrogen variables are on a daily basis. Fig.1 shows the model structure (Stock and Flow Diagram) of developed model by Matinzadeh et al. (2016) with Vensim Professional software.

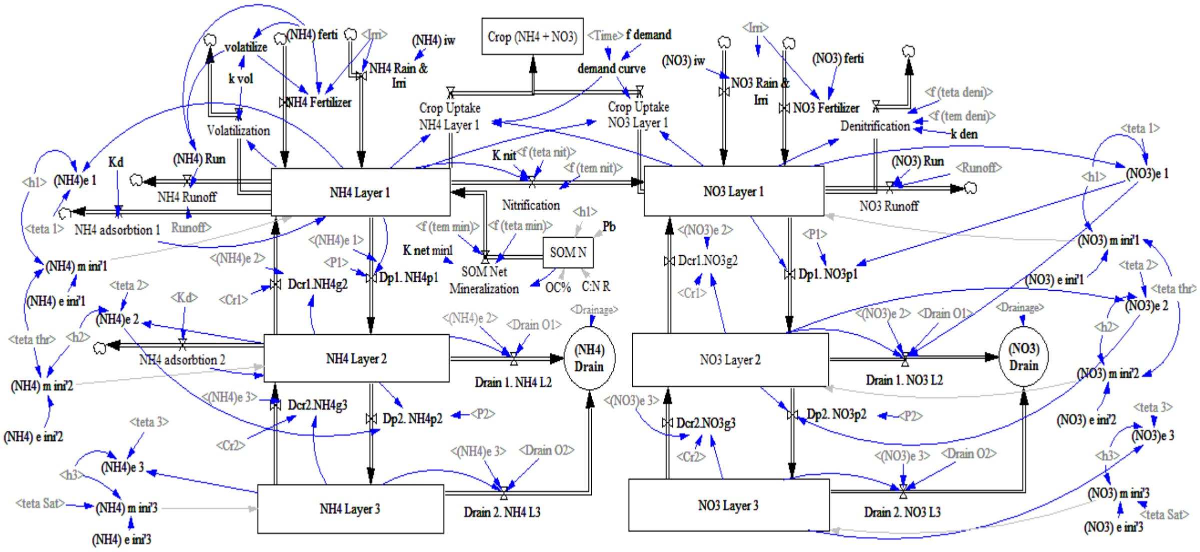

Figure 1. Developed model structure

For calibration and evaluation of developed model, we used the data measured from the study of Sadeghi-Lari (2013). These data measured from field B-129 with an area of 21 hectares that located in the Imam Khomeini agro-industrial Company at Khuzestan province of Iran. Therefore, this calibrated model was used to simulate the scenarios of the impact of drain spacing and depth on the amount of nitrogen losses from tile-drainage system in a sugarcane farmland at Imam Khomeini agro-industrial Company.

Research Area

Imam Khomeini agro-industrial Company is one of the seven sugarcane development Company that located in Khuzestan province, Iran. This region is part of the Khuzestan Shoeibieh Plain with the total area of 15800 hectares located in 40 km distance in the south of the city of Shooshtar and 50 km of the city of Ahvaz. The farmlands in sugarcane cultivations and industrial centers have been divided into fields of 21 hectares (i.e 250×850 m) and 25 hectares (i.e 250×1000 m) that include 480 farms. As well as, the subsurface drainage system parameter in this region is drain spacing 75 m and drain depth 2.1 m. The annual average temperature in the region is 24.5ºC, the average annual rainfall is 266 mm and the average annual evaporation is 2800 mm.

Tile-drainage system designing scenarios (drain spacing and depth)

The optimal designing of subsurface drainage systems plays the substantial role in reducing the concentration of nitrate and ammonium in drain outflow. Thus, spacing and depth of tile-drains are two essential parameters in designing subsurface drainage systems that have important role in drain environmental quality impacts. Therefore, in this research, 16 scenarios for subsurface drainage system designing have been implemented that include the combination of four different drain depths (1.1, 1.4, 1.7 and 2 meters) and for drain spacing (60, 70, 80 and 90 meters) to compare the effect of drain spacing and depth on the amount of ammonium losses through runoff, nitrate and ammonium losses through drainage water, nitrogen losses by denitrification process and nitrogen uptake by plant.

Results and discussion

The results of modelling 16 combination of drain spacing and depth scenarios have been presented in Table 1 and Fig. 2. As it can be seen in Table 1, by increasing the drain spacing, the nitrogen losses in the form of denitrification process and runoff will increase. This is because the increase of the drain spacing would reduce the drainage outflow and accordingly risen ups the water table level that leads to decreasing the infiltrated water into the soil and more water is discharged from the end of the farm due to runoff. Thus, denitrification process would increase because of waterlogging; and ammonium losses in the runoff would increase due to producing more runoff.

Moreover, with increasing the drain spacing, the amount of nitrate and ammonium losses by drainage water would decrease. The reason is that due to the generation of more runoff, less ammonium is infiltrated into the soil in one hand, and on the other hand because of reducing the drainage outflow and decreasing the leaching, the losses of nitrate and ammonium through drainage water will also decrease.

Meanwhile, Table 1 shows that with increasing the depth of drain, the nitrogen losses will be decreased in the form of denitrification process and runoff, since increasing the drain depth would lead to the increasing of the volume of the soil water storage, increase of infiltrated water into the soil. The result is that the drainage outflow will increase that leads to declining the level of the water table and reducing the runoff losses. Therefore, denitrification process would decrease due to the more aeration in the soil; and ammonium losses through the runoff would decrease because of decreasing runoff losses. The drain depth increase would add to the nitrate and ammonium losses through drainage outflow because of the less runoff generation, more ammonium enters into the soil, and due to the increasing of the leaching and the rate of the drainage outflow, nitrate and ammonium losses by drainage water will be more.

Table 1. Modeling nitrogen losses in different scenarios of drain spacing and depth (applied urea fertilizer was 450 kg/ha).

Drainage design		NH_4^+ runoff loss (kg/ha)	Drainage losses			Denitrification (kg/ha)	N crop uptake (kg/ha)
L (m)	D (m)		NH_4^+ (kg/ha)	NO_3^- (kg/ha)	Total N (kg/ha)		
60	1.1	50.2	20.9	91.2	112.1	97.8	123.8
	1.4	20.7	42.9	144.4	187.3	62.7	123.8
	1.7	9.7	48.8	162.9	211.7	49.5	123.8
	2	1.8	53.7	177.7	231.4	39.2	123.8
70	1.1	60.7	16.8	75.2	92.0	109.5	123.8
	1.4	28.6	38.6	125.4	164.0	80.8	123.8
	1.7	12.6	46.3	150.0	196.3	65.0	123.8
	2	4.5	52.5	170.7	223.2	46.3	123.8
80	1.1	77.1	12.9	55.9	68.7	118.2	123.8
	1.4	39.5	33.2	102.9	136.1	98.4	123.8
	1.7	21.3	41.8	130.4	172.2	80.5	123.8
	2	8.0	50.1	154.7	204.8	65.6	123.8
90	1.1	91.2	11.8	36.1	47.9	127.5	121.3
	1.4	60.5	27.1	80.6	107.7	107.1	122.5
	1.7	31.1	36.9	112.3	149.2	95.3	123.2
	2	16.1	45.5	136.3	181.8	81.1	123.6

To summarize, the highest nitrogen losses by denitrification process and runoff and the lowest total of nitrate and ammonium losses through the drainage water are in the combination of drain spacing and depth scenario of (1.1, 90 meters) that equal to 127.5, 91.2 and 47.9 kg/ha, respectively. The lowest amount of nitrogen losses due to denitrification process and runoff and the highest total of nitrate and ammonium losses through the drainage water are in the combination of drain depth and spacing scenario of (2.0, 60 meters) that equal to 39.2, 1.8 and 231.4 kg/ha, respectively. This modeling results of drain spacing and depth affecting on nitrogen drainage losses are similar to the field drainage experimental results that carried out by Darzi et al. (2013), Alibakhshi et al. (2013) and Darzi and Shahnazari (2014).

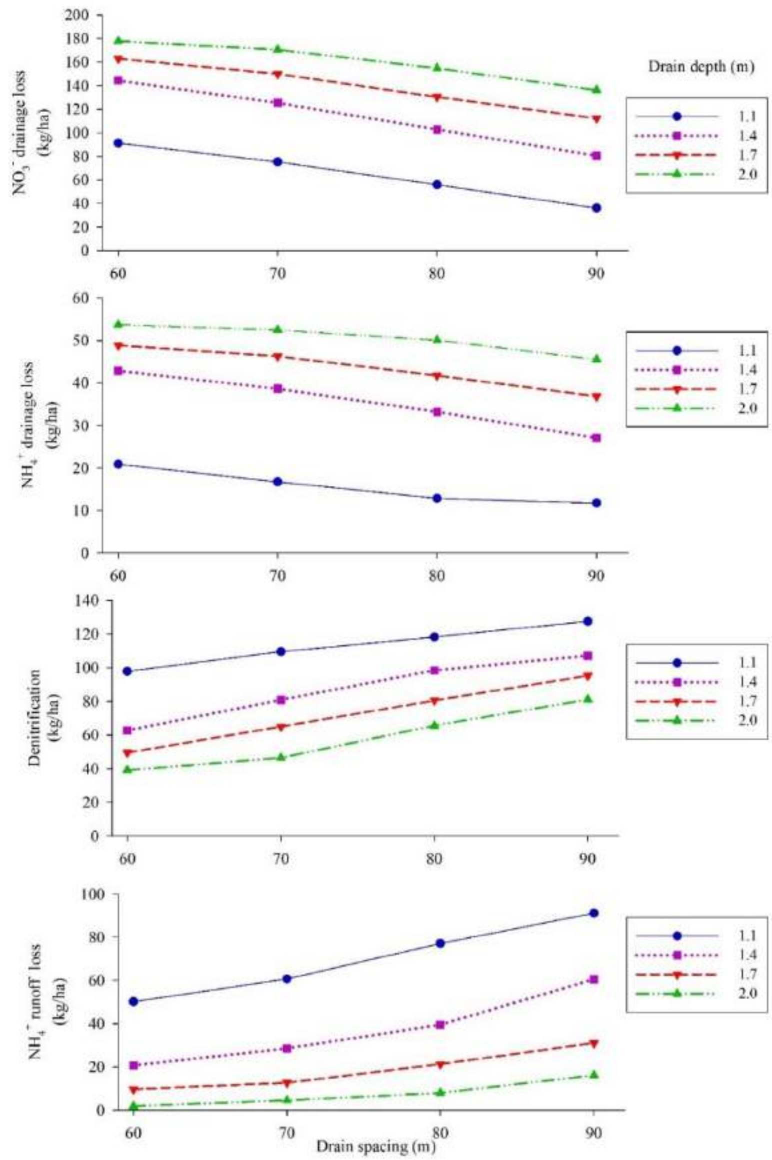

Figure 2. Modelling of nitrogen losses through denitrification, runoff and subsurface drainage system in different scenarios of drain spacing and depth (the amount of applied urea fertilizer was 450 kg/ha).

As it can be seen in Fig. 2, by increasing drainage system density (close spacing and more depth), the amount of nitrogen losses by denitrification and runoff will reduce and nitrate and ammonium losses through the subsurface drainage will increase. Therefore, the worst-case scenario in terms of nitrate and ammonium losses through drainage water is related to the highest drainage system density (scenario of 2.0 m depth and spacing 60 m). The worst-case scenario in terms of nitrogen uptake by the plant and nitrogen losses through runoff and denitrification is in the less density of drainage system (scenario of 1.1 m depth and spacing 90 m)

According to Table 1 and Fig. 2, nitrogen losses are high both through denitrification and runoff and also by tile-drainage system, and this is because of the excessive use of urea fertilizer in the Imam agro-industrial Company (applied urea 450 kg/ha).

Therefore, it is not possible to determine the optimal tile-drainage system density. Thus, to achieve this purpose, it is necessary first to apply the optimum urea fertilizer. The optimal drainage system density is a combination of drain depth and spacing that reduces the nitrogen losses through denitrification, runoff and drainage to the environment.

As mentioned previously, in order to determine the optimal density of tile- drainage system, it is necessary first to apply an optimized fertilizer in the farmland. Abbasi et al. (2015) and Matinzadeh et al. (2016) recommended 210 kg/ha of optimized urea fertilizer for the sugarcane in Imam Khomeini agro-industrial Company that should be applied during four split according to conventional fertilization timing in this area. Thus, 16 different scenarios of drain spacing and depth with 210 kg/ha of applied urea fertilizer were modeled to select the optimum tile-drainage system density. The results have been presented in Table 2 and Fig. 3.

Table 2. Modeling nitrogen losses in different scenarios of drain spacing and depth (applied urea fertilizer was 210 kg/ha).

Drainage design		NH_4^+ runoff loss (kg/ha)	Drainage losses			Denitrification	N crop uptake
L (m)	D (m)		NH_4^+ (kg/ha)	NO_3^- (kg/ha)	Total N (kg/ha)	(kg/ha)	(kg/ha)
60	1.1	23.2	8.3	31.6	39.9	45.6	123.8
	1.4	9.6	18.5	56.4	74.9	29.4	123.8
	1.7	3.7	22.4	63.6	86.1	23.6	123.8
	2	0.6	23.8	70.0	93.8	18.3	123.8
70	1.1	28.6	6.2	20.8	27.0	54.6	123.8
	1.4	12.5	16.6	50.1	66.8	38.1	123.8
	1.7	5.8	20.2	59.8	80.0	30.1	123.8
	2	1.3	22.9	66.7	89.7	22.8	123.8
80	1.1	38.0	5.3	15.5	20.8	61.5	122.3
	1.4	17.9	14.5	42.7	57.2	47.5	123.1
	1.7	9.2	18.3	53.8	72.1	38.1	123.6
	2	3.5	21.5	61.8	83.4	30.8	123.8
90	1.1	45.1	4.2	12.2	16.4	65.7	120.1
	1.4	28.0	12.2	34.8	47.0	52.2	121.3
	1.7	13.4	16.2	47.1	63.3	46.3	122.0
	2	7.0	19.5	56.0	75.5	38.9	122.4

As Fig. 3 shows, the trend of nitrogen uptake by the plant and nitrogen losses through denitrification, runoff and drainage to the variation of drain depth and spacing are similar to Fig. 2. So that through reducing drain depth and increasing drain spacing (reduction of tile-drainage system density), nitrogen loss in the form of denitrification and runoff would increase; and the nitrate and ammonium losses through the drainage water would decrease.

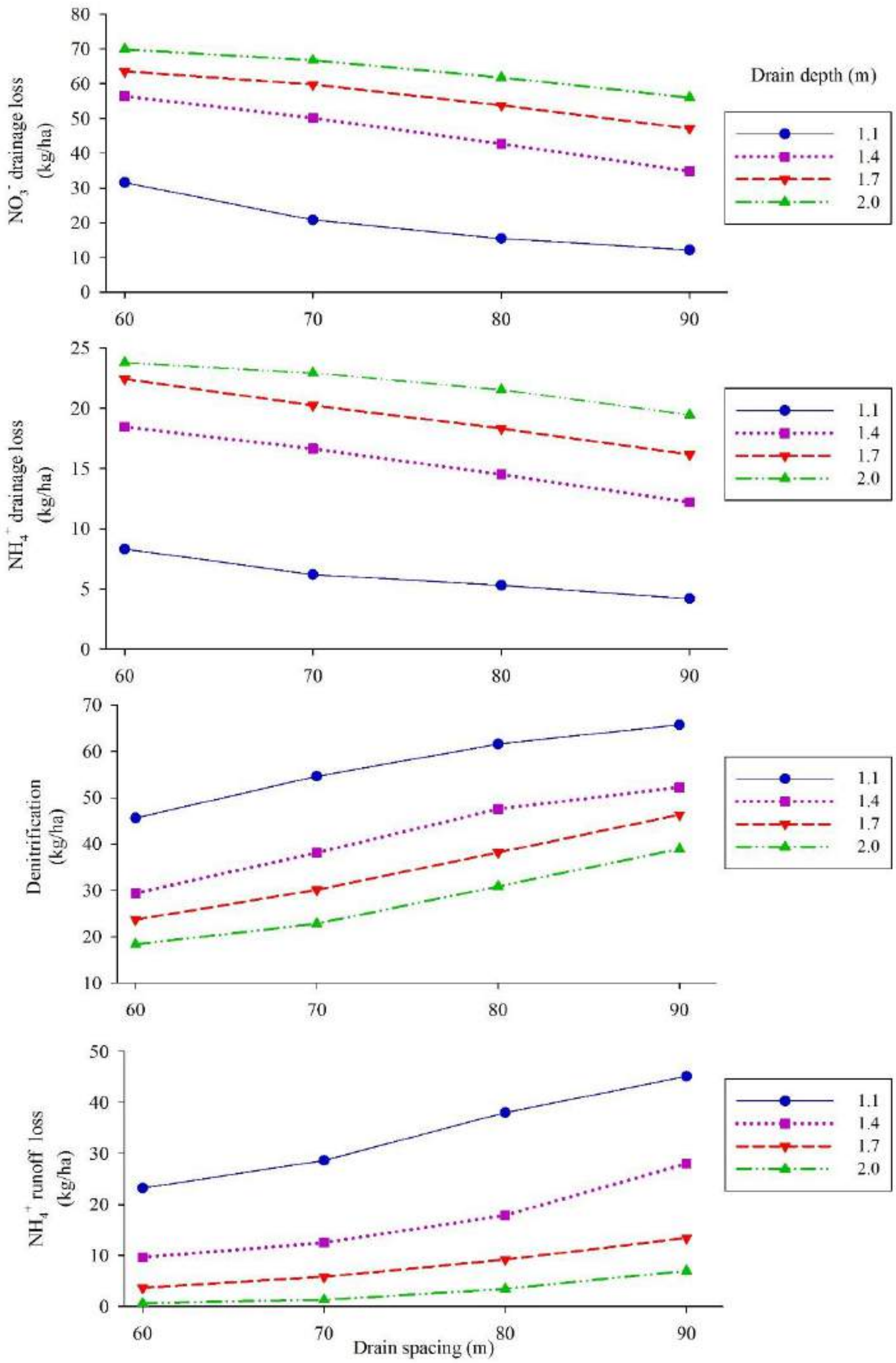

Figure 3. Modelling of nitrogen losses through denitrification, runoff and subsurface drainage system in different scenarios of drain spacing and depth (the amount of applied urea fertilizer was 210 kg/ha).

According to the results of this study and the environmental criteria, for reducing the nitrogen losses from the tile-drainage system, the depth of drain should be decreased and drain spacing should be increased. Therefore, in this area for the optimized density of subsurface drainage system the depth is 1.1m and the spacing is 80 m, so that the total tile-drainage losses of nitrogen would reduce to less than 25 kg/ha.

In this optimum density of the tile-drainage system, the total amount of nitrate and ammonium drainage losses compared to the current situation (236.8 kg/ha) would decrease by 71.3% for 450 kg/ha of applied fertilizer and 91.2% for 210 kg/ha of fertilizer. Therefore, this has a significant effect on reduction of nitrogen pollution load into the water resources and environment.

Conclusion

In this study, a simple but comprehensive developed model for water cycle and nitrogen dynamics was used to simulate the effect of drain spacing and depth (drainage design parameters) on nitrogen losses by system dynamic approach. The optimum designing of the tile-drainage systems according to environmental criteria can control pollution at the farm-level. The results of this research indicated that the more density of tile-drainage system would cause reduction of denitrification process, reducing nitrogen losses through the tail water runoff, increasing the drain installation costs and increasing nitrogen losses by the drainage water (increasing losses of fertilizer). On the other hand, less density in the subsurface drainage system would result in increasing denitrification process, increasing nitrogen losses by runoff, reducing the drain installation costs and reducing nitrogen losses through the drainage water (reducing losses of fertilizer).

Therefore, it is suggested to change the approach towards the criterion and principles of designing the tile-drainage systems to environmental standards.

Furthermore, this study recommends that in farmlands of Imam Khomeini agro-industrial Company, the drains should be installed at the shallow depth of the field (1.1 meter). This leads to reduce fertilizer losses and other pollutants.

Moreover, the system dynamics approach was found a powerful approach among available techniques that incorporates multidisciplinary research efforts and deals with the dynamic nature of the management problem for effective decision-making. The advantages of this approach include clear conceptualization, easy model adaptation, fast programming and accessible user interface.

Acknowledgement

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RECONSTRUCTION OF RECLAMATED AREAS DRAINED BY PIPE DRAINING SYSTEMS

Yuri G. Yanko[1,*]

Abstract

According to monitoring of drainage systems data, regardless depreciation guidelines, the main elements of pipe drainage systems are efficient and are able to significantly prolong effective work of systems with the help of pipe line flashing. Impartial assessment of drainage systems can be obtained on the basis of systematic monitoring which is part of extended monitoring of meliorated lands. On practice, monitoring is based on recognition observations and extraction of drainage pipes. In order to prepare planning documentation for repairing and reconstruction of pipe drainage systems, operating set of documents must be analyzed and afterwards detailed monitoring to be performed in accordance with approved methodology. Here with, reasons of soil water-logging and soil type units are being settled, areas with normal conditions and areas with not satisfied quality of drainage are being determined, conditions of exterior parts of drainage systems (soils, wells, filters) are being examined, and also areas for subsequent test drillings are being traced. While stripping of drainage pipes estuarial parts of reservoirs, draw wells and pipe connections, connections of drainage pipes and reservoirs are being examined, reservoirs and drainage pipes conditions, pore space of pipes, filtering materials and back filling are also being examined. Besides depth of drainage systems and their elevation are being determined in order to create measures to eliminate dysfunctions.

KEY WORDS: Land reclamation, Subsoil drainage, Humid zone, Reconstruction.

Introduction

Major part (more than 70%) of reclaimed lands in Leningrad region are drained by subsurface drainage. Common use of subsurface drainage for the purpose of drainage in Leningrad region started at the end of 1950-ies. To specify efficiency of subsurface drainage network in Leningrad region surveys and state estimation of subsurface drainage have been performed since 1980. Since 2002 survey of drainage systems with detailed description of all structural components has been performed in Leningrad region. The target of the survey is to receive objective information about

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status and operability of some drainage structural components, to find out deficiencies of structures on the base of this information and to introduce suggestions on these elements improvement.

Materials and methods

For 2002-2013 the drainage network survey has been performed at 35 sites with different soil conditions with total area of 2,380 hectares (ha). Total length of surveyed collector and drainage network is 995,049 meters (m), including 111,749 m of collectors, 883,300 m of drains and 59 drain wells and 545 mouths. Detailed survey of collector and drainage network status has been performed at 16 reclamation sites with total area of 1,012 ha; length of surveyed part of collectors is 38,921 m, drains – 183,594 m, 630 pits at collectors and 718 drains. At the same time description has been made of pipes cavity, joints of clay pipes, protective filtering material, trench filling material, connection of drains with collector, pipe connection in mouths and wells. Survey was mainly focused on the following statuses of main design parameters and structural components of drainage:

Slope and depth of collector and drainage network

In Leningrad region minimum permissible slope of 0.003% for regulating network is accepted. Minimal depth of drains in 1970-ies was 0.8 m and then was increased up to 1.0 m. Practically for all collection networks required slope is met; 19 sites without slope and 5 sites with adverse slopes (sites of Kupriyanovka and Kondokopshino) were found out. Inadmissible small depth of collectors imbedding was found out in 38 pits (6%) – sites of Sobolevka, Kupriyanovka, Kondokopshino. Significant part of regulating drain network is located at extremely small depths and part of drains (33%) is located at depth less than 0.8 m.

Drain pipes integrity

Practically all surveyed collectors are made of clay pipes with diameter of 7.5; 10 and 15 cm. While surveying drain systems several facts of drain pipe destruction were found out; these are facilities constructed later and destroyed mainly by linear facilities (cable networks, gas-pipe lines, etc.) – site of Pobedovka. At the site Plavuchi Most of Volokhovskoye CJSC smashed clay pipes were found; probable reason of destruction is an impact of frozen ground block during back filling of the trench. At the same time it is necessary to note that no cases of clay pipes destruction and layering were found due to their ageing. In 1980-ies use of corrugated polyethylene pipes with diameter of 63 millimeters (mm) with slot perforation increased. At all sites, where polyethylene drain pipes were penetrated, complete integrity of pipes was observed.

Joints of clay pipes

In compliance with norms and recommendations in regard to drainage systems used at the time of their construction optimal gap width between joints of clay pipes is 2 mm and permissible lateral tilt shall not exceed 1/3 of pipe wall thickness. Estimation of clay drainage joints was performed basing on such requirements. Joints of clay pipes are mainly tight:

- at collection network joints are tight in 560 cases (89%), in 70 pits gaps are found that exceed permitted rate (11%). It is explained largely by low quality of clay pipes with large diameter of 10 and 15 centimeters (cm)
- at regulating network joints are tight in 587 cases (97%), inadmissible large gaps are found in 16 cases (the gap was equal to 3-5 mm) – 3% of all open joints.

Inadmissible large gaps in joints of clay pipes at non-availability of protecting filtering material (moss digestion) were the main reason of drainage cavity siltation and decrease of its operability at sites of Kupriyanovka and Kondokopshino.

Protective filtering material (PFM)

Moss and later glass-fiber mat was used as protective filtering material up to 1970-ies. Glass-fiber mat used in the form of strips as PFM is still preserved; its normal status is guaranteed practically in all cases of its usage (433 joints at collectors – 70.5% of opened clay pipe joints). There are single cases of rooting at glass-fiber mat surface (Picture 1).

Picture 1. PFM penetrated by roots

Moss used for protection of clay pipe joints rotted and only in several cases moss remains are present; in majority of cases even traces of this material are absent (sites Chyornaya rechka LPOOS, Mykkolovo, Prirezka and a part of Kondokopshino site) – 228 pits at collectors – almost 37% of opened joints. Protective material was not found at drains in 46 pits (24% of surveyed sites). In eroded and unstable soils it is the main reasons for essential siltation of clay pipes cavity, especially with large gaps at joints. At the site of Mykkolovo clay drains were penetrated with plastic couplings that also did not provide protection from siltation – up to 25% of drain cavities are silted. During survey it was stated that all types of PFM are preserved at polyethylene pipes.

Mud fill of PFM by ocherous compounds was found out in mouth parts of single drains at the site of Agrofirma Rassvet CJSC (Picture 2).

Picture 2. Ochreous deposits at PFM

Status of trench filling material

Taking into consideration that drainage with depth filter has been used practically at the end of large-scaled reclamation projects at major part of drained lands the drainage systems is constructed with drain padding by soil. Water receiving capacity of such drainage strongly depends on status of trench filling material. Surveys performed in 1986 noted intensive compaction of subsoil, and it was considered at that period as one of the main reasons for significant efficiency decrease of subsurface drainage systems at low permeability soils. That is why during current survey status of trench filling material has been subjected to obligatory examination. Status of trench filling material has been surveyed in 708 pits. It was found out during survey that:

-loose trench filling material with soil traces is found out in 396 pits (56%);

- condensed trench filling material is found out in 276 pits (40%), including 61 pit where trench filling was practically the same as ground itself;

- in 36 pits drain trenches are filled with peat;

- in 3 pits sand depth filter has been penetrated with height of 0.2 m;

- in 3 pits sand depth filter has height of 0.8 m;

- in 1 pit at Kondokopshino site filtering elements of textile manufacture waste were found.

Compacted drain filling, especially at sites consisting of heavy soils (Kondokopshino, Sobolevka, Mykkolovo, Prirezka 1, Choyrnaya rechka), is one of the main factors witnessing efficiency decrease of subsurface drainage. Examples of dtrais disctructions are shwown on a Picture 3.

Picture 3. Silty clay drainage pipe

Drains connection with collector

Drains connection with collector has been mainly performed by holes overlapping in drainage and collector network. 84 drain connections with collectors were found out, 68 are performed by clay pipes overlapping with holes adjustment, 16 are connected by means of plastic connection angles. Connections are mainly well preserved; in major part there are supports by stone or clay pipe; place of connection is wrapped by glass-fiber mat; for 5 connection moss was used as PFM (moss remains are found), in 17 connections there is no PFM; in 2 cases clay pipes were used with prefabricated holes. Siltation of pipe cavity at place of connection is found out in 8 cases (7 cases at Kupriyanovka site, 1 case – at Kondokopshino site); a cracked clay pipe is found out at one connection.

Status of pipes cavity in collector and drainage network

State estimation of collectors and drains cavities has been made during pipe cavities opening in 1,339 pits, including 630 pits at collectors and 718 pits at drains. Data about cavity status of collector and drain network are specified in the Table 1. More than half of surveyed collection network has clean cavity of pipes (336 pits – 53%), in 163 pits deposit fills up to 25% of pipe cavity (26%), siltation of more than 25% of pipe cavity is found out in 63 pits and in 68 pits more than 50% of pipe cavity is silted. In 3 cases (at sites of Kondokopshino and Sobolevka) root mass penetrated to pipe cavity. In 131 cases siltation occurred in the result of PFM non-availability (including moss rotting), inadmissible big gaps in pipe joints or collector destruction. Weediness of collection pipe cavity is found out in 3 cases in mouth part. Pipe cavity of almost 80% of collectors is clean or silted less than per 25% and collection network is in rater well operable status. To recover operability of a major part of collectors washing and repair of mouths will be sufficient. Siltation changes of collection pipe cavity were evaluated by 4 pits located in lower 120 m part of collector. Pits were located in the mouth in each 25-30 m. These data prove that there are no essential changes in siltation degree along the collector length (except for mouth). Major part (87%) of regulating network also has clean pipe cavity or a cavity with insignificant siltation (up to 25%). Intensive siltation at Podobedovka site is induced by destruction of drainage network by the pipeline constructed later that cut drainage. At sites Experimental Field and Central Department joints of clay pipes are compacted; siltation is induced probably in result of moss rotting as moss was used for protection at eroded unstable soils that did not allow creation of natural soil filter at joints of clay pipes. Significant siltation of drains at Kondokopshino site is induced by inadmissible large gaps in pipe joints (3-5 mm). All drains, except for mouth part of single drains at the site Prigorod of AgroRassvet CJSC, performed of polyethylene pipes have clean non-silted pipe cavity. At the mouth of drains at the site of Sobolevka root corks were penetrated.

Drain wells

For subsurface drainage network of Leningrad region small area of drainage systems is the most specific feature. That is why drainage systems include rather small number of wells. At 15 reclamation sites with total area of 1,686 ha statuses of 59 drainage wells have been evaluated. All wells turned out to be back-drop manholes made of reinforced concrete rings with diameter of 1.0 m. Only two wells are blind (one well at Kupriyanovka site and one well at Sobolevka site), other wells are inspection. Only 8 wells (14 %) out of 59 were in normal status; other wells were silted and 30 wells (51%) were destroyed. In 11 wells pipe joints were damaged. Main reason of wells destruction is displacement (or breaking away) of the upper ring, holes around the well. Upper ring breaking away and displacement with seal failure is induced mainly by agricultural equipment running during field works and in some cases (in cohesive soils subjected to frost heaving) by deformation in result of frost heaving. Upper ring were absent in part of wells. Practically at all wells setting vessel is silted or filled with waste, there are no covers. Thus, it is necessary to note that practically all wells (92%) at drainage network are in unsatisfactory status being at the same time an essential factor of drainage efficiency. Considering typical reason of well destruction, it is necessary to change well structure.

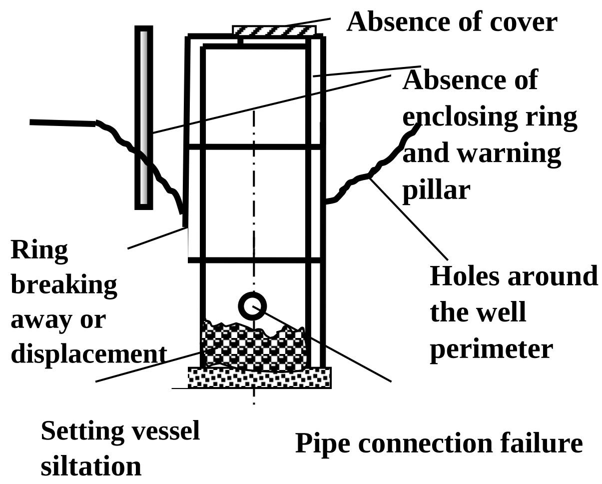

Figure. 1. Typical structure of drain well with specification of main deficiencies

Mouths

For the period of reclamation facilities survey 545 mouths were examined. The following facts were found out during the survey:
- 147 mouths are in normal condition (27%);
- 157 mouths are silted (29%);
- 241 mouths are destructed – mouth heads are displaced or absent;
- in 58 cases connection of mouth pipes with collector are damaged.

The biggest siltation degree and the biggest degree of root corks formation are specific for mouth part of collectors.

Excluding mouths of single drains at Prigorod site of Agrofirma Rassvet CJSC, ochreous formation at the mouth part was not found at the surveyed sites. At mouths of single drains at Prigorod facility ochreous formation at PFM is observed. Heads cut in to the bank are subjected to displacement most of all. Mouth walls mounted at the slope foot, as a rule, remain in better condition. It is necessary to note that washing of collectors in mouth part was not observed. Pipe joint failure indicates mainly use of short (less than 2 m) moth pipes.

Results and discussion

Even using just visual inspection without pipes disclosure is possible to determine factors affecting efficiency of pipe drainage systems, for example:

- afflux of drainage system by inlet channel or reservoir;

- distraction of pipe drainage system by later constructed facilities (line structures manly);

Some features of pipe drainage systems dysfunction these are requiring pipers disclosure:

- estuarial part of reservoir absence and allocation of drainage pipes on water-logged contours;

- water stagnation, wet spots or their traces presence on the territory drained by pipes.

Sludge setting of pore space of pipe drains is mainly occurs on unstable sandy and sandy clay soils. Pipes sludge setting causes decrease of intake and water transmission capacity in a drainage system. A pipe sludge setting around 30% decreases water transmission capacity on 40%, sludge setting on 70% causes decrease more than on 80%. Dependence of water intake capacity of pipe drainage on sludge setting level is presented on a Figure 2.

To improve efficiency of pipe drainage system is required to maintain in good conditions conductive channels receiving the drainage water, estuarial parts of reservoirs, dumb wells and pipe connections in dumb wells. In low water conductive subsoil water transmission of bulk filling is necessary to be estimated. Water transmission of bulk filling must be no less than 1.5 m per day. For areas where compaction and low water transmission capacity of bulk filling are found is recommended:

- carry out agroeliormative measures such us soil stratification and breaking up of compressed plough pan. Soil stratification depth must lay upper than drainage pipes layer;

- partial replacement of bulk filling with material of high filtering capacity by virtue of filtering stations and absorbing stations arrangement.

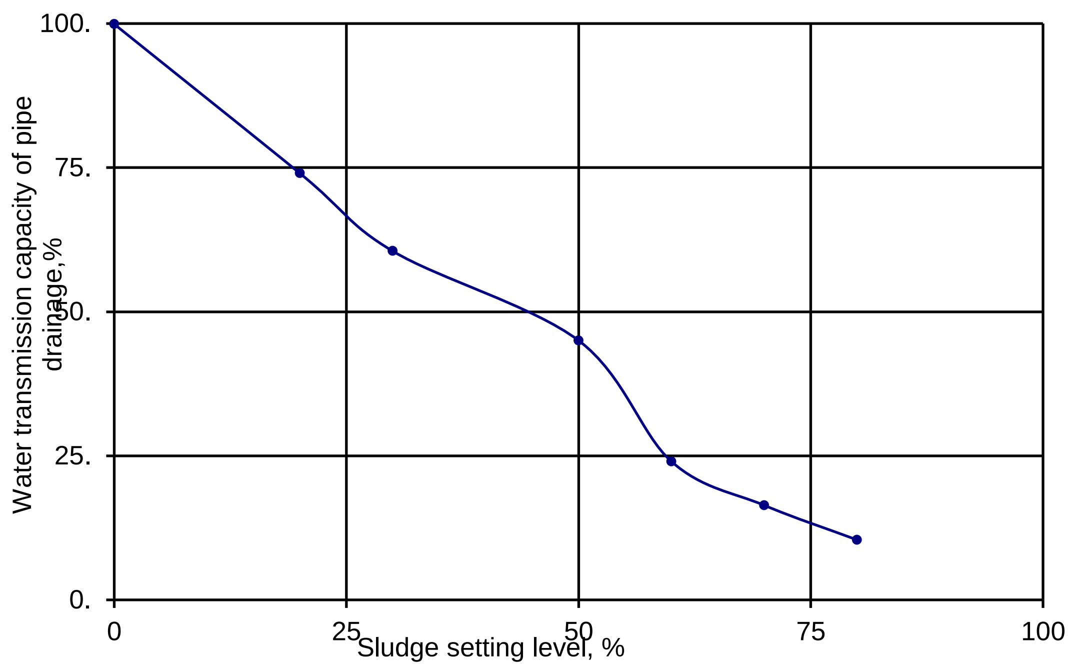

Figure 2. Dependence of water intake capacity of pipe drainage on sludge setting level

If drainage systems dysfunction caused by low-low cover thickness of drainage pipes, counter slopes of drainage lines, high-high gaps between clay pipes, displacement or drainage distraction then drainage functionality can be achieved only by reconstruction of damaged areas or by new drainage system creation. New drainage system arrangement must be preformed if sludge setting level of pipes exceeds 50% of dry mass. Pipe line flushing is the main measure of reconstruction of drainage systems. Pipe line flushing is recommended when sludge setting or chemical erosion cover more than 80 % of pipe section by the dry mass. Flushing of pipes is time-consuming process and efficient only in case if sludge setting found on no more than 30% of pipe section. Flushing provides cleaning of drainage pipe pores from clay sheet and rust and also provides restitution of water intake and water transmission capacity of pipes. Water pressure in a pipe should not exceed 20 mPas in order to prevent formed depth filter to be destroyed by manometric pressure. In other case pipe drain will be cleaned, but efficient field drainage will not be obtained. Capping mass in dependence on sludge setting intensity and pipe diameter is presented in a Table 1.

Table 1. Capping mass in dependence on sludge setting intensity and pipe diameter

Sludge setting intensity, %	Capping mass intensity,%	Capping mass volume / pipe diameter, м3/100 m			
		50 mm	75 mm	100 mm	150 mm
10	26	0,02	0,04	0,08	0,18
20	34	0,04	0,09	0,16	0,35
30	39,5	0,06	0,13	0,24	0,53
50	50	0,10	0,22	0,39	0,88
70	83,6	0,14	0,31	0,55	1,24
80	89,6	0,16	0,35	0,63	1,41

For development of design specifications and estimates for reconstruction and maintenance of pipe drainage systems is reasonable to carry out the development within two phases: the first one is field monitoring and dysfunctional pipes disclosure for listing of necessary documentation, and the second is project development.

Conclusion

1. One of the most efficient ways for rehabilitation of pipe drainage systems is pipes flushing with low pressure and considerable water expense;
2. To provide high long-term efficiency of pipe drainage system pipe flushing must be performed systematically.

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Topic 3:
Adaption of New Design Criteria in Favor of the Environment

EFFECTS OF VEGETATIVE BUFFERS ON SEDIMENT AND ITS ASSOCIATED POLLUTANTS TRANSPORT AND DEPOSITION

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Abstract

Silt and clay are primary carriers of adsorbed chemicals- especially phosphorus, chlorinated pesticides- and, most metals, and pathogens which are transported by sediment into aquatic systems. Sediments originate mainly from erosion of valuable topsoil of agricultural land. The control of agricultural pollution usually begins with measures to control erosion and sediment runoff.

Grass buffer strips impact overland flow hydraulics and consequently sediment delivery from hillslopes. Mathematical models facilitate the evaluation of performance of grass strips in reducing sediment delivery by simulating and predicting flow characteristics and sediment transport adjacent to and within grass strips. The GUSED-VBS 2 model has been developed to simulate flow, erosion and deposition processes in the upstream area and within grass strips.

The model is capable of estimating the proportion and amount of different sediment size classes in the outflow. The modified Green-Ampt equation was used to simulate infiltration. Gradually varied flow and a kinematic wave approximation were used to simulate flow characteristics upstream and within grass strips. The GUEST model was modified in order to use its basic approaches in the sediment transport module for grass strips. Model predictions agree well with measured data from a set of controlled experiments. The sensitivity analysis showed that the initial soil moisture and flow rate were the most sensitive parameters in predicting runoff loss. Increasing the slope steepness and flow rate dramatically decreased the efficiency of grass strips in reducing sediment concentration and sediment delivery.

Comparing the results of the model simulations for different prevalent scenarios showed that the backwater region upstream of dense grass strips is the main region for sediment deposition on low slopes. In agreement with the experimental observations, the model predicted the proportion of coarse particles to be higher in the deposited material upstream of grass strips compared with the deposited material within the grass strip. The efficiency of grass strips in reducing the concentration of sediment is much higher for coarser than finer particles. Grass strips can thus substantially decrease the delivery of fine particles if a significant reduction in runoff (i.e. infiltration) occurs within the strip. As no backwater forms on high slopes and the flow velocity is high in steep lands, particles will not have enough time to deposit ahead of the strip. Having long grass strips can amend the low trapping efficiency associated with extreme conditions such as high slope, wet soil and sparse grass strips by providing more opportunity for particles to settle and more runoff reduction. The new model is a tool to simulate transport and deposition of sediment along with its associated pollutants into the surface drains, rivers, lakes, wetlands and other receiving water bodies.

KEY WORDS: Model, Grass Strip, Sediment, Vegetated Strip.

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Introduction

Grass strips have been extensively tested and used to alleviate sediment and associated pollutants delivery to rivers (Abu-Zreig et al., 2004; Dabney et al., 1993; Hook, 2003; Parsons et al., 1994; Raffaelle et al., 1997; Rey, 2004). The two processes of increased roughness and infiltration enhance trapping of sediment particles upstream from and within grass strips (Akram et al., 2014; Deletic and Fletcher, 2006; Le Bissonnais et al., 2004; Schmitt et al., 1999; Shrestha et al., 2005).

A few models have been developed to predict the performance of grass strips in removing sediment. Although these models have helped decision makers, the models are not yet sufficiently accurate in some aspects and cannot explicitly describe the sediment transport and deposition processes in time and space.

The objectives of the paper are 1) to develop a new approach for predicting the fate of water and sediment in and around grass buffer strips, and 2) test the performance of this new model with two sets of controlled experiments, and 3) assess model sensitivity in order to clarify the effect and importance of various factors in the performance of grass strips. The highlight of this new model is the process-based simulation of the combined effect of buffer strips on sedimentation upstream and vegetation induced infiltration and sedimentation within the buffer strip. This has not been achieved in the papers reviewed above. The research by Hussein et al. (2007) which simulates the hydrology and sediment transport in the upstream section from grass strips is extended in this paper to include what occurs inside buffer strips. The model is based on Hairsine and Rose (1992) method, which assumes that soil erosion and deposition processes occur simultaneously.

Materials and methods

The model, hence called Griffith University Soil Erosion & Deposition-Vegetative Buffer Strips2 (GUSED-VBS 2), is a process-based model which simulates the deposition and erosion processes upstream and within grass buffer strips in single runoff events.

Following assumptions have been made in developing this model:

- The inflow is steady and subcritical.
- Deposition and re-entrainment (detachment of deposited sediment by overland flow) are the two main processes occur concurrently which change sediment concentration along the path.
- As the length of backwater is short and the permeability of bare soil is dramatically lower than vegetated ground, infiltration is neglected in the upstream region.
- Particles are trapped due to infiltration regardless of their size.
- Deposited mass due to infiltration settles on the soil top and does not percolate within.
- Vegetation is non-submerged.

Hydrology and sediment transport are modelled primarily in the upstream region. Water depth and sediment concentration of different particle size classes at the upstream end of backwater region in every time step are considered as initial conditions within buffers. Gradually varied flow equation is used to calculate flow characteristics upstream the grass strip:

$$\frac{dD}{dx} = \frac{S_0 - S_f}{1 - Fr^2} \tag{1}$$

where D is the water depth (m), x is the downslope distance (m), S_0 is the bed slope (m m^{-1}), S_f is the frictional slope (m m^{-1}), and Fr is the Froude number.

Change of sediment concentration over distance is calculated using the following equations:

$$q\frac{dc_\mathrm{i}}{dx} = -v_\mathrm{i}c_\mathrm{i} + Hr_\mathrm{max}\frac{v_\mathrm{i}c_\mathrm{i}}{\sum v_\mathrm{i}c_\mathrm{i}} \tag{2}$$

$$r_\mathrm{max} = \frac{F\sigma(\Omega - \Omega_\mathrm{o})}{g(\sigma - \rho)D} \tag{3}$$

$$\Omega = \rho g q S_f \tag{4}$$

where q is the unit flow rate (m^3 m^{-1} s^{-1}), c_i is the sediment concentration in size class i (kg m^{-3}), v_i is the fall velocity for size class i (m s^{-1}), H is the ratio of soil covered by deposited sediment to the whole area, r_{max} is the maximum rate of entrainment (kg m^{-2} s^{-1}), F is the available stream power available for entraining particles, σ is the wet density of sediments (kg m^{-3}), Ω and Ω_o are stream power and threshold stream power per unit area (W m^{-2}), and ρ is the water density (kg m^{-3}).

The distribution of particle size classes is to be given as input data to the model. Settling velocity for every class is estimated using Cheng method (Cheng, 1997):

$$v_\mathrm{i} = \frac{\left(\sqrt{25 + 1.2{d_*}^2} - 5\right)^{1.5}\vartheta}{d} \tag{5}$$

$$d_* = \left(\frac{(\sigma - \rho)}{\rho\vartheta^2}g\right)^{1/3} d \tag{6}$$

where v is the kinematic viscosity (m^2 s^{-1}), and d is the mean diameter of the particle size class (m). Cheng method is applicable to both laminar and turbulent flow regimes.

Deposition and entrainment processes change the bed elevation. The model is able to dynamically change the slope by:

$$\frac{dz}{dt} = -\frac{q}{\sigma(1 - \lambda)}\frac{dc}{dx} \tag{7}$$

$$S_0 = \frac{dz}{dx} \tag{8}$$

Where z is the bed level (m), $\boldsymbol{\lambda}$ is porosity, and t is time (s).

Equations 1 to 8 are identical to those used in Hussein et al. (2007).

The processes within grass strips are more complex. Infiltration intensifies particles settling; the infiltration rate is therefore also added to the settling velocity of each particle size class. The other complexity of the processes within the grass strip is that the flow is gradually varied, and unsteady.

Kinematic wave approximation is used in order to predict flow characteristics spatially and temporally along grass strip by the following equations:

The continuity equation:

$$\frac{\partial q}{\partial x} + \frac{\partial D}{\partial t} = -f \quad (9)$$

Manning formula is used as the momentum equation:

$$q = \frac{1}{n} D^{5/3} {S_f}^{0.5} \quad (10)$$

where f is the infiltration rate (m s^{-1}), and n is the equivalent Manning roughness coefficient inside grass strips.

The surface flow module is coupled with the Infiltration module which is based on modified Green-Ampt method:

The continuity equation:

$$\frac{\partial y}{\partial t} = \frac{f}{\theta_s - \theta_i} \quad (11)$$

Darcy's formula is used as the momentum equation:

$$f = K_s \frac{|h_c| + y + D}{y} \quad (12)$$

where y is the depth of wet front (m), θ_s is the water content of the soil while saturated, θ_i is the initial water content of the soil, K_s is the saturated hydraulic conductivity (m s^{-1}), and h_c is the capillary fringe pressure (m).

As the actual cross section area within a grass strip is lower than calculated one (due to the area covered by leaves and foliage), following equation is used to estimate the actual flow rate:

$$q_a = \frac{q}{(1 - Bl)} \quad (13)$$

Where q_a is the actual flow rate (m^2 s^{-1}), and Bl is the fraction of cross section which is covered by stems and foliage.

Sediment transport processes are described by the following equation:

$$q_a \frac{dc_\mathrm{i}}{dx} = -\,(v_\mathrm{i} + f)c_\mathrm{i} + Hr_\mathrm{max}\frac{v_\mathrm{i}c_\mathrm{i}}{\sum v_\mathrm{i}c_\mathrm{i}} \tag{14}$$

Changes in topography over time within grass strips are calculated using the following equation:

$$\frac{dz}{dt} = -\frac{1}{\sigma(1-\lambda)}\frac{d(q_a c)}{dx} \tag{15}$$

Computational scheme and numerical solutions

Upstream the grass strip

The flow rate and sediment concentration upstream the backwater region are assumed to be steady and to be given to the model as input data. The water depth at the upstream edge of the backwater region is equal to the normal depth of the flow over the bare soil. The downstream depth of water in the backwater region is the normal depth of the steady flow over the grass strip.

The equations for predicting the flow and sediment characteristics upstream the grass strip (eqs 1 and 2) were solved using the fourth order Runge-Kutta method. As the downstream water depth which is equal to the normal depth of the flow within the grass strip is the control point for solving equation 1 and the concentration of particles of different size classes upstream the backwater were control points for equation 2, the two equations solved separately and results from equation 1 were used for solving the equation 2. The equations were solved at every time step taking the topography at the end of the previous time step as the initial condition for the next time step.

Within the grass strip

The sediment concentrations of different particle size classes at the entrance of the grass strip, which are the outputs of the "upstream" module, are taken as the upstream boundary condition for the "within the grass strip" module. The flow rate considering the infiltration rate at every time step at the lower edge of grass strip is a boundary condition for the numerical calculations. The water depth at the lower edge is equal to the normal depth of the corresponding flow rate over the bare soil.

The ordinary differential equation of the infiltration module (Eq 11) was solved using the fourth order Runge-Kutta method. The kinematic wave module was numerically solved utilising finite difference techniques. Fully implicit method was used to solve the kinematic wave partially differential equations (Eqs 9 and 10). Equation 14 was solved using fourth order Runge-Kutta method.

Model application and validation

The performance of the model in predicting the fate of water and sediment in and around grass strips was evaluated by comparing the model outcomes with the results of a set of experiments. conducted by Jin and Romkens (2001) in an experimental flume using artificial grass.

The tests were carried out in a laboratory flume evaluating the effects of different grass densities, bed slopes, flow rates, particle size distribution, and concentrations on fate of sediment upstream and within the vegetated area. Vegetation was simulated with polypropylene bristles which were inserted and glued in a staggered pattern. The surface was impermeable and infiltration effects were not tested. The length of grassed part and the upstream zone were 2.4 and 1.2 m respectively. Two different densities of 2500 and 10000 bunches of four bristles per square meter were used to see the effects of grass density on sediment retention. Three different particle size distributions of coarse sand, fine sand, and silt loam were used in a steady run-on to evaluate the effectiveness of grass strips in the fate of different particle sizes and combinations. Sediment was uniformly mixed in a tank and steady flow was distributed in the flume. Durations of the events were between 80 and 140 minutes.

Deposited sediments in the upstream area, upper half, and lower half of the grass strip were collected after every event. The collected samples were oven dried and sieved through a series of sieves to measure the fraction of different size classes in the deposited sediment. Run-on samples were also collected every two or three minutes at the outlet to measure concentration of different size classes in the pass through flow. More details can be found in Jin and Romkens (2001).

The parameters used to simulate the experimental conditions in the model are as Table 1.

The model results were compared with the observed data using different evaluation techniques.

The "Bias" of the model was calculated from the model predictions and the observations as:

$$\text{Bias} = \frac{\sum M_i}{\sum O_i} \tag{16}$$

where M_i and O_i are modelled and observed data respectively. The Bias criterion shows whether the model over-estimates or under-estimates the observations on average.

Table1. Model parameters and their values for Jin and Romkens (2001) experiment

Module	Parameter	Symbol	Unit	Values (Jin and Ramkens, 2001)
Hydrology	Buffer width	b	m	0.64
	Buffer length	L_{in}	m	2.4
	Upstream length	L_{up}	m	1.2
	Upstream Manning coefficient	n_{up}	s $m^{-1/3}$	0.015
	Grass Manning coefficient	n	s $m^{-1/3}$	0.075 in low density 0.12 in high density
	Width blocked by grass	Bl	-	0.01 for low density 0.04 for high density
	Flow rate	Q	L s^{-1}	1.45-7
	Surface slope	S_0	%	2-6
	Infiltration rate	f	m s^{-1}	0
Sediment	Kinematic viscosity of water	v	m^2 s^{-1}	10^{-6}
	Sediment concentration	c	kg m^{-3}	1.44-7

Effective excess stream power	F	-	0.1 in upstream area 0.002 in grassed zone
Water density	ρ	kg m^{-3}	1000
Sediment density			2630 for coarse sand 2630 for coarse sand 2520 for silt loam
Deposited sediment porosity	λ	-	0.4
Threshold stream power	Ω_0	kg m^{-3}	0.008

The observed data of grass strips of different conditions were also compared to the model predictions. The coefficient of model efficiency *Ec* (Nash and Sutcliffe, 1970) was calculated from the observations and model output as:

$$Ec = 1 - \frac{\sum(O_i - M_i)^2}{\sum(O_i - \bar{O})^2} \quad (17)$$

Where $\bar{O}$ is the average of the observed values. The model efficiency measures the level of accordance between the modelled and observed values. *Ec* value of 1 indicates perfect agreement. The *Ec* value can be negative, indicating the model predictions are worse than those predicted with the average observed values

In addition, the root mean squared error (*RMSE*) was calculated as:

$$RMSE = \sqrt{\frac{1}{N}\sum(O_i - M_i)^2} \quad (18)$$

Where *N* is the number of observations. *RMSE* quantifies the error in the modelled values in the unit of the original variable. *RMSE* equal to zero shows the perfect fit and the lower the *RMSE* value, the better the agreement. *RMSE%* (*RMSE/*$\bar{O}$) was also calculated to represent the relative magnitude of errors.

Results and discussion

The model was run for every scenario tested in the first set of experiments (Jin and Romkens, 2001) and Table 2 shows the performance indicators for this set of flume experiments.

Table 2. Model performance indicators for three predicted variables of importance to the effectiveness of vegetation buffer strips

Variable	Bias	Ec	RMSE	RMSE%
Water depth in grass strip (m)	1.07	0.95	0.01	8
Efficiency in trapping sediment (%)	0.99	0.58	12.70	-
Fraction of different size classes in the outflow (%)	1.01	0.67	6.62	69

As it is shown in Table 3 the model predicts the water depth within the grass strip with high accuracy. The model predictions for the efficiency of grass strips in reducing sediment concentration and the particle size distribution in the outflow are also quite accurate. Figure 1 shows the observed and modelled efficiencies for a total of 28 runs of the flume experiment.

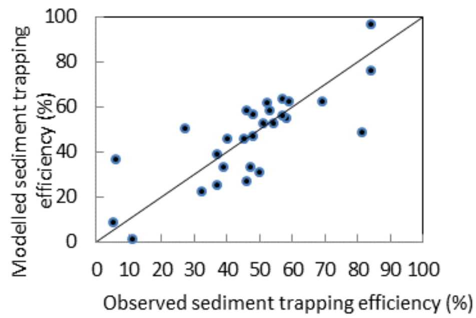

Figure 1. Observed versus modelled efficiency of grass strips in reducing sediment outflow

The distribution of different particle size classes in the deposited sediment upstream the grass strip for different inflow particle distributions is shown in Figure 2. The fraction of fine particles is less than that of in the inflow in both observed and modelled data. The model has predicted that there cannot be any deposition of particles finer than 106 μm in the upstream area, while it actually happened. However the fraction of particles finer than 106 μm in the observed deposited sediment upstream the grass strip was considerably lower than that of in the inflow. The proportion of coarse particles was higher than that of in the inflow in both observed and modelled data while the model over-predicts it in the upstream region.

Figure 3 shows the observed and modelled distribution of different particle size classes in the deposited sediment in the upper half of the grass strip for different inflow sediment types. The proportion of finer particles is higher in this area compared to the upstream region in both modelled and observed data. As the model over-predicted the proportion of coarse particles in the deposited sediment upstream the grass strip, consequently the predictions show lower fraction of coarse particles in the upper half deposited sediment.

High resistance of the grassed area and high infiltration capacity within the grass strip enhance sediment deposition upstream and within the buffer strips. Changes to the water profile because of the presence of grass strips reduce the flow friction slope and consequently the stream power. This increases the deposition rate comparing to non-grassed areas. Infiltration not only reduces the mass of sediment in the outflow, but also lowers the flow velocity by decreasing the flow rate, which enhances settling of particles.

As an illustration, Figure 4 shows a slope of 1 m in length with 50 cm upstream and 50 cm within the grass strip, and the modelled water surface and deposited sediment profiles in a hypothetical grass strip after 10 and 30 minutes of a runoff event over the slope. The particle size distribution is the same as the fine sand in Jin and Romkens (2001) test. As Figure 4 shows that the deposited sediment increases over time, the location where the maximum rate of deposition occurs migrates towards the grass strip. The length and depth of the backwater region upstream the grass strip increases over time. The reason is that the depth and length of deposited sediment in the upstream area increases in time. The rate of deposition in the grassed area is much lower comparing to the upstream region because of the high rate of deposition of coarser particles upstream the grass strip. The flow velocity is also higher within the grass strip than in the upstream section. Figure 4 also shows that the water depth decreases slightly downstream within the grass strip due to infiltration, and the decrease becomes less pronounced with time as infiltration is reduced from the 10th to 30th min.

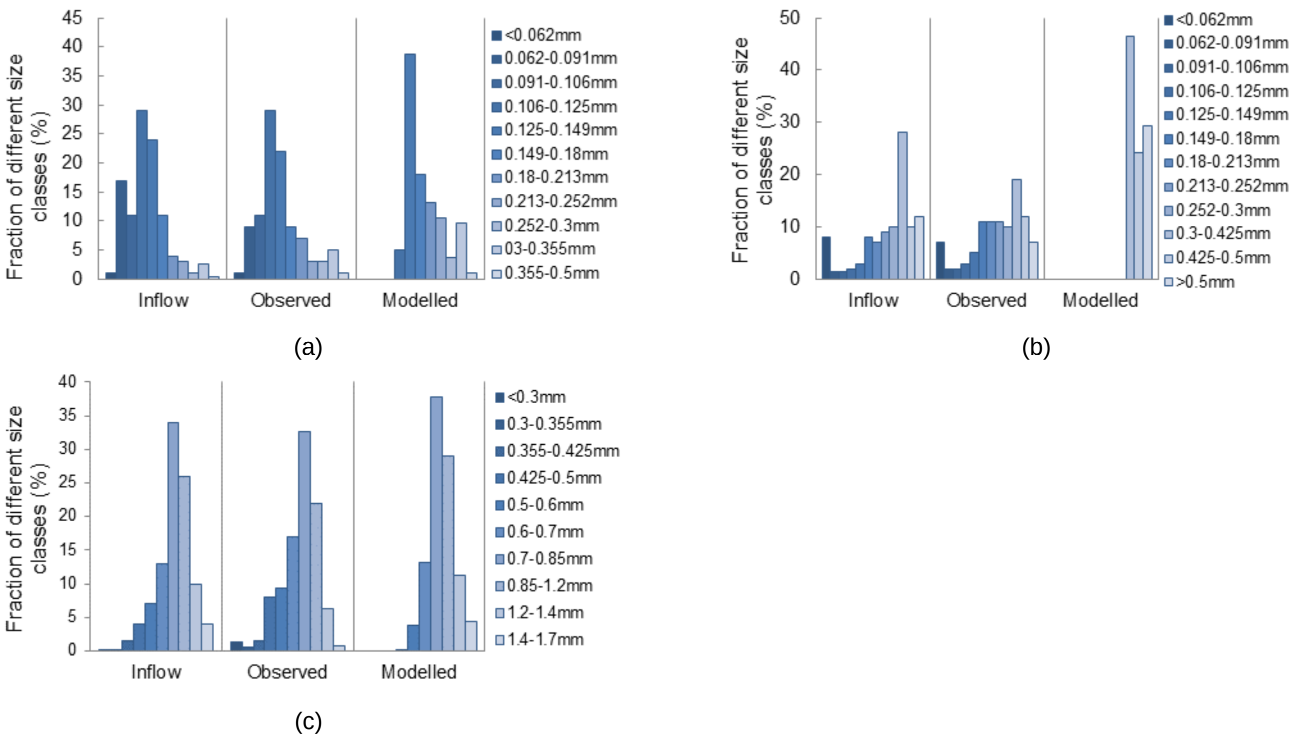

Figure 2. The proportion of different particle size classes in deposited sediment upstream grass strip. a) Run 02, b) Run 05, c) Run 07

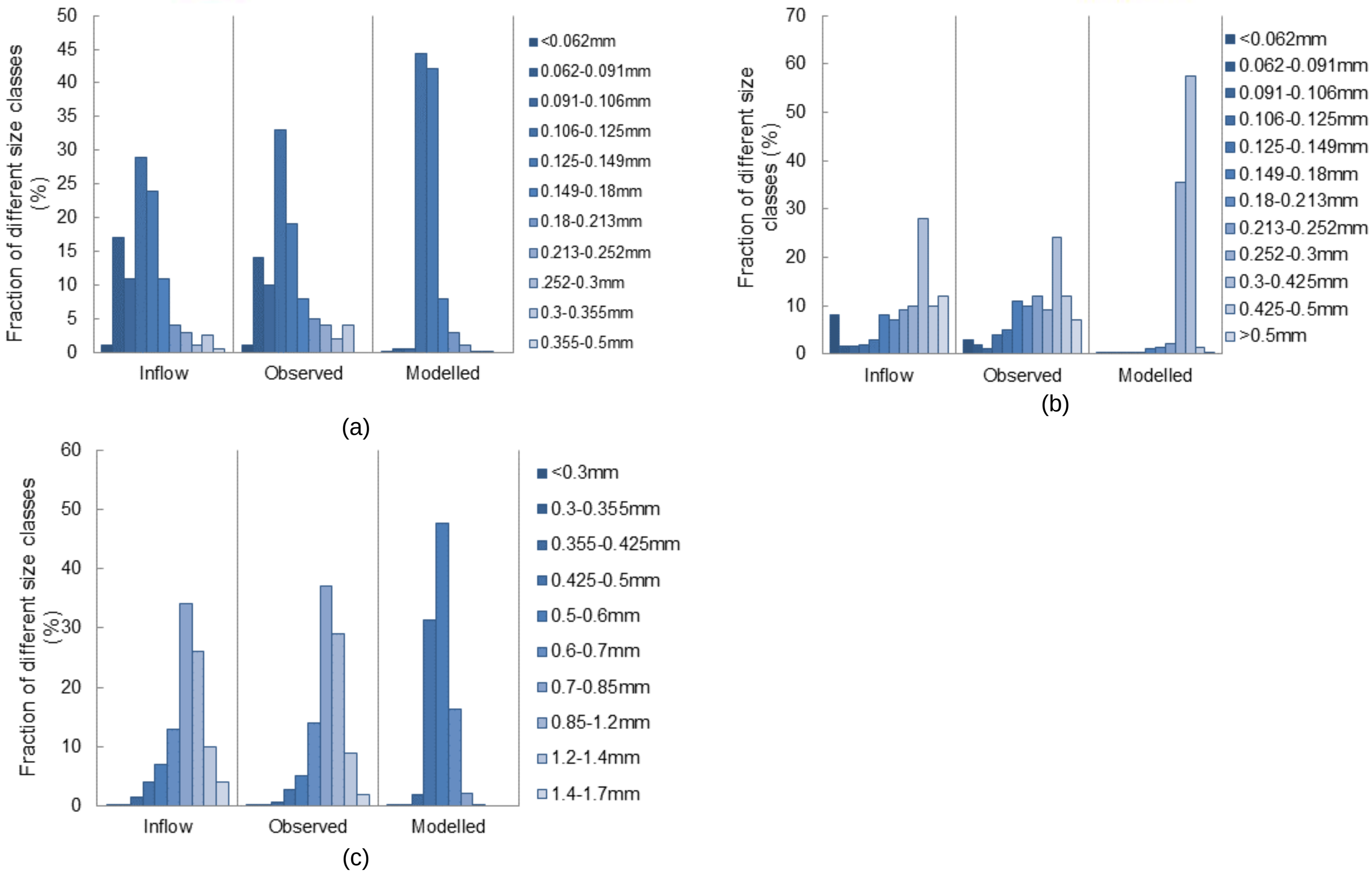

Figure 3. Distribution of different particle size classes in deposited sediment in the upper half of grass strip. a) Run 02, b) Run 05, c) Run 07

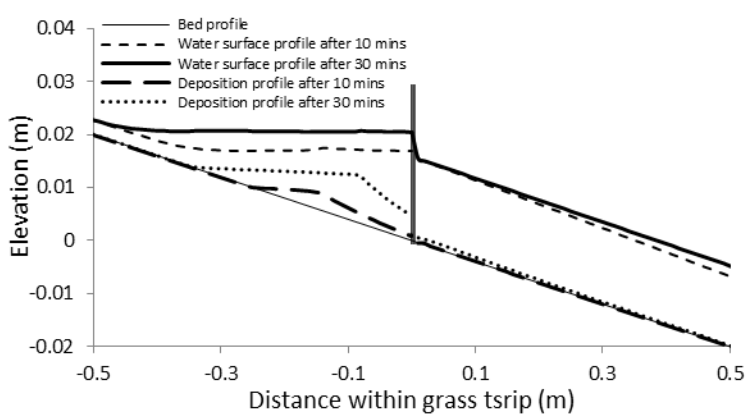

Figure 4. Simulated water surface and deposited sediment profile upstream and within grass strip with q=0.001 $m^2 s^{-1}$, S_0=4%, n=0.2, Ks=10^{-5} m s^{-1}, θ_s=0.43, and θ_i=0.3

Sensitivity analysis was performed to estimate the uncertainty of the model outputs based on uncertainty in different input parameters. The ranges of input parameters for conducting the sensitivity analysis are presented in Table 3. The minimum and maximum values of these parameters all differ by a factor of 4 to allow a consistent comparison. The distribution of particle size classes is the same as the fine sand in the Jin and Romkens (2001) experiment. The fixed values of the parameters are presented in Table 3. Sensitivity of these 7 parameters was evaluated one at a time. When the value of a parameter was changed, the remaining parameters were held at these fixed values according to Table 3. In order to be able to compare the effectiveness of different parameters in reducing runoff, and sediment concentration and mass, parameters were normalised as following:

$$\acute{X} = \frac{X - X_{min}}{X_{max} - X_{min}} \tag{19}$$

where X' is the normalised factor, X is a model parameter, and X_{min} and X_{max} are the minimum and maximum values of this parameter respectively.

Table 3. Range of input parameters for sensitivity analysis

Parameter	q ($m^2 s^{-1}$)	Manning's n	L (m)	K_s ($m s^{-1}$)	θ_i	S_0 (%)	Duration (min)
Range	0.0005-.002	0.1-0.4	1-4	$2*10^{-5}$-$8*10^{-5}$	0.1-0.4	2-8	20-80
Fixed value	0.001	0.2	2	$4*10^{-5}$	0.3	4	40

The effect of different parameters on runoff reduction is showed in Figure 5. As Figure 5 shows the performance of grass strips in reducing runoff is most sensitive to the initial soil moisture. When the initial soil moisture is high the efficiency of grass strips in runoff reduction is dramatically lower comparing to initially dry soils. Figure 5 also shows that changes in flow rate effects the performance of grass strips in runoff reduction. As flow rate increases from low to medium or high rates, the volume of water infiltrates the soil dramatically decreases. The length of the grass strip is also as effective as the flow rate. The runoff reduction is considerably higher in long strips comparing to short ones. Slope steepness and hydraulic roughness did not have significant effect on runoff reduction, so are not illustrated in Figure 5.

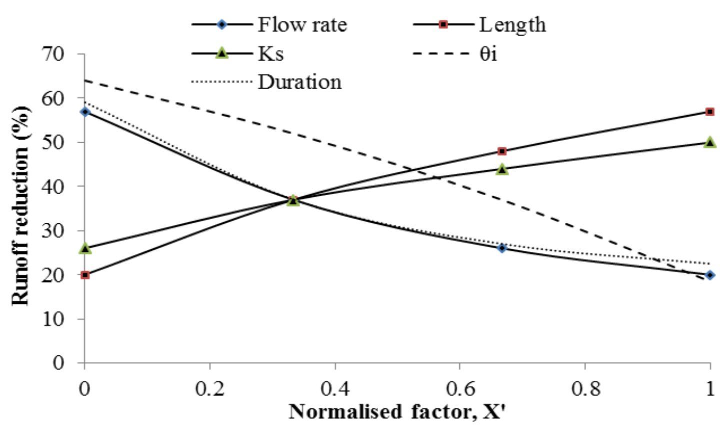

Figure 5. Effectiveness of different factors in efficiency of grass strip in runoff reduction

Figure 6 shows the sensitivity of grass strips in reducing sediment concentration in the outflow to variation in different parameters. Slope steepness is most sensitive to the reduction in outflow sediment concentration due to grass strips. As slope increases from 2% to 8% the backwater region upstream the grass strips tends to contract to an area close to the grass strip, hence limits the amount of deposition upstream, and leads to higher concentrations in the outflow. The rate of sediment deposition decreases in high slopes due to high flow velocities. Stream power is also higher in steeper fields and that enhances the re-entrainment process. The efficiency of grass strips also decreases dramatically as the flow rate increases.

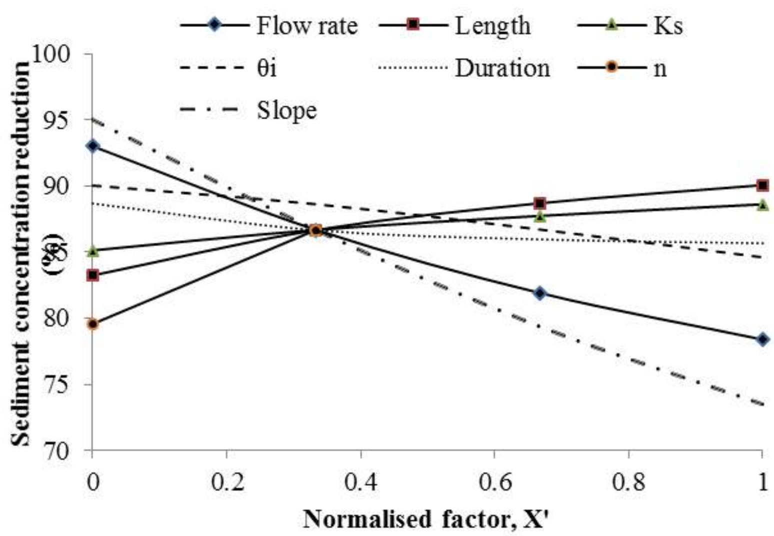

Figure 6. Effectiveness of different factors in efficiency of grass strip in reducing sediment concentration

Figure 7 illustrates changes in sediment mass reduction in grass strips in varied input parameters. Similar to Figure 6, slope is the most important factor in reducing sediment mass. The significance of flow rate in sediment delivery reduction by grass strips is almost as high as slope steepness as the efficiency of grass strips in reducing sediment delivery is considerably lower in high flow rates comparing to low flow rates. The effect of initial soil moisture is more pronounced in reducing the mass comparing to the concentration.

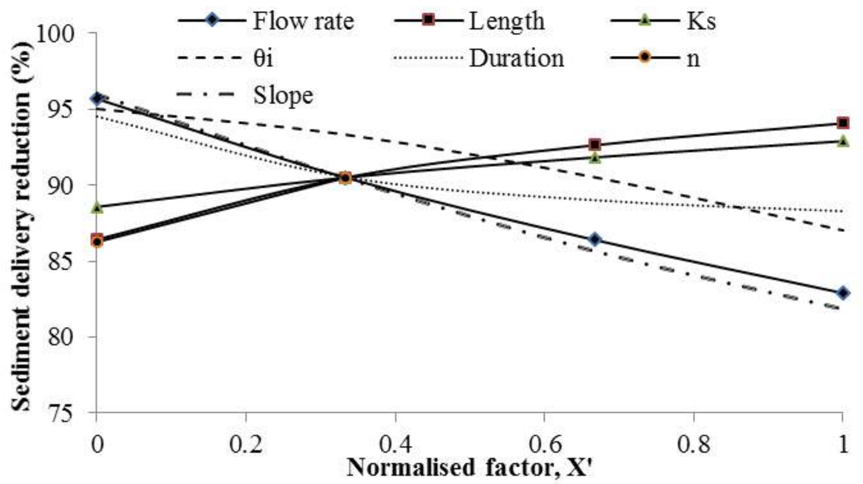

Figure 7. Effectiveness of different factors in efficiency of grass strip in reducing mass of sediment

Conclusion

A process-based model was developed in order to predict and simulate the fate of water and sediment in and around grass strip. As the size of sediment particles is very important in order to use the model for water pollution predictions, the model calculates the concentration and mass of sediment in the outflow for different particle size classes separately. The model consisted of hydrology and sediment transport sub-models. The two sub-models primarily model flow and sediment transport in the backwater area upstream the grass strip and these backwater simulation results specify the conditions of the grass strips upstream edge.

Modified Green-Ampt method is used to calculate the infiltration rate over time and distance. Gradually varied flow equation and kinematic wave approximation were used to simulate flow characteristics upstream and within the grass strip respectively. The Hairsine and Rose (1992) module for predicting water erosion and deposition in sheet flow is modified in order to be used in grass strip.

The model outputs were compared with a set of experiments carried out in controlled conditions. The model predictions of flow and sediment transport characteristics were accurate. The sensitivity analysis showed that the initial soil moisture of the grass buffer strip is the most sensitive parameter in predicting the runoff loss. Increase in the slope steepness and the flow rate dramatically decreases the efficiency of grass strips in reducing sediment concentration and delivery. The efficiency of grass strips reduces over time during events.

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COMPARISON OF THE BENEFIT FOR APPLYING SHALLOW DRAINAGE METHOD OF FOOD CROPS AND DEEP DRAINAGE OF TREE AT THE RECLAIMED LOWLANDS IN JAMBI-INDONESIA

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Abstract

This research focuses on the projection of an irrigated tidal peat-swamp in the Rantau Makmur village, Jambi, Indonesia, in order to assess the impact of peat losses due to the drainage system. Several drainages scenarios were considered carefully to find the best scenario suitable for the region. In order to quantify the impact of drainage, we developed a 3-D (x,y,t) EmSub model. The model can be used to estimate the CO_2 emissions due to peat oxidation, as well as the estimating of the subsidence based on soil consolidation and peat losses. Short-term simulation for 4 years showed a good agreement between the simulated subsidence and the observational data. Therefore, the utilization of this model for a long-term projection may be promising. The impacts from various scenarios are investigated using 100 years simulation. The model shows clearly that the deep water table causes more CO_2 emission and more subsidence than the shallow water table. Every plant has a different drainage depth. Two groups of plants have been introduced: 1) Tree crops (industry and forestry) which live on deep water table (acacia and palm oil); 2) Food crops which live on shallow water table (paddy). The simulations show that tree crops release abundant CO_2 emission and strong subsidence which lead to not-usable soils due to inundation. Therefore, profit/loss ratio of food crops drop significantly and is less than tree crops. In general, the model shows that tree crops group (acacia, palm oil, rubber, jelutong) contribute largely to CO_2 emission and subsidence. This may be related to the depth of drainage. In addition, high CO_2 emission and large subsidence could reduce profit margins significantly. In particular, the highest rate of CO_2 emission and subsidence is triggered by acacias, which need a very deep water table. Detailed results and discussions of every plant are shown in this paper. This will help users and decision makers to choose the best scenarios for long-term land management planning in the study area.

KEY WORDS**:** Spatial model, Drainage, Peat swamp, Subsidence, CO_2 emission.

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Introduction

Previous study has shown that drained peat swamp could release significant CO_2 emission and cause rapid land subsidence due to peat oxidation (Hooijer et al., 2001). However, the method used for calculating the CO_2 emission is still under debate. This study, therefore, propose a numerical method to simulate groundwater flow in peat swamp and estimate the impact of various drainage scenarios. Aswandi et al [2015] have developed a groundwater model for a tidal peat swamp, which was coupled with open-canal system in 3-dimensional (x,y,t) frame. They named the model as Groundwater-Canal Flow (GCFlow) model. Based on their model, this study introduces a model for simulating CO_2 emission and land subsidence, so-called the Emission-Subsidence (EmSub) model. The EmSub model uses predefined water table map calculated by GCFlow model to estimate the amount of CO_2 loss and subsidence in various drainage scenarios. Based on estimated CO_2 emission and land subsidence, we evaluate the impact of drainage on food crops and various forest scenarios.

Materials and methods

Research site is located in an irrigated block in Berbak Delta, Jambi, Indonesia, with an area of ±100 ha bounded by two primary canals and two secondary canals (Figure 1). It is B/C typology class land where always inundated during high tide, or where the water will come only during high tide.

Figure 1: Research Site in the Berbak Delta, Jambi-Sumatera, Indonesia

In this research, two main models were developed. The first model is the GCFlow model, which has been developed in our previous study [Aswandi *et al*., 2015]. The second model is the EmSub model, which simulates CO_2 emission and land subsidence. Firstly, the GCFlow model is run for 365 days to get 1-year averaged water table. Outputs from the GCFlow model were used as input for 100-years simulation of the EmSub model. As the land subsides, drainability limit of the land is calculated which is used to reveal"age of usable land" and percentage of land condition in each year. Finally, we calculated the profit/lost ratio by comparing the crop productions and profit with CO_2 losses.

Model design

There two main components in the EmSub model, those are the CO_2 emission and the land subsidence. Note that the CO_2 emissions come from peat decomposition To calculate CO_2 emission, we use a proxy that relates annual average of CO_2 emissions rate per one meter of water table depth. Thus, this component uses the annual average of ground water table as the input. While the component of land subsidence (*hereafter* subsidence – S) consists of two sub-components; (a) subsidence due to oxidation of peat mass loss (S_E) and (b) physical compaction (also called consolidation) as a result of changes in effective stress in Terzaghi model (S_C). Therefore, total Subsidence (S) is sum of these two: $S = S_E + S_C$. (1)

Subsidence due to the loss of peat mass is converted from annual CO_2 emission rate based on the content of C and bulk density of peat. It uses annual CO_2 emissions as input. While the consolidation component uses the lowest ground water level as input.

The CO_2 emission and subsidence scheme

The model uses horizontal partitions on *X-Y* axis with an annual time-step. The CO_2 emission using the annual groundwater level as a proxy can be formulated as follows.

$$E_{i,j,k} = c\left(H_{top,i,jk} - H_{i,jk}\right), \quad (2)$$

$$H_{top,i,j,k} = H_{top,i,j,k-1} - S_{i,j,k-1}, \quad (3)$$

where E is the rate of annual CO_2 emissions due to peat oxidation, H_{top} is the elevation of the land surface relative to the averaged sea level (L) and S is the subsidence (L). In addition, the coefficient of CO_2 emissions rate in the peat land is defined as c ($ML^{-3}T^{-1}$) (M, L, and T are unit for mass, length, and time, respectively). i, j, k are the indices representing the column, row, and layer, respectively. Hooijer proxy explains that for each depth of the ground water level of 1 m, the rate of CO_2 emissions amount to 90 ton ha^{-1} per year, or 9 kgm^{-3} per year. The CO_2 emissions can be converted into components of subsidence (S_E) with the following equation,

$$S_{E,i,j,k} = \frac{E_{i,j,k}\left(\frac{M_C}{M_C + 2M_O}\right)}{\rho_{b,i,j,k} N_C}, \quad (4)$$

where M_C and M_O are the atomic weight of carbon and oxygen (kg/mol), respectively.
Meanwhile, ρ_b and N_C are bulk density (L^3M^{-3}) and fraction carbon content of peat (MM^{-1}), respectively On the other hand, subsidence due to compaction (S_C) consists of primary and secondary consolidation components, which can be calculated with the following equation,

$$S_{C,i,j,k} = L_{0,i,j,k}\frac{C_c}{1+e_{0,j,j,k}} log\left(\frac{P_{0,i,j,k} + \Delta P_{i,j,k}}{P_{0,i,j,k}}\right) + L_{0,i,j,k}\frac{C_\alpha}{1+e_0} log\left(\frac{t}{t_0}\right), \quad (5)$$

where L_0 is the initial thickness of the peat layer, C_c and C_α are the indices for primary and secondary compression (no units), e_0 is the initial void ratio (LL^{-1}), while P_0 and ΔP respectively represent the initial effective stress and change in effective stress due to decrease in ground water level ($ML^{-1}T^{-2}$). Meanwhile, t and t_0 respectively represent the time parameter and the time at the beginning of secondary consolidation. The first term in the right hand side of represents primary consolidation, while the second term represents secondary consolidation. Primary consolidation takes place very quickly (in a few days or weeks), while the secondary consolidation is lasting longer over years. In our simulation, the primary consolidation is defined to zero because the first drainage was done in past years.

Effective stress is assumed as weight of peat mass minus buoyancy of groundwater. Effective stress increases when the water level decreases (deeper water table). Effective stress during pre-drainage (or pre-dredging) is calculated based on the lowest ground water level before the drainage, and it is written as

$$P_0 = \rho_b g L_0 - \frac{\rho_b}{\rho_s} \rho_w g H_0 , \quad (6)$$

WhereP0 is the largest effective stress at initial pre-drainage or pre-dredging ($ML^{-1}T^{-2}$). g is the gravitational acceleration constant (LT^{-2}). ρ_b, ρ_s and ρ_w are respectively the bulk density of peat, the density of peat particles, and the density of water (ML^{-3}). H_0 is ground water level calculated from the water table to the bottom of peat (L).

During drainage, effective stress can increase due to lowering of water table and can be calculated as follows,

$$P = \rho_b g L - \frac{\rho_b}{\rho_s} \rho_w g \left(H_0 - \Delta H \right). \quad (7)$$

P is the largest effective stress after drainage ($ML^{-1}T^{-2}$) and ΔH is the change in ground water level depth (L). By calculating the subsidence, the surface elevation can be simulated dynamically. Note that the simulated subsidence is used for estimating the surface elevation, the peat depth and the ground water level of the next year. Therefore, we may say that our model can simulate the spatial and dynamical process of the water table.

The age of usable land

The spatial-map of age of usable land can be calculated based on the output of elevation that has been simulated. First, we calculate gravity-drainability limit with Euclidian distance method which is controlled by the nearest boundaries of the river or the sea. Drainability limit (E_{dr}) is calculated as: $E_{dr} = E_b + 0.00002D$ (8)

Where E_b is the elevation of the nearest river or sea, D is the shortest distance to the boundary of the river or the sea, and the constant of 0.00002 is the gravity-drainability slope coefficient, which means 2 cm/km. If the elevation is lower than E_{dr}, then the land is no longer used and thus reduces the productivity of the crop. This map will be created in a grid format with a unit cell size of 10 m. Size of the usable zone tends to decrease due to subsidence. Agricultural cultivation can only be done on a drainable zone (i.e gravity-drainable zone), by assuming that there is no mechanical pumping performed gravity-drainability when the limit is reached.

Profit/loss ratio of crops production

This is a simple model that aims to calculate the ratio of profit/loss of a crop scenario. The model takes into account the potential revenue from the sales profits and potential losses due to emission and/or subsidence, and then calculates their ratio. Calculation period is divided into per-life of each plant and per 100 years. In this model, we assumed that 1 ton CO_2 loss costs about USD 5.5 or equivalent to IDR (Indonesian Rupiah) 77,000.

Model resolutions and assumptions

The spatial models run with 10 × 10 m spatial resolution. *EmSub* model uses 1-year time step for calculation. In profit/loss model, it is assumed that the crop prices and expenses are constant. For each crop scenario, the harvest time is only once a year. The drainage values for combined-plants scenarios are weighted based on the age of the plant. For example, plant A has life time of 3 months with 0.3 m drainage depth, while plant B has life time 5 months with 0.5 m drainage depth. Scenario for combined plant A and B has annual drainage depth of $(0.3 \times 3/8) + (0.5 \times 5/8) = 0.425$ m.

Results and discussion

Data preparation and model evaluation

The main data for the *GCFlow* consists of hydraulic conductivity, storage coefficient, DEM, daily rainfall, channel structure and manning roughness coefficient (see *Aswandi et al*., 2015). We used daily rainfall data for a period of April 1st, 2012 to March 31st, 2013. Note that we assumed the daily rainfall data for that period also applies to other years on the same date. The output is daily water table (WT), which is, then, annually averaged. For *EmSub* models, data and parameters are shown in Table 1. In particular, it uses annual WT from *GCFlow* and peat thickness as the input. Dataset of peat, DEM, and hydraulic conductivity vary spatially. The CO_2 content parameter is based on several findings from similar areas in Indonesia. We use *Couwenberg*'s CO_2 emission coefficient for every 1 meter of drainage depth based on Hooijer *et al*. in [8, 9, 10]. The primary and secondary compression indices are obtained by following previous study [4]. Other soil characteristic data are based on *in-situ* observation. Meanwhile, data for crop prices in the market and crop expenses are obtained through direct observation and interview with the farmers.

Table 1: Data for *EmSub* model

No	Name	Value and unit
1	Annual water table elevation (from *GCFlow* model)	m
2	Peat thickness	m
3	Surface elevation (DEM)	m
4	Soil characteristics (general)	
	• Hydraulic conductivity	$mday^{-1}$
	• Storage coefficient	0.3 $m^3 m^{-3}$
5	Soil characteristics (CO_2 emission)	
	• CO_2 content	0.58 kg kg^{-1}
	• Couwenberg coefficient	9 kg m^{-2} $year^{-1}$ m^{-1}
6	Soil characteristics (consolidation)	
	• Bulk density	200 kg m^{-3}
	• Particle density	1200 kg m^{-3}
	• Primary compression index	2.2
	• Secondary compression index	0.06
7	Time step output	1 year
8	Drainability limit	
	• Gravity-drainability coefficient	0.00002 km km^{-1}
	• Distance to the river	3 km
	• Elevation of the nearest river	5 m

Source: Aswandi *et al* (2015)

Impact of different drainage scenarios in 100 years simulation

Model output in the 100th year simulation

Depth of water table is proportional to subsidence and thus affects the land cover. Model outputs show that scenario of 0.8 m drainage (current condition) potentially releases about 794,000 ton of CO_2 or equivalent to IDR 61.2 billion (Table 2). In addition, the 0.8 cm drainage scenario causes 52 cm subsidence and leaves 62% of usable land cover. The losses become smaller (bigger) in the shallower (deeper) drainage scenario. For instance, the drainage scenario of 0.1 m has potential CO_2 emission of about 279,500 ton (IDR 21.5 billion), 19.8 cm subsidence, and no damage on the land cover. However, the drainage scenario of 1.5 m can result in 1.4 million ton CO_2 emission (IDR 108 billion), 90.6 cm subsidence, and only 35.9% usable land left.

Table 2: Projection of CO_2 emission and subsidence for different scenarios.

Drainage scenario (m)	Result for 100 years simulation			
	CO2 emission (1000 ton)	CO2 loss (IDR billion)	Subsidence (cm)	Land condition (%)
1.5 (*max*)	1407.1	108.3	90.6	35.9%
1.2	1283.8	98.9	82.8	36.3%
1.0	1093.7	84.2	70.9	48.2%
0.8 (*real*)	794.9	61.2	52.1	62.3%
0.6	595.8	45.9	39.6	76.6%
0.4	450.7	34.7	30.5	89.1%
0.3	412.9	31.8	28.1	95.2%
0.2	364.4	28.1	25.1	99.4%
0.1	279.5	21.5	19.8	100%

Spatial features

One advantage of the *EmSub* model is its capability in spatially simulating the land subsidence, emission, and profit/loss ratio. We reveal spatial distributions of the projected DEM, cumulative CO_2 emissions, peat thickness, and age of usable land in 100 years (Figures not shown). Since the subsidence is large, the emission is very high and the lifetime of usable land is very short. We found that the soils near to canal's boundary will suffer most subsidence and emission. This is probably due to deeper water table in this location than the water table in the center of block (curvature effect of water table surface). DEM data shows that the lowest elevation area resides in the middle block (tertiary block), which is vulnerable to inundation.

Time-series

Figure 2 shows the time-series of simulated peat thickness, cumulative subsidence, DEM, cumulative emissions, and rate of emission per year in several WT scenarios. We can clearly see that peat amount is decreased which results in increasing subsidence, lowering DEM, and increasing CO_2 emission (Fig. 2a-b). Shallow WT table scenarios are seen to have small impact, while deep WT scenarios show large impact (20-60 cm). In the early years, their values increase or decrease rapidly. After long simulation, their impacts are reduced logarithmically, especially for deep WT scenarios (1-1.5 m). Therefore, its rate is reduced and stopped in particular year (Fig. 2d). For 1.5 m and 1.2 m scenarios, the peat is predicted to disappear around 90th year and 120th year (Fig. 2a), respectively. However, the shallower WT simulations show that the peat still exists, at least until 200th year in the future. These results clearly show that deeper WT scenarios release more CO_2 rapidly, which directly contributes to the speed of global warming.

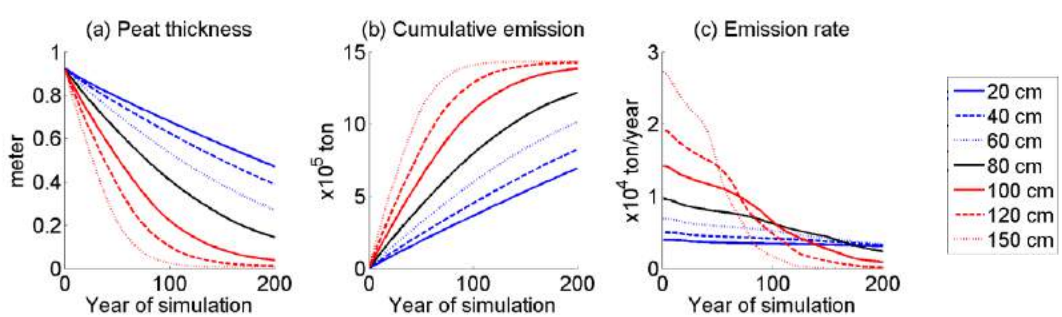

Figure 2: Time-series of model outputs. (a) peat depth, (b) Cumulative emission, and (c) emission rate per year. The model runs are extended to 200 years. Legend is shown in bottom-right of figure.

Profit/loss ratio for several plantations and crops

In order to evaluate the impact of emission and subsidence to the plantations and crops, we run several particular drainage scenarios for each plant, so-called plant scenario. The information of the plants (i.e., typical drainage depth, age, production, price, and expense) is shown in the Table 3. For example, paddy uses drainages of about 0.1 - 0.2 m depth. Then, in the simulation scenario, we run the model twice using both data so that we obtain the approximate impact caused by paddy. The emission released by plant is considered as the losses, which can be converted into money loss. The amount of crop production is affected by land condition (active usable area that can be drainaged).

Table 3: Two group of crop scenarios. It consists of 11 crops and plantation.

No	Plant scenario	Drain Min	Drain Max	Lifetime	Production (kg/ha/year)	Price (IDR/kg)	Expense (IDR)
	Group I						
1	Acacia	80	100	5 year	30000	350	0
3	Oil Palm	60	80	25 year	18000	800	41,000,000.00
2	Rubber	40	60	50 year	2400	5500	3,000,000.00
4	Jelutong	20	40	100 year	3200	5000	3,000,000.00
	Group II						
1	Paddy	10	20	3 month	3000	4500	3,000,000.00
2	Corn	30	40	4 month	5000	3200	2,500,000.00
3	Soybean	30	40	3 month	1500	6000	2,000,000.00
4	Cassava	30	40	5 month	5000	2000	1,000,000.00
5	Red Chilli	20	30	4 month	1000	40000	10,000,000.00
6	Long bean	20	30	2 month	3000	4000	2,500,000.00
7	Peanut	30	40	3 month	1200	10000	3,000,000.00

Figure 3 exhibits model results comparison between plants scenarios. The plants in the first group release high CO_2 emission (Fig. 3a). Among plants in the first group, *acacia* is the highest contributor (795 - 1094 thousand ton), followed by palm oil (596 – 795 thousand ton), rubber (451 – 596 thousand ton), and *jelutong* (364 – 451 thousand ton). The largest subsidence is also caused by *acacia* with averaged subsidence of 52 – 71 cm, while the smallest subsidence is caused by *jelutong* (25 – 31 cm) (Fig. 3b). In case of percentage drainable area due to subsidence, farmers are expected to lose about 50% of area if the *Acacia* would be planted (Fig. 3c). Meanwhile, the *jelutong* scenario could save the drainable area up to 89 – 99%. *Acacia* lives in the deep drained land of about 80 – 100 cm depth. Palm oil and rubber are also considered using deep drainage of about 60 – 80 cm and 40 – 60 cm depth, respectively. We may suggest that the deep drainages are susceptible and inappropriate to the peat swamp because it could affect the peat substantially, release more CO_2 emissions, and trigger strong subsidence. On the other hand, *jelutong* has been shown to contribute be friendly to the environment. *Jelutong* also lives quite long (Table 4, lifetime). In 100 years, farmers need only 1 time planting, compared to *acacia*, palm oil and rubber that need 20 times, 4 times, and 2 times planting in 100 year, respectively. Finally, *jelutong* gives the highest profit/loss ratio among industrial forests, which is very profitable to be applied (Fig. 3d). Otherwise, *acacia*, palm oil and rubber are less appropriate in the study area and should be avoided.

In individual food crops scenarios, corn, soybean, cassava and peanut are the largest contributors of CO_2 emission (413 – 451 thousand ton) (Fig. 3a). The second contributors for CO_2 emission are red chilli and long bean (364 – 413 thousand ton). Corn, soybean, cassava, and peanut cause land subsidence of about 28 – 31 cm (Fig. 3b). The lowest emission is coming from paddy (280 - 364 thousand tons). Land subsidence in paddy is also the smallest (about 20 – 25 cm).

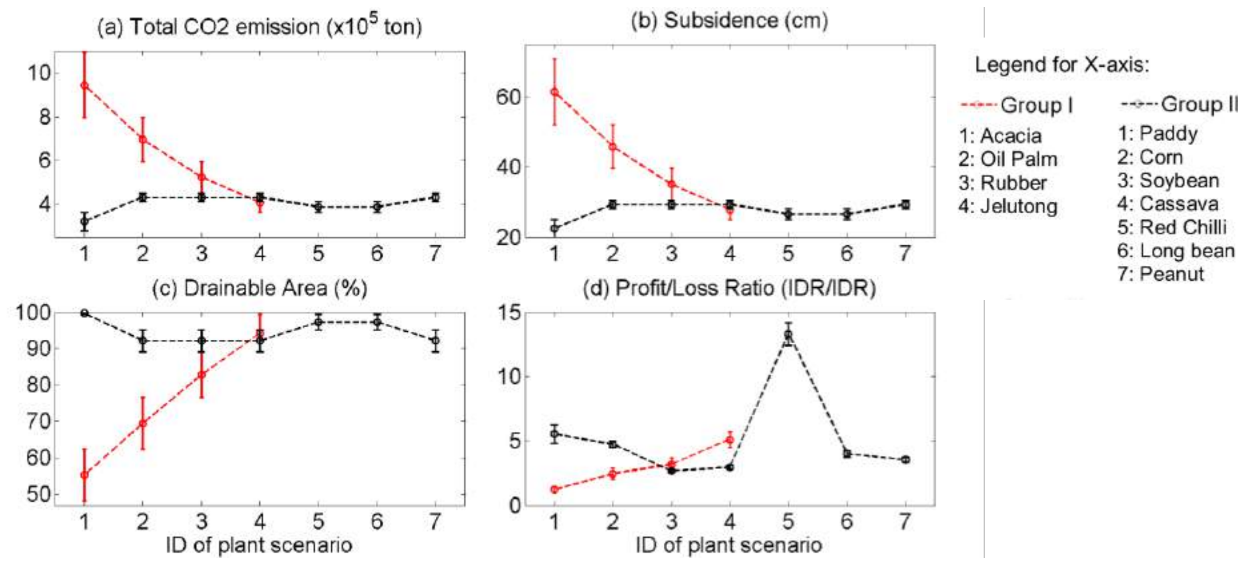

Figure 3: Distribution of impacts on different plantations. (a) and (b) exhibits area average of 100 years CO_2 emission and subsidence, respectively. (c) shows drainable area in the 100th year. (d) shows profit/loss ratio measured by annual selling profit divided with predicted CO_2 loss. Horizontal axis denotes the ID of plant scenario. Legend of scenario ID is shown in the right.

Conclusion

The model shows clearly that the deep water table causes more CO_2 emission and more subsidence than the shallow water table. In addition, the lowered soils may cause wide-inundated area which are not suitable for plantation. The effects can be smaller and higher depending on the depth of drainage. In order to evaluate the impact of emission and subsidence to the plantations and crops, sensitivity experiments using selected and combined plantations are conducted. In general, the model has shown that the industrial plantation group (e.g. *acacia*, palm oil, rubber, *jelutong*) contributes largely to the CO_2 emission and subsidence. This may be related to the depth of drainage. In addition, high CO_2 emission and large subsidence could reduce profit significantly. In particular, the highest rate of the CO_2 emission and subsidence is triggered by *acacia*, which needs very deep water table. The impacts caused by food crops group (paddy, corn, soybean, cassava, red chilli, long bean, peanut) are much smaller. The paddy contributes the smallest CO_2 emission and subsidence. Farmers should consider changing the forest into food crops in order to both save the environment and stabilize the profit.

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SHALLOW SUBSURFACE DRAINAGE IN PADDY FIELDS: ENVIRONMENTAL CONSEQUENCES AND CROP RESPONSES ANALYSIS

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Abstract

Increased population along with decreased productive lands due to urban expansion are major challenges of policy makers emphasizing on better use of limited available profitable land resources. Rice production systems in northern Iran which generally experience single crop per year, could be a suitable target for improving self-sufficiency of the country if their drainage problems were controlled in a sustainable manner. On the other hand, drainage should secure sustainable agriculture in the region with less consequences on the fragile environment. A comprehensive- drainage pilot study was conducted on a 4.5 ha consolidated paddy fields of Sari Agricultural Sciences and Natural Resources University, Mazandaran province, Iran, to explore effects of different drainage strategies on crop yields and salt, phosphorus and nitrate losses for developing a drainage system as a new approach. The pilot consisted of 11 shallow subsurface drain lines with 0.65 and 0.9 m depths and 15 and 30 m spacings resulting in three conventional subsurface drainage systems and a bilevel subsurface drainage system. Moreover, the traditional surface drainage of the consolidated paddy fields was included in this study. Two types of water management including mid-season drainage and alternate irrigation and drainage were experienced during 4- rice growing seasons (2011- 2015). Additionally, free drainage was practiced during 4- canola growing seasons in the study period. Nitrate and phosphorus losses, salt loads and crop yields were monitored in the growing seasons. Salt loads and phosphorus losses were generally higher under shallow drains than deep drains. Under different water management strategies, increase in drainage intensity resulted in more nitrate loss. Subsurface drainage caused gradual improvement in the overall productivity of the study area through increase in rice and canola yield. Based on the results, shallow drainage systems could ensure agricultural sustainability in northern Iran's paddy fields.

KEY WORDS: Annual cropping, Nitrogen, Phosphorous, Salt load, Productivity.

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Introduction

Due to continued population growth until 2050, overall demand for food or agricultural products is expected to increase. At present, more than 1.5 billion hectares of the globe's land surface (about 12 percent) is used for crop production. In spite of the presence of considerable amounts of land potentially suitable for agriculture, much of it is covered by forests, protected for environmental reasons, or employed for urban settlements (FAO, 2012). Rapid industrialization and urbanization will put more pressure on the profitable lands and water resources which consequently limit horizontal development of agriculture. Under such circumstances, increased crop production per capita arable land is mainly possible through land and water management systems in the cultivated area.

Occupying about 30 % of the world's irrigated cropland (Lampayan et al., 2015), rice production systems are suitable targets for investment to improve food security in future. Based on the Iranian ministry of Jihad Agriculture (2015), 4.55 percent of total 11.84 Mha cropped lands of the country is allotted to paddy fields. The major part of the fields is located in Northern provinces (Mazandaran, Gilan and Golestan) of Iran. Most of these fields experience once crop a year and remain fallow during rainy seasons due to ponding and waterlogging. These conditions made paddy cultivation as an unsuitable job from economic viewpoint for farmers who only rely on the income of their paddy fields resulting 1.4 % decrease in the area of Iran's paddy fields during 2000-2011 (FAO, 2014). To prevent change in land use from paddy fields to other uses, the government of Iran has initiated land consolidation projects in the fields several years ago to increase agricultural productivity (Asgari et al., 2012). Improved water management through separate water supply and drainage canals, is another merit of such projects. Due to the inability of land consolidation projects to combat waterlogging and ponding problems in northern Iran's paddy fields (Darzi-Naftchali and Shahnazari, 2014), the feasibility studies for installation of subsurface drainage were done to include the crop diversification and low cost rice farming to the objectives of paddy land consolidation. Subsurface drainage provides suitable condition for intensive agriculture in the paddy fields. However, before adoption of such a new technology at large scale, its environmental effects should be quantified at pilot level. A drainage pilot comprising different drainage systems was implemented at the Sari Agricultural Sciences and Natural Resources University (SANRU) in 2011 to find out various effects of subsurface drainage systems. This paper presents major results of this pilot study.

Materials and methods

Poorly drained- consolidated paddy field of the SANRU (36.3◦N; 53.04◦E; 15 m below sea level) was selected as representative conditions of northern Iran's paddy fields. Minimum, maximum and average daily air temperature of the area are -6, 42.5 and 17.6 ^{o}C. The soil on the field is silty clay and clay to a depth of 3 m with a very low conductive layer approximately at 30-60 cm depth. Through national land consolidation projects, the irregular paddy plots of the study site were shaped as standard plots with 30 m wide and 100 m long. Providing access roads and improving irrigation and drainage facilities were other aspects of the projects. In 2011, different subsurface drainage systems were installed at the study area using two drain depths (0.65 and 0.9 m) and two drain spacing (15 and 30 m). Depth and spacing of subsurface drains were selected based on national recommendations and field conditions. The drainage systems were: D0.9L30, D0.65L30 and D0.65L15 in which, the subscripts of D and L demonstrate depth and spacing of the drainage systems, respectively. Additionally, another subsurface drainage system consisting 4 drain lines with 15 m spacing and 0.65 and 0.9 m depths as alternate (Bilevel) was installed at the study area. All subsurface drain pipes were connected to an open drain with a depth of 1.2 m. A paddy plot which was only under the influence of the open drain was considered as Control plot. Detailed description of the drainage systems can be found in Darzi-Naftchali et al., (2013).

The study is comprised of 8 growing seasons (2011-2016) including 4- rice growing seasons and 4- canola growing seasons. Rice cultivation (Daylamani Tarom cultivar) was done under two water managements including midseason drainage (July 21 to October 10 in 2011 and May 28 to August 11 in 2012) and alternate irrigation and drainage (May 10 to August 5 in 2014 and June 4 to August 28 in 2015). Shallow groundwater was extracted to irrigate the paddy plots during rice growing seasons. Average values of electrical conductivity (EC) of irrigation water during 2011, 2012, 2014 and 2015 rice growing seasons were, respectively, 1.12, 1.29, 1.25 and 1.3 ds m^{-1}. After rice harvest in 2011, 2012, 2014 and 2015, respectively, 6, 7, 7 and 8 kg of canola seeds were cultivated in subsurface- drained area. During canola growing seasons (November 28, 2011- May 8, 2012; October 4, 2012- May 15, 2013; October 10, 2014- May 10, 2015; October 3, 2015- May 3, 2016), the fields were under free drainage unless short periods at the end of the seasons when the outlet of drains were closed to prevent deficit water stress. A summary of water management practices and fertilizations is provided in Table 1.

Measurements of nitrate and total phosphorus (TP) concentration in drainage effluents as well as electrical conductivity (EC) of drainage water were carried out during different growing seasons (at least three successive days during each drainage periods of rice growing seasons and 15- day intervals during 2011-12 and 2014-15 canola growing seasons). Moreover, drainage outflow was measured daily whenever subsurface drains were discharged. Using these measurements, total losses of nitrate, TP and salt were calculated. At harvest, in each growing seasons, crop yield was determined under different drainage systems. Data analysis was performed using statistical software package SAS (SAS Institute, 2004).

Table 1. Water management practices and fertilizations during rice and canola growing seasons

2011- rice	Activity
Basal fertilizer	140 kg ha^{-1} triple superphosphate
8 DAP	90 kg ha^{-1} urea
25-31 DAP	Midseason drainage
68-82 DAP	End- of season drainage
2012- rice	
9 DAP	90 kg ha^{-1} urea
25-31 DAP	Midseason drainage
72-86 DAP	End- of season drainage
2014- rice	
Basal fertilizer	100 kg ha^{-1} triple superphosphate, 100 kg ha^{-1} potassium sulfate, and 80 kg ha^{-1} urea
13 DAP	80 kg ha^{-1} urea
31 DAP	30 kg ha^{-1} urea
25-34 DAP	1st drainage period
44- 49 DAP	2nd drainage period
64-88 DAP	End- of season drainage
2015- rice	
Basal fertilizer	50 kg ha^{-1} triple superphosphate, 50 kg ha^{-1} potassium sulfate, and 100 kg ha^{-1} urea
12 DAP	50 kg ha^{-1} urea
28-32 DAP	1st drainage period
39- 43 DAP	2nd drainage period
71-86 DAP	End- of season drainage
2011-12 canola	
100 DAP	35 kg ha^{-1} urea
121 DAP	35 kg ha^{-1} urea
2012-13 canola	
155 DAP	35 kg ha^{-1} urea
2014-15 canola	
21 DAP	70 kg ha^{-1} urea
128 DAP	70 kg ha^{-1} urea
2014-15 canola	
Basal fertilizer	50 kg ha^{-1} triple superphosphate
52 DAP	50 kg ha^{-1} urea

1- Days after planting

Results and discussion

Salinity can occur even using good quality irrigation water in poorly drained soils (Ritzema et al., 2008). Relatively flat- heavy texture soils of the study site as well as the salinity of irrigation water (1.12- 1.3 ds m^{-1} during the study period), necessitate salt load monitoring through different drainage systems. The results of mean comparison of EC of drainage effluents are presented in

Table 2. Total water samples used for EC measurements were 46 and 10 for subsurface drainage systems and Control, respectively. Generally, the salinity of drainage effluents were maximum in the first rice growing season after subsurface drainage installation and then gradually decreased mainly due to removal of accumulated salts in flow paths during earlier growing seasons. After the 2014 rice growing season, the variations of EC were almost negligible depending on EC of irrigation water or precipitation. Moreover, relative increase in EC in 2014 and 2015 rice growing season probably attributed to further improvement in soil structure due to alternate irrigation and drainage practice which provides suitable conditions for appearing cracks on the soil surface (Ye et al., 2013). Comparing EC of different drainage systems having same depth or spacing in rice and canola growing season indicate that shallow drains resulted in more EC in drainage effluents than deep drains. Overall comparison of EC well demonstrate this result unless for the most intensive drainage system (Bilevel). EC of surface runoff was significantly higher than that in subsurface drainage effluents in the 2011 rice season while it was comparable with the corresponding EC in subsurface drain discharge in 2012, 2014 and 2015 rice growing seasons.

Table 2. Mean comparison of electrical conductivity (ds m^{-1}) of drainage water as affected by different drainage systems and growing seasons

Drainage System	**Growing season**						**Overall**
	Rice 2011	Canola 2011-12	Rice 2012	Rice 2014	Rice 2015	Canola 2015-16	
D0.90L30	1.62^{b}	1.45^{e}	1.08^{b}	1.06^{d}	1.19^{c}	1.32^{b}	1.25^{d}
Bilevel-D0.65	1.97^{b}	1.66^{c}	1.10^{b}	1.10^{dc}	1.51^{b}	1.38^{b}	1.39^{cd}
Bilevel-D0.90	2.37^{b}	2.22^{a}	1.23^{ab}	1.31^{bcd}	1.79^{a}	1.72^{a}	1.71^{b}
D0.65L30	1.83^{b}	1.55^{d}	1.33^{ab}	1.55^{ab}	1.60^{b}	1.40^{b}	1.50^{c}
D0.65L15	2.04^{b}	1.88^{b}	1.44^{a}	1.61^{a}	1.73^{a}	1.63^{ab}	1.68^{b}
Control	4.24^{a}	-	1.12^{b}	1.32^{bc}	1.51^{b}	-	1.92^{a}

Means followed by the same letter in a column are not significantly different at $P < 0.05$ by LSD test.

Subsurface drainage system may cause losses in various forms of nitrogen through the drainage effluent (Gilliam and Skaggs, 1986). Seasonal variations of nitrate concentrations in drainage effluents and surface runoff is presented in Table 3. Total water samples used for nitrate measurements were 55 and 14, respectively, for subsurface drainage systems and Control. Nitrate concentration in drainage effluents showed various patterns in different growing seasons. In 2011, 2012 and 2014 rice seasons, maximum nitrate concentration was observed in shallow drains while in 2015 rice season and canola growing seasons, its maximum was found in deeper drains. In addition to the depth and spacing of a drainage system, water management practices, hydrological conditions, amounts and types of applied fertilizers, crop characteristics, soil properties and agricultural operations are major factors affecting nitrate losses through drainage systems. Longer drainage period in canola seasons may cause extending preferential flow paths to lower soil profile resulting more nitrate losses through deeper drains. Overall, among subsurface drainage systems, maximum and minimum nitrate concentrations were related to D0.9L30 and D0.65L30, respectively.

Table 3. Mean comparison of nitrate concentration (mg L^{-1}) in drainage water as affected by different drainage systems and growing seasons

Drainage System	Growing season						Overall
	Rice 2011	Canola 2015-16	Rice 2012	Rice 2014	Rice 2015	Canola 2015-16	
D0.9L30	3.89^{c}	4.63^{a}	11.40^{ab}	2.70^{a}	4.67^{abc}	21.85^{a}	9.23^{a}
Bilevel-D0.65	4.62^{abc}	3.71^{ab}	10.92^{ab}	3.42^{a}	5.57^{ab}	12.23^{ab}	6.81^{a}
Bilevel-D0.9	4.44^{bc}	4.67^{a}	11.65^{ab}	4.00^{a}	6.43^{a}	9.15^{b}	6.58^{a}
D0.65L30	5.39^{abc}	3.47^{b}	9.23^{ab}	3.66^{a}	4.50^{abc}	10.08^{b}	6.17^{a}
D0.65L15	6.67^{ab}	4.50^{a}	12.42^{a}	4.55^{a}	3.57^{bc}	10.15^{b}	7.05^{a}
Control	6.44^{a}	-	5.63^{b}	4.81^{a}	3.33^{c}	-	5.19^{a}

Means followed by the same letter in a column are not significantly different at $P < 0.05$ by LSD test.

Figure 1 shows the results of mean comparison of nitrate losses among different growing seasons and drainage systems. In canola seasons, nitrate losses were significantly higher than those in rice growing seasons while, no significant differences were found among the losses in 2012, 2014 and 2015 rice seasons. Generally, there were no considerable differences between nitrate losses under two water management practices in rice growing seasons. Short periods of drainage as well as time opportunity between fertilization and drainage initialization provided suitable condition for nitrogen uptake by rice plants (Darzi-Naftchali et al., 2016a). Moreover, transformation of nitrate to other components of nitrogen cycle probably resulted in less nitrate to be available for losses through drainage. In 2015-16 canola season, nitrate loss was 320 % more than that in 2011-12 canola season. Part of this increased losses may related to improved soil structure and formation of flow paths in the soil profile due to the performance of subsurface drainage systems during several years after installation. Nitrate concentration in drainage effluents were much higher in 2015-16 canola season than those in 2011-12 canoal season (Table 3). Additionally, in 2015-16 canola season, total drainage water through D0.9L30, Bilevel, D0.65L30 and D0.65L15 was, respectively, 8.60, 78.98, 13.90 and 20.25 % higher than the corresponding one in 2011-12 canola season (data not shown).

Maximum and minimum nitrate losses were 8.14 and 4.17 kg ha^{-1} per growing season related to Bilevel and D0.65L30, respectively, the most intensive and less intensive subsurface drainage systems. Total nitrate losses through D0.65L30 was also lower than that in Control indicating that suitable subsurface drainage may have less environmental effects from nitrate loss viewpoint than conventional farming in the study area. Moreover, measurement of soil nitrogen at the end of 2011 rice season and the beginning of 2012 rice season in Control (which was fallow during this period) indicated 220.2 kg ha^{-1} nitrogen loss from soil profile (Darzi-Naftchali et al., 2016a) through different processes. On the other hand, canola cropping in the subsurface drained area provided suitable condition for soil nitrogen to be used as plant uptake.

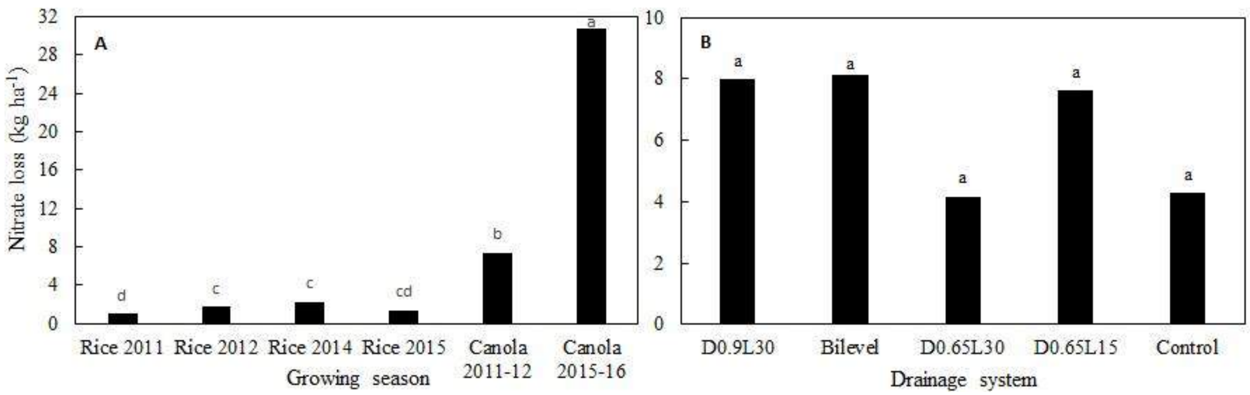

Figure 1. Mean comparison of nitrate loss among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Phosphorus losses were monitored during three first growing seasons after drainage installation. Results of mean comparison of TP losses among growing season as well as drainage systems are displayed in Figure 2. TP loss in 2011-12 canola season was significantly higher than that in 2011 and 2012 rice seasons however, such losses were not considerable in all growing seasons. Among different drainage systems, D0.65L15 resulted in maximum TP loss indicating decrease in drain depth and spacing provides more favorable condition than deeper drains with more spacing for phosphorus loss. This matter was demonstrated in some previous studies such as Poole (2006). Narrow drain spacing or less drain depth decreases the lateral flow path to drain or increases preferential flow to drains both consequently cases increase in P losses through subsurface drainage (Darzi-Naftchali et al., 2016b). Mean comparison analysis indicated that the D0.65L15 drainage system had more negative environmental effects on receiving water bodies than Control which is common condition in the northern Iran's paddy fields. This matter demonstrate that shallow subsurface drainage systems can remove P from heavy textured soils. Significant losses of P through subsurface drained fields were reported in different studies (Gardner et al. 2002; Gentry et al. 2007; Beauchemin et al., 1998).

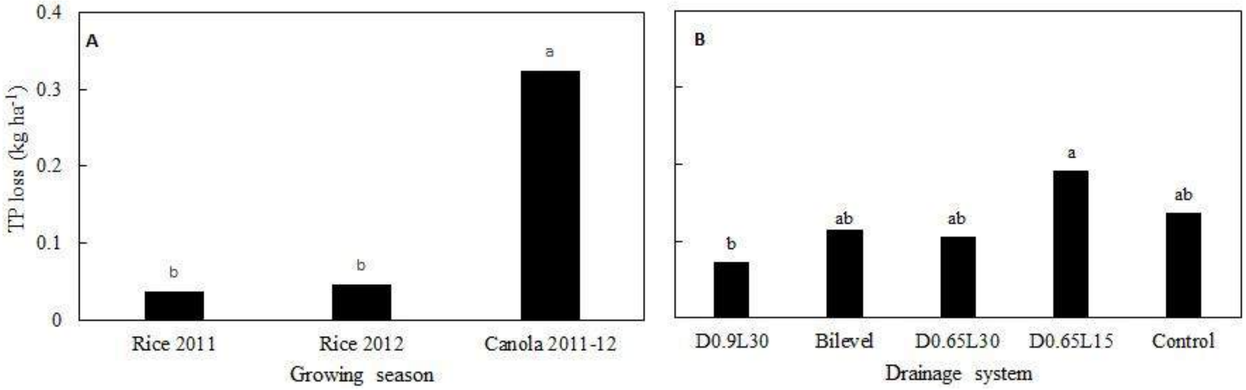

Figure 2. Mean comparison of TP loss among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Figure 3 shows variations in salt load during different cropping seasons and through drainage systems. Salt loads in canola seasons were significantly higher than those in rice seasons due to longer drainage periods and consequently more drainage water. Generally, alternate irrigation and drainage had more negative environmental effects than midseason drainage practice from salt transport point of view. Significantly increase in salt loads through Bilevel and D0.65L15 than D0.9L30 and D0.65L30 emphasizes that more intensive subsurface drainage systems resulted in higher salt load. Salt load in the Control was considerably higher than that in D0.9L30 and D0.65L30 suggesting that these drainage systems are more suitable than conventional mono culture in the study area. Moreover, such drainage systems provide appropriate condition for winter cropping as an additional merit that boosts the overall productivity of the poorly drained paddy fields.

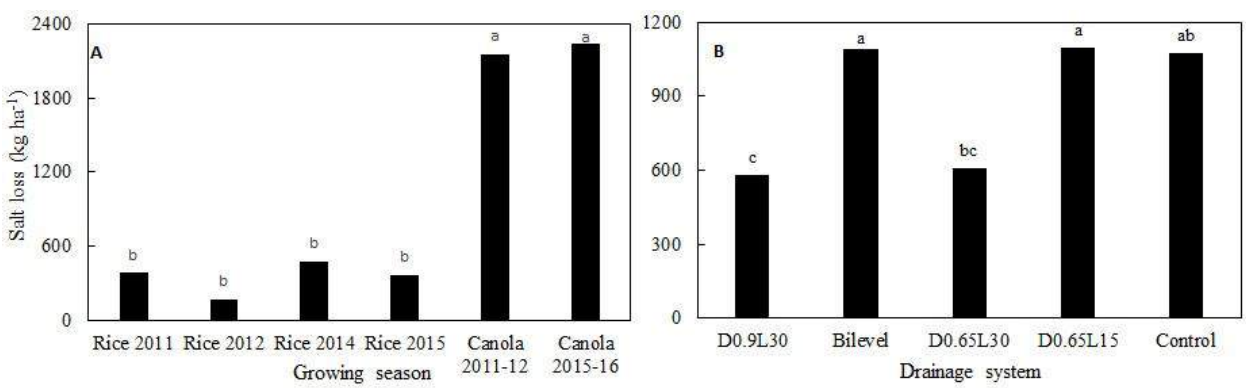

Figure 3. Mean comparison of salt load among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Figures 4 and 5 show, respectively, variations in canola and rice yield during 4 growing seasons. Subsurface drainage resulted in continuous improvement in the productivity of the study area. In 2015- 16 growing season, canola yield was significantly higher than that in 2011-12 and 2012-13 while no differences were found between canola yields in 2014-15 and 2015-16 growing seasons.

In 2015-16, canola yield increased by 1764.2, 407.2 and 133.7 kg ha^{-1} as compared with the yield in 2011-12, 2012-13 and 2014-15, respectively. Based on 4- year data, maximum canola yield is related to D0.90L30. However, no significant difference was observed among canola yields in different drainage systems. Rice yield well responded to differences in the types of water management. Rice yields in 2014 and 2015 were significantly higher than those in 2011 and 2012 suggesting that alternate irrigation and drainage is more suitable strategy than midseason drainage in the study field. Moreover, integrated analysis of rice yields under two water managements indicate that subsurface drainage systems increased rice yield compared with conventional farming in the region. The maximum increase achieved under Bilevel followed by D0.65L30, D0.65L15 and D0.9L30. Various factors such as agricultural inputs and practices, soil characteristics and hydrological conditions influence yield and growth traits of any crop (Darzi- Naftchali and Shahnazari, 2014). Such conditions were generally similar during each growing season and the only difference was the type of drainage system. However, the conditions differed somewhat among growing seasons. Generally, yield data demonstrate that subsurface drainage improved the productivity of the rice fields through providing year- round crop production conditions and increasing rice yield as a major crop in the area. Subsurface drainage has been reported to increase crop yield in some studies (Carter and Camp, 1994; Mathew et al., 2001; Satyanarayana and Boonstra, 2007; Ritzema et al., 2008). Subsurface drainage improves root zone environment from both supplying oxygen to soil and removing toxic substances viewpoints resulting better condition for root development than undrained condition.

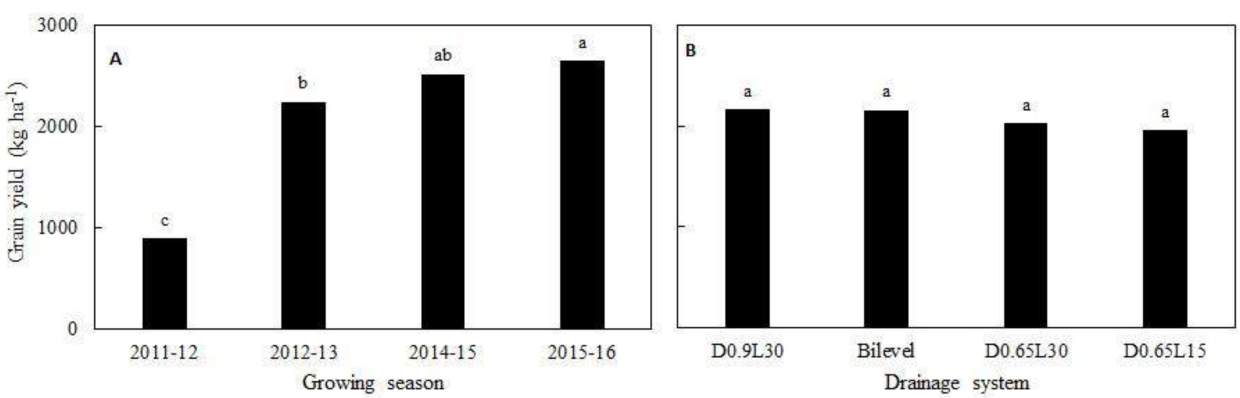

Figure 4. Mean comparison of canola yield among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

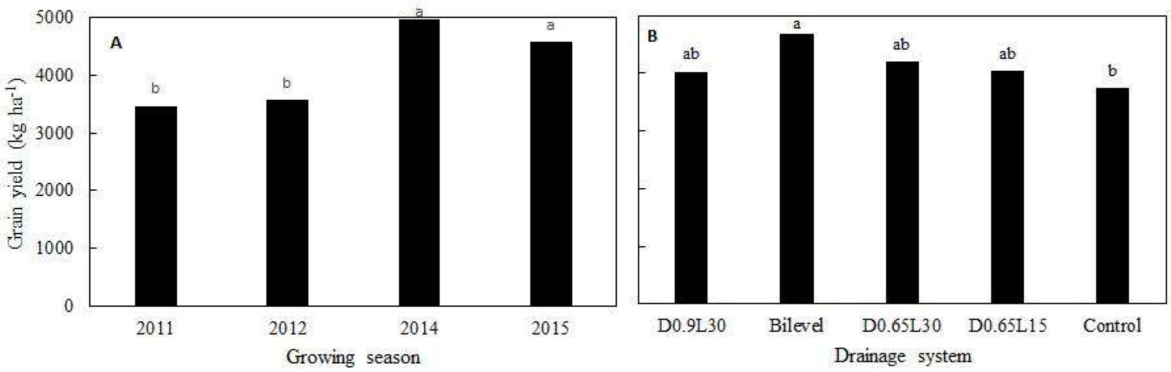

Figure 5. Mean comparison of rice yield among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Conclusion

This study was conducted to clarify different aspects of providing annual cropping system of rice-canola rotation in northern Iran's paddy fields under different subsurface drainage systems and a conventional surface drainage. Field investigations during 4- rice and 4- canola growing seasons revealed that subsurface drainage could increase the productivity of the poorly drained paddy fields with negative environmental effects that comparable with conventional drainage in the study area. Considering yield increases and environmental aspects related to different drainage systems, it could be concluded that the installation of subsurface drains at 0.65 m depth and 30 m spacing could provide suitable condition for sustainable and economic agriculture in the study area.

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UPSCALING HYDRAULIC CONDUCTIVITY IN SOILS: TECHNIQUES FROM STATISTICAL PHYSICS

Behzad Ghanbarian[1,*]

Abstract

Estimating single- and two-phase hydraulic conductivities in soils, particularly in large scales, is essential for designing irrigation systems and drainage networks. Therefore, upscaling hydraulic conductivity *K* has been a challenge over the years, and rigorous techniques applicable to heterogeneous soils are still required. In the literature, most of the applied methods used for determining an effective and representative value of *K* are based on weighted arithmetic and harmonic means corresponding, respectively to the parallel (layered soils parallel to flow direction) and series (layered soils perpendicular to flow direction) models. In reality, however, soils, exist neither in series nor in parallel form, but are complex multi-scale networks. In this study it is proposed that techniques, such as critical path analysis and effective-medium approximations from statistical physics to upscale hydraulic conductivity in heterogeneous porous media like soils be considered. The former is valid in strongly heterogeneous media, while the latter is applicable to homogeneous and relatively heterogeneous systems. Advantages and disadvantages as well as practical applications of each method are discussed in details.

KEY WORDS: Critical path analysis, Effective-medium approximation, Hydraulic conductivity, Upscaling.

Introduction

Soil hydraulic conductivity *K* is an essential component to design irrigation systems and drainage networks. Therefore, determining an effective value of hydraulic conductivity, representing the porous medium's ability to transit fluid flow, under both fully- and partially-saturated conditions has been of great importance but challenging over years. Although various models were developed to upscale saturated and unsaturated hydraulic conductivities, rigorous techniques applicable to heterogeneous soils are still required. In the literature, mostly applied methods to determine an effective and representative value of *K* are based on weighted arithmetic and harmonic means corresponding, respectively, to the parallel, layered soils parallel to flow direction (Fig. 1), and series, layered soils perpendicular to flow direction (Fig. 2), models.

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In the parallel model, the arithmetic mean hydraulic conductivity K_a in a porous medium equally composed of *n* parallel components each of which has a specific hydraulic conductivity value K_i (see Fig. 1a) is given by

$$K_a = \frac{1}{n}\sum_{i=1}^{n} K_i \quad (1)$$

However, if the fraction of each component is different (see e.g., Fig. 1b), the weighted arithmetic mean hydraulic conductivity K_{aw} should be determined as follows

$$K_{aw} = \frac{1}{n}\sum_{i=1}^{n} w_i K_i \quad (2)$$

where w_i represents the corresponding weight associated with each component such that $\sum_{i=1}^{n} w_i = 1$.

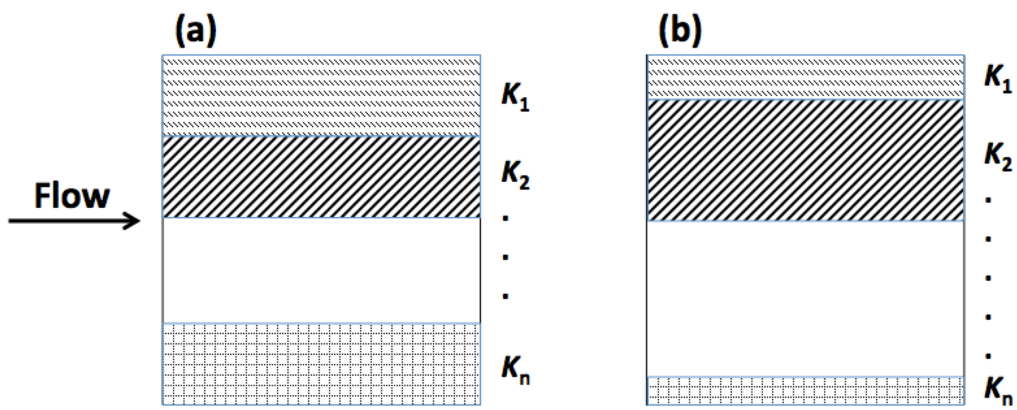

Figure 1. Parallel combination of soil layers of various hydraulic conductivities e.g., K_1, K_2,..,K_n with (a) identical and (b) different thicknesses.

In the series model, the harmonic mean hydraulic conductivity K_h in a porous medium equally composed of *n* components in series (see Fig. 2a) is

$$K_h = \frac{n}{\sum_{i=1}^{n}\frac{1}{K_i}} \quad (3)$$

If components have different weights (see Fig. 2b), then the weighted harmonic mean hydraulic conductivity K_{hw} should be determined as follows:

$$K_{hw} = \frac{n}{\sum_{i=1}^{n} \frac{w_i}{K_i}} \quad (4)$$

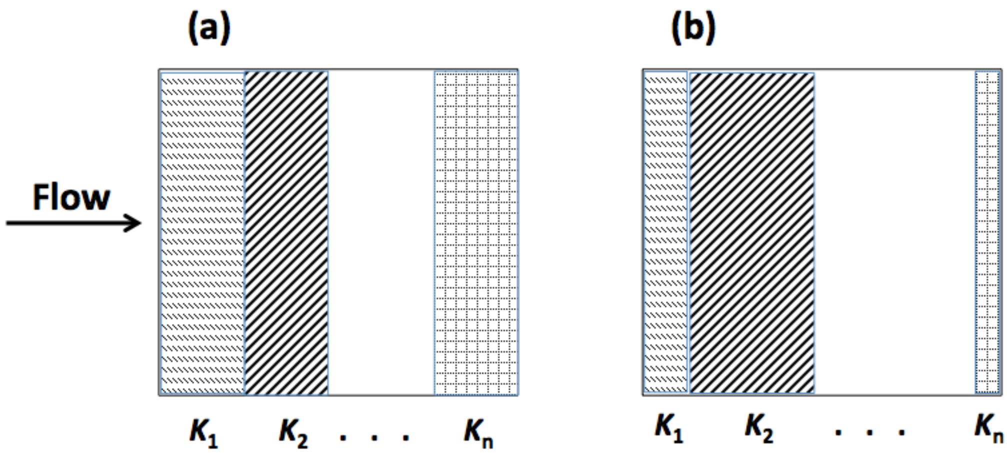

Figure 2. Series combination of soil layers of various hydraulic conductivities e.g., K_1, K_2,…, K_n with (a) identical and (b) different thicknesses.

The series and parallel models define the upper and lower bounds, also known as the Wiener bounds (Wiener, 1912), for the representative hydraulic conductivity of heterogeneous porous media randomly composed of components of various volumes and conductivities. In addition to arithmetic and harmonic means, geometric and weighted geometric means have been also used in the literature (e.g., Gutjahr et al., 1978; Koltermann and Gorelick, 1995; Porter et al., 2013) to determine the representative hydraulic conductivity in soils and rocks

$$K_g = exp\left[\frac{1}{n}\sum_{i=1}^{n} \ln(K_i)\right] \quad (5)$$

$$K_{gw} = exp[\sum_{i=1}^{n} \mathrm{w_i} \ln(K_i)] \quad (6)$$

One should note that the (weighted) geometric mean always lies between the (weighted) harmonic and (weighted) arithmetic means ($K_{wh} \leq K_{wg} \leq K_{wa}$; Wiener, 1912). A comprehensive review of harmonic, geometric, and arithmetic means are given by Sanchez-Vila et al. (2006).

The generalized mean hydraulic conductivity K_G of hydraulic conductivities K_1, K_2,…, K_n associated with weights w_1, w_2,…, w_n may be expressed as

$$K_G = \left[\frac{1}{n}\sum_{i=1}^{n} w_i K_i^p\right]^{\frac{1}{p}} \tag{7}$$

where p is a real number. Note that Eq. (7) reduces to the weighted harmonic, geometric, and arithmetic models for p = -1, 0, and 1, respectively. Although the generalized mean hydraulic conductivity (Eq. 7) includes several other models as its special cases, the value of p is priory unknown to determine the representative hydraulic conductivity practically.

For isotropic mixtures of components K_1, K_2, …, K_n, the representative hydraulic conductivity would be independent of the medium structure (Tong et al., 2009). Hashin and Shtrikman (1962) proposed lower and upper bounds for macroscopically homogeneous and isotropic media. For the lower bound, Hashin and Shtrikman (1962) found

$$K_{HS}^{l} = K_1 + \frac{1-w_1}{\frac{1}{K_2-K_1}+\frac{w_1}{3K_1}} \tag{8}$$

and for the upper bound

$$K_{HS}^{u} = K_2 + \frac{w_1}{\frac{1}{K_1-K_2}+\frac{1-w_1}{3K_2}} \tag{9}$$

Note that the Hashin-Shtrikman bounds (Eqs. 8 and 9) necessarily duplicate the results of the Maxwell-Eucken model (Maxwell, 1954; Eucken, 1940). For a more comprehensive review of the applications of the effective permeability models to porous media see Renard and de Marsily (1997).

Tong et al. (2009) extended the Hashin-Shtrikman bounds to porous media with n components. For the lower bound, they found

$$K_{EHS}^{l} = K_1 + nK_1 \frac{\sum_{i=1}^{n}\frac{w_i}{\left(1+C_i^l\right)}}{w_1+\sum_{i=1}^{n}\frac{w_i C_i^l}{\left(1+C_i^l\right)}} \tag{10}$$

and for the upper bound

$$K_{EHS}^{u} = K_n + nK_n \frac{\sum_{i=1}^{n}\frac{w_i}{\left(1+C_i^u\right)}}{w_n+\sum_{i=1}^{n}\frac{w_i C_i^u}{\left(1+C_i^u\right)}} \tag{11}$$

in which $C_i^l = nK_1/(K_i - K_1)$ and $C_i^u = nK_n/(K_i - K_n)$.

In reality, soils, however, exist neither in series nor in parallel form but are complex multi-scale networks, stochastically heterogeneous mixtures of various components. In what follows, we propose techniques, such as effective-medium approximations and critical path analysis from statistical physics to determine the effective hydraulic conductivity in heterogeneous porous media like soils. The former is valid in strongly heterogeneous media, while the latter is applicable to homogeneous and relatively heterogeneous systems.

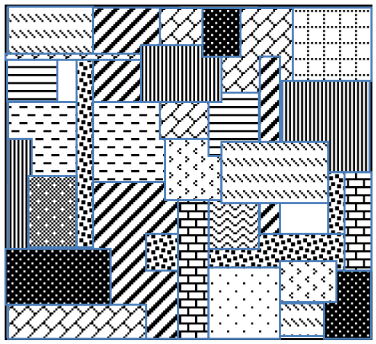

Figure 3. Schematic stochastic combination of soil components of various hydraulic conductivities e.g., K_1, K_2,…, K_n.

Materials and methods

Effective-medium approximation

The effective-medium approximation (EMA) is an upscaling technique from statistical physics in which a heterogeneous porous medium with local hydraulic properties is replaced with a homogeneous medium with the same macroscopic hydraulic properties, such as hydraulic conductivity ($K = K_e$; see Fig. 4). The main idea underlying the EMA is to infer an average hydraulic conductivity for such a heterogeneous medium from local hydraulic conductivities (David et al., 1990; Sahimi, 2011). The macroscopic effective hydraulic conductivity of the homogeneous medium K_e is the same as the macroscopic hydraulic conductivity of the original heterogeneous medium. How is K_e calculated using the EMA and statistics of local conductivities? The spatially dependent permeability in the disordered medium results in local perturbations about the effective permeability of the ordered medium. The effective permeability is then determined by setting the average perturbation to be zero (Kirkpatrick, 1973).

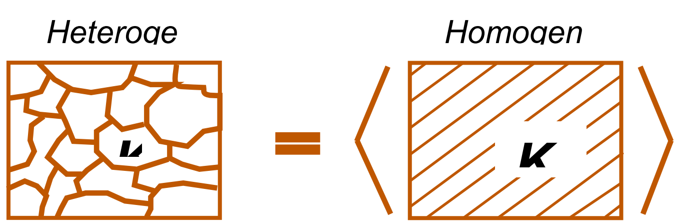

Figure 4. Scheme of a disordered porous medium with an actual permeability K replaced by a uniform one with an effective permeability K_e in the effective-medium approximation framework (a modified version from Hori and Yonezawa, 1977).

Two-component porous media

In binary materials built up of two components, the concept of the EMA may be used to determine the effective hydraulic conductivity. To calculate the effective hydraulic conductivity of a binary mixture with various portions of the two components one has (Kirkpatrick, 1973; Ghanbarian and Daigle, 2016)

$$(1-w_1)\frac{K_2-K_e}{K_2+\left(\frac{Z}{2}-1\right)K_e}+w_1\frac{K_1-K_e}{K_1+\left(\frac{Z}{2}-1\right)K_e}=0 \qquad (12)$$

where Z is the average pore coordination number. Note that Eq. (12) reduces to Bruggeman's approximation (Bruggeman, 1935) and Eq. (3) – the well-known weighted harmonic mean discussed above – when Z = 6 and 2, respectively.

We show the effective hydraulic conductivity calculated using Eq. (12) for a medium composed of two components with K_1 = 0.1 and K_2 = 10 (arbitrary units) in Fig. 5. As can be observed, the greater the pore coordination number Z, the more the pore connectivity and thus the greater the effective hydraulic conductivity.

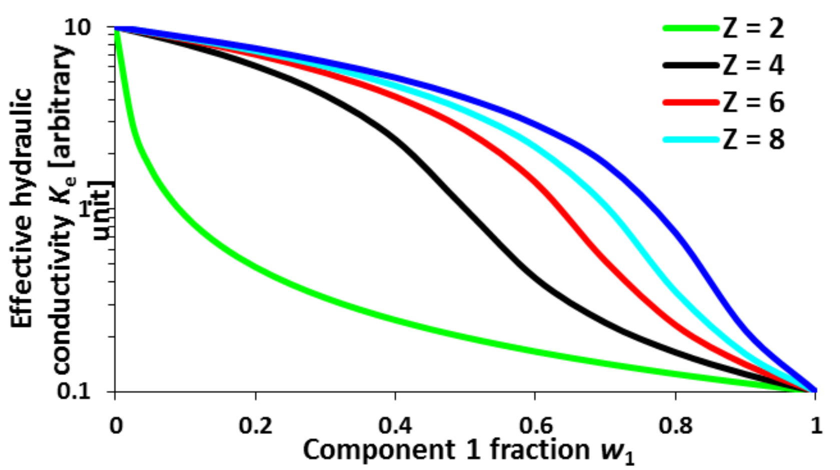

Figure 5. Effective hydraulic conductivity K_e calculated using the effective-medium approximation (Eq. 12) versus the component 1 fraction (w_1) for various values of the coordination number Z, K_1 = 0.1 (arbitrary unit), and K_2 = 10 (arbitrary unit). Note that Eq. (12) with coordination number Z = 2 reduces to Eq. 4, the weighted harmonic mean.

Ghanbarian and Daigle (2016) numerically simulated the saturated hydraulic conductivity in binary mixtures of spheres and ellipsoids (two components) using the lattice-Boltzmann (LB) method and compared that with the effective-medium approximation (EMA) results. They demonstrated that the EMA estimated K_{sat} within a factor of two of the LB simulated values in simple and body-centered cubic packs. Ghanbarian and Daigle (2016) found that the EMA results depend on several factors, such as packing arrangement, grain shape, and porosity.

n-component porous media

Porous media are complex in nature and constructed of more than one or two components. Natural porous media are inherently heterogeneous, typically poorly sorted, and have broad grain- and pore-size distributions. A heterogeneous medium has, therefore, spatially dependent or local hydraulic conductivity K following a distribution. The general EMA formula to determine the effective hydraulic conductivity K_e is

$$\sum_K \frac{K-K_e}{K+\left(\frac{Z}{2}-1\right)K_e} f(K) = 0 \qquad (13)$$

where $f(K)$ is the hydraulic conductivity distribution.

Recently, Ghanbarian et al. (2016a) applied concepts from the EMA to estimate unsaturated hydraulic conductivity in soils from pore throat-size distribution reflected in desaturating capillary pressure curve. For fully saturated conditions, Ghanbarian et al. (2016a) proposed

$$\int_{r_c}^{r_{max}} \frac{g_e(S_w=1) - r^g}{r^g + \left[(1-S_{wc})/S_{wc}\right] g_e(S_w=1)} f(r)dr = 0 \qquad (14)$$

where $g_e(S_w = 1)$ is the effective hydraulic conductance under fully saturated conditions, $f(r)$ is the pore throat-size distribution, r is the pore throat radius, r_c is the critical pore throat radius, S_w is the water saturation, and S_{wc} is the critical water saturation at which $K(S_w) = 0$.

For unsaturated conditions one has

$$\int_{r_c}^{r} \frac{g_e(S_w) - r^g}{r^g + \left[(1-S_{wc})/S_{wc}\right] g_e(S_w)} f(r)dr = 0 \qquad (15)$$

where $g_e(S_w)$ is the effective hydraulic conductance under partially saturated conditions. Therefore, $K(S_w)$ may be defined as

$$K_r = \frac{K(S_w)}{K_{sat}} = \frac{g_e(S_w)}{g_e(S_w{=}1)} \quad (16)$$

Note that Eqs. (14) and (15) are implicit in form, and $g_e(S_w{=}1)$ and $g_e(S_w)$ should be determined numerically.

The EMA, however, does not produce accurate results near the critical water saturation S_{wc}. Thus, one should use the EMA only at high to intermediate water saturations. A remarkable scaling law from percolation theory is that, above but near the critical water saturation, unsaturated hydraulic conductivity should conform to the following universal power law

$$K_r = K_0(S_w - S_{wc})^2 \quad (17)$$

Thus, to estimate K_r over the entire range of S_w, one should utilize Eq. (16) in combination with Eqs. (14) and (15) for $S_{wx} \le S_w \le 1$, and apply Eq. (17) for $S_{wc} \le S_w \le S_{wx}$. S_{wx} is the water saturation at which the scaling law from the EMA switches to that from percolation theory (Eq. 17). Note that the value of S_{wx} and K_0 are determined numerically.

The estimated K_r and the measured values versus water saturation S_w are shown in Fig. 6 for 9 soil samples from the UNSODA database. It is well documented in the literature that the EMA produces precise results as long as the pore throat-size distribution is not too broad (see e.g., Kirkpatrick, 1971). However, the term "broad" has never been satisfactorily quantified. Therefore, a reason for imprecise estimation of K_r for samples 4162 and 4592 shown in Fig. 6 might be due to intrinsic inaccuracy of the EMA for highly disordered porous media with broad pore throat-size distribution. However, there might be other reasons for such underestimations, such as ignoring film and corner flow, which might effectively contribute to fluid flow at low water saturations.

Critical path analysis

Critical path analysis (CPA) is a promising method to understand transport in porous media with no correlation and/or short-range correlation (random systems). According to CPA, hydraulic conductivity in an uncorrelated and disordered medium is mainly controlled by conductances with magnitudes slightly less than the critical conductance g_c, where the critical conductance is the smallest possible value of the conductance for which the set of all larger conductances still forms an infinite connected cluster (Katz and Thompson, 1986).

Katz and Thompson (1986; 1987) were first to apply critical path analysis to relate the saturated hydraulic conductivity, K_{sat}, to electrical conductivity and critical pore radius. Their model is

$$K_{sat} = \frac{f}{56.5}\frac{\sigma_b}{\sigma_w} r_c^2 \quad (18)$$

where f is the fluidity factor, σ_b is bulk electrical conductivity, σ_w is saturating fluid electrical conductivity, and r_c is the critical pore radius.

Following Katz and Thompson (1987) one may approximate σ_b/σ_w from the optimum pore radius. Ghanbarian-Alavijeh and Hunt (2012) also proposed a method to estimate r_c from capillary pressure data, such as the pore space fractal dimension D. By estimating the critical pore radius r_c and electrical conductivity σ_b/σ_w using the methods proposed respectively by Ghanbarian-Alavijeh and Hunt (2012) and Katz and Thompson (1987), Ghanbarian et al. (2017) proposed the following model to calculate the saturated hydraulic conductivity based on critical path analysis

$$K_{sat} = f\frac{A^2 P_a^{-2}}{56.5}\frac{\phi}{3}\left[1-\left(\frac{1}{3}\right)^{3-D}\left(1-\frac{\theta_t}{\beta}\right)\right]\left(1-\frac{\theta_t}{\beta}\right)^{\frac{2}{3-D}} \tag{19}$$

where A is the constant coefficient in the Young-Laplace equation, P_a is the entry pressure, θ_t is the critical water content for percolation, and ϕ is the porosity.

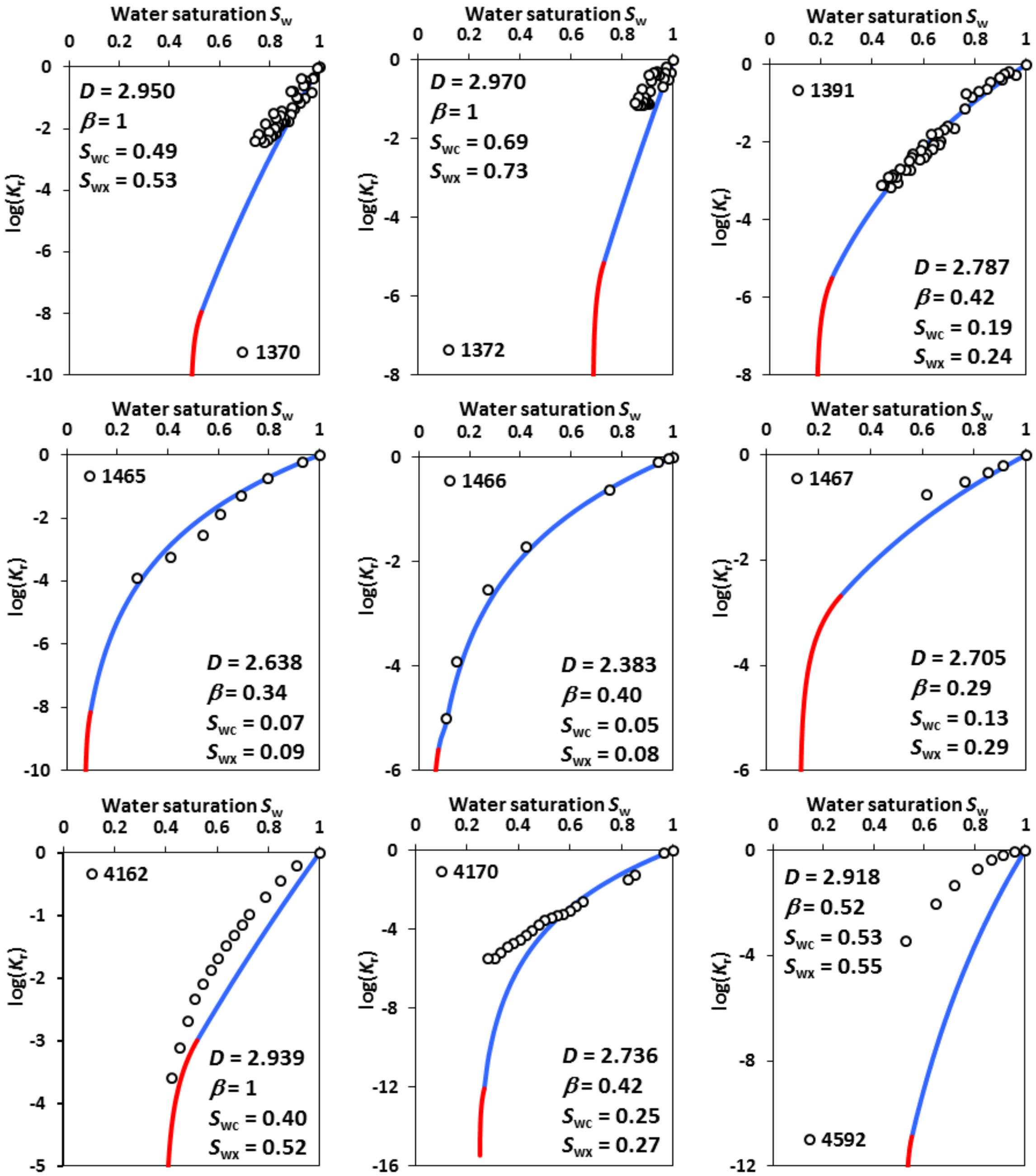

Fig. 6. Comparison of the estimated relative hydraulic conductivity K_r, calculated based on the desaturating capillary pressure curve, and the experimental data, for 9 soil samples from the UNSODA database. The blue and red lines represent the results of effective-medium approximation and percolation theory, respectively (after Ghanbarian et al. 2016a).

The unknown parameters in Eq. (19), such as D, P_a and β are determined by directly fitting the following fractal capillary pressure curve model to measured data

$$S_w = 1 - \frac{\beta}{\phi}\left[1 - \left(\frac{P_c}{p_a}\right)^{D-3}\right], \quad |P_a| \le |P_c| \le |P_{cmax}| \tag{20}$$

in which P_c is the capillary pressure, P_a is the entry pressure, and P_{cmax} is the maximum capillary pressure.

Figure 7 presents the saturated hydraulic conductivity estimated using the CPA (Eq. 19) as a function of the average saturated hydraulic conductivity data for 11 soil texture classes from Rawls et al. (1982). As can be observed, critical path analysis estimated K_{sat} within a factor of three of the measured hydraulic conductivity. Interestingly, critical path analysis estimated K_{sat} for fine-textured soils more precisely than that for coarse-textured soils (see Fig. 7), which is consistent with the fact that the CPA produces accurate estimation in heterogeneous soils with broad pore throat-size distribution.

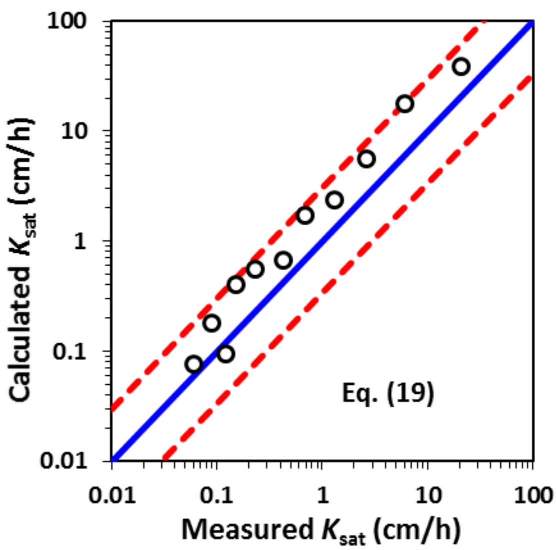

Figure 7. The estimated saturated hydraulic conductivity using the critical path analysis and Eq. (19) versus the average measured value for eleven USDA soil texture classes from Rawls et al. (1982). The blue solid and red dashed lines represent the 1:1 line and the factor of three boundaries, respectively (after Ghanbarian et al., 2017).

Following Hunt (2001), Ghanbarian-Alavijeh and Hunt (2012) proposed a model based upon critical path analysis to estimate the unsaturated hydraulic conductivity of soils. The Ghanbarian-Alavijeh and Hunt (2012) model is

$$\frac{K(S_w)}{K_{sat}} = \begin{cases} \left[\frac{\beta/\phi - 1 + S_w - S_{wc}}{\beta/\phi - S_{wc}}\right]^{\frac{\lambda}{3-D}}, & S_{wx} \le S_w \le 1 \\ \left[\frac{\beta/\phi - 1 + S_{wx} - S_{wc}}{\beta/\phi - S_{wc}}\right]^{\frac{\lambda}{3-D}} \left[\frac{S_w - S_{wc}}{S_{wx} - S_{wc}}\right]^2, & S_{wc} \le S_w \le S_{wx} \end{cases} \quad (21)$$

in which

$$\mathrm{S_{wx}} = \mathrm{S_{wc}} + \left[\frac{2(\beta - \phi)}{\lambda/(3-\mathrm{D}) - 2}\right] \quad (22)$$

where $\lambda = 2(4 - D) - (3 - D)/(2D - 3)$ (Ghanbarian et al., 2016b). For a comprehensive review of various unsaturated hydraulic conductivity models based on the CPA for different conditions, see Ghanbarian et al. (2015).

To evaluate Eq. (21), Ghanbarian and Hunt (2017) selected 104 soil samples from the UNSODA database. The input parameters, such as D and β were determined by fitting Eq. (20) to the drainage capillary pressure curve.

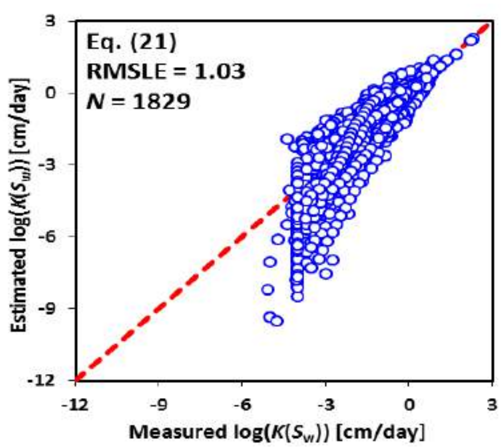

Figure 8. The logarithm of the estimated unsaturated hydraulic conductivity $K(S_w)$ using Eq. (21) with $\lambda = 2(4-D)-(3-D)/(2D-3)$ versus the logarithm of the measured one for 104 soil samples from the UNSODA database. RMSLE is the root mean squared log-transformed error and N is the total number of values. The red dashed line denotes the 1:1 line (after Ghanbarian and Hunt, 2017).

Figure 8 shows the estimated log($K(S_w)$) versus the measured log($K(S_w)$) for 104 soil samples from the UNSODA database. Equation (21) with $\lambda = 2(4 - D) - (3 - D)/(2D - 3)$ estimates $K(S_w)$ suitably scattered around the 1:1 line over the entire range of saturation. However, there still exist tendencies to underestimate $K(S_w)$ at lower water saturations. Errors in the estimation of $K(S_w)$ in particular at lower water saturations might be due to lack of equilibrium conditions in the measurements. Another plausible source of error for $K(S_w)$ underestimation might be due to multimodal pore-size distribution behavior in some soil samples analyzed. In addition, neglecting film and corner flow in the model Eq. (21) development might be another reason for $K(S_w)$ underestimation. One should note that Eq. (21), developed based on concepts from critical path analysis and percolation theory, is neither a function of capillary number – a dimensionless quantity measuring the ratio of viscous to capillary forces (Lake, 1989) – nor a function of flow rate, while both factors may significantly affect hydraulic conductivity measurements and estimations.

Conclusion

In this study, we applied upscaling techniques from statistical physics, such as the effective-medium approximation (EMA) and critical path analysis (CPA) to estimate the saturated and unsaturated hydraulic conductivities (i.e., K_{sat} and $K(S_w)$) in soils from pore-scale characteristics. Theoretically, the EMA upscales properly in homogeneous and relatively heterogeneous porous media, while the CPA works accurately in heterogeneous media with broad pore-size distribution. By comparison with numerical simulations and experiments, we showed that both the EMA and CPA methods estimated K_{sat} and $K(S_w)$ reasonably accurate in porous media. More investigation is required to address the effects of film and corner flow as well as capillary number via critical path analysis and percolation theory and the effective-medium approximation.

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EFFECTS OF CONTROLLED DRAINAGE ON NON-POINT SOURCE DISCHARGE FROM PADDY RICE IN KOREA

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Abstract

The objective of this study was to develop water management practices to reduce pollutant loads and to develop guidelines for paddy rice cultivation. The experimental fields were established at Chunpo-myeon, Iksan-si, in the Saemangeum watershed. The experiment was performed during the growing season to assess water and mass balances of the study field in 2013 and 2015. In this study the two different farming practices were applied: conventional and water treatment. Conventional practices were applied to maintain an average water depth of paddy fields at 7 cm, while the water depth of water treated plots were maintained at 7 cm to midsummer drainage and then raised to 12 cm afterward. Chemical fertilizer was applied in both plots. The water balance analysis indicated that the drainage of water treatment decreases by 24.2% (conventional: 394.5 mm, water treatment: 298.4 mm) as compared to the conventional treatment. Drainage when compared to the inflow of water treatment decreases from 0.9% to 9.6% as compared to the conventional treatment. The mass balance analysis indicated that T-N (Total-Nitrogen) drainage load of water treatment decreases by 27.1% (conventional: 1.25 kg/10a, water treatment: 0.91 kg/10a) and T-P (Total Phosphorus) decreases by 38.0% (conventional: 0.125 kg/10a, water treatment: 0.077 kg/10a) as compared to the conventional treatment. T-N drainage load when compared to the inflow of water treatment decreases from 0.5% to 3.3% and T-P decreases from 0.6% to 3.3% respectively as compared to the conventional treatment. The results of this study confirmed that water treatment in paddy fields reduces pollutant loads and could be used as a guidelines for farmers.

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KEY WORDS: Paddy, Non-point source, Drainage outlet heighten, Water balance, Mass balance

Introduction

Point source pollutant control has been implemented to improve water quality and thus most investment has been poured to this respect. As the result, approximately two thirds of total pollutants to water bodies is attributed to nonpoint source origin and thus has to be managed properly for further enhancement in water quality (Korean Relevant Ministerial Consortium, 2012).

Nutrient runoff from agricultural field is a substantial contributor to the surface water impairment and thus the nutrient loads reduction from paddy field has become an important issue in the Asian monsoon region (Kao et al. 2001; Yoon et al. 2003; Hama 2012). Paddy field accounts for more than 60 % of farm land and uses about 80 % of agricultural water use. Thus, the Korean government has run much efforts to reduce runoff from paddy fields (Choi et al. 2015).

Reducing surface drainage is effective in reducing nutrient loss from paddy field and some water saving methods was proposed including shallow ponding, raising drainage outlet, and minimizing midseason drainage (Yoon et al. 2003; Song et al. 2012). Paddy rice cultivation with outlet dikes and forced drainage alters paddy hydrological characteristics and thus water quality dynamics along with farmer's over-fertilization than the recommended in Korea (Kim et al. 2014)

The objective of this study was to investigate paddy nutrients runoff with some water saving method in comparison of conventional paddy farming practice.

Materials and methods

Experimental site layout

The field study was carried out from 2013 to 2015 on duplicated paddy plots of each 0.3 ha of fine sand loamy soil for the two different water management: one conventional and the other water treatment. Experiment fields were located at Iksan city of Jeonbuk Province in Korea. Overall experimental setup is presented in Figure 1.

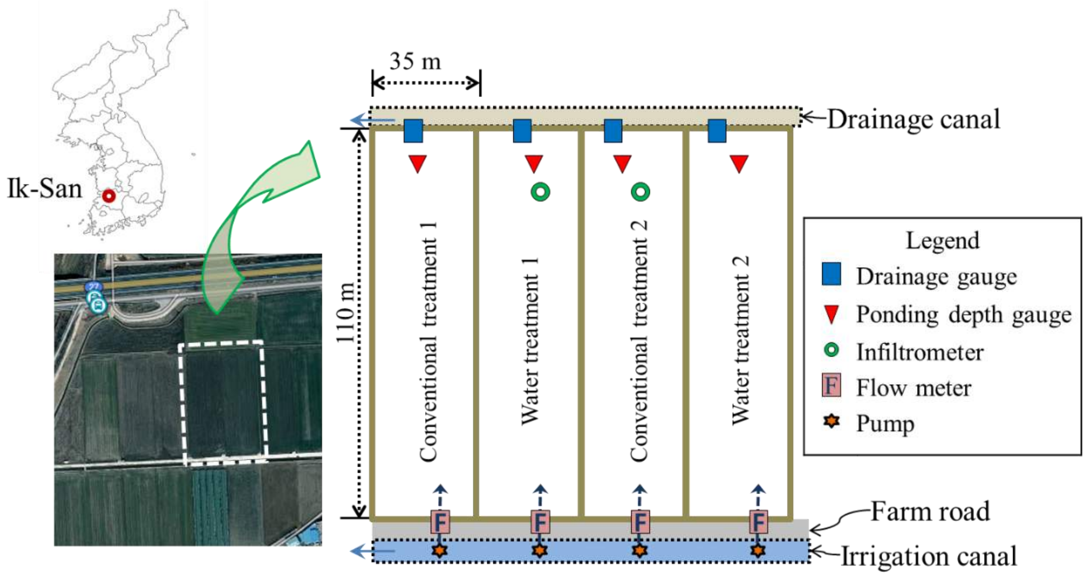

Figure 1. Study location and experimental setup

Experimental treatment and field monitoring

The two different farming (water management) practices were applied: conventional and water treatment. Conventional practices were to maintain an average water depth of paddy fields at 7 cm, while water depth of water treated plots were maintained at 7 cm to midsummer drainage and then raised to 12 cm afterward. Chemical fertilizer was applied in both plots.

In order to investigate hydrology in each paddy field, irrigation and drainage water amount were measured by respective flow meter and drainage weir continuously. Paddy ponding depth was also measured every 30 min with ultrasonic water level, while an infiltrometer was installed in a paddy field of each water treatment methods. Biweekly water samples were collected from paddy water in non-rainy, while continuous waters were sampled from the drainage outlet when rainfall event occurred. Water samples were transported to the lap for the analysis of nutrient contents along with basic water component. Paddy nutrient runoff was then calculated by multiplying drainage flow rate with corresponding water quality.

Results and discussion

The water balance analysis indicated that drainage of water treatment decreases by 24.2% (conventional: 394.5 mm, water treatment: 298.4 mm) compared to the conventional treatment. Drainage compared to inflow of water treatment decreases from 0.9% to 9.6% compared the conventional treatment. As shown in Table 1, there was no statistical significant difference in rice harvest between water treatment methods.

Table 1. Rice harvest comparison between conventional and water treated plots

Year	Treatment	Yield (kg/10a)			
		Rough rice	Brown rice	Milled rice	Head rice
2013	Conventional	718	594	549	503
	Water treatment	671	559	499	460
2014	Conventional	778	666	592	544
	Water treatment	814	715	632	583
2015	Conventional	769	646	588	449
	Water treatment	768	633	571	425

Figure 2 presents the results of nutrient loads from the two different water management schemes. Annual mean total nitrogen loads for the three years of experiment were 1.25 and 0.91 kg/10a for the conventional and water treated paddy plots, respectively. About 27 % of nitrogen loads was reduced with water treatment as compared to the conventional practice. Total phosphorus runoff was even more reduced by up to 38% with water treatment as compared to the conventional farming (T-P loads of 0.125 kg/10a and 0.077 kg/10a, correspondently). Considering phosphorus moving along with suspended solid, more ponding water with water outlet raising may reduce greatly the force of rainfall hit to soil particle and thus reduce soil detachment potentially transportable with drainage and resulted in reduction in TP loads. This confirmed that water treatment in paddy farming can reduces pollutant loads and can be used as a paddy BMP.

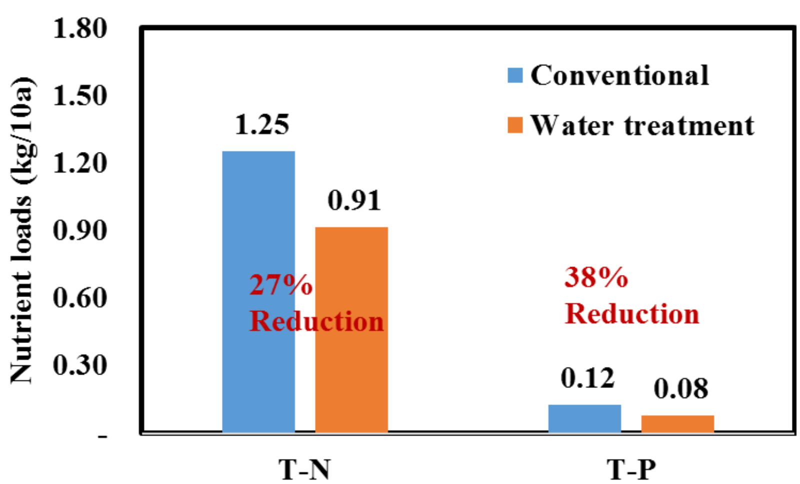

Figure 2. Nutrient loads reduction with water treatment

Conclusion

In this study, the two different farming (water management) practices were investigated in order to evaluate the effect of water treatment in paddy nutrient loads reduction. Annual nutrient loads was substantially reduced with alternative water management of drainage outlet raising as compared to conventional practice. Mean nitrogen loads was 1.25 and 0.91 kg/10a for the conventional and water treated paddy plots and about 27 % reduction was achieved with water treatment. Greater percentage of total phosphorus loads reduction (38%) was attained with water treatment than conventional farming. The study finding confirmed that water treatment in paddy farming can reduces pollutant loads and can be used as a paddy BMP.

Acknowledgement

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NON-EXCAVATION SUBSURFACE IRRIGATION AND DRAINAGE SYSTEM IN THE RECLAIMED LOWLAND TO BE CULTIVATED WITH UPLAND FIELD CROP

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Abstract

Although in the past reclaimed land was developed and used mainly as paddy fields in Korea, there is a currently a need to improve the reclaimed land to be cultivated for highland-field crops, due to the necessity for a smooth management of grain supply and demand in order to be able to cope with the changes in the international and domestic agricultural environment, and the earning of a higher revenue from farming highland-field crops instead of rice. However, it is difficult to cultivate highland-field crops in reclaimed land, because it is mostly located in lowland zones containing high salinity soil that is difficult to drain due to the characteristics of fine grained soil which is a major component of reclaimed land. In addition, there is the major problem of re-salinization of root zone soil caused by the capillary rise of saline groundwater during the dry season. In this study, seepage analysis was conducted on each type of subsurface drainage system to draw a high-capacity drainage system, and subsoil breaking and no-excavation subsurface drainage system were proposed to be utilized for the improvement of reclaimed land at low-cost to cultivate highland-field crops. The following results were acquired through pilot construction in the field.

i. Reclaimed soil of Korea, which is mostly impermeable ($k<1\times10^{-4}$ cm/s), requires the introduction of ①subsurface drains and ②subsoil breaking method, to improve the land to be cultivated for highland-field crop.

ii. In order to array the appropriate spacing (3~10m) by soil type, it is necessary to develop and introduce cost-effective non-excavation subsurface drainage system installation methods.

iii. The introduction of a subsurface irrigation and drainage system is necessary to clean drain systems and to prevent re-salinization.

iv. As a result of the construction of a pilot a cost-effective non-excavation subsurface irrigation and drainage system, it was confirmed that workability improved due to the application of a non-excavation method, whatsmore, construction cost dropped significantly (75%) and subsurface drain and desalinization performance was far superior (over 150%) with 5m intervals in parallel with subsoil breaking method than that of the existing method with 10m intervals.

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v. It was proven that subsoil breaking and subsurface irrigation and drain systems were efficient to clean the drain system using underground irrigation water as well as to prevent re-salinization. And it was also confirmed that the system made the desalinization of soil from 10~15ds/m to 2~5ds/m within a year under the condition of natural rainfall possible.

vi. As the result of crop cultivation on the pilot reclaimed land desalinized by subsoil breaking and subsurface irrigation and drain system, it was found that crop growth had a moderately high status without any damage by moisture during the wet season, and it led to the conclusion that the system is highly effective for the development of reclaimed land.

KEY WORDS: Subsoil breaking, subsurface irrigation and drainage, Subsurface horizontal filter system, Non-excavation system.

Introduction

Korea has been utilizing the reclaimed low land for paddy field to produce mainly rice as staple food, but nowadays it is required to develop the reclaimed land to cultivate upland crops for income improvement, control of cereal supply and demand.

Generally the reclaimed land is located at a lowland area with high salinity and fine-grained soil. Fine-grained soil causes a difficulty in subsurface drainage that leads to the poor cultivation of upland crops. In order to cultivate the upland crops in the reclaimed farmland, subsurface drain facilities have been installed, but it could not be actively implemented due to the high construction cost and low desalination effects. In addition, there is another challange that reclaimed low land, even if upland crop could be cultivated after desalination, may be re-salinized due to capillary rise of saline water under the ground during dry season.

The purpose of this study is to develop subsoil breaking method and low cost non-excavation subsurface drainage system to improve subsurface drainage and desalination in the reclaimed land. The efficiency of the low cost non-excavation subsurface irrigation and drainage system has been confirmed through the test construction.

Materials and methods

The Necessity for Development of Subsoil Breaking and Drain Construction Method

According to the calculation using Van Schilfgaarde and Hooghoudt equations in the basic design, optimum spacing of culvert is highly correlated with the permeability coefficient of the soil, which is shown in Fig. 1.

If the permeability coefficient (k) of the soil is less than $3*10^{-4}$ cm/s, the spacing of culvert should be less than 10 m, and if k = $1*10^{-4}$ cm/s, the spacing of culvert should be less than 5 m. If the coefficient of permeability is equal or less than $1*10^{-4}$ cm/s, it may be efficient to improve the permeability of the soil by breaking subsoil.

Low and wet paddy field in Korea usually has a coefficient of permeability less than $1*10^{-4}$ cm/s, but the culverts have been constructed with the spacing more than 10 m due to economic issues for which the culverts could not to be functioned properly.

In order to solve these problems, it is required to develop subsoil breaking and the low cost & high efficient non-excavation subsurface drainage construction methods suitable for the reclaimed soil in Korea.

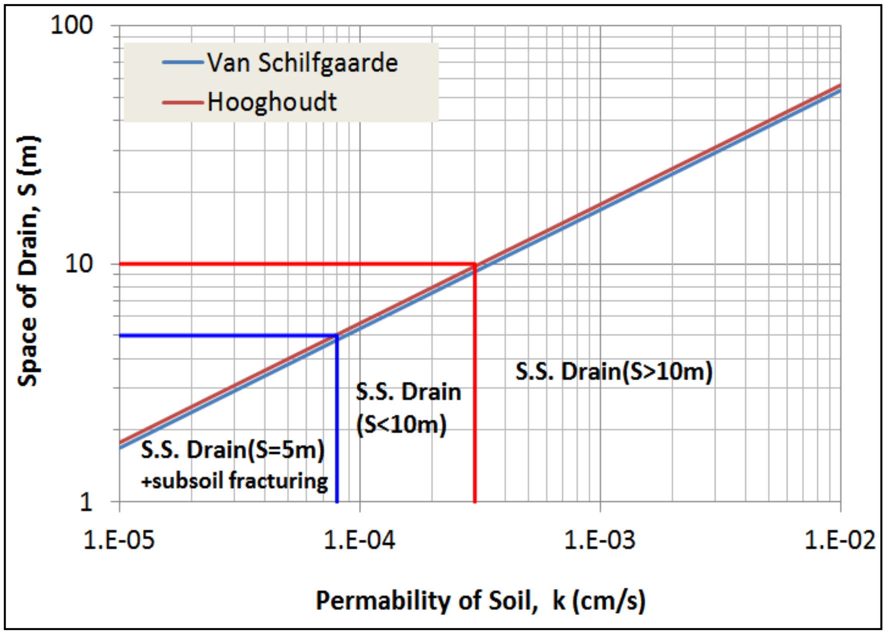


Figure 1. Permeability Coefficient and Spacing of Culvert (Formal Theoretical Model)

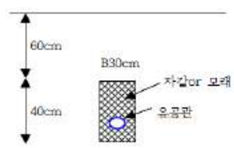
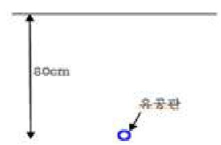
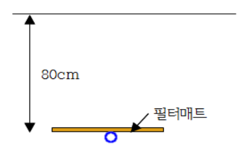
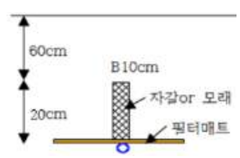
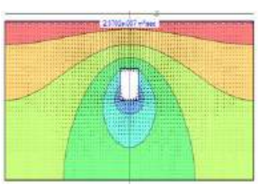
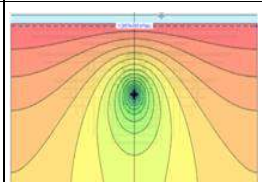
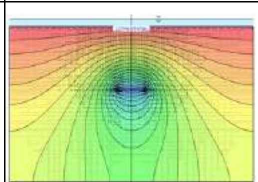
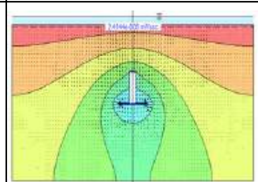
Introduction of Low Cost & Highly Efficient Subsurface Drainage System

Evaluation on the Performance of Subsurface Drainage System by Culvert Types

As shown in Table 1, numerical seepage analysis were conducted to check the performance of subsurface drainage system by four(4) types of culverts, such as ① the existing trench perforated drain pipe + gravel improved culvert ② non-excavation perforated drain (50mm) ③ perforated drain (50mm) + 50cm non-excavation horizontal drain mat ④ perforated drain (50mm) + 50cm wide horizontal mat + non-excavation gravel improved culvert. As a result, subsurface drainage discharge from soil to culvert per meter was in order of ④>①>③>②.

However, ②, ③ and ④ are 1/3 times cheaper than ①. If ① is installed at 10m interval, and ②, ③, ④ are installed at 5m interval, the subsurface drainage per unit area is ④> ③> ②> ①, but the construction cost is ①> ④> ③> ②. In other words, ③ and ④ have higher performances (1.75 times) and lower construction cost (67%) than ①, which means that these culvert construction methods are low in cost and highly efficient.

Table 1. Drainage effects of Subsurface Drainage Culvert by Types

Type of Culvert	**①Excavated Culvert** (gravel B30*H40cm)	**②Non-excavation Culvert** (50mm perforated pipe)	**③Non-excavation Culvert 2** (50mm perforated pipe + filter mat B50cm)	**④Non-excavation Culvert 3** (perforated pipe + filter mat + sand B10cm)
				
Shape of Subsurface Drain				
Discharge of drainage water (m^3/s/m)	**$2.37*10^{-6}$**	**$1.29*10^{-6}$**	**$2.17*10^{-6}$**	**$2.41*10^{-6}$**
Remark(%)	**100**	**54**	**92**	**102**
Installation space (m)	**10**	**5**	**5**	**5**
Discharge of subsurface drainage water per unit area (mm/d)	**20.5 (100%)**	**22.3 (109%)**	**35.8 (175%)**	**41.6 (209%)**
Construction cost (million Won)	**45 (100%)**	**20 (44%)**	**25 (56%)**	**30 (67%)**

The Necessity for Optimization and Test Constructions of Subsurface Culvert

When the permeability coefficient (k) of the soil is less than $3*10^{-4}$ cm/s, the spacing of culvert should be less than 10m and when the k = $1*10^{-4}$ cm/s, the spacing of culvert should be less than 5m. However, due to economic problems, it was forced to be over 10m.

Number ③ (50mm perforated pipe + 50cm horizontal mat) and ④ (wrinkle perforated pipe + 50cm horizontal mat + rice husks improved non-excavation culvert) construction methods can be used to resolve the problems in association with their lower construction cost (67%) and higher drainage performances (175%).

However, the calculation of drainage performance obtained through theoretical numerical analysis needs to be verified in the field. Therefore, test construction of number ① and ② for verifying their drainage performance were carried out.

In addition, since the permeability coefficient of the simulation site was less than $1*10^{-4}$ cm/s, the subsoil breaking was also carried out.

Subsurface Irrigation and Drainage System to Prevent Re-Salinization

Re-Salinization Characteristics in Dry Season

As shown in Fig. 2, the soil salinity repeatedly changed after the installation of the subsurface culverts. Soil salinity decreased in the wet season and rose again in the dry season. This phenomenon was caused by capillary rise of brine water. Hence, capillary rise during dry season should be prevented.

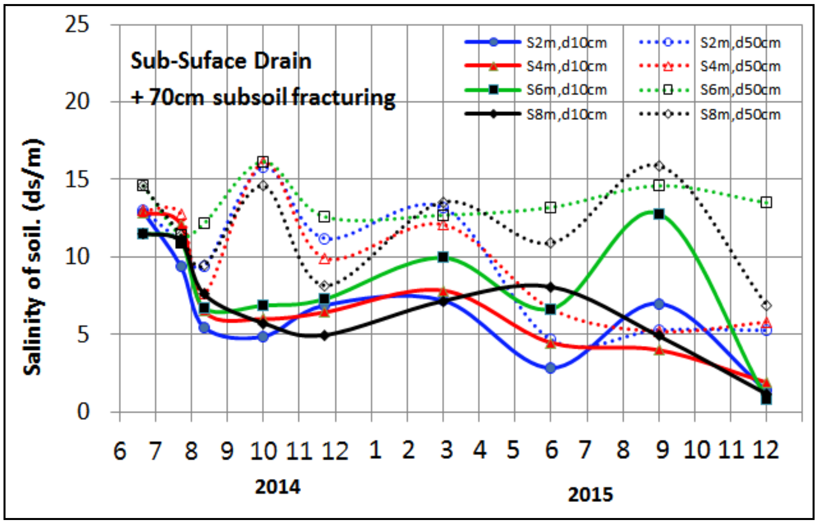


Figure 2. Changes in Soil Salinity of Reclaimed Land during Wet and Dry Seasons

Subsurface Irrigation System for Preventing Re-salinization in Dry Season

As shown in Fig. 3, capillary rise in dry season can be blocked by artificially forming freshwater layer above the saline water. To confirm this method, test construction was carried out.

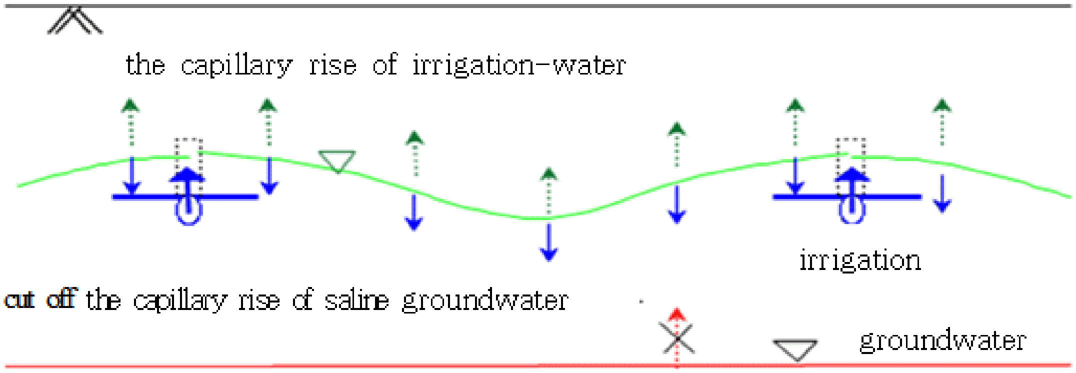


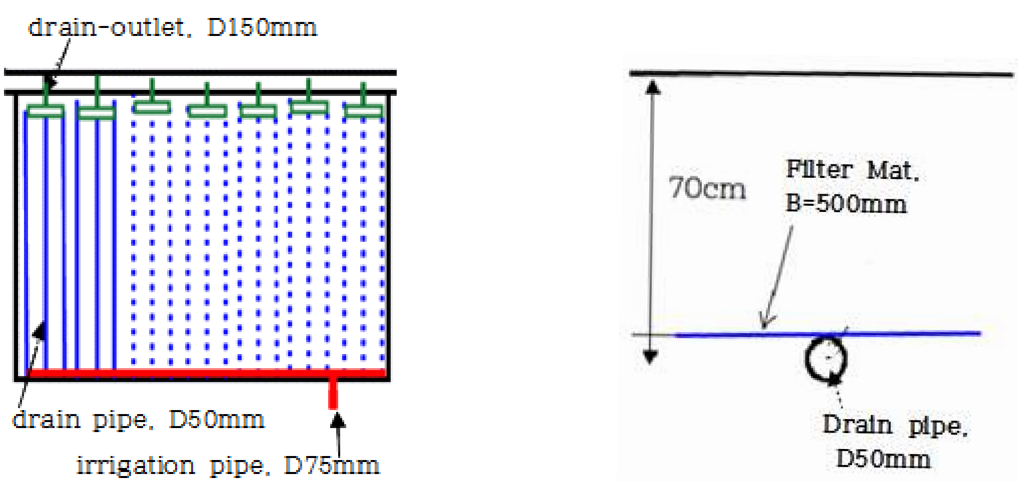
Figure 3. Schematic Diagram of Re-salinization Prevention through Subsurface Irrigation System in dry seask

Layout of Test Site

Test Construction of Non-Excavation Subsurface Irrigation and Drainage System

Plan and Cross Section of Test Construction

As shown in Fig. 4, test construction of subsurface irrigation and drainage system was carried out by using non-excavation single pipe method (0.3 ha). The culvert was constructed by ϕ50mm perforated pipe and 500mm horizontal mat with 5m spacing.

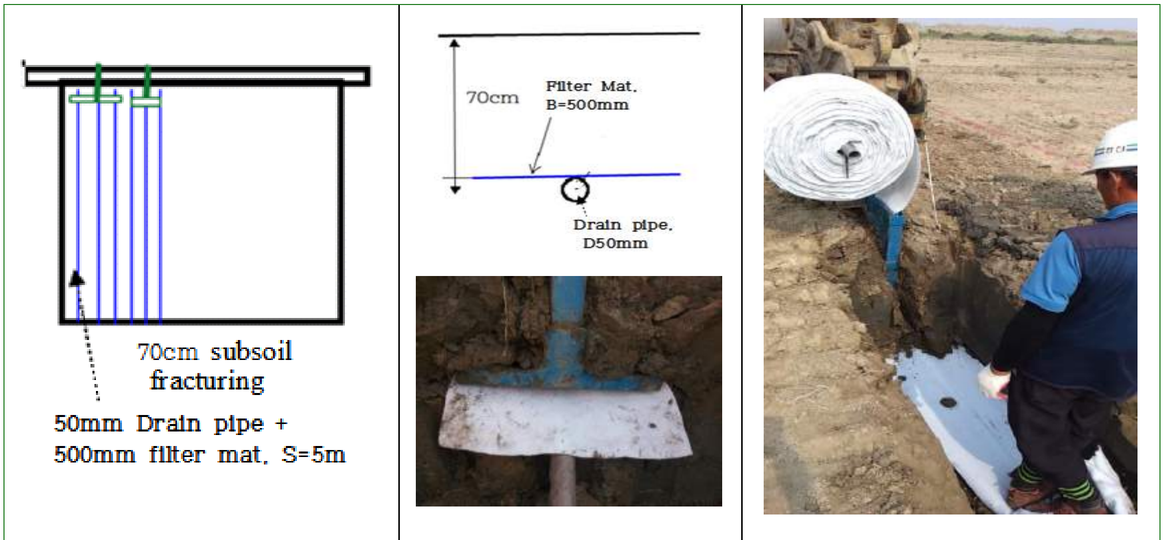


a) Plan of Subsurface Irrigation & Drainage Culvert b) Cross Section of Non-Excavation Culvert

Figure 4. Plan and Cross Section of Non-Excavation Subsurface Irrigation and Drainage System

Test Construction of No-Excavation Single Pipe Subsurface Culvert

Figure 5 shows the test construction of subsurface irrigation and drainage culvert using non-excavation single pipe in 0.3 ha area.



a) Plan of Culvert	b) Cross Section of Culvert	c) Construction of Non-Excavation Culvert

Figure 5. Test Construction of Subsurface Irrigation and Drainage Using Non-Excavation Single Pipe Method

Subsoil Breaking

After the installation of the subsurface culvert as shown in Image 1, subsoil with the depth of 0.7m was crushed by using a backhoe breaker. After subsoil breaking, the soil was completely crushed and the water penetrated evenly into the ground. Almost all the water penetrated into the ground immediately after the rainfall.

Image 1. Subsoil Breaking Using A Backhoe

Results and discussion

Effects of Rainfall Penetration and Subsurface Drainage

As shown in Image 2, the surface water in the no ss block has not been discharged for more than 20 days after rainfall, but a block with culvert and crushed subsoil in the ss drain block has been dried immediately within a day by infiltration after rainfall.

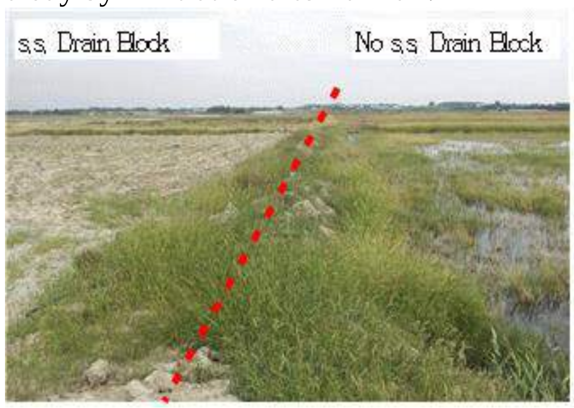
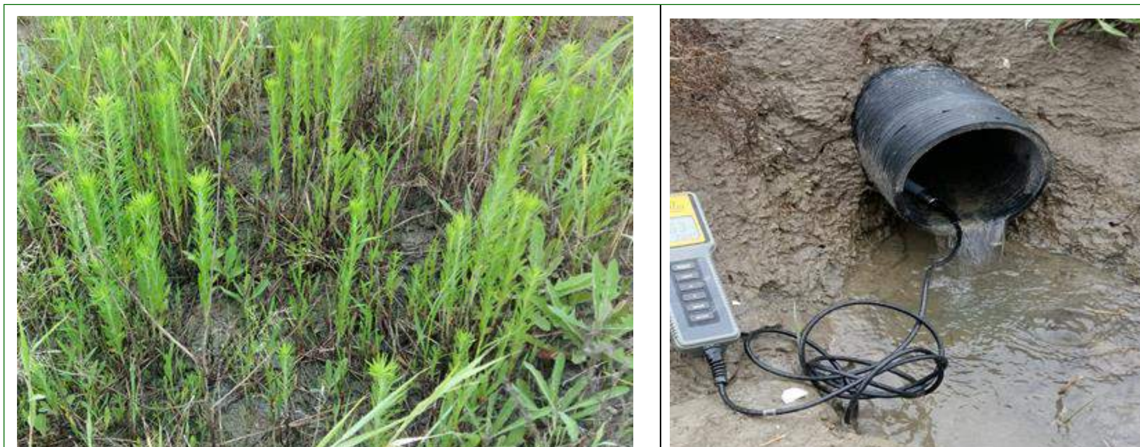


Image 2. Effects of Subsurface Culvert and Subsoil Breaking

Continuity of Subsurface Drainage in Three Years after Construction of Subsurface Culvert and Subsoil Breaking

As shown in Image 3, in three years after construction of subsurface culvert and subsoil breaking, it can be seen that subsurface drainage can effectively drain the water even without surface water drainage after rainfall of 100mm/day. Subsoil breaking improves the soil structure and soil permeability.



a) Vegetation and Subsurface Drainage Status in the Non-excavation Culvert Block	b) Drainage Status of Culvert Drain

Image 3. Condition of Subsurface Drainage After 100mm/day Rain (3 years after construction)

The effects of expediting Desalination and preventing Re-salinization by Subsurface Irrigation and Drainage System

As shown in Fig. 6, the untreated block showed almost no desalination for 2 years. However, the salinity in block with drainage culvert (No I+D System) decreased from the initial salinity of 12 ds/m to 4.2 ds/m in 2 years. The salinity of soil tends to decrease in wet season and increase in dry season.

Non-excavation subsurface irrigation and drainage system (+backhoe breaking) was desalinated up to 2~5ds/m in the first year and the salinity continuously decreased until the end of experiment period without re-salinization.

Through this experiment, it was confirmed that the subsurface irrigation and drainage system has a great effect of preventing re-salinization.

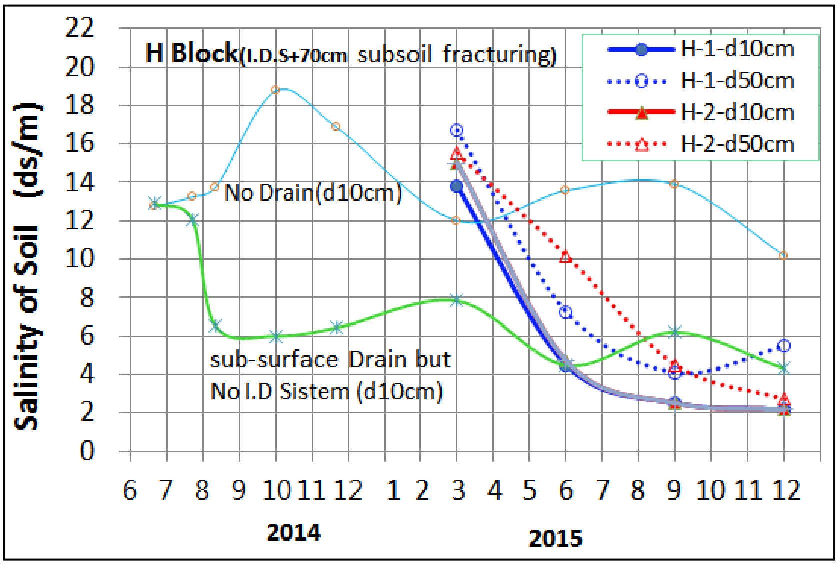


Figure 6. Effects of expediting Desalination and preventing Re-salinization by Subsurface Irrigation & Drainage System and Subsoil Breaking

Vegetation Changes after Desalination

Vegetation changes after desalination for 1 to 2 years is shown in Image 4. It shows that the untreated block was overgrown by halophytes vegetation, while the block with non-excavation culvert (+backhoe breaking) was overgrown by common vegetation.

It is confirmed that the area with subsurface irrigation and drainage culvert is well drained and the soil moisture is suitable for cultivation of upland crops.

a) Untreated Block (Halophytes)

b) Block with Subsurface Culvert + Subsoil Breaking (common vegetation)

Image 4. Vegetation Status after 100mm/day Rainfall

Crops Cultivation in 2 Years after Culvert Construction and Subsoil Breaking

The block over 2 years after construction of subsurface irrigation and drainage system and subsoil breaking had a salinity of 1~4 ds/m and was overgrown by crops as shown in Image 4.

It was confirmed that the construction of subsurface culverts in appropriate intervals with subsoil breaking can improve the soil structure even in impermeable reclaimed land and subsurface drainage which expidite desalination and prevent re-salinization to cultivate upland crops possible.

a) Growing Status of Kidney Beans

b) Growing Status of Corns

c) Growing Status of Sorghum

d) Growing Status of Green Onion

Image 5. Growing Status of Upland Crops in 3 Years after Test Construction

Conclusion

In order to convert the reclaimed land to highland crop field, the disadvantages of subsurface culvert were re-analyzed, and construction of non-excavation irrigation & drainage system with subsoil breaking were proposed. The study resulted in conclusions as follows:

i. Reclaimed land in Korea, in which soil is mostly impermeable ($k<1*10^{-4}$ cm/s), requires the introduction of ①appropriate interval(less then 10m) of subsurface drainage system and ②subsoil breaking method, to improve the land to be cultivated for upland crops.

ii. In order to array the appropriate spacing (3~10m) by the soil type, it is necessary to develop and introduce cost-effective non-excavation subsurface drainage system installation method.

iii. The introduction of subsurface irrigation and drainage system is necessary to clean drain system and to prevent re-salinization.

iv. As a result of the pilot construction of cost-effective non-excavation subsurface irrigation and drainage system, it was confirmed that workability was improved due to the construction of non-excavation method, and construction cost was lower (75%) and subsurface drain and desalinization performance was far superior (over 150%) with 5m intervals in parallel with subsoil breaking method than that of existing method with 10m intervals.

v. It was proved that subsoil breaking and subsurface irrigation and drain system were efficient to clean the drain system using underground irrigation water as well as prevent re-salinization. And also it was confirmed that the system made the desalinization of soil from 10~15ds/m to 2~5ds/m within a year under the condition of natural rainfall possible.

vi. As the result of the crop cultivation on the pilot reclaimed land desalinized by subsoil breaking and subsurface irrigation and drain system, it was found that crop growth without any damage by moisture during wet season was shown in good status, and it led to conclusion that the system is highly effective for the development of reclaimed land.

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POTENTIAL OF SUPER ABSORBING MATERIAL IN A SUBSTRATE MIX FOR EXTENSIVE GREEN ROOFS

Farhad Misaghi[1,*], Zeinab Bigdeli[2], Masoud Saeedi[3]

Abstract

The application of green roofs is increasingly recognized in many countries as a solution to improve environmental quality and reduce runoff quantity. This study investigates the viability of super absorbing materials in a substrate mix for extensive green roofs, where plants are supported by lightweight growing media (substrate) overlying a drainage layer. In addition, the role of super absorbing materials as a growth medium, drainage properties of the substrate mix containing recycled materials, as well as its susceptibility to erosion and resistance to sliding when placed on a slope were investigated. Therefore, the main aim of this study is to investigate the impact of natural zeolite on rainfall infiltration into the soil, runoff, and soil water storage capacity in green roofs .This study includes the establishment, development, and performance of both grass and sedum model green roofs under simulated rainfall events. It indicates supportive suitability of the substrate mix containing recycled waste materials for plants growth. It is resistant to erosion and slippage and capable of providing good drainage. The results showed that infiltration in zeolite-treated soil is very high and treated soil can reduce drained water volume. In the treatment analysis, the highest rate of drained water was recorded as 20.5 (ml) and it was shown that in untreated soil there is a lacks of water as runoff, thus drainage and preserving water in the soils were too low and the lowest rate of drained water was seen in soil treated with 3% zeolite (5 ml).The results of this laboratory investigation were used to extend green roofs into the wider perspective of sustainability benefits.

KEY WORDS: Green Roof, Super Absorbing Material, Drainage.

Introduction

Urbanization is increasing globally and urban populations are congregating in cities (UNDP, 2008). One of the effects of urbanization in such areas is increasing the percentage of impervious surfaces which in itself causes environmental problems, and such a trend is common in urban cities. Moreover, studies show that global warming causes an increasing in extreme rainfall events (Arnell, 1999; Bates et al., 2008) and one of the solutions to cope with such problems is the

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adopting of new storm-water management strategies such as Low Impact Development policies (Voyde et al., 2010), Sustainable Urban Drainage Systems (SUDS) (Stovin, 2010), Low Impact Urban Design and Development policies (LIUDD) (Van Roon, 2005) and Water Sensitive Urban Design strategies (WSUD) (Beecham and Chowdhury, 2012)., The utilization of Green infrastructure through WSUD is among the possible solutions to reduce the negative impacts of urbanization particularly. As well as providing additional amenities and water quality benefits for communities and environment (Beecham, 2003; Beecham et al., 2012, Sharma et al., 2016). Since, green roofs have become widely used in recent years (Emilsson et al., 2006). A green roof refers to the roof of any building which is partially or completely covered with vegetation, planted over a water proofcurtain. It may also include additional layers such as root barrier and drainage and irrigation systems. Green roofs have several purposes for a building such as rainwater harvesting, supplying insulation, increasing neighborliness and the decreasing of urban stress levels of people living in the vicinity by providing a more aesthetically pleasing view, moderating urban air temperature and mitigating the heat island effect (Vandermeulen et al., 2011). There are two types of green roofs: intensive roofs, composed of brushwood with a minimum depth of 12.8 cm (5.0 in) which can support a wider range of plants,yet which are heavier and require more conservation. The other type are called extensive roofs, which are shoal with a minimum depth ranging from 2 cm (0.79 in) to 12.7 cm (5.0 in), and which are lighter than the former type, requiring minimal conservation (Volder et al., 2014). The ever increasing trend of urban development worldwide including Iran is an unavoidable consequence of the science and technology era. Urbanism has a direct relationship with urban frame development and it tends to move away from nature and violates the interaction between man and the natural environment (MoharramNejad and Bahman Poor, 2009). Oneof the most important objectives in green roof studies is assessing how green roofs can affect storm-water quality and quantity. This in itself requires an knowledge of the hydrological performance of green roofs. Hydrological studies of green roofs, particular studies on their water retention capacity, began in Germany several decades ago (Mentens et al., 2006).

Zeolite is a relative superabundant mineral resource with excellent properties including Cation Exchange Capacity (CEC), free structural water storage and surface adsorption which provides it with a significant potential for application in soil improvement. Some advantages like increasing water retention and a much more cost effective fertilization capability can be gained by using zeolite. Zeolite usages are suitable for water-efficient agricultural purposes (Xiubin and Zhanbin, 2001). In recent years, an increasing interest in using natural super absorbants such as zeolite in agricultural activities has been reported (Ozbahce et al., 2014). Adding zeolite to the soil will increase the infiltration rate and improve its ability to hold nutrients and water content (Brannvall, 2007).

Materials and methods

The study area was a greenhouse site located at the University of Zanjan, Iran, at 36.6751°N latitude and 48.4845°E longitude with an ASL elevation of 1500m. Zanjan receives approximately 200-400 mm precipitation per year and the temperature varies between 9°-17˚C. This study was conducted at the greenhouse site with simulated rainfall events (Fig. 1), using 3 treatments and 3 repeats, and a steady flow rate of 35 mm/hr on a steady slope of 5%.

Figure 1. Rainfall simulator system

In this study, a total of nine 31×25×15 cm plastic boxes were used. At the bottom of the system, several holes were made which acted as drainage outlets to allow for quick drainage of excess water from the system after each rainfall event (Fig. 2). After each draining event, a layer of 3 cm sandy soil was used at the bottom of the box, and of the exterior of the boxes were covered by textile to prevent any flowing on the box's walls. Soil samples were taken from the Agricultural Research Farm of Zanjan University located in Zanjan Province, in the Northwest of Iran. Table 1 shows some physical properties of the soil samples.

Table. 1 Some physical properties of soil samples used in the study

Soil texture	Clay- Loam
Bulk density	1.30 gr/cm^3
Total weight of box	15.12 kg

Figure 2. Experiments setup

The zeolite mineral sample was obtained from the natural zeolite mineral collected in Iran. Before using the zeolite, it was ground and then 1 to 3 percent of zeolite, was added to the top layer of the soil (0–15 cm). The statistical design was based on three criteria. The first criterion was a 5 degree slope. Followed by a consistent rainfall at a rate of 35 mm/hr for the whole experiments. Another criteria was the type of treatments including the using of nine transparent plastic boxes to conduct the tests, three treatments (i.e. barren areas, soil treated with 1% and 3% zeolite) with three replicates. A rainfall simulator was used for a specific period with steady rainfall. To setup these green roof beds, all of the systems were arranged and included a drainage collection point to measure outflow rates. Furthermore nine bottles were placed at the bottom of the boxes to collect outflow water in order to measure volumes and perform the analysis. To measure volumes of drained water nine containers were place under the boxes.After 48 hours when moisture reached the FC point, the drained water volume was measured.
The present study aims to investigate the impact of natural zeolite on rainfall infiltration into the soil, runoff, and soil water storage capacity in green roofs. The experiment started after preparing the boxes and after noting the results (Schematic of the study field plot shown in Fig.3). For the statistical analysis of the results, SAS statistical (Statistical Software) and Excel (Microsoft Office Excel ver. 2010) packages were used.

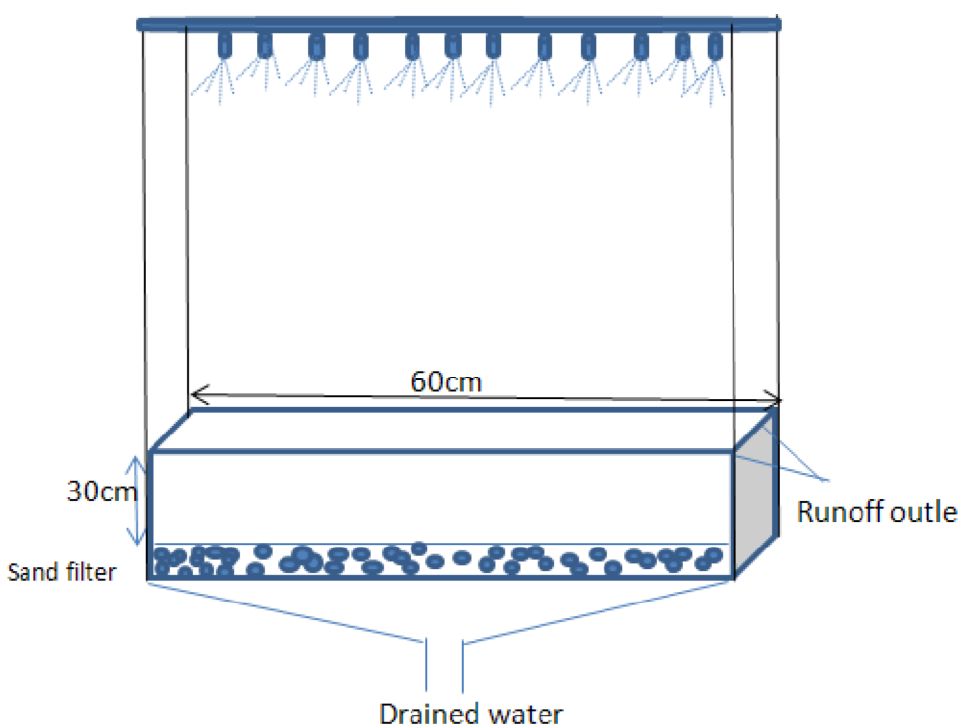

Figure 3. Schematic of the study field plot

Result and discussion

Impact of zeolite application on runoff

According to the results, runoff and drained water were significantly different in the soil samples treated with zeolite (1% and3%) than those with untreated soil samples (Table 2). Table 2 shows that the maximum volume of runoff and drained water was obtained from untreated soil and in the samples containing zeolite, the volume of the runoff and drained water decreased with the least volume obtained for treatment 3. According to the results (Table 2), a significant decrease was observed in the runoff volume, and the drained water volume after the application of zeolite.

Table.2 Impact of zeolite application on runoff

Drained water	**Runoff**	Treatments
3.54[a]	4.51[a]	1
2.95[b]	4.20[b]	2
2.18[c]	3.95[c]	3

Results indicate a significant decrease in runoff volume and drained water through the application of zeolite ($P<0.01$). The volume of surface runoff of zeolite-treated soil samples is significantly decreases, as compared with the untreated soil samples ($P<0.01$). Such a result parallels studies carried out by Ghazavi (2015) that reported an increase of the infiltration rate and soil water content in soil treated with zeolite as compared to the untreated soil. A significant decrease in runoff, drained water and sediment has been observed zeolite is applied ($P<0.01$). Afrous (2015) found that the highest and lowest concentrations of nitrate in outlet drain water was observed in soil samples without zeolite and calcium zeolite with average rates of 83.5 and 6.8 mg/lit, respectively.

Runoff

The comparison of the runoff rate in three main groups of treated and untreated soil samples with 1% and 3% zeolitein (Fig. 4), show that Treatment 3 generally tend towards the highest retention performance. Soil water content, measured in one day, was significantly different in the soil samples treated with zeolite and untreated soil. The high rate of water holding capacity, and high absorption capacity of natural zeolite was reported in many researches (Akbar et al., 1999, Pickering et al., 2002). In controlled treatment, the highest rate of runoff was 3.5 (ml) and the lowest volume of runoff is related to the soil treated with zeolite 3% was 1.8 (ml). The results show that green roofs can significantly reduce runoff, especially the rate of maximum runoff (Fig. 4).

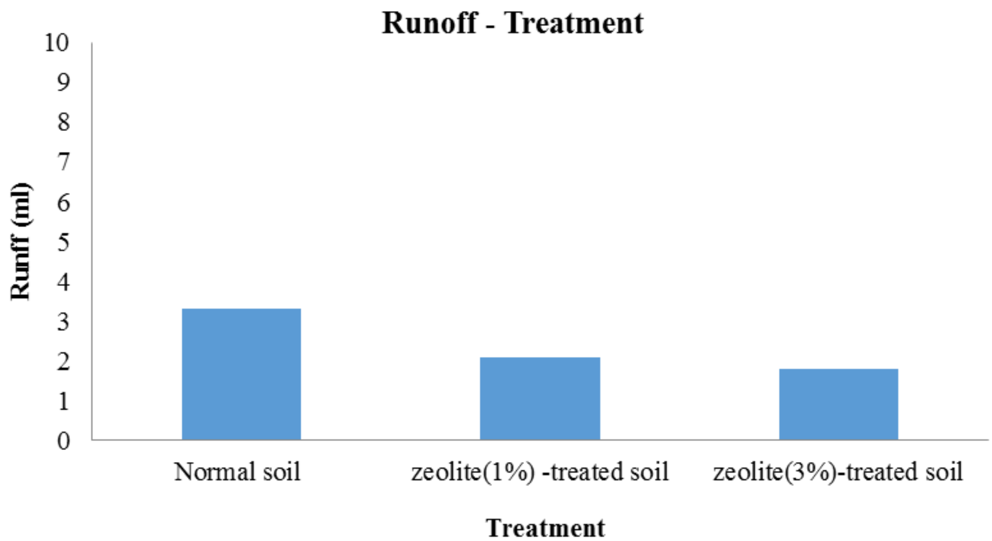

Figure 4. The variations of runoff volume (ml) in normal and zeolite-treated soils

Drained water

Fig.3 illustrates drained water content in three main groups of treatments. Fig. 5 shows that the infiltration of the zeolite-treated soil was very high and treated soil can reduce drained water volume.There was a significant difference between drained water content in normal and treats soil with soil samples treated by 1% and 3% of zeolite. In treatment analysis, the highest rate of drained water was recorded as 20.5 (ml) and it was shown that untreated soil lacks a lot of water as runoff, drains and reserved water volumes in the soils were too low and the lowest rate of drained water was seen in the soil treated with 3% zeolite (5 ml).

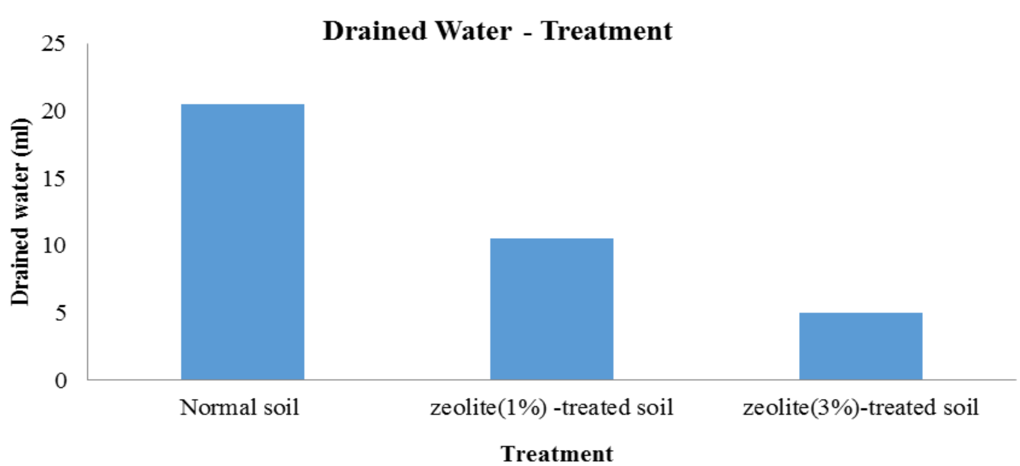

Figure 5. The variations of volume (ml) of drained water in normal and zeolite-treated soils

Conclusion

Green roofs are widely used in many countries as a solution to improve environmental quality and reduce runoff quantity. Green roofs, defined as roofs of buildings that are partially or completely covered with vegetation planted in a growing medium, can provide several advantages in terms of sustainability. This study consistently showed that the high levels of storm-water attenuation can be achieved by using green roofs and concluded that green roofs can significantly reduce the maximum rate runoff and drained water .It can help retaina lot of rainfall content and reduce the height rate of the peak flow. There is a potential opportunity to increase the advantages of green roofs by using super absorbing materials in green roof construction. This study investigated the viability of using super absorbing materials in a substrate mix for extensive green roofs where plants are supported by lightweight growing media (substrate) overlying a drainage layer. The adequacy of super absorbing materials as a growth medium, drainage properties of the substrate mix containing recycled materials as well as its susceptibility to erosion and resistance to sliding when placed on a slope were also investigated. This study included the establishment, development and performance of both grass and sedum model green roofs under simulated rainfall events. It was found that the substrate mix containing recycled construction waste materials was successful in supporting plant growth, resistant to erosion and slippage and was capable of providing good drainage. The results of this laboratory investigation has been recommended to be used to extend green roofs into the wider perspective of sustainability benefits.

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THE EFFECTS OF DIFFERENT DRAIN SPACING AND DEPTHS ON WATER TABLE LEVEL AND SOIL SALINITY IN HARRAN PLAIN OF TURKEY

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Abstract

Harran plain, totally 225000 hectares, is the first big scale irrigated area in South Eastern Anatolia Project (GAP) in Turkey. This Plain has been irrigated since 1995. Approximately, the part of 50.000 ha in this plain has a high water table which was caused by irrigation, geological-hydrogeological structure. The low quality waters infiltrated from irrigation has raised the water table of the perched aquifer which is resulted in a direct hydrological connection between waters of different quality. Thus, high water table and soil salinization increasingly spread. In this study, some drainage criteria were studied. Different drain spacings and different drain depths on the effects of water table, salinization and corn yield are investigated. Three different drain spacings (45 m, 60 m and 75 m)and three different drain depths (1,2 m, 1,5 m and 1,8 m) were used in this study. In addition, a cross drain pipe was placed between two parallel drains spaced 120 m. In the first year, corn was planted between parallel drains and the same agricultural process has been applied for the whole fields. There were no significantly effects between different drain spaces on the crop yields. The depths of water table were ranged from 120 cm to 140 cm during the irrigation season for both of the areas of crosswise drains and different drain spacings and drain depths. The effects of different drain spacings on the salt variation of root zone will be evaluated at the end of the first year and the third year of the study.

KEY WORDS: Drainage, Drain depth, Drain space, Salinity.

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Introduction

The successfully irrigated agriculture needs the moisture-oxygen and salt balance in the soil zone of the plant root for crop growth. When a saline water table rises and remains in the root zone longer than about two days or more, resulting in a high saline moisture condition, the crops grown and agricultural production is usually seriously affected.

Waterlogging may be defined as excessive moisture and anaerobic conditions occurred in the plant root zone. There could be some reasons for the waterlogging such as flood and excessive irrigation, seepage and infiltration of the water from the canals or rivers. However, subsoil conditions and soil texture, inadequate drainage, topography and climate could also stimulate the waterlogging. Overtime, water table could rise. Thus, a good drainage facility is very essential. The waterlogged area may be reclaimed by underground drainage schemes.

Southeastern Anatolia Project, known as the "GAP" in Turkish acronym, in Turkey aims to develop water and land resources in the region and planned as a package that comprised of 13 individual projects on irrigation and energy production on the Euphrates-Tigris basins (GAP, 2016). Harran Plain, totally 225 000 ha, is one of the lands firstly irrigated by GAP in 1995. Currently, 150 000 ha of the plain is irrigated. However, salinity and raising water table have been expanded since excess irrigation and inadequate drainage systems. Approximately 10 years later irrigation, water table levels were 0-1.0 m and 1.0-2.0 m for the area of 16 500 and 34 000 ha, respectively in Harran Plain. For this, the instructions of drainage systems are need to prevent and/or to remove waterlogging (DSI, 2004).

An appropriate drainage is a function of total irrigation water applied to the lands, water quality, crop pattern, soil salinity and soil aeration. All these factors have highly variation for the different lands. For this, the data pertaining to the lands constructed drainage systems should be considered. Otherwise, excessive drainage can cause expensive cost; inadequate drainage might cause environmental problems. An appropriate drainage for the waterlogging lands needs to be known and provided real data related these lands such as drain spacing, water table height level and different envelope materials.

Depth, spacing, and dimensions of ditches or pipe drains for agricultural drainage are the most important engineering factors. The relationship between engineering factors and crop production should be considered together with each other. Some works on drainage in Harran Plain were started by DSI and it was determined the drain depth (1.50 m) and drain spaces (48-125 m) using Donnan equation (DSI, 1978).

In this study, it is aimed to determine drainage criteria based on the instruction of the drainage systems for the lands having salinity problems and high water table in Harran Plain of Turkey.

Materials and Methods

This study was carried out in Harran Plain of Southeastern Anatolia Region in Turkey. The study area is located in (37° 9.7′ and 36° 42′ N lat., 38° 49.6′ and 39° 7.9′ E long; Fig. 1). The plain was developed for irrigated agriculture (150 000 ha) by GAP. The climate of the study area is semiarid with mean temperature, precipitation and evaporation of 17.2°C, 365 mm and 1848 mm, respectively. The precipitation is almost received during the fall season. Elevation of the study area ranges from 345 m in the south to 550 m in the north. The soils have been formed on calcareous materials and are classified as Vertisols, Fluvisols, Calcisols, Cambisols, and Leptosols. A total of 25 soil series have been described in the study area. Soils are mostly finely textured (clay loam to clay) and contain very low to low amounts of organic matter (0.5 to 1.5 %) and high amounts of $CaCO_3$ (on average 250 to 350 g/kg). Dominant clay minerals within salinized area are smectite, polygorskite, chlorite, illite, and kaolonite, in decreasing order of abundance (Dinc et al., 1988; Bilgili, 2013).

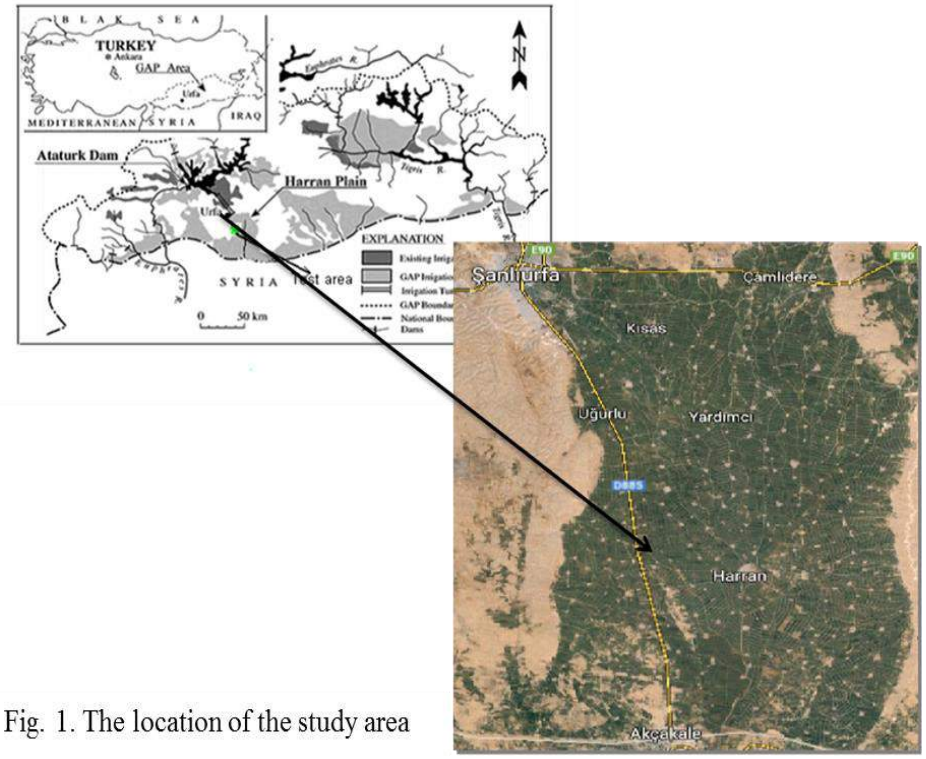

Fig. 1. The location of the study area

Experimental site layout

The study was included 2 different components of the drainage criteria.

Treatment

The effects of different drain spacings on crop yield and soil salinity

A cross drain pipe were placed between two parallel drains spaced 120 m. Thus, different drain spaces were obtained (Fig. 2). In the first year, corn was planted between parallel drains and the same agricultural process has been applied for the whole fields. The effects of different drain spacing on the salt variation of root zone will be evaluated at the end of the first year and the third year of the study.

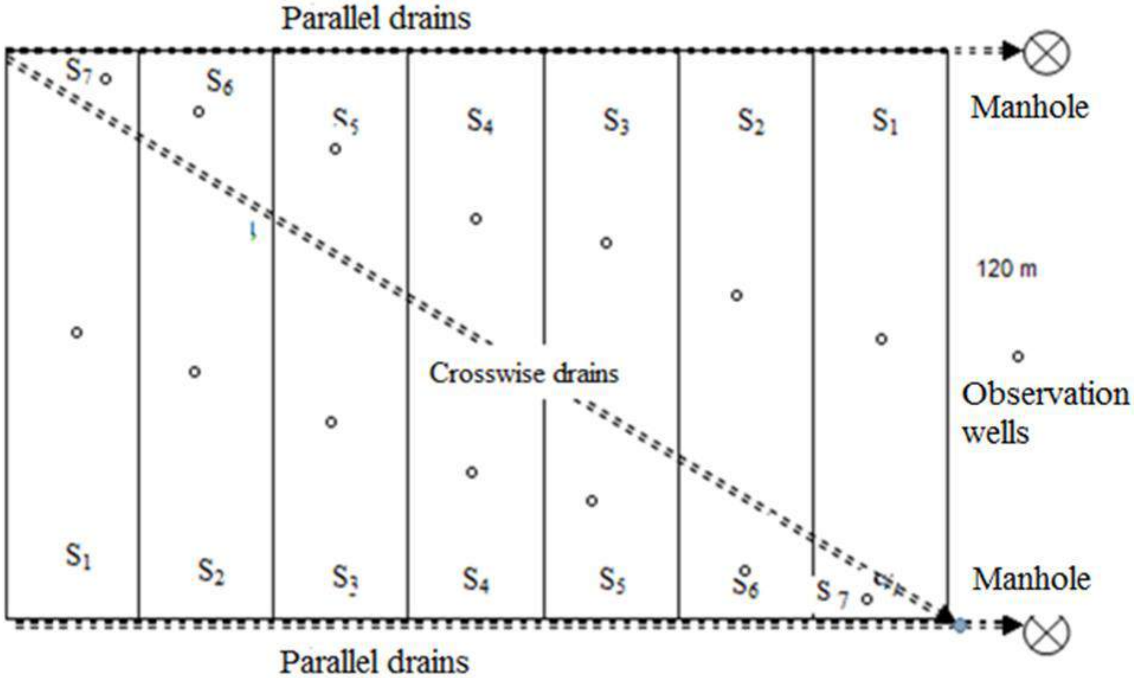

Fig. 2 The shematic layout of the different drain spacings

Treatment

Drain spacing according to the constant water table

Drain spacings and drain depths, and the layout of drains are given in Fig 3.

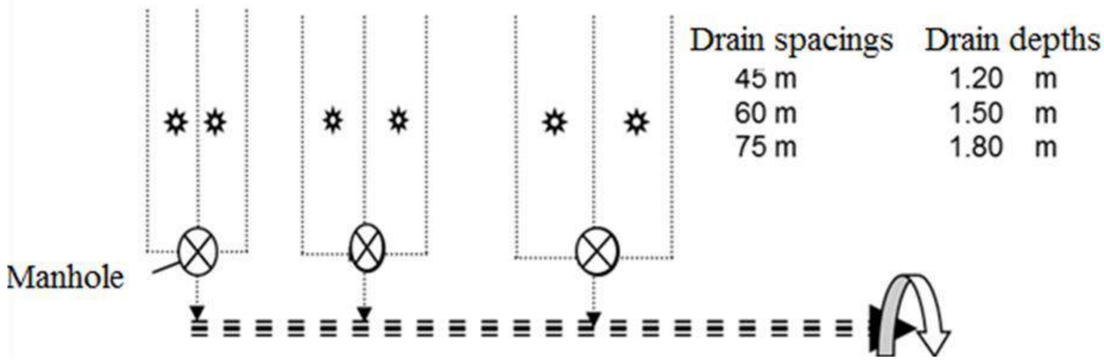

Fig. 3. The layout of the different spacing and depths of the drains for the experiment 2 (D-2)

Results and discussion

Basic properties of soil and water table

The values of hydraulic conductivity for the experimental site are given in Table 1. According to the Auger-hole method for 4 different sites of the study area, the hydraulic conductivity for the experimental site was "medium" level. Considering the texture class of the experimental soils were heavy clay, the hydraulic condructivity was more appropriate.

In addition, infiltration rate was determined using double ring infiltrometer. The parameters of Kostiakov's equation were computed using the test data. This equation $Z = 0{,}198\ (t)^{0{,}875}$ and basic intake rate is 4,2 cm/h. Thus, infiltration rate is very high at the topsoil.

Table 1. The values of hydraulic conductivity for the experimental site

	D1		D2	
	(Crosswise drain)	(75 m)	(60 m)	(45 m)
hydraulic conductivity (m/day)	1.51	1.1	1.98	1.98

The disturbed soil samples were taken from the soils of each experimental site considering the soil profile of 0-210 cm depth. The saturation capacity of the all experimental soils for all depths varied from 65 to 101%. The percentage of clay for the soils were 38-62%. Thus, soil texture were almost clay for the all soil depths. The pH of the soils were 7.28-7.85 and electrical conductivity (ECe) varied from 0.56 to 1.91 dS/m. The lime content fof the soils were high and it was varied from 29.2 to 50.8 %.

Water table measurements

The measurements of water table were started together with irrigation. The obtained data were given in Table 2 and 3.

Table 2. The measurement of water table for crosswise drain (D1)

Observation well no	D1													
	Replication 1							Replication 2						
Days	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	145	133	125	126	110	112	119	116	108	126	131	139	120	145
2	143	133	124	125	114	110	119	114	108	127	131	137	120	144
3	143	130	124	123	110	108	118	115	106	125	128	135	118	143
4	144	133	123	120	113	121	75	116	101	127	90	137	120	144
5	144	137	127	126	112	110	114	113	103	124	131	138	121	145
6	149	139	131	130	117	116	124	120	112	131	136	142	125	150
7	146	135	128	128	113	115	120	116	110	130	134	140	125	147
8	145	136	129	130	116	114	121	118	110	129	132	139	123	146
9	143	135	128	115	114	110	118	115	106	127	137	137	119	143
10	143	133	125	124	112	111	116	116	106	126	129	136	118	143
11	149	137	130	130	116	115	123	119	112	131	135	142	124	145
12	147	137	130	129	117	115	122	119	106	129	135	141	125	148
13	146	136	130	126	114	113	117	118	87	128	139	140	121	148
14	148	137	129	129	116	115	121	120	111	130	135	141	123	149
15	153	139	132	131	119	117	123	121	113	133	137	143	127	153
16	149	131	131	131	119	117	123	121	113	114	136	142	125	150
17	150	139	132	131	119	117	123	121	113	116	136	143	125	150
18	147	136	129	127	113	112	114	118	103	128	132	139	121	147
19	147	135	128	126	115	114	118	119	107	129	134	140	123	148
20	152	141	134	132	121	121	126	125	116	135	140	146	128	153
21	153	142	135	134	123	122	126	126	117	136	140	147	129	154

The effects of the different drain spacings on water table are given in Table 3. As seen in Fig. 2, the depths of the water table for the boreholes numbered as S3 and S7 were approximately 140-145 cm while those were 100-110 cm for the S13 (Table 2).

Table 3. The water table measurements for the different drain spacings determined according to costant water table

Observation well no	D2-2 (60 m)				D3-3 (60 m)				D2-3 (45 m)			
Days	1	2	3	4	1	2	3	4	1	2	3	4
1	118	134	141	120	120	115	125	111	126	131	134	129
2	113	131	141	117	119	118	127	116	122	128	131	130
3	129	129	140	113	126	118	125	130	111	129	133	115
4	121	134	140	124	124	118	123	117	129	133	134	131
5	120	134	141	123	122	116	125	120	128	133	134	130
6	117	132	140	120	114	118	125	116	125	130	132	123
7	113	131	142	116	116	118	126	114	112	125	131	117
8	110	130	141	111	113	119	126	114	123	123	130	124
9	119	134	142	122	124	119	125	116	125	130	134	126
10	121	134	142	124	125	118	127	116	130	131	134	132
11	116	133	143	121	110	110	119	117	121	128	133	121
12	119	135	142	124	115	112	122	119	126	133	135	126
13	122	135	143	127	121	125	132	114	128	133	135	130
14	137	138	141	138	134	121	127	129	134	137	138	138
15	130	137	141	137	128	122	130	119	133	136	137	135
16	129	137	143	139	131	123	129	124	134	136	137	137
17	130	139	143	137	130	122	128	122	134	137	139	137
18	150	142	143	141	133	131	136	126	135	140	142	138

As seen in Fig. 4, The water table depths were measured as 130-140 cm for drain spacing of 75 m and drain depth of 180 cm while the water table depths were measured almost the same for the drain spacing of 45 m and drain depth of 120 cm. All the different drain depths (120 cm, 150 cm and 180 cm) give the same results. However, taking into account more drain spacings and drain depths could be more economical if the downstream conditions are appropriate.

Bahceci and Nacar (2007) were simulated the effects of varying drain depth (the original average drain depth was 1.5 m) on the ground watertable and root zone salinity. To do so, the simulation model was run for a drain depth from Dd = 1.0 to 1.8 m, with an interval of 0.2 m for 10 years. When drain depth was set to 1.0 m, the root zone salinity became 3.83 dS/m in the summer and 3.53 dS/m in the winter. When the drain depth increased from 1.0 to 1.2 m, the root zone salinity decreased from 3.83 to 2.63 and from 3.53 to 2.44 dSm-1 in the summer and the winter season, respectively. Simulations indicated that as drain depth increased from 1.2 to 1.4 m, the root zone salinity decreased from 2.63 to 2.19 and from 2.44 to 2.0 3dSm-1 in the summer and winter seasons, respectively. When the drain depth increased from 1.4 to 1.6 or1.8 m, it would result in no change in root zone salinity.

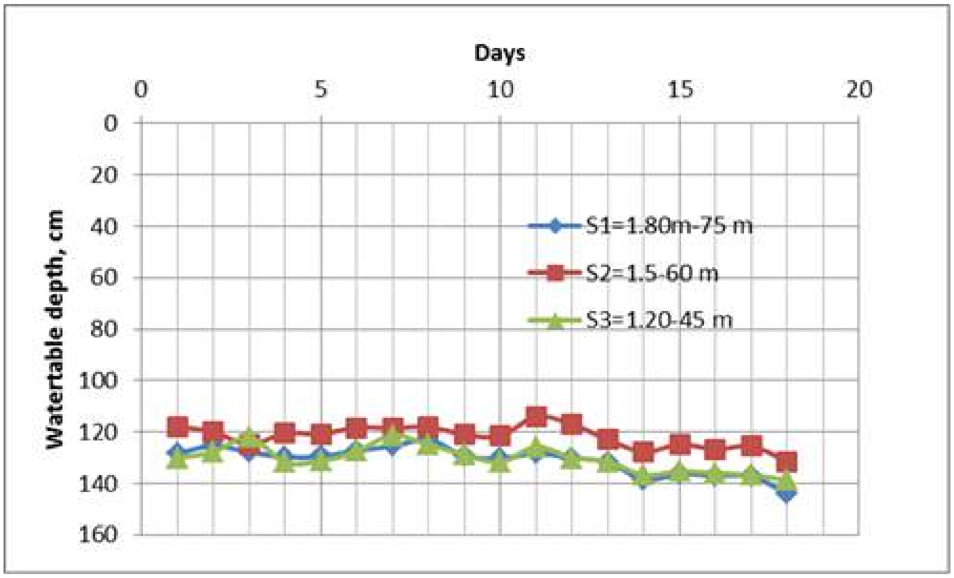

Fig. 4. Watertable depths for different drain spacing and drain depths

Safwat and Ritzema (1990) and Oosterbaan and Abu Senna (1990) have shown that, for Egypt's Nile Delta, average seasonal depths of the water table in the range of 1.0 to 1.2 m are amply sufficient for effective salinity control, whereas maintaining deeper water tables may even negatively affect the irrigation efficiency.

There were no significantly relationships between corn yield and the depths of water table. Average corn yield was 75 tonnes/ha. Considering some studies using different crops, the relative yields of potatoes, onions, maize, and carrots in dependence of the depth of the water table in a muck soil, A depth of 0.6 m is safe for all four crops, although potatoes and carrots perform slightly better when the depth is 0.8 m or more. The yield of onions even decreases at depths of more than 0.8 m. This effect is probably related to the quality of the muck soil (Oosterban, 1994).

Drain Performances

The drain performances were evluated using the measurements of the water table and the results were given considiering Criteria of Ritzema (1994) in Table 4. The piozemetric measurements in the study area are shown as a shematic layout in Fig. 5.

Accoroding the results obtained, the calculated entarnce resistances were 0,28, 0,26 and 0,12 for the drain spacings of 75 m, 60 m and 45 m, respectively. The entrance resistance for all the three drain spacings was normal, the drain performance was good.
Considering silt content of drainge water, the amount of silt in the drainage water were claculated as 63.3, 31.8 and 69.0 g/m3 for the drain spacings of 75, 60 and 45 m, respectively. On the other hand, there were no significantly differences the values of pH and EC in the drainage water (Table 5).

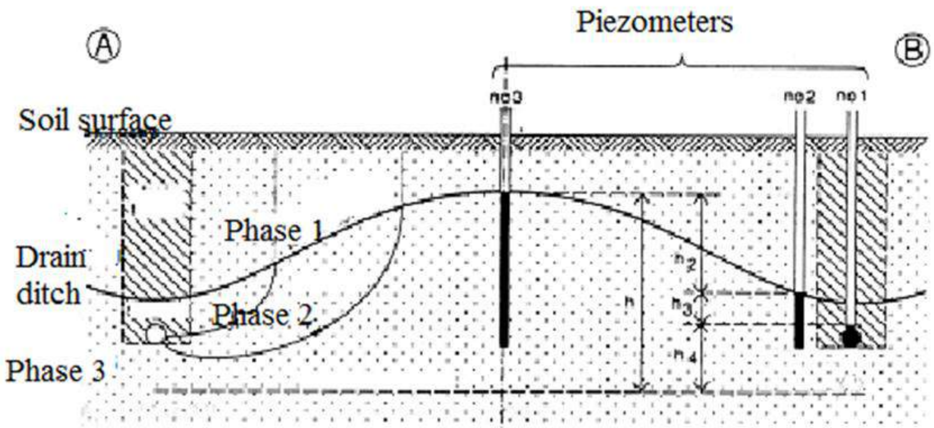

Fig. 5 The piezometers and head losses

Table 4. The evalutaion criteria of water entrance resistance (Ritzema, 1994).

Evaluation criteria $h_3/(h_2+h_3)$	Entrance resistance	Drain performance
<0.2-0.3	Normaly	Good
0.3-0.6	High	Medium-weak
>0.6	Very high	Very weak

Table 5. The analysis results of the water samples collected from the drains

	pH	EC	Cations (me/L)					Anions (me/L)				
		dS/m	Na	K	Ca	Mg	Total	CO_3^-	HCO_3^-	Cl	Total	Silt (g/m^3)
D1(1)	7,33	0,702	1,85	0,05	4,43	1,82	8,15	0,94	3,57	3,64	8,15	19,1
D1(2)	7,25	0,872	1,85	0,05	4,26	2,43	8,59	1,6	3,3	3,69	8,59	30,5
D2-1(75 m)	7,10	0,895	2,09	0,04	4,66	2,59	9,38	1,22	4,05	4,11	9,38	63,3
D2-1(60 m)	7,97	0,788	1,65	0,04	3,91	2,09	7,69	1,16	3,15	3,38	7,69	31,8
D2-1(45 m)	7,76	0,696	1,61	0,04	4,54	1,89	8,08	1,52	3,28	3,28	8,08	69,0

Conclusion

The depths of the water table were ranged from 120 cm to 140 cm during the irrigation season for both of the areas of crosswise drains and different drain spacings and drain depths. In addition, there were no difference in terms of soil salinity. In this study, the gravel was used as the envelop and the entrance resistance was "normal" and the drain line performance was "good". In addition, there were no considerably sediment risk considering the content of silt in the drainage water. Thus, it might be stated that the envelope material, gravel, performed appropriately.

As a result, the currently application of the drain depths and drain spacings for Harran Plain performed an appropriate the depth of water table. The variation of the soil salinity will be able to evaluate at the end of this study.

Acknowledgement

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ASSESSMENT OF DIFFERENT LEVELS OF NITROGEN AND CONTROLLED DRAINAGE ON YIELD AND WATER PRODUCTIVITY

Masoud Noshadi[1,*], Samaneh Karimi[2]

Abstract

The growth of world population and demand for agricultural products is a majora global issues. Controlled drainage (CD) is a management technique to control water level for increasing the yield. This research was conducted to evaluate the effect of controlled drainage and nitrogen fertilizer on wheat yield and water productivity as a factorial randomized complete block design. The treatments were consisted at three fertilizer levels; 0, 200 and 300 kgN/ha and three water table depths including control water tables at 60cm (CD60), 90 cm (CD90) and 120 cm (CD120) depths. The results showed that the wheat yield in CD60 was 10% lower than CD120 and in CD90 was 18% more than CD120. The water productivity in CD60 and CD90 was 52.6 and 57.9% more than CD120, respectively. By increasing the values of nitrogen fertilizer the wheat yield and water productivity were also increased.

KEY WORDS: Controlled drainage, Fertilizer, Wheat, Water productivity.

Introduction

Irrigation and drainage have sensitive roles in providing stability in worldfood prodiction.. In agriculture, drainage is important for the regulating of soil salinity, water logging and improving the plant environment (Jia et al., 2006). Controlled drainage is an appropriate management method for the improving of the use of water resources (Ayars et al., 2006). Nitrogen is one of the essential nutrients for plant growth.;therefore, soil fertility and soil nitrogen are synonymous with each other. Wheat in different stages of growth needs different values of nitrogen. Therefore, the use of nitrogen is important to a certain level and for a specific time (Lotfelahi et al., 2012). Water

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resources play a key role in the economic development of any country. Water productivity (WP) is indicator of crop production (Kg) or crop revenue per unit (m^3) of applied irrigation water. The improvement of WP could be an effective method for food production in limited water resources (Heidare, 2012). An increase in water productivity might aid in the farmer being able tto cope with water scarcity in agriculture and it could serve as an indicator for sustainable agricultural intensification (FAO, 2012; WWAP, 2012). The interaction of controlled drainage (management of the water table and retaining it at an acceptable depth) and the application of a suitable nitrogen fertilizer could increase the water productivity and yield of a crop.

Wesstrom et al. (2001) investigated the effect of controlled drainage on wheat yield and losses of nitrogen and phosphorus fertilizers in sandy loam soils. The results showed that the volume of drainage water in water table depths of 60 and 70 cm decreased by 65% to 95% in respect to free drainage respectively. The yield in controlled drainage was 2% to 18% and nitrogen uptake by plants was 3 to 13 kg/ha more than free drainage.

Fisher et al. (1999) compared controlled drainage in a 40 cm water table with free drainage for corn and soybean crop in a silt loam soil. The mean yield in corn and soybean was 19% and 64%, respectively which was more than that of the free drainage crop. The nitrogen uptake in controlled drainage for corn and soybean was 13% and 62% higher than that of free drainage.

In this research the effects of controlled drainage on crop yield and water productivity has been investigated.

Materials and methods

This research was conducted in the form of a factorial randomized complete block design with three replications. The treatments consisted of three fertilizer levels; 0, 200 and 300 kg N/ha and three water table depths including control water tables at 60cm (CD60), 90 cm (CD90) and 120 cm (CD120) depths. The fertilizer treatments consisted of three fertilizer levels including 0, 200 and 300 (kg N/ha) and three water table depths including 60 cm (CD60), 90 cm (CD90) and 120 cm (CD120) depths. In this research 27 lysimeters were used in the College of Agriculture research field, Shiraz University, Shiraz, Iran, with latitude of 29º 36' and longitude of with 1810 meters above mean sea level.

The lysimeters were made of GRP pipes with an inner diameter of 2.1 m and laid at a depth of 3.1 m with an 8% Floor slope. The lysimeters were installed on agricultural land. 10 cm gravel were placed at the bottom of the lysimeters, and then the lysimeters were filled with field soil. The four exit pipes were installed at depths of 30, 60, 90 and 130 cm on top of the lysimeters for drainage sampling. To establish the level of the water table at depths of 60 and 90 cm of soil, water was slowly passed throughand a slight discharge from the bottom of the lysimeters was observed (pipes which were installed at 130cm depth).

Irrigation requirements were calculated using a Penman-Monteith Reference crop equation and coefficients recommended by FAO 56. Irrigation intervals were considered at 10 days. After each irrigation, irrigation water depths were observed to be 30% more than the net irrigation water depth. In lysimeters with controlled drainage, the water table dropped because wheat uses sub-irrigation water,;therefore, the sub-irrigation water entered the lysimeters as underground water in the control water table depths. The irrigation method applied was in the form of surface irrigation and irrigation water was measured using a volumetric flow meters. The values of the irrigation water and groundwater are portrayed in Table 3.

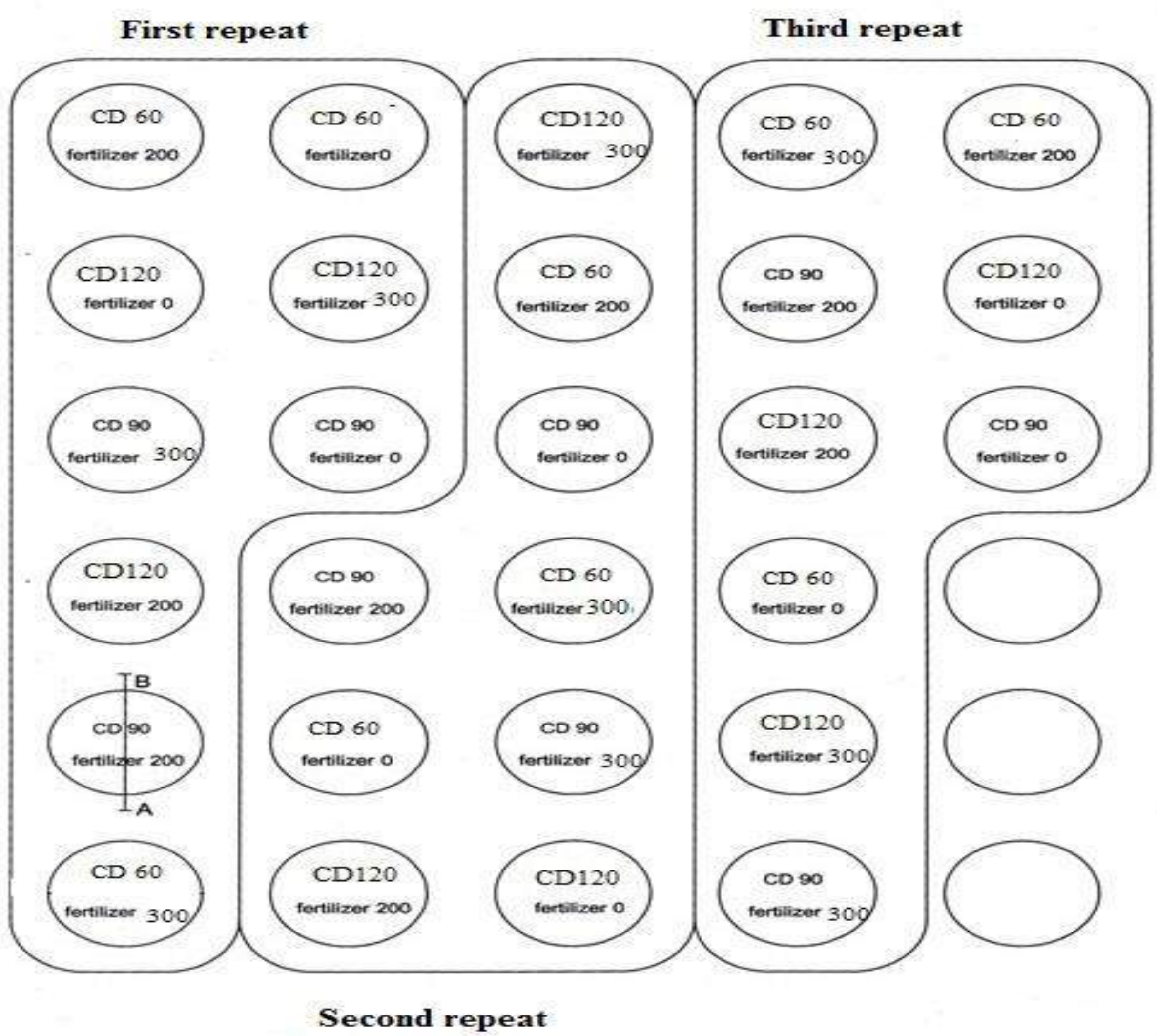

Figure 1. A schematic design on Treatments

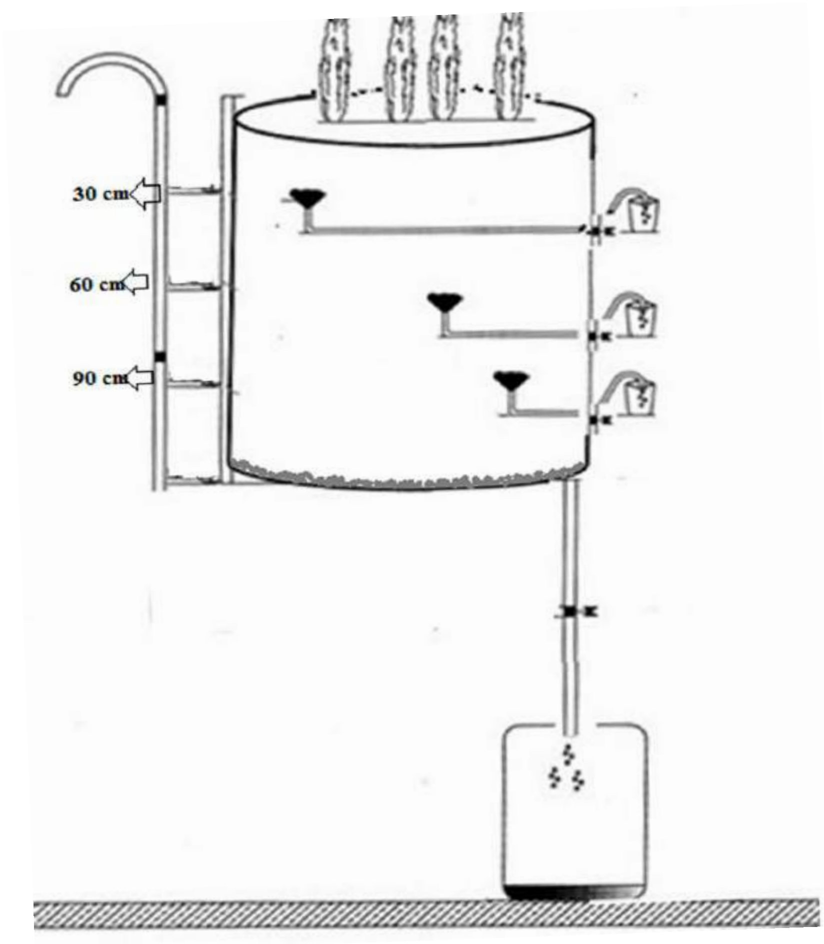

Figure 2: Cross section of the lysimeter used (section AB)

Results and discussion

Irrigation water

Based on the results obtained, the irrigation water depths in CD60 and CD90 were 40.1 and 24.4% lower than CD120, respectively. The irrigation water depths in CD60 decreased by 20.9% as compared to CD90. The effect of nitrogen fertilizer on the reducing of irrigation water was significant at 5% level probability, thus by increasing the values of fertilizer, the values of the irrigation water depth decreased. The mean irrigation water depths in 200 and 300 kg N/ha were 2.1 and 4.1% lower than 0 kg N/ ha, respectively (Table 1). The maximum and minimum irrigation water depths were in CD120 and CD60 treatments with 300 kg N/ha, respectively. This difference was significant at 5% level of probability. According to Table (2), the interaction effect of controlled drainage and nitrogen levels on irrigation water depths was significant.

Table 1. The total irrigation water depths in different treatments (mm)

Drainage treatment	Nitrogen(kg/ha) 0	200	300	Mean
CD60**	480.78 *e**	451.73 f	437.37 g	456.63 C
CD90	590.80 b	580.45 c	559.76 d	577.01 B
CD120	763 a	763 a	763 a	763 A
Mean	611.53 A	598.39 B	586.71 B	

*According to Duncan's test data with the same letters are not significantly different at the 5% level.

** CD60: controlled drainage at depth of 60 cm, CD90: controlled drainage at a depth of 90 cm, CD120: controlled drainage at a depth of 120 cm

Table 2. Analysis of variance of wheat grain yield in different treatments

Source	DF	Type III SS	Mean Square	F Value	Pr > F
C	2	428843.86	214421.928	11126.9	<.0001
F	2	2773.5431	1386.7716	71.96	<.0001
c*f	4	1658.2807	414.5702	21.51	<.0001
Error	16	308.3307	19.2707		
Corrected Total	26	433609.75			

Table 3. The irrigation water depth indifferent treatments (L)

Treatment	Sub irrigation	Surface Irrigation	Total irrigation water depth
CD(60)-F1	319.03	543.47	862.5
CD(60)-F2	351.86	510.64	862.5
CD(60)-F3	368.1	494.4	862.5
CD(90)-F1	194.66	667.84	862.5
CD(90)-F2	206.36	656.14	862.5
CD(90)-F3	229.75	632.75	862.5
CD(120)-F1	0	862.5	862.5
CD(120)-F2	0	862.5	862.5
CD(120)-F3	0	862.5	862.5

Yield

The results showed that the maximum and minimum grain yields were 7.12 Mg/ ha (with 300kg N/ha) in CD90 and 3.29 Mg/ha (with 0 kg N/ha) in CD60 treatments, respectively. The total grain yield in CD60 and CD90 treatments decreased 10% and increased 18% relative to CD120, respectively. This difference was significant at 5% level of probability. Statistical analysis show that the interactions of controlled drainage and nitrogen levels on the grain yield was significant (Table 4).

According to Figure 3, the grain yield increased by increasing the amount of fertilizer. The mean grain yield in 200 and 300 kg N/ha fertilizer treatments were 43 and 65% more than 0 kg N/ha, respectively. The results showed that the grain yield in 300 kg N/ha fertilizer increased 15% as compared to 200 kg N/ha fertilizer.

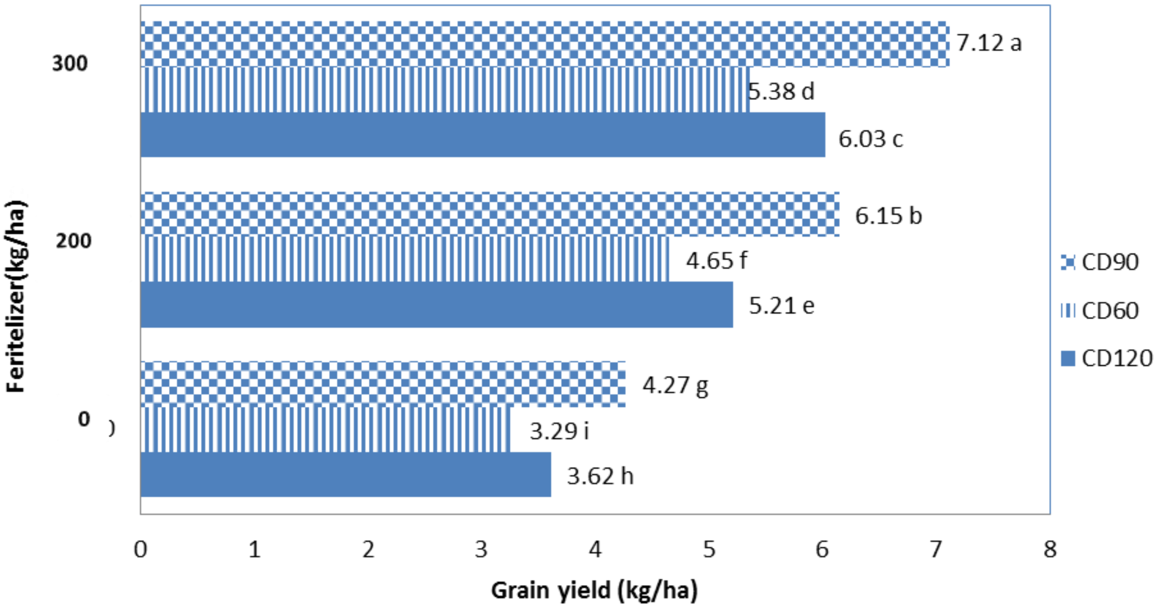

Figure 3. The mean grain yield in different fertilizers levels

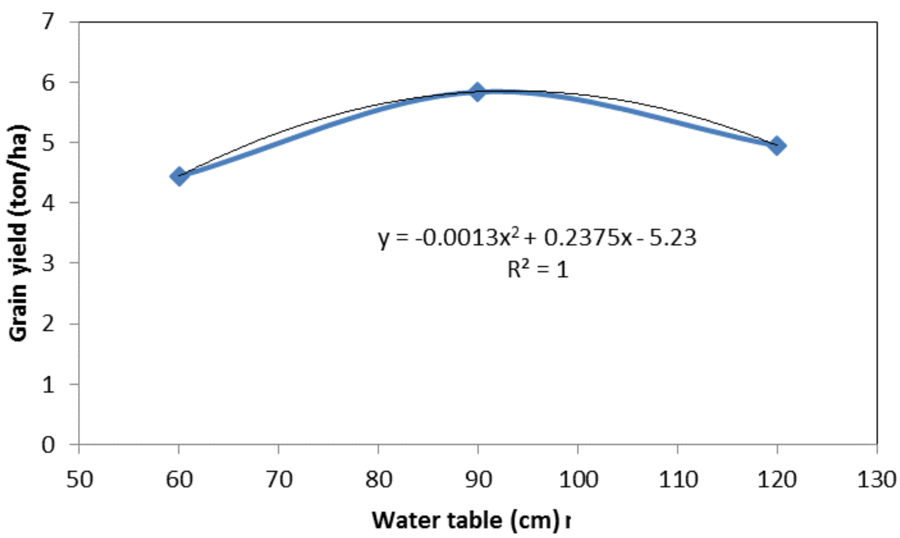

Figure 4. The relationship between yield and water table depth

According to Figure 4, water table depth of more than or lower than 90 cm could reduce the yield. One of the reasons for the reducing of the yield in water tables lower than 90 cm is the lack of ventilation in the root zone and in water tables of more than 90 cm the capillary rise (sub-irrigation) is too low. The results showed that the lack of ventilation (water logging) in the root zone has a greater effect in decreasing the yield.

The total yield in CD60 and CD90 treatments decreased by 6.1% and increased by 14.4% relative to the CD120 treatment, respectively.

Water productivity

According to Table (4) the water productivity in CD60 and CD90 treatments were 52.6 and 57.9% more than the CD120 treatment, respectively. This difference was significant at 5% level of probability. The water productivity in the CD60 treatment decreased 3.3% as compared to the CD90 treatment. Statistical analysis show that the interaction of controlled drainage and nitrogen levels on water productivity was significant. The mean WP in 200 and 300 kg N/ha fertilizer was 49 and 76.3% more than 0 kgN/ ha, respectively. Water productivity in 300 kg N/ha fertilizer increased by 18.2% as compared to 200 kg N/ha fertilizer. This difference was significant at 5% level of probability.

Table 4. The mean water productivity in different treatments (kg/m^3)

Drainage treatment	Nitrogen(kg/ha)			Mean
	0	200	300	
CD60**	0.61 g^*	0.91 d	1.09 b	0.87 B
CD90	0.64 f	0.94 c	1.13 a	0.9 A
CD120	0.42 h	0.6 g	0.7 e	0.57 C
Mean	0.55 C	0.82 B	0.97 A	

*According to Duncan's test data with the same letters are not significantly different at the 5% level.

** CD60: controlled drainage at depth of 60 cm, CD90: controlled drainage at a depth of 90 cm, CD120: controlled drainage at a depth of 120 cm

Conclusions

The results show that with the increasing of the water table depth, the irrigation water depth increases and sub-irrigation decreases. Moreover; by controlling the water table depth more or lower than 90 cm (CD90), the total yield and grain yield decreased. The water table at depths lower than 90 cm causes a lack of aeration in the root zone and in water table depths more than 90 cm the sub-irrigation is not sufficient.

In can be concluded that, in terms of both yield and water productivity, the optimum water table depth is 80 cm (CD80) with 200kg N/ha fertilizer (Fig. 5).

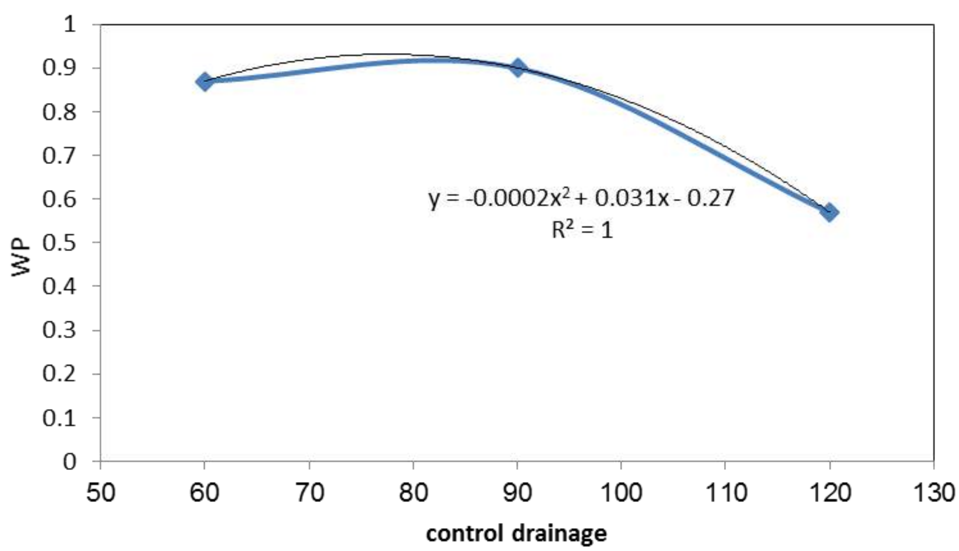

Figure 5. The relationship between water table depth and water productivity

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RAINFALL FREQUENCY ANALYSIS FOR LAND DRAINAGE CRITERIA IN BIHAR - A CASE STUDY

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Abstract

Irrigation and drainage are complimentary to each other. Normally land drainage is a problem in very flat or level land. Drainage congestion leads to waterlogging. The problem of waterlogging is a world-wide phenomenon which occurs mainly due to the rise of the groundwater table beyond permissible limits. Land subjected to waterlogging has already affected about 3 to 6 M ha of cultivable land in India.

Bihar is an agriculture based state of India and is facing the two problems of floods and droughts. Among the adverse effects of floods is waterlogging in agriculture fields, since there is no adequate land drainage system in the state. In this study, the determining of the effects of one to seven consecutive days of maximum rainfall corresponding to a return period varying from 2 to 20 years and a crop tolerance period, which helps in the determination of a drainage coefficient for agricultural fields, utilizing the daily rainfall data of Patna for the period 1980-2009 has been considered. A positions plotting method and other probability distributions have been applied to estimate one day to seven consecutive days of maximum rainfall over various return periods.

The comparison of these methods, show that Gamma distribution gives the best coefficient for the determination and predicts values closer to the values obtained by the plotting position method. Results also show that for a return period of 2 to 20 years, the plotting position method gives the lowest values of one day maximum rainfall. Drainage coefficient with a bund height as 100 mm and 150 mm have also been determined from depth duration frequency curves.

KEY WORDS: Land drainage, Waterlogging, Rainfall frequency analysis, Drainage coefficient, Gamma distribution

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Introduction

Rainfall causes flow on land, some water Infiltrates into the soil .This water must be removed from agriculture lands so that it does not create problem of waterlogging. Excess water removed from the surface of land is called drainage. The draining of water from a catchment after precipitation is known as runoff. When all the losses are abstracted from the precipitation it is reduced to runoff. Waterlogging is defined as the retention of area under water for a considerable period, causing severe damage or complete loss of crop. An area is waterlogged when water table rises to an extent so that it interferes with effective root zone of a crop.

Drainage coefficient (DC) is the amount of water to be removed from a crop land in one day so that plants do not destroy due to excess water. A commonly used unit of DC is mm/day. DC represents a flow rate lower than the peak of the hydrograph. Drainage coefficient is the key parameter in hydraulic design of any drainage system.

Gupta et al (1971) gave the values of DC for agricultural lands for different parts of India which can be readily used by the planners and designs in the field of irrigated agriculture.

As per IS: 8835 (1978) criteria drains should be designed for 3 days rainfall of 5 year occurrence interval. However, in exact cases, requiring higher degree of protection, the frequency of 10 to 15 years can be justified in terms of economy. This code has recommended that cross-drainage structures should be designed for 3-day rainfall of 50 years frequency for different periods of disposal depending upon the tolerance period of crops.

Bhattacharya and Sarkar (1982) analysed 40 years (1931-70) rainfall data of Hoshangabad in M.P. for four heavy rainy months of June, July, August and September to conclude 1 day to 5 consecutive days rainfall of 5 years recurrence interval. They found that 15-30 years data will be sufficient to give a sensible self-belief on the predicted 5- year return period rainfall values.

A design DC is obtained by considering runoff from design rainfall. For determination drainage coefficient, one day to seven consecutive days rainfall from 30 year data from 1980 to 2009 of Patna district have been used. The location map and the soil map of the study area are as given in Figure 1, 2 respectively. In the present study, DC has been calculating by plotting position method, normal distribution, log normal distribution, Pearson method, log Pearson method, Extreme distribution, log extreme distribution and Gamma distribution method (Thom, 1958). Also an effort has been made to determine best fit Probability distribution for this. The objective of this is

- To determine drainage coefficient / design discharge of drain from 1 day to 7 days consecutive maximum annual rainfall series by using depth – duration - frequency curves
- To determine the best fit probability distribution for 1 to 7 days consecutive maximum annual rainfall series

Location of the study area

Patna has latitude $\mathbf{25^{\circ}60'}$N, longitude of $\mathbf{85^{\circ}11'}$E and altitude of 54.0 m. It is the capital of Bihar, an easterly state of India. It comes under eastern part of India and has seasons of south - west monsoon from June to September, north - east monsoon from October to December, winter season from January to Feb with single rainfall peak .This case study area experiences mono-model type rainfall characterized by single rainfall peak during a year. Mean annual rainfall of Patna is 1054 mm. Normal rainfall in SW monsoon (June-sep) is 906 mm, in NE monsoon (Oct-Dec) is 71mm, in winter (Jan-Feb) is 28 mm and in summer (Mar-May) is 49 mm. Rice is the major field crop and for which productivity is 3171 kg/ha. Planning commission of India has kept in the area middle genetic plain region. Also the geographical location and soil group map for Patna district of Bihar are as given in Figure 1 and 2 respectively. There are mainly three types of major soils present in Patna district as given below.

Major Soils	Area ('000 ha)	Percent of total
Clay to clay loam soils	67.1	31.3
Sandy loam soils	70.5	32.9
Medium to heavy soils	76.2	35.6

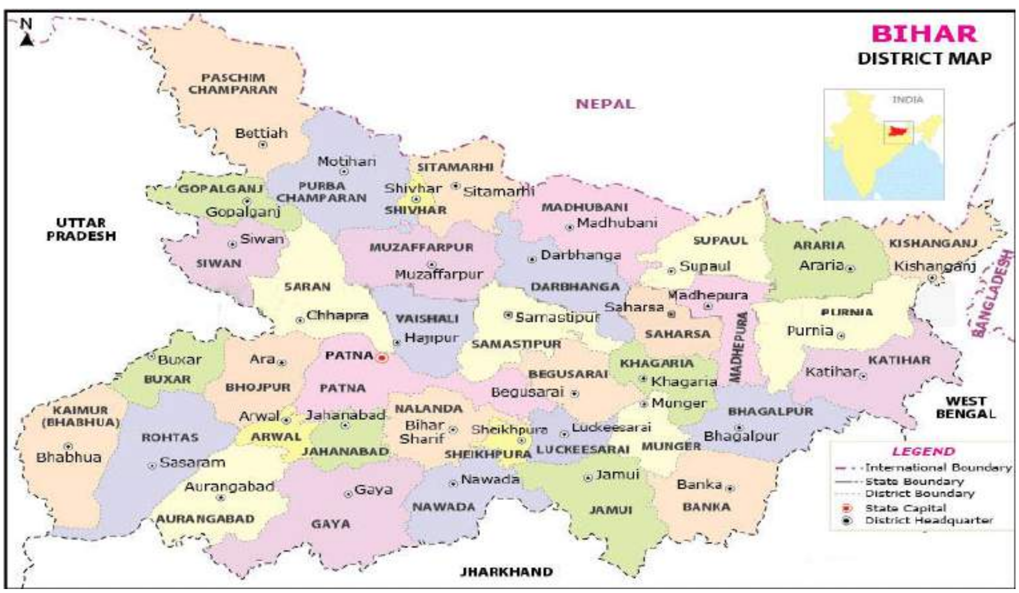

Figure1. Location the Study area

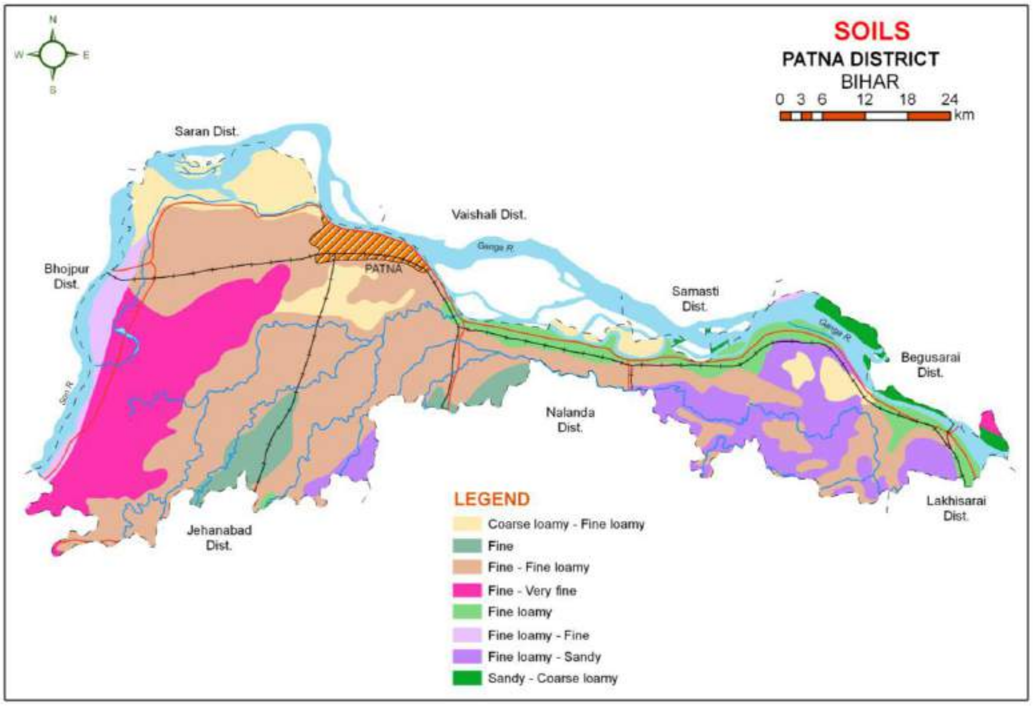

Figure2. Map for Soil groups in Patna district (Source: www.krishi.bih.nic.in)

Materials and methods

In general, 24 hrs rainfall of 5-10 years return period is taken for design of drainage system. In agriculture 5 year return period value is commonly used. Therefore, it is necessary to have information on maximum amount of rainfall of various durations.

The values of the annual maximum rainfall for a given catchment area for large numbers of successive years constitute a hydrologic data series and it is called annual series. The data are then arranged in decreasing order of magnitude and the probability of exceedence of each event is calculating by the Weibull's formula in plotting position method. Further other probability distributions like normal distribution, log normal distribution, log normal distribution, Pearson type III distribution, log Pearson type III distribution, extreme value type distribution, log extreme value type distribution and Gamma distribution have also been used.

From above frequency analysis, rainfall values and probability corresponding to these values are generated in the form of tables. By applying the linear interpolation one can compute rainfall corresponding to different probability levels and thus corresponding to different return periods. A graph is plotted between return period and maximum consecutive days rainfall as per Upadhayaya and Singh (1998). The best fit curve is plotted and tangent is drawn from 100 mm bund height and

150 mm bund height to each of the curves. The length of the ordinate gives allowable safe storage of water in the cropped field. The slope of the tangent lines indicates the design discharge or drainage coefficient.

In general, 24 hrs rainfall of 5-10 years return period is taken for design of a disposal drainage system. In agriculture 5 year return period value is more commonly used (WAPCOS, 1988). If the tangent line is shifted parallel to pass through the zero point of the co-ordinate axes, design discharge is commuted.

Drainage coefficient which is determined by plotting position method has been compared to frame different distribution functions and frame which the highest and lowest drainage coefficients are determined. All distributions, as mentioned above, have used for determination of consecutive days maximum rainfall with desired return period but it has been found that normal, log normal, Pearson, log Pearson type III, Extreme, log extreme distributions are not fit in calculating the maximum rainfall and only Gamma distribution is fit in calculating the consecutive days maximum rainfall with desired return period**.**

As submergence depth of 10 to 15 % for rice crop is safely allowed in crop field, assuming the tall rice variety of 1 m depth, 100 mm and 150 mm depth of rainfall is assumed to be the allowable storage. Thus tangent lines are drawn for all the four curves of 2, 5, 10 and 20 year return periods joining the ordinate at 100 mm and 150 mm.

Results and discussion

Using a computer program in FORTRAN 77, first of all rainfall, maximum one day rainfall to seven consecutive days rainfall were calculated as given in Table 1. These maximum rainfalls are analysed by plotting position method. By this method probability and return period are calculated. Maximum rainfalls are calculated with 2 years, 5 years, 10 years,15 years and 20 years return period by normal distribution, log normal distribution, Pearson type III distribution, log Pearson type III distribution, Extreme type I distribution, log Extreme type I distribution and Gamma distribution method with desired return periods. Some of the results are as given in Table 2 and 3.

Graphs are plotted between consecutive days maximum rainfalls for return period varying from 2 to 20 years as given in Figure -3. Rainfall values are computed by different theoretical probability distributions and plotting position method. Some of the theoretical probability distributions need standard deviation, mean and coefficient of skewness of the original data series for computation of rainfall corresponding to desired return period.

These Consecutive days rainfalls should be compared with rainfall values which are computed by plotting position method. On comparison it was found that normal distribution, log normal distribution, Pearson method, Log Pearson method, extreme value type I distribution, Log extreme value type I distribution are not best fit in all consecutive day maximum rainfall but Gamma distribution is the best fit among all probability distributions because computed **chi square** value is lower than tabulated **chi square** value as given in Table 4. However, in some cases log normal distribution is best fit. In some other cases extreme and log extreme distribution are best fit.

Gamma distribution is best fit but in all consecutive days maximum rainfall as shown in Table 5. For illustration the comparison of 1 day, 2 days, 3 days and 7 days of maximum rainfall computed from different distributions are as given from 6 to 9.

From comparison of 1 day maximum rainfall from plotting position method and that from Gamma distribution method it was found that the percentage difference varies from 3.95 % to 11.53 %. Similarly for two days maximum rainfall, the difference varies from 0.76 % to 8.4 % and that for 3days maximum rainfall varies from 2.42 % to 10.25 %.and that for 7 days maximum rainfall varies from 0.2 % to 9.41 %.

For Drainage coefficients derived from depth – duration – frequency analysis for the study area assuming bund height as 150 mm and 100 mm are given in Table 10 and 11 respectively. Also the drainage coefficients derived from plotting position method and Gamma distribution method assuming rainfall losses as 50% are given in Table 12 and 13 respectively.

From depth duration frequency curves, the design discharge for 2 years, 5 years, 10 years,15 years and 20 years return period were found as 10 mm/day, 30 mm/day, 40 mm/day, 50 mm/day and 60 mm/day respectively with the bund height as 150 mm and 20 mm/day 50 mm/day, 60 mm/day, 80 mm/day and 90 mm/day respectively, when the bund height is kept as 100 mm for the agricultural land in Patna district.

Table 1 Maximum Consecutive Days Rainfall for Patna for 30 Year (1980-2009)

S. No.	Year	1 Day Max	2 Day Max	3 Day Max	4 Day Max	5 Day Max	6 Day Max	7 Day Max
1	1980	135.3	181.4	188.2	221.6	257.1	268.8	268.8
2	1981	200	200	200	206.6	218.55	230.95	238.35
3	1982	51.3	67.2	87.1	104.7	104.7	107.1	116.5
4	1983	58.1	93.3	113.7	122.5	125.5	125.7	128.9
5	1984	97.2	152.4	179.5	183.4	188.2	207.6	215.1
6	1985	102.6	192.8	209	250.1	311.7	315.1	315.1
7	1986	90.4	161.2	202.7	246.2	265.1	284.1	288.6
8	1987	79	128.5	139.3	158.5	172.3	212.6	233.4
9	1988	166	219.8	240.6	243.5	313.9	367.7	394.6
10	1989	111.3	114.7	134.3	155.6	159.6	161.5	178.2
11	1990	129.8	245.3	292.2	293.4	295.8	309.1	309.1
12	1991	93.4	185.3	189.6	197.1	201.4	202.7	207
13	1992	71.2	119.1	169.7	180.5	185.4	185.4	185.4
14	1993	131.8	137.1	141.5	157.3	236.6	237	237
15	1994	96.8	105.6	116.9	147.6	179.6	196.05	204.85
16	1995	98.7	103	180.2	180.2	180.2	181.5	181.9
17	1996	98.7	103	180.2	180.2	180.2	181.5	181.9
18	1997	205.4	307.2	380.8	467.4	496.1	521.7	524.8

S. No.	Year	1 Day Max	2 Day Max	3 Day Max	4 Day Max	5 Day Max	6 Day Max	7 Day Max
19	1998	74.5	93.1	123.7	139.5	157.3	165.5	179.9
20	1999	94.8	152	163.6	171.6	172.3	180.3	181.1
21	2000	117.5	121.7	127	147	159.4	168.6	181.8
22	2001	102.9	161.8	202.7	278.9	288.8	291.6	292.6
23	2002	158.4	164	166.1	171.5	174.1	176	181.2
24	2003	99.1	127.2	177.3	250.8	268.7	280.3	287.3
25	2004	75.4	96.4	99.2	115.5	146.3	164	165.6
26	2005	71	119.4	126.6	141.8	187.7	194.2	198.5
27	2006	157	220.9	232	310.6	318.6	326.2	331.7
28	2007	166.7	212.3	251.1	296.7	332.5	333.3	368
29	2008	81.6	100.8	138.4	177	209.1	217.4	223
30	2009	94.1	102.2	105.6	105.9	125.8	129.2	150

Table 2 One day to seven consecutive days maximum rainfall by plotting position method for Patna district for 30 years (1980-2009)

Consecutive days Rainfall	2 Year Return Period (mm)	5 Year Return Period (mm)	10 Year Return Period (mm)	15 Year Return Period (mm)	20 Year Return Period (mm)
1 Day Max	98.7	152.3	166.61	196.78	201.57
2 Days Max	132.46	198.4	220.77	242.95	263.97
3 Days Max	173.5	207.6	249.86	288.22	317.92
4 Days Max	180.2	250.6	296.27	309.25	356.12
5 Days Max	187.95	294.6	317.99	331.15	379.99
6 Days Max	205.15	305.3	332.39	364.37	412.4
7 Days Max	211.05	305.5	363.36	392.02	432.4

Table 3 One day to seven consecutive days maximum rainfall from Gamma distribution for Patna district for 30 years (1980-2009)

Consecutive Days	Computed Chi Square values	Tabulated Chi Square values
1 Day Max	39.32	42.56
2 Days Max	29.39	42.56
3 Days Max	30.58	42.56
4 Days Max	32.02	42.56
5 Days Max	31.09	42.56
6 Days Max	31.03	42.56
7 Days Max	31.42	42.56

Table 4 Chi Square Values For Gamma Distribution for Patna District

Consecutive Rainfall	2 Year Return Period (mm)	5 Year Return Period (mm)	10 Year Return Period (mm)	15 Year Return Period (mm)	20 Year Return Period (mm)
1 Day Max	105.78	141.35	162.75	174.08	181.85
2 Days Max	143.59	192.64	222.38	234.38	249.12
3 Days Max	168.49	223.22	255.93	273.45	285.32
4 Days Max	191.45	257.77	297.68	319.04	333.45
5 Days Max	211.17	283.18	326.43	349.44	365.18
6 Days Max	220.88	296.98	342.75	367.21	383.81
7 Days Max	228.62	304.88	350.80	375.08	391.70

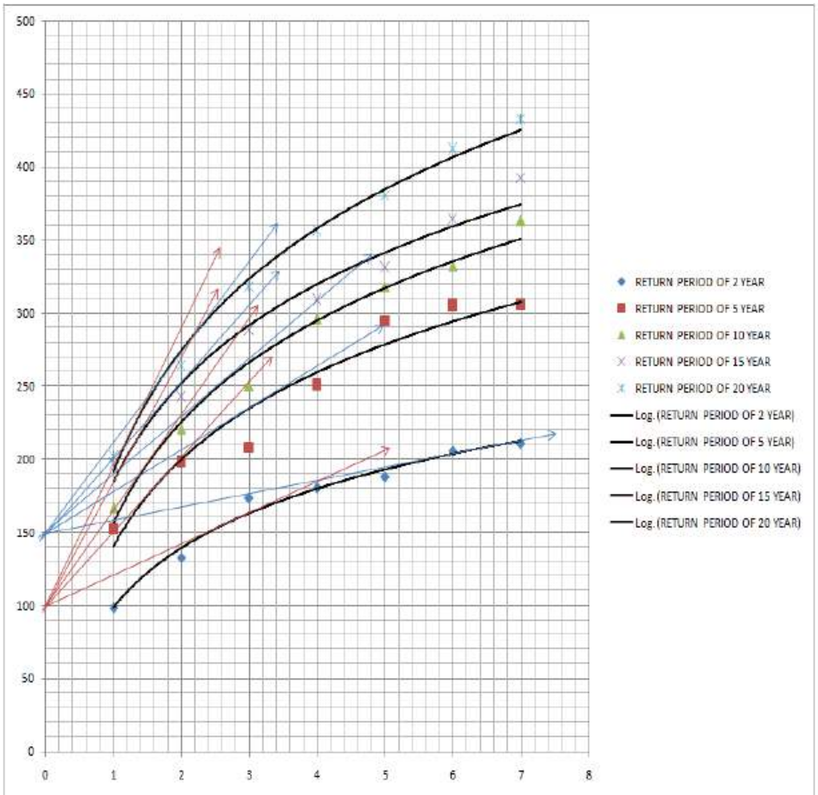

Figure 3 Consecutive Days Maximum Rainfall and Return Period for Patna District.(*x-axis: Days & y-axis: Maximum Rainfall in mm)*

Table 5 Best Fit Distributions for the Study Area, Patna

Consecutive Rainfall	Normal	Log Normal	Pearson	Log Pearson	Extreme	Log Extreme	Gamma
1 Day Max	Not Fit	Not Fit	Not Fit	Not Fit	Not Fit	Best Fit	Best Fit
2 Days Max	Best Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
3 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Not Fit	Best Fit
4 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
5 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
6 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
7 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit

Table 6 Comparison of 1 Day Maximum Rainfall Computed from Plotting Position Method and that Computed from Gamma Distribution for Patna

Return Period (Year)	Plotting Position Method (mm)	Two Parameter Gamma Distribution (mm)	Difference (mm)	Percentage %
2	98.7	105.78	- 7.08	7.17
5	153.3	141.35	11.95	7.79
10	166.61	162.75	3.86	3.95
15	196.78	174.O8	22.70	11.53
20	201.57	181.85	19.72	9.78

Table 7 Comparisons of 2 Days Maximum Rainfall Computed from Plotting Position Method and that Computed from Gamma Distribution for Patna

Return Period (Year)	Plotting Position Method (mm)	Gamma Distribution (mm)	Difference	%
2	132.46	143.59	- 11.13	8.40
5	198.40	192.64	5.76	2.90
10	220.70	222.38	-1.68	0.76
15	242.95	234.38	8.57	3.52
20	263.97	249.12	14.85	5.62

Table 8 Comparisons of 3 Days Maximum Rainfall Computed from Plotting Position Method and Rainfall Computed from Gamma Distribution for Patna

Return Period (Year)	Plotting Position (mm)	Gamma Distribution (mm)	Difference (mm)	%
2	173.50	168.49	5.01	2.88
5	207.6	223.22	- 15.63	7.52
10	249.86	255.93	-6.07	2.42
15	288.22	273.45	14.77	5.12
20	317.92	285.32	32.6	10.25

Table 9 Comparisons of 7 Days Maximum Rainfall Computed from Plotting Position Method and Rainfall from Gamma Distribution Method for Patna

Return Period (Year)	Plotting Position (mm)	Gamma Distribution (mm)	Difference (mm)	%
2	211.05	228.62	-17.57	8.32
5	305.5	304.88	0.62	0.20
10	363.36	350.8	12.56	3.45
15	392.02	375.08	16.74	4.32
20	432.4	391.7	40.70	9.41

Table 10 DC for Patna District Assuming Bund Height as 150 mm

Return Period (Year)	**Slope**	**Drainage Coefficient (DC)**
2	$\frac{200-150}{5.5-0}$	9 ≈ 10 mm/day
5	$\frac{235-150}{3-0}$	28.33 ≈ 30 mm/day
10	$\frac{255-150}{2.7-0}$	38 ≈ 40 mm/day
15	$\frac{260-150}{2.2-0}$	50 mm/day
20	$\frac{300-150}{2.5-0}$	60 mm/day

Table 11 Drainage Coefficients for Patna District with Bund Height as 100 mm

Return Period (Year)	**Slope**	**Drainage Coefficient**
2	$\frac{150-100}{2.4-0}$	20.83 ≈ 20 mm/day
5	$\frac{180-100}{1.6-0}$	50 mm/day
10	$\frac{200-100}{1.6-0}$	62.5 ≈ 60 mm/day
15	$\frac{218-100}{1.4-0}$	84.28 ≈ 80 mm/day
20	$\frac{230-100}{1.4-0}$	92.85 ≈ 90 mm/day

Table 12 Drainage Coefficient by plotting position method for Patna Assuming Rainfall Losses as 50 %

Consecutive Days	5 Year Return Period (mm/day)	10 Year Return Period (mm/day)	20 Year Return Period (mm/day)
1 Day Max	76.15	83.30	100.78
2 Days Max	49.60	55.19	65.99
3 Days Max	34.60	41.64	52.98
4 Days Max	31.32	37.03	44.51
5 Days Max	29.43	31.79	37.99
6 Days Max	25.44	27.69	34.36
7 Days Max	21.82	25.95	30.88

Table 13 Drainage Coefficient by Gamma Distribution method for Patna Assuming Rainfall Losses as 50 %

Consecutive Days	5 Year Return Period	10 Year Return Period	20 Year Return Period
1 Day Max	70.67	81.38	90.92
2 Days Max	48.16	55.59	62.28
3 Days Max	37.20	42.65	47.55
4 Days Max	32.22	37.21	41.68
5 Days Max	28.32	32.64	36.51
6 Days Max	24.75	28.56	31.98
7 Day Max	21.77	25.05	27.98

Conclusions

Plotting position method and various other probability distribution methods like normal, log normal, Pearson, log Pearson extreme, log extreme and Gamma distributions were tested with 1 to 7 days consecutive maximum rainfall series corresponding to various return periods for Patna district. These distributions take different parameters into account likes mean, standard deviation, coefficient of skewness and 7 days consecutive rainfall. None of probability distributions except Gamma probability distribution was found fitting in the rainfall series for Patna district, because computed chi square values were always less than the tabulated chi square values only in the case of two parameters Gamma distribution.

Thus Analysis of above consecutive days maximum rainfall data series applying above distributions showed that to get best estimate of 1 day, 2 days, 3 days, 4 days, 5 days, 6 days and 7 consecutive days maximum rainfall, Gamma distribution should be applied for the area under study.

For secured disposal of drainage water, design discharge of 2 year, 5 year, 10 year, 15 year and 20 year return periods are 10 mm/day, 30 mm/day, 40 mm/day, 50 mm/day and 60 mm/day respectively for bund height as 150 mm and 20 mm/day 50 mm/day, 60 mm/day, 80 mm/day and 90 mm/day for bund height as 100 mm respectively for the area under study.

Acknowledgement

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POLDER DRAINAGE SYSTEM TO MITIGATE VULNERABLE ECOSYSTEM OF COASTAL BANGLADESH

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Abstract

People of the coastal belt of Bangladesh are fully dependent for their comprehensive livelihood on the coastal embankment. Bangladesh Water Development Board (BWDB) constructed an embankment in the 14 coastal districts of Bangladesh. They have made 139 polders since 1960s to grow more food by protecting coastal land from saline intrusion caused by tidal flooding and to ensure the preservation of sweet water in canals for agricultural production in dry seasons. Embankments built to prevent flooding or coastal tidal surge of low-lying land are also called a levees or dykes which are constructed along a riverbank and at some distance from the river to retain floodwater or tidal effect. These embankments provide a protected environment for people's resources. The coastal region of Bangladesh portrays acute socio-ecological complexities, where people are gradually becoming powerless, socio-economically marginalized and vulnerable. The complexity arise through vulnerable coastal and mangrove ecosystem and fluctuating socio-economic life patterns that are caused by a number of ecologically inconsistent developmental intervention and land use practices. There are many natural and man-made hazards like cyclones, embankment erosion, tidal surges, salinity, water logging, floods during heavy rain fall, drought, pests in crops etc. that increase the risk of disaster among the vulnerable community. Under the programme of flood control and drainage improvement, about 7,555 km of embankment (including coastal embankments of about 4,000 km), 7,907 hydraulic structures including sluices, and around one thousand river regulators, 1,082 river closures and 3,204 km of drainage channels have been built at the cost of a thousand core taka. Under the scheme a total of 332 projects, aimed at protecting 3.5 million ha of land from flood inundation, have been implemented. Thus, about 24% of the total land area and 39% of the net cultivated area have been protected. However, the success of embankment construction depends technically on the natural detention basin, channel improvements, flow diversions and bank stabilization and anti-erosive measures. The CEP comprises a complex network of dikes and drainage sluices and was the first comprehensive plan for providing protection against flood and saline water intrusion in the coastal area. The function of the embankment depends on many coastal factors of which the most prominent issues were the management of sluice gates, managing canals downstream the sluice gate, operation & maintenance of sluice gate, regular monitoring of the embankment, illegal cutting of the embankment to set pipes for shrimp farming, etc. Here the greatest concern was people's involvement or a community based approach to manage the polder system for embankment &

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canals in the context of sustainability. The Embankment and Drainage Act 1952 ensures the protection of lands from floods, erosion or other damage by water through the constructing and repairing of the embankment, but it has developed gaps over the years. Sluice gates were also constructed at certain places to control water channeling from the sea /channel to inland canals. But since, 1980s people with money and access to power started taking lease of the water bodies inside Polders to cultivate saline water shrimp farms; and as a result thousands of unplanned cannels were made in the embankment causing it to become thin and weak. Whatsmore, it also excluded poor farmers from accessing and controlling water bodies, causing them to cultivate their land with a single crop. The local government officials now properly understand community demands and feel more accountable to construct and maintain a sustainable embankment.

KEY WORDS: Polder, Ecosystem, Mitigation, BWDB, Zaminder, CRA.

Introduction

Embankment a ridge built with earth or rock to contain flood water or to construct a road, railway, and canal. Embankments vary in nature and function under a variety of situations. Designed to control or prevent flooding, flood control embankment is one of several types of embankments on the floodplains. An embankment built to prevent flooding of low-lying land is also called a levee or dyke constructed along a riverbank and at some distance from the river to retain floodwater. (Baseline, 2012) The earliest recorded embankment in this subcontinent was built during the Sultani period (1213-1519 AD). In Bangladesh coastal embankments were constructed as early as the 17th century on private initiative under the patronage of zaminders. Systematic development of large-scale embankments for flood control started in the 1960s. Since then hundreds of kilometers of embankments have been built along rivers and in the coastal areas of Bangladesh. These embankments provide a protected environment for agricultural and other economic activities. Food security challenges were major consideration under the programme of flood control and drainage improvement, about 7,555 km of embankment (including coastal embankments of about 4,000 km), 7,907 hydraulic structures including sluices, and around one thousand river regulators, 1,082 river closures and 3,204 km of drainage channels have been built spending a hundred million taka. Under the scheme a total of 332 projects, aimed at freeing 3.5 million ha of land from flood water, have been implemented. Thus, about 24% of the total land area and 39% of the net cultivated area have been protected. However, in this programme some form of natural detention basin, channel improvements, flow diversions and bank stabilization and anti-erosive measures have been tried. Other than the flood control embankments on the floodplains, the railway and national road embankments constructed during the colonial period played a major role in flood mitigation. A brief account of major embankments in Bangladesh is given here. Brahmaputra Right Bank Embankment One of the first planed embankments constructed in 1960s to provide flood protection to about 230,000 ha lying on the western side of the Brahmaputra-Jamuna and Tista rivers. It is 217 km long and extends from Kaunia in Rangpur at the northern end up to Beraupazila in Sirajganj district at the southern end. Construction of the embankment started in 1963 and was completed in 1968 at a cost of about BDT 80 million. The average height is 4.5m, crest width 6m and side slope 1:3 on both sides. The embankment has been under constant threat of erosion by the Jamuna River and needs relocation further away from the river bank till now. The Coastal Embankment Project (CEP) covers the coastal districts of Bangladesh and includes Cox's Bazar, Chittagong, Feni, Noakhali, Lakshmipur, Bhola, Barisal, Patuakhali, Jhalokati, Barguna, Pirojpur, Khulna, Satkhira and Bagerhat districts. The CEP comprises a complex network of dikes and drainage sluices and was the first comprehensive plan for providing protection against flood and saline water intrusion in the coastal area. The project was implemented between 1961 and 1978 by the BWDB (Bangladesh Water Development Board) in two phases. Phase I comprises some 92 polders providing protection to one million ha of land. Phase II consists of 16 polders covering another 0.40 million ha. ‘Polder’ is a Dutch word meaning an area enclosed by dikes. Within the CEP more than 4,000 km of embankment and 1,039 drainage sluices have been constructed. But since, 1980s people start to enter from the outsider with money and access to power through taking lease of the water bodies inside Polders to farming saline tolerance shrimps and crab fattening; as a result thousands of unplanned cannels were constructed into embankment thus it is causing weak and thin. And, it also excluded poor farmers accessing and control over water bodies. Moreover their cropping land turns into single crop. According to the geological physical characteristics coastal zone is defined by three hydrological indicators tidal influence, salinity intrusion and influence of cyclones and storm surges. It covers an areas of 47150 sq. km with a population of 38.5 million (BBS 2011), of 817 persons per sq.km.

Materials and Methods

This study based on the secondary materials and long time working experience with coastal rural people. Here the empirical and descriptive research as well as. It is very close observation in different projects, IGA, Early Response project, Cash for Work, CRA (Community Risk Assessment) and community mobilization orientation reports. Those voices are included in here they are always vulnerable in their life time. FGD and KII with different stakeholders of polder surrounded population. Polder construction was the mega project for coastal area. This polder become changed due to natural and manmade calamity. Once mismanagement and malpractice creates vulnerable ecosystem.

Limitation of Study

This study based on the empirical research and descriptive research which is massive challenges of sustainable output. Community voice have some biasness and intention to hide core message from the truth. Most of the people tried to defenses him/herself and try to establish own opinion. Lack of resource and time it is very much critical to identify the principal of the vulnerable ecosystem. There have the opportunity to further study and action plan to mitigation of ecosystem.

Experimental site analysis

The Bay of Bengal is very much rich in coastal and marine ecosystem such as fisheries, crabs, shrimps etc. On the other hand this area cyclone risk zone during the monsoon period in every year. Moreover world largest mangrove forest are exists in here. This area is very much important for diversified ecosystem. The wetland is main feature in coastal zone, including mudflats and mangroves. The world largest uninterrupted stretch of mangrove ecosystems, the Sunderbans, has been declared World Heritage Site in 1997.

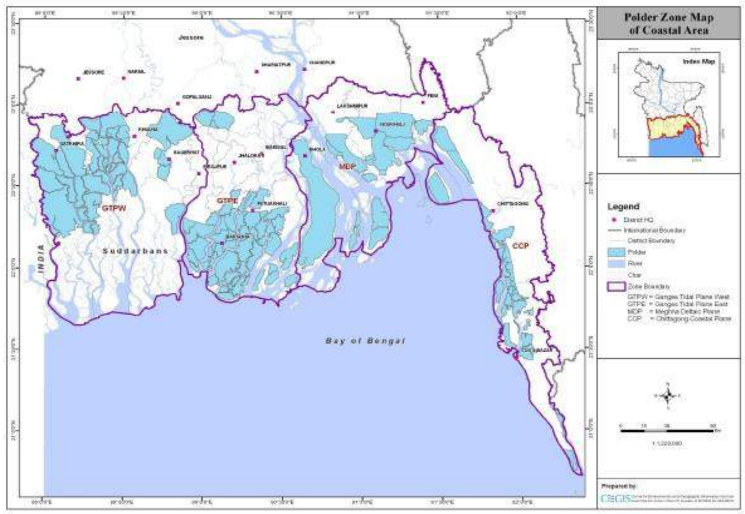

Figure 1 .Source: CEGIS, 2013

Current Maintenance System

The polders are organized into Water Management Groups (WMGs) at village level and Water Management Associations (WMAs) at polder level, with an aim to create effective cooperatives that are in a position to formulate community priorities. Effective operational government agencies

Figure 2

are BWDB, DAE, DoC and LGED. The WMG/WMA's are involved in quality checking of the construction works. The earthworks are carried out by LCS's (Landless Contracting Societies), including women participation. There is different management practice in different level. Union parishad plays a vital role for embankment management. Near about community people and BWDB plays their own management practice. So the management practice of the embankment is a social and organizational both. According to the water management act 1953 embankment is a public property. So, the public authority is strong to protect the any kind of illegal activity on embankment surface. For the good governance the local community and local authority both will be work together for the betterment of the embankment.

Ecosystem of Polder Area

Low dyke construction temporarily for eight months around a year until mid-sixties. On that time grass, weeds and mat-making leaves grew abundantly. Cattle and buffaloes grazed and fish grew naturally. Due to reduction of sweet water flow from upper side like the river Padma, Kopotakho, Tista and Brahmaputra become silted. As a result the saline water getting access easily into the upper stream of Bangladesh. After a long time the ecosystem of these areas are not same as previous century. Due to salinity the ecosystem and livelihood pattern is going to changing gradually. (Bakuluzzaman, 2012) Local paddy of Amon, open fishing and vegetable grow out before the polder system. Local leaseholder constructed dyke to protect flash flood during the monsoon period. Near 1970-1980's the ecosystem were sweet water dependent, too. During the 1972-96 the shrimp started after the polder construction. After 1996 shrimp is the major crop for this area. Huge amount of saline water into the polder for shrimp culture. As a result saline destroy the vegetation into the polder. Slowly domestic animal become reduce from this area. Paddy no longer sustain against shrimp culture due to less profitable sector. Environmentally this area become degraded for saline water.

Figure 3

Problems and Challenges

According to previous discussion the coastal area of Bangladesh are becoming vulnerable through climate changing issues of globalization. Here some visual problems found through different study.

Waterlogging

Waterlogging is problem large parts of coastal, especially in the southwest (Satkhira, Jessore, Khulna and Bagerhat district) and southeast (Noakhali, Feni) coastal zones. This region is characterized by numerous morphologically active tidal river, this is the main drainage network for coastal polder and low lying beels. Since 1960 those areas are restricted for tidal continuation. (Baseline, 2012) Continuous siltation process over the years resulted rise of the river bed level and thereby reduction of conveyance capacity of Peripheral River of the coastal polder significantly leading to large scale of water logging problems inside the polders particularly in the Satkhira, Jessore, Khulna and Bagerhat district. Ecosystem becomes changed due to water logging condition.

Cyclonic storm surges

Bangladesh is the global hotspot for the cyclone storm. Due to global climate change cyclone exposure become causes monsoon period of Bangladesh. During concentration of low pressure amplify the surge in the north part of Bay of Bengal. This is very much challenging for coastal peripheral population.

Salinity intrusion

River water in coastal zone of Bangladesh depends on upper stream fresh water discharge from India which is depending on international water policy. Unethical behavior is influencing salinity intrusion. This is why ecosystem not likes previous century.

Ground water salinity

The shallow groundwater is generally too saline for domestic or irrigation use due either to connate salts or estuarine flooding. However, sufficient flushing of saline water has taken place in isolated pockets to enable a limited domestic use of fresh water in the shallow aquifer. In the deep aquifer the pattern of salinity distribution is more uniform on a regional basis, as is the continuity of the aquifer. The change from potable water to very saline water is sharp and occurs over a relatively short distance (IWM, 2014).

Coastal erosion

This is the natural significance of river characteristics that the delta of the Ganges- Brahmaputra Rivers has not grown significantly toward the sea over last two periods. Changes can be noticed in Sandwip and adjacent islands, in Hatiya Island, in Bhola Island and in the coastline of the Noakhali mainland. Sandwip Island reduced in size in about 200 years. Sandwip channel was nearly isolated from the main distributary network of the rivers in 1764-1793. The Hatiya island elongated and migrated considerably southward during this period. Bhola Island is also elongated north-south (Nuruzzaman, 2015). Due to biggest mangrove forest at Bagerhat, Khulna and Satkhira district comparatively low erosion than South-east part of Bangladesh. Geographically river is changing its nature constantly. Thus the river adjacent embankment become destroy natural changes. On the other hand human behavior responsible for coastal erosion. Unethical cutting and illegal saline water entrance is influencing erosion and ecosystem of that polder.

Gap analysis

There are two types of context work in here. They are external context and internal context. In the global context there are external factor influence through global climate change and its impact. Due to carbon footprint it is less vulnerable for recent time. But in the long run it may turn into vulnerable area. In recent disaster pattern is warning for future vulnerability. On the other hand internal context community people are not aware about impact of destruction of polder. There are clear illustration of coordination gap between external and internal factor. This is the high time to mitigate the vulnerable ecosystem with the conflict management and considering other issues like alternative livelihoods.

Results and Discussion

According to previous discussion and observation it is very much clear about polder history, management system, structure and policy. But there is no doubt that polder enhance the community socio-economic perspective. It is very much essential to mobilize the existing resources to keep it sustainable.

Mitigate Vulnerable Ecosystem

Due to natural siltation rivers are going to sediment through mud, but polder is surrounded by the embankment. As a result mean sea level of river higher than polder surrounded area in some context. In this case TRM (Tidal River Management) in small scale can keep the polder stable. Newly sediment into the polder will enhance fertility in agriculture and vegetation. Moreover people now know about disaster management, embankment and responsibilities of government authorities. This conciseness has been created by the NGOs, who has mobilized community through forming groups and eco-friendly action plan. The local government officials now understand properly about the community demands and feel more accountable to have a sustainable embankment. The Embankment and Drainage Act 1952 ensures the protection of lands from floods, erosion or other damage by water constructing and repairing embankment, but it has developed gaps over the years and decreasing the ecosystem slowly.

Debate through polder

Indigenous flexible water system occurred during the pre-1960s. Structural engineering and mega projects implemented without participation at 1960s. Next steps were small scale projects and pro-poor targeting at 1970s-80s. Without participation the polder management is not maintaining properly. This is why participation as a tool to tackle deferred maintenance. After 40 years later, formalization and standardization of participatory water management for the better practice. But yet the polder became turn into terrifying for the local community. Muscle man take empower to maintain the polder fluently. Unethical water consumption enhance the conflict and life risk. On the other hand polder change the cropping patterns to 1 to 2/3 crops. It increased productivity, more food security and protect population migration. But the tidal surge, inland siltation, water logging and reduction of water flow are the worry about polder.

Major Highlighted Issues

- Proper management of water resources including river flow & implementation of National Water Management Plan
- Enhancing coastal defense system
- Community-based disaster risk reduction
- Increased risks to human health and nutrition
- Safeguarding infrastructure
- Ensuring livelihoods
- Addressing climate induced displacements
- Paradigm shift to wet period crop has been prioritised
- Two dimensional problem for dry season:
- Salinity intrusion
- Lack of efficacy
- Lack of equity
- Lack of sustainability
- Rural inequalities and conflict

Lessen learn

Disaster is the common phenomena for this coastal area and people achieved the copping capacity to survive through alternative livelihood. Different types of NGOs, INGOs and government implementing hundreds of project in this area. There are three things come up to mitigate the vulnerable ecosystem.

1. Ensure participation without biasness and ensure contribution of local people by finance and kind.
2. Empower local government to establish social safety.

3. Fund for polder ecosystem

Thus the polder may effective than the previous period. To make sustainable polder need to maintain some recommendation in here.

- Revise the water policy and master plan with the consideration of ecofriendly.
- Clear understanding of institutional governance system
- Clear roles and responsibility of each actor and factor
- Prioritize environmental issues

Conclusion

The livelihood of the coastal community actually depends on the function of embankment sustainability. Proper management of the coastal polder drainage system is essential to make sustainable development. Different bodies and organizations are working for maintaining the coastal embankment & canals or relative regulators. Due to old drainage design of BWDB, no full repairing works and frequent cyclonic effects are always damaging the coastal embankment which affect the community make them vulnerable in day by day. Various players were involved and united around solutions and finding common demands that include; (i) Construction and repair of sustainable embankment to protect and diversified agricultural production systems and livelihoods (ii) Participation of community people and civil society actors in construction, maintenance, management, removal and control of embankments. Finally, it has to ensure their rights through community participation and build their ownership in the context of polder comprehensive management and ecological health of environment.

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ESTIMATING SOIL HYDRAULIC AND SOLUTE TRANSPORT PARAMETERS IN SUBSURFACE DRAINAGE SYSTEMS USING INVERSE MODELING APPROACH

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Abstract

Due to the time and spatial limitations of subsurface drainage pilots, simulation models have been extensively applied for evaluating such systems. Simulation models are powerful tools which are used for the describing of the interactions between subsurface drainage systems, crop yield and environmental issues. Since the accuracy of simulation models depends extensively on the accuracy of the model inputs, the aim of this study is to present an inverse modeling approach with a genetic algorithm in estimating soil hydraulic and solute transport parameters in subsurface drainage systems and compares it with in-situ determination of soil properties. Inverse modeling is defined as the process of estimating model inputs by matching a forward model to measured data within an optimization algorithm. In this method, sensitivity analysis has a vital role in allowing a possible reduction in the number of parameters that must be estimated, thereby reducing the computational time required for inverse modeling. In this study, measured data was obtained from Amirkabir and Shaeibie sugarcane plantations which have subsurface drainage systems. Both studied areas are semi-arid regions with fine-texture soils. The available measured data for Amirkabir site was drainage discharge and salinity while water table depth was also available for Shaeibie site. SWAP model was used for simulating the outputs of subsurface drainage systems. This model simulates transient water flow using Richards' equation including the extraction rate by drain discharge in the saturated zone as sink terms. The accuracy of different objective functions which were based on the discrepancies between measured and simulated values of drainage discharge, water table depth and drainage salinity was evaluated in the inverse modeling approach. Sensitivity analysis of the SWAP model in both studied areas showed that n shape parameter, lateral hydraulic conductivity (K_h), depth to impermeable layer (D), saturated water content (θ_s), and α shape parameter are the most sensitive parameters in simulating subsurface drainage outputs. Thus, these parameters were selected in order to be determined by the inverse modeling approach. In the Amirkabir study area, minimizing the objective function which is based on drainage

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discharge and salinity is the most appropriate approach which can determine soil hydraulic parameters. By applying an inverse modeling approach, Nash–Sutcliffe efficiency (*NSE*) value for predicting drainage discharge and salinity were 0.63 and 0.79, respectively. In Shaeibie study area, minimizing the objective function which included salinity of drainage water and water table depth and also the objective function, based on the combination of drainage discharge, watertable depth and drainage salinity are influential in obtaining soil hydraulic properties that could simulate the outputs of the drainage systems accurately. By using this objective function in determining soil properties, *NSE* value for predicting drainage discharge, water table depth drainage salinity were 0.83, 0.95 and 0.89, respectively.

KEY WORDS: Indirect methods, Soil properties, Simulation, Drainage, Optimization

Introduction

Subsurface drainage systems are an important water management practice tool for farming throughout the world (Ebrahimian et al., 2011; Negm et al., 2014). Although these systems can improve crop production by removing excess water and controlling soil salinity, they have been considered as one of the major sources of pollution that release agrochemicals from agricultural fields to both surface water and groundwater (Negm et al., 2014). Over the past decades, field experiments have contributed substantially to our knowledge and understanding of drainage design and water management for different soils and climates; however, limitations in predicting long-term effects in addition to the impact on areas beyond the field level and the cost effectiveness of these experiments are their major drawbacks (Haan and Skaggs, 2003). Simulation models are useful tools applied for the overcoming of these limitations, as compared to different strategies, suggest solutions, and predict consequences in the medium to long term with much less cost (van Dam et al., 2008; Skaggs et al., 2012). One such drainage simulation model is SWAP (Kroes et al., 2008). The SWAP model has already been applied and tested for various agricultural water management studies throughout the world and has been proven to produce reliable and accurate results (Xu et al, 2016; van Lier et al., 2015; Droogers et al., 2010; van Dam et al., 2008). It has been observed that the SWAP model can be successfully applied to subsurface drainage studies (Qureshi et al., 2013; Noory et al., 2011; El-Sadeq et al., 2001; Sarwar et al., 2000). Sarwar and Feddes (2000) and Sarwar et al (2000) successfully applied the SWAP model to evaluate drainage design parameters for the Fourth Drainage Project in Pakistan. However, they discovered that laboratory determined soil hydraulic parameters could not adequately represent the field conditions for simulation purposes. Sue et al (2005) reported that the performance of SWAP was satisfactory in the simulation of hydrological processes at field scale, including the responses of the watertable and drainage volume and salinity to irrigation and rainfall inputs in a semi-arid region. Verma et al (2010) evaluated the SWAP model for its capability to simulate crop growth and salinity profile for the cyclic irrigation of saline water in an area with a shallow water table that has a a subsurface drainage system. They concluded that the crops could grown very well under such subsurface drainage conditions; but, in dry rainfall years, salinity build-up might occur. The model simulations of Qureshi et al., (2013) suggested that a subsurface drainage system should be installed in arid areas of Iraq to maintain the groundwater table depth at an optimum level.

Although SWAP is now routinely applied for addressing agricultural water management issues, both in research and managerial applications, the problem of obtaining soil hydraulic properties remains a major challenge (Van Dam et al., 2008). A variety of direct measurement methods exists (Dane and Topp, 2002), but since they require strictly defined experimental set-ups and hydrostatic or steady-state conditions with plain boundary conditions, it makes them very time consuming, and thus unsuitable for applications to larger scales (Durner et al., 2008). This necessitates the development of alternative methods to derive the soil hydraulic properties of the application scale of the model (Vrugt et al., 2008; Ritter et al., 2003). An attractive procedure for obtaining model parameters in recent years has been through inverse modeling. This approach involves obtaining easily measured variables (model outputs), and using this information to estimate a set of unknown model parameters using an optimization algorithm (Simunek and Hopmans, 2002). The type of optimization algorithm (Vrugt, et al., 2008; Wöhling, et al., 2008) as well as the sensitivity of unknown parameters to measured variables (Simunek and van Genuchten, 1996) is an issue of great concern in the field application of inverse problems. Ritter et al (2004) evaluated the applying of three different measured data to determine the soil hydraulic properties of volcanic soil. They showed that taking into account all of the measured data gave the best results; however, the monitoring of water content in combination with either pressure head or bottom flux was sufficient. Samani et al. (2007) used the watertable measurmentdata to inversely determine the saturated hydraulic conductivity and the effective porosity in five different unsteady subsurface drainage analytical models of the Boussinesq equation simultaneously. Their findings show that by applying the inverse problem technique, all the analytical models will show good agreement with the measured data. Shin et al. (2012) stated that in an under layered soil profile, when the subsurface flows are dominated by upward fluxes, the solution to the inverse problem appears to be more elusive. However, when the soil profile is predominantly drained, the soil hydraulic parameters can be fairly estimated well across all soil layers. Excellent reviews on inverse modeling of soil hydraulic properties have been presented in Hopmans and Šimůnek (1999), Hopmans et al., (2002), Vrugt et al., (2008) and Mohanty (2013).

Previous researches have shown that optimized values from local optimization algorithms, such as the LevenbergeMarquardt algorithm and Simplex algorithm depend on the location from which these algorithms arise;terefore, they might not be appropriate for calibrating complex and highly nonlinear problems (Wohling et al., 2008). However, the genetic algorithm (GA) method searches the entire population instead of moving from one point to the next and can, therefore, overcome the limitations of traditional methods (Mohanty, 2013, Sedaghatdoost and Ebrahimian, 2015).

Genetic algorithms have been successfully applied in the past decades for optimizing design and management of irrigation systems for different purposes (Ebrahimian et al., 2013). The objective of this study is to apply an inverse modelling approach with the genetic algorithm to estimate the soil hydraulic and solute transport parameters in two subsurface drainage systems using drainage discharge, watertable depths and drainage salinity data.

Materials and Methods

The inverse modeling approach for estimating soil hydraulics and solute transport properties in subsurface drainage systems was implemented by combining a physically based Soil–Water–Atmosphere–Plant model, SWAP with a GA optimization algorithm. The following sections present these items in detail.

Field Experiment

The data collected from Shoeibiyeh and Amir Kabir subsurface drainage experimental sites (31˚52´56″ N, 48˚40´57″ E and 31˚01´24″ N, 16˚52´52″ E, respectively) , in the Khuzestan province of Iran which are located in arid and semi arid regions. In the Shoebiyeh site, the collected data included drainage discharge, drainage salinity and watertable fluctuations collected from April 14 to November 02 , 2011. In the Amir Kabir site, however, watertable data were not available and drainage discharge and salinity data were collected from April 9 to July 24 of 2008. Both sites generally have heavy soils with poor drainage condition and are cropped with sugarcane. Irrigation water was suppliedvia conventional furrow irrigation methods during the study period. Low application efficiency of the irrigation systems resulted in the rise of the saline water table which necessitates the existence of a subsurface drainage system. The subsurface drainage systems in Shoay biyeh and Amir Kabir sites consist of 845 and 500 m long drain tubes installed at 2.1 and 2.0 m below the soil surface, respectively. Horizontal hydraulic conductivity (K_h) was measured using the auger hole method. The position of the impermeable layer (D) was identified via observation in a deep auger hole. A summary of the subsurface drainage design is available in Table 1.

Table 1. A summary of drainage design parameters in Shoeybiyeh and Amir Kabir study areas

Study area	Drain depth (m)	Drain spacing (m)	Depth to impermeable layer (m)	Hydraulic conductivity (m/d)	Initial depth to watertable (m)	Wet perimeter (m)
Shaeibie	2.1	70.0	6.0	1.2	1.8	0.6
Amir Kabir	2.2	40.0	6.0	1.0	1.9	0.6

In-situ measurements indicated that the soil in the study areas consist of two layers containing high amount of silt and clay. A silty clay loam was placed above a silty clay layer in Shaeibie site whereas a silty clay layer covered a silty clay loam in Amir Kabir site. According to Durner et al. (2008), both studied areas consist of weakly heterogeneous soil which can be expressed as a single-layer soil medium to enhance the efficiency of inverse modeling approach. Thus, we assumed a homogeneous soil profile for both study areas to reduce the number of optimized parameters. A summary of soil parameters was presented in Table 2.

Table 2. Summary of soil hydraulic parameters in Shaeibie and Amir Kabir study areas

Study area	texture	θ_r (cm^3 cm^{-3})	θ_s (cm^3 cm^{-3})	α (-)	n (-)	λ (-)	K_s (cm d^{-1})
Shaeibie	Silty clay loam	0.010	0.520	0.037	1.101	0.5	24.8
Amir Kabir	Silty clay	0.073	0.388	0.120	1.188	0.5	3.37

Piezometers were installed in the sample fields and across the laterals to monitor depth to watertable. Drainage discharge rate from laterals were measured at the manholes with the help of a bucket and a stopwatch.

SWAP model

SWAP is a one-dimensional, physically based model for water, heat and solute transport in variably saturated soils (Kroes et al., 2008). Richards' equation, including root water extraction and the extraction rate by drainage discharge in the saturated zone (as sink terms) is applied to compute the transient soil water flow (Eq. 1) under specified upper- and lower-boundary conditions:

$$\frac{\partial \theta}{\partial t} = \frac{\partial \left[K(h) \left(\frac{\partial h}{\partial z} + 1 \right) \right]}{\partial z} - S_a(h) - S_d(h) \qquad (1)$$

where θ is volumetric water content (cm^3 cm^{-3}) , t is time (d), $K(h)$ is hydraulic conductivity (cm d^{-1}), h is soil water pressure head (cm), z is the vertical coordinate (cm), $S_a(h)$ is soil water extraction rate by plant roots (cm^3 cm^{-3} d^{-1}), and $S_d(h)$ is the extraction rate by drainage discharge in the saturated zone (d^{-1}). In SWAP model, crop growth was simulated using three different routines: a simple module, a detailed module and a detailed module for grass (re)growth. The simple module is useful when crop growth doesn't need to be simulated or when detailed crop growth input data were not available so, in this study, the simple module was applied during the simulations. The Mualem-Van Genuchten relations, with a modification near saturation, describe the soil hydraulic functions (Eqs. 2 and 3):

$$\theta = \theta_{res} + \left(\theta_{sat} - \theta_{res}\right)\left(1 + \left|ah\right|^{n}\right)^{-m} \quad (2)$$

$$K = K_{sat} S_e^{\lambda} \left[1 - \left(1 - S_E^{\frac{1}{m}} \right)^{m} \right]^{2} \quad (3)$$

where θ_{res} is residual water content (cm^3 cm^{-3}), θ_{sat} is the saturated water content (cm^3 cm^{-3}), α (-), n (-) and m (-) are empirical shape factors, K_{sat} is saturated hydraulic conductivity (cm d^{-1}), S_e is relative saturation, and λ is a shape parameter. The drainage discharge rate is computed with the classical steady-state drainage equations of Hooghoudt and Ernst. The difference in hydraulic properties of the layered soil profile determines whether the Hooghoudt or Ernst equation should be used. The drain discharge rate depends on the simulated groundwater level midway between drains. The general equation used for subsurface drainage is:

$$q_{drain} = \frac{h_{gwl} - h_{drain}}{\gamma_{drain}} \quad (4)$$

Where h_{gwl} is the watertable level midway between drains (cm), h_{drain} is the drainage level (cm) and γ_{drain} is the drainage resistance (d). Applying Ritzema's theory (Ritzema, 1994), SWAP assumed five typical drainage situations. For each of these situations the drainage resistance, γ_{drain}, can be defined. In this study, we applied Hooghoudt equation as we assumed the drain is above impervious layer in a homogenous profile.

$$\gamma_{drain} = \frac{L^2}{8K_s d + 4K_s\left(h_{gwl} - h_{rain}\right)} + \gamma_{entr} \quad (5)$$

Where L is the drain spacing (cm), K_h is lateral hydraulic conductivity (cm d^{-1}), d is the equivalent depth (cm) and γ_{entr} is entrance resistance (d). The convection, dispersion and diffusion are the three main processes of solute transport embedded in the SWAP model. The total solute flux is calculated by SWAP model using Eq.(5), given by:

$$J = qc - \theta\left(D_{dif} + D_{dis}\right)\frac{\partial c}{\partial z} \quad (6)$$

Where J is total solute flux (g cm^{-2} d^{-1}), q is Darcy flux (cm d^{-1}), which is averaged over a certain cross section, c is the solute concentration in soil water (g cm^{-3}), D_{dif} is the diffusion coefficient (cm^2 d^{-1}), D_{dis} is the dispersion coefficient (cm^2 d^{-1}). In this study, the molecular diffusion coefficient was assumed to be negligible.

Sensitivity Analysis

Sensitivity analysis is defined as a process which determines how different values of an independent variable (i.e. model inputs) will impact a particular model output under a given set of assumptions. An important aim of the parameter sensitivity analysis is to allow the possible reduction in the number of parameters that must be estimated, thereby reducing the computational time and effort required for model calibration. Sensitivity coefficients were calculated according to Simunek and van Genuchten (1996), as presented in Eq. 7.

$$s\left(z,t,b_j\right)=0.01b_j\,\frac{\left|\partial h\left(z,t,b_j\right)\right|}{\partial b_j}\approx 0.01b_j\,\frac{\left|h\left(b+\Delta b e_j\right)-h\left(b\right)\right|}{1.01b_j-b_j}=\left|h\left(b+\Delta b e_j\right)-h\left(b\right)\right| \qquad (7)$$

Where $s(z,t,b_j)$ is change in the auxiliary variable h (drainage discharge, drainage salinity, and watertable depths) corresponding to a 1% change in parameter b_j, e_j is jth unit vector, and Δb is $0.01b$. To compare the sensitivity values among different parameters, time-averaged coefficients were calculated according to the following expression (Inoue et al., 1998):

$$s\left(z,b_j\right)=\frac{1}{t_{end}-t_0}\int_{t_0}^{t_{end}} s(z,t,b_j)dt \qquad (8)$$

The range of variables was obtained from existed soil databases (Table 3). By applying Eqs. 7 and 8, the most sensitive parameters were ranked according to their influence on desired model outputs.

Table 3. Minimum and maximum values of decision variable applied in sensitivity analysis

Input parameters	Symbol	Minimum	Maximum
Soil hydraulic parameters			
Residual water content (cm^3 cm^{-3})	θ_r	0.034	0.120
Saturated water content (cm^3 cm^{-3})	θ_s	0.320	0.950
Empirical shape factor (-)	n	1.090	3.180
Inverse of the air-entry value (cm^{-1})	α	0.005	0.145
Empirical shape factor (-)	λ	0.100	5.0
Saturated hydraulic conductivity (cm d^{-1})	K_s	0.500	700.0
Subsurface drainage parameters			
Depth of impermeable layer (m)	D	2.1	17.0
Lateral hydraulic conductivity (cm d^{-1})	K_h	5.0	1000.0
Drain entry resistance (d)	H_e	1.0	60.0
Solute transport parameters			
Dispersion length (cm)	D_l	5.0	100.0
Freundlich adsorption coefficient (cm^3 mg)	K_f	0.0	100.0
Potential decomposition rate (d^{-1})	μ	0.0	10.0
Relative root solute uptake (-)	K_r	0.0	10.0
Freundlich exponent (-)	N_f	0.0	10.0
Reference solute concentration for adsorption (mg cm^3)	c_{ref}	0.0	1000.0
Factor reduction decomposition due to temperature (C^{-1})	γ_T	0.0	0.5
Minimum water content for μ (cm^3 cm^{-3})	θ_{min}	0.0	0.4
Exponent in reduction decomposition due to dryness (-)	f_{dry}	0.0	2.0

Genetic algorithm (GA)

A genetic algorithm was chosen in the purposed inverse modeling procedure to apply the optimization process due to its remarkable ability in a variety optimization problem (Shin et al., 2012; Ebrahimian et al. 2013). GA includes four major operators including selection, crossover, mutation and elitism. First, an initial population of individuals is generated in a gene pool. Then using the fitness of objective function as a selection criteria, some of the created individuals selected to enter the mating pool while others die. Information of each selected individuals (known as parents) are exchanged through crossover with a specified probability (rate). Mutation reproduces individuals to create the next generation. The best individual in each generation survive during using elitism. This operator makes the genetic algorithm converge more rapidly. Using Carrol (1996) guidelines, crossover, mutation rate, number of generations, and population size were set as 0.5, 0.01, 300, and 200, respectively. The ranges of decision variables, which will optimize through optimization algorithm, were presented in Table 3. The SWAP model was linked to the GA to optimize the decision variables by minimizing seven objective functions. Each decision variables set was optimized through seven objective functions (Eqs. 9-15, Table 4) which minimized the differences between observed and simulated values of drainage discharge, drainage salinity, watertable depths, and the combination of them. As watertable depths were not available in Amir Kabir site, equations 1, 3, and 5 were only applied in the inverse modeling approach in this site. We assumed that all observed data obtain with the same accuracy so the optimization was performed with equal weighting on all the observed data which showed that all data have the same accuracy in the objective functions. In objective functions using combination of observed data with different units, the objective function became dimensionless by dividing the differences between measured and simulated of each variable by its corresponding measured data. The flowchart of the inverse modeling approach is presented in Figure 1.

Table 4. Various objective functions applied in this study

Objective functions*	Equation
$OF1=\sum_{i=1}^{N}(D_{obs}(t_i)-D_{sim}(b,t_i))^2$	(9)
$OF2=\sum_{j=1}^{M}(W_{obs}(t_j)-W_{sim}(b,t_j))^2$	(10)
$OF3=\sum_{k=1}^{O}(S_{obs}(t_k)-S_{sim}(b,t_k))^2$	(11)
$OF4=\sum_{i=1}^{N}\left(\frac{D_{obs}(t_i)-D_{sim}(b,t_i)}{D_{obs}(t_i)}\right)^2+\sum_{j=1}^{M}\left(\frac{W_{obs}(t_j)-W_{sim}(b,t_j)}{W_{obs}(t_j)}\right)^2$	(12)
$OF5=\sum_{i=1}^{N}\left(\frac{D_{obs}(t_i)-D_{sim}(b,t_i)}{D_{obs}(t_i)}\right)^2+\sum_{k=1}^{O}\left(\frac{S_{obs}(t_k)-S_{sim}(b,t_k)}{S_{obs}(t_k)}\right)^2$	(13)
$OF6=\sum_{j=1}^{M}\left(\frac{W_{obs}(t_j)-W_{sim}(b,t_j)}{W_{obs}(t_j)}\right)^2+\sum_{k=1}^{O}\left(\frac{S_{obs}(t_k)-S_{sim}(b,t_k)}{S_{obs}(t_k)}\right)^2$	(14)
$OF7=\sum_{i=1}^{N}\left(\frac{D_{obs}(t_i)-D_{sim}(b,t_i)}{D_{obs}(t_i)}\right)^2+\sum_{j=1}^{M}\left(\frac{W_{obs}(t_j)-W_{sim}(b,t_j)}{W_{obs}(t_j)}\right)^2+\sum_{k=1}^{O}\left(\frac{S_{obs}(t_k)-S_{sim}(b,t_k)}{S_{obs}(t_k)}\right)^2$	(15)

* D_{obs}, W_{obs} and S_{obs} are observed values of drainage discharge, watertable depth and drainage salinity respectively. D_{sim}, W_{sim} and S_{sim} are their corresponding simulated values, respectively.

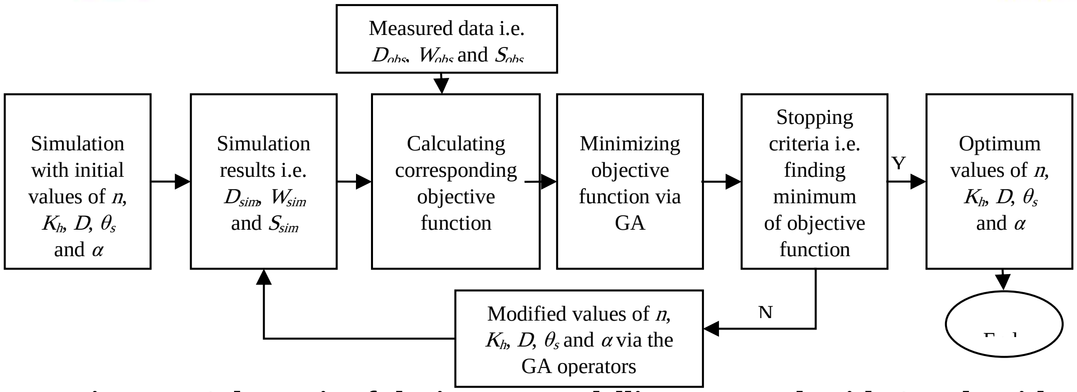

Figure 1. Schematic of the inverse modelling approach with GA algorithm.

Evaluation Criteria

To evaluate the accuracy of the optimized parameters, the performance of the SWAP model was assessed using estimated parameters to simulate drainage discharge, water table depth and drainage salinity. The coefficient of determination (R^2), root of the mean square error (*RMSE*), and Nash–Sutcliffe efficiency (*NSE*) were applied to evaluate the inverse modeling approach. A value of R^2 and *NSE* close to 1 and a small *RMSE* indicate that the simulated values were in a good agreement with the measured values. Skaggs et al. (2012) recommended that NSE>0.40, NSE>0.60 NSE>0.75 could be regarded as acceptable, good, and excellent, respectively, for simulating daily water table depth and drainage discharge.

Results and discussion

Results of time-averaged sensitivity for desired outputs in Shaeibie and Amir Kabir study areas were provided in Table 5. Results showed that van Genuchten shape parameter *n* was, by far, the most influential parameter for all outputs in Shaeibie and Amir Kabir study areas. Parameter *n* is a measure of the pore-size distribution and governs the shape and slope of water retention curve which considered as a sensitive parameter in most vadose zone studies. Lateral hydraulic conductivity (K_h) and depth to impermeable layer (*D*) were second and third sensitive parameters, respectively. K_h governs the ease of water flow from watertable to drain tubes and, previous researches (Skaggs et al., 2012; Wang et al., 2006) indicated that, it was one of the most sensitive parameters in subsurface drainage predictions. The depth of impermeable layer in the soil profile has an important impact on the amount of drainage and the time it takes before the salt accumulation in the drain outflow becomes noticeable; deeper barrier layers result in very long periods before equilibrium is reached (Jury et al., 2003). Moreover, the variability and difficulty of determining field values of depth to the impermeable layer makes calibration desirable when possible and, in some cases, necessary (Skaggs et al., 2012). The parameter θ_s is a capacity parameter that determines the maximum storage of water in a soil, and plays a major role at or near saturation which influences consequently the performance of a drainage system. The soil hydraulic parameter α is the inverse of the air-entry value of a soil, which describes the relationships between water table depth versus volume drained and water table depth versus upward flux. These two parameters ranked fourth and fifth, according to their time-averaged sensitivity values, respectively. Other parameters played a less dominant role and had less sensitivity. It has been noticed that soil hydraulic properties and drainage parameters had much more influence on the drainage salinity in comparison with solute transport parameters. This may arise from the fact that the hydrology part of simulation models, which consists of soil hydraulic properties and drainage parameters, is the main driver of water flow and solute transport (Negm et al. 2014) and consequently had more influence on the outputs models. This result was consistent with the findings of Negm et al. (2014). Based on the results of sensitivity analysis, the five most influential parameters including n, K_h, D, θ_s, and α were chosen to be estimated in both study areas using inverse modeling approach.

Table 5. Time-averaged sensitivity coefficients for soil hydraulic and solute transport parameters in Shaeibie and Amir Kabir study areas*

Outputs	Soil hydraulic and subsurface drainage parameters								
	θ_r	θ_s	α	n	λ	K_s	D	K_h	H_e
Drainage discharge	1.9×10^{-5} 8.9×10^{-5}	1.4×10^{-3} 3.9×10^{-3}	7.5×10^{-4} 4.3×10^{-3}	2.2×10^{-2} 1.6×10^{-2}	6.0×10^{-4} 1.1×10^{-4}	6.4×10^{-4} 8.2×10^{-4}	2.5×10^{-3} 1.9×10^{-4}	2.8×10^{-3} 4.0×10^{-4}	6.4×10^{-4} 4.7×10^{-4}
Watertable depth	5.4×10^{-3} 1.1×10^{-2}	0.31 0.46	0.17 0.55	4.60 1.75	0.10 5.8×10^{-2}	0.13 0.19	0.45 6.5×10^{-2}	0.49 0.11	0.11 6.5×10^{-2}
Drainage salinity	2.5×10^{-3} 1.1×10^{-3}	3.5×10^{-3} 5.7×10^{-2}	2.4×10^{-3} 6.2×10^{-2}	3.8×10^{-2} 0.23	1.6×10^{-3} 3.4×10^{-3}	2.3×10^{-3} 1.3×10^{-2}	4.7×10^{-3} 4.1×10^{-3}	5.2×10^{-3} 7.1×10^{-3}	2.0×10^{-3} 7.8×10^{-3}
	Solute transport parameters								
	D_l	K_f	μ	K_r	N_f	c_{ref}	γ_T	θ_{min}	f_{dry}
Drainage salinity	1.8×10^{-3} 1.5×10^{-5}	1.3×10^{-3} 1.7×10^{-4}	0.0 0.0	0.0 0.0	1.4×10^{-3} 1.8×10^{-5}	2.9×10^{-4} 0.0	0.0 0.0	0.0 0.0	0.0 0.0

* Top and below values are for Shaeibie and Amir Kabir study areas, respectively.

In Shaeibie study area, among all studied objective functions, OF4 and OF7 which are based on two and three different sets of observed data, respectively derived optimum values of parameters that simulated all model outputs precisely. Simunek and van Genuchten (1996), Ritter et al. (2004), Sedaghatdoost and Ebrahimian (2015) were also proved that applying objective function that consists of a combination of datasets determined the unknown parameters suitably. Table 6 showed that parameters obtained by OF4 and OF7 differed substantially with initial values. Generally, in

OF4 and OF7 in the Shaeibie study area, θ_s was estimated lower than initial value while α and n were estimated higher. However, D and K_h parameters were quite similar to the initial values.

Table 6. Soil hydraulic properties estimated by inverse modeling approach using selected objective functions GA in both study areas

Study area	Objective function	θ_s (cm^3 cm^{-3})	α (-)	n (-)	D (cm)	K_h (cm d^{-1})
Shaeibie	OF4	0.363	0.087	1.187	606	156
	OF7	0.377	0.104	1.188	590	174
Amir Kabir	OF5	0.390	0.125	2.417	221	57

Table 7 indicated that *RMSE* values for simulating drainage discharge, watertable depth, and drainage salinity by parameters obtained by optimizing OF4 were 0.16 cm/d, 23.82 cm, and 0.17 mg/cm^2, respectively which proved that the parameters adequately predicted all outputs during study period (Figure 2). Additionally, *NSE* values for outputs were between 0.81 and 0.83 which could be rated as excellent (Skaggs et al. 2012). The results of OF4 demonstrated that the exclusion of drainage salinity in obtaining parameters did not compromise the ability to reproduce model outputs accurately. Since solutes are primarily transported as dissolved components in the water phase (Mishra and Parker, 1989), indeed, the effect of outflow salinity was hidden in the drainage discharge as the majority of salinity is carried with subsurface flow to drainage system.

The unit of RMSE for OF1, OF2, OF6 and OF7 are min, min, l s_1 and mg l_1, respectively.

Table 7. Evaluation criteria of parameters derived by inverse modeling approach using selected objective functions GA in study areas

Study area	Objective function	Drainage discharge			Watertable depth			Drainage salinity		
		R^2	*RMSE* *	*NSE*	R^2	*RMSE*	*NSE*	R^2	*RMSE*	*NSE*
Shaeibie	OF4	0.83	0.16	0.81	0.93	23.82	0.83	0.90	0.17	0.83
	OF7	0.84	0.15	0.83	0.93	12.87	0.95	0.90	0.13	0.89
Amir Kabir	OF5	0.53	0.55	0.63	-	-	-	0.78	14.25	0.79

*The unit of *RMSE* for Drainage discharge, watertable depth, and drainage salinity are cm d^{-1}, cm, and mg cm^2, respectively.

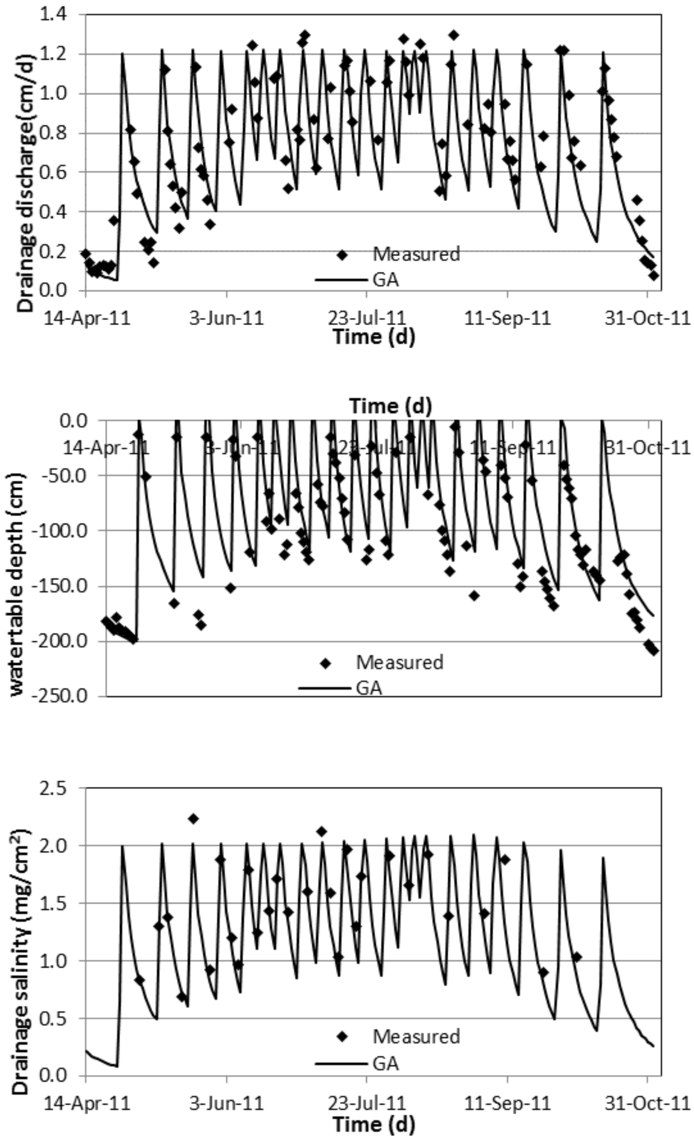

Figure 2. Simulation of drainage outputs via parameters derived by inverse modeling approach using OF4 in Shoeybiyeh **site**

The results of OF7 which are based on minimizing the differences between simulated and measured values of drainage discharge, the watertable depth and drainage salinity indicate that the optimized parameters resulted into the most accurate estimation of all outputs in the Shoeybiyeh study area (Table 7, Figure 3). *NSE* values for drainage discharge, watertable depths, and drainage salinity were 0.83, 0.95, and 0.89, respectively which were rated as excellent based on the figures provided in Skaggs et al. (2012) This was consistent with Ritter et al. (2004), Sedaghatdoost and Ebrahimian (2015) findings which showed that the best parameter sets came from an objective function using all the measured data. Finally, the results proved that although inverse modeling using all measured data gives the best results, monitoring of drainage discharge in combination with watertable depth proves to be sufficient.

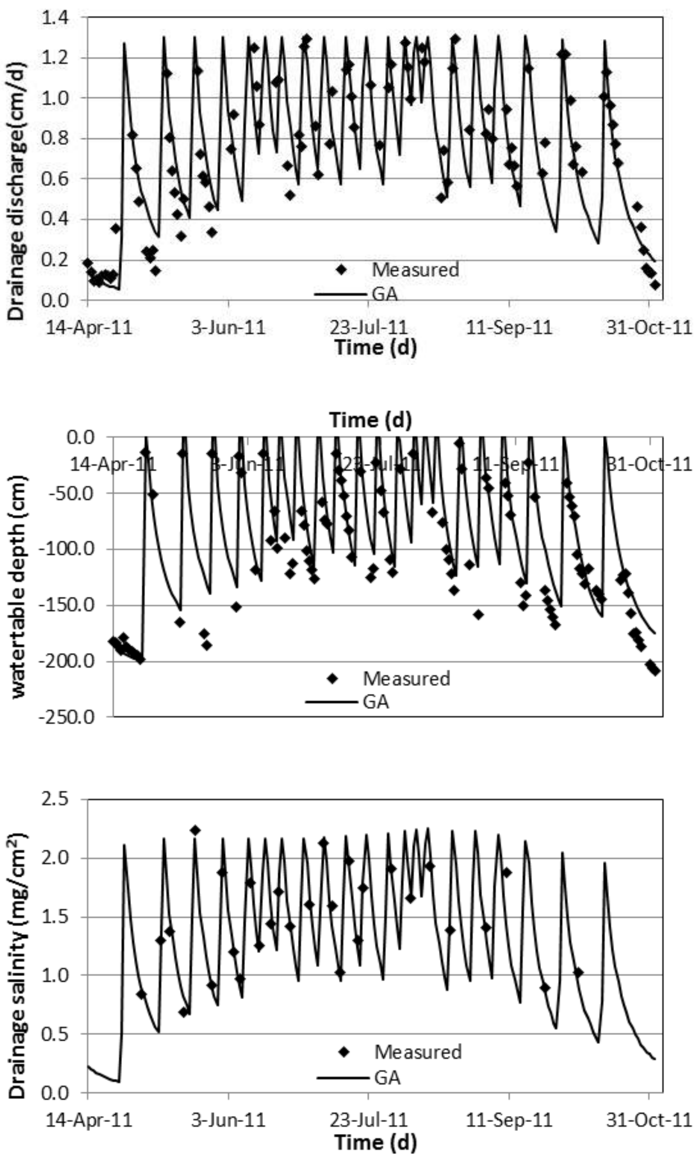

Figure 3. Simulation of drainage outputs via parameters derived by inverse modeling approach using OF7 in the Shoeybiyeh **site**

In the Amir Kabir study area, OF5 which is based on minimizing the differences between simulated and measured values of drainage discharge and drainage salinity estimated parameters resulted into the best estimation of all outputs. In this objective function, θ_s, α and n were estimated as being higher than initial values whereas D and K_h were significantly lower than initial values. In the Amir Kabir site, NSE values for drainage discharge and drainage salinity were 0.63 and 0.79, respectively which were rated as good and excellent, respectively, as perto Skaggs et al., (2012) recommendation. As seen in Table 7, the accuracy of simulations was better in Shoeybiyeh as compared to the Amir Kabir site. This may arise from the fact that objective functions were not included watertable data in the Amir Kabir site. According to Table 5, watertable predictions were highly sensitive to soil hydraulic parameters; hence, they provided watertable data as objective functions which helped the inverse modeling approach to find soil properties more precisely.

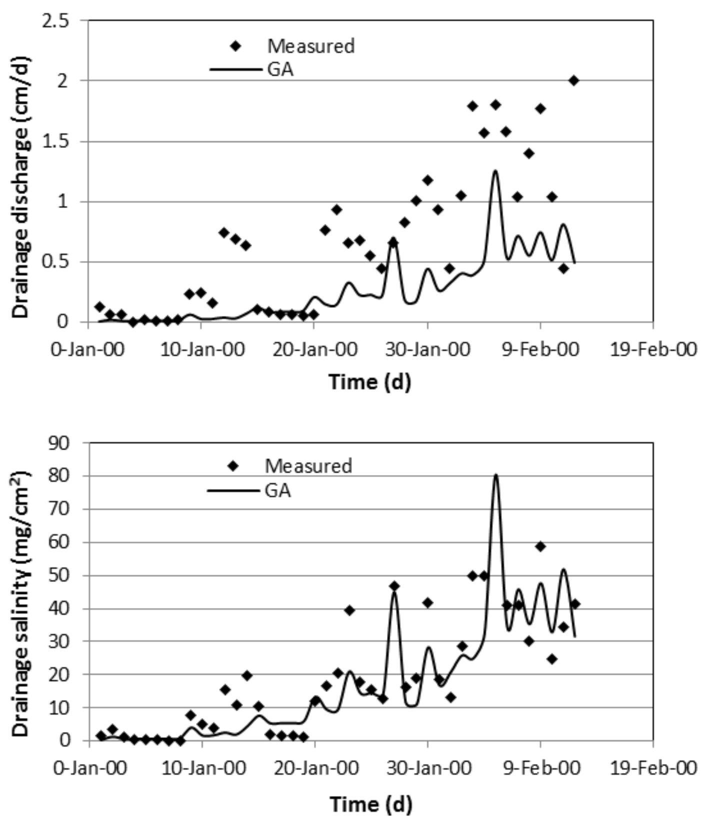

Figure 5. Simulation of drainage outputs via parameters derived by inverse modeling approach using OF5 in Amir Kabir site

Conclusion

In this study, an inverse modelling approach with GA algorithm was introduced to estimate the soil hydraulic parameters in two subsurface drainage systems located in the Khuzestan province, Iran. This approach combined drainage discharge, watertable depth data and drainage salinity data with seven objective functions to identify the optimal values of these coefficients by minimizing differences between simulations of the SWAP model and measured data. The result of the sensitivity analysis showed that the most sensitive parameters were n, K_h, D, θ_s and α in both study areas. In the Shoeybiyeh site, both OF4 and OF7 could precisely find soil parameters and were thus able to simulate all outputs perfectly. However, from a practical point of view, one prefers to use OF4 since it applies less measured data. In the Amir Kabir site, the OF5 algorithm which used drainage discharge and salinity had the best performance, but, the accuracy of model predictions at the Amir Kabir site was less than Shoeybiyeh since it did not have any watertable data. To sum up, in this study, the inverse modelling approach utilizing a GA algorithm has been identified as a robust tool to estimate soil hydraulic parameters that are very important when designing, evaluating and simulating subsurface drainage systems.

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THE IMPACT OF REDUCING SUB DRAIN DEPTH ON ESTIMATED DRAINAGE COEFFICIENT AND SALINITY OF DRAINAGE WATER

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Abstract

The drainage coefficient is a determinative criterion in subdrain network design. Over estimation of this coefficient results in congested subdrain network and costly design. On the other hand, underestimation of it may cause a rise in the water table in the root development zone, limiting uptake of appropriate combination of water, air and nutrients by the roots and the reducing of soil workability conditions for agricultural practices. Therefore optimizing the drainage coefficient is done with the objective of preparing the most economical and efficient applicable method, which in addition to keeping the water table at an appropriate maximum level to provide better conditions for the aeration of plant roots, while salinity remains at its highest desirable level in the soil profile, without any salinity build up and plant yield reduction.

Based on the obtained calculations, drain spacing is inversely proportional to the square root of the drainage coefficient. Recently Jahad-e-Nasr Institute, the implementing agency for land reclamation projects in the Khuzestan & Ilam provinces is implementing the sub drain network in an area of 550, 000 hectares. In the above said provinces. The drain spacing is determined on the basis of recommended cropping patterns and the calculated drainage coefficients.. In contrary with to the designed specifications, the implementing agency has made some changes in the network, ,of which the most important one is the reduction of the depth of lateral installation from an average of 1.5 – 1.7 to 1.3- 1.5 meters. Based on the calculations, as the result of these changes the drain spacing must be reduced by 20%, But, the changes for drain spacing have not taken into account during execution works for installing subdrains.

In this research in order to assess the impact of reducing subdrain depths on the calculated drainage coefficient and drainage water salinity loads, two implemented subdrain network laterals in the Mianab-e-shushtar and Shoeibieh plains with areas of 14000 and 10000 respectively were selected. In order to measure the drainage coefficient and compare it with the calculated drainage coefficient, some parts of the above mentioned plains were selected. In addition, by measuring the water level between the sub drains, the role of drainage for reducing ground water table was evaluated. The findings of the research are as follows:

1- the rise of water table exceeds the allowable design 2- the outflow of laterals were reduced 3- electrical conductivity decreased 4- the final water table dropped from one meter to 89 cm 5- a few days after irrigation the electrical conductivity of drain outflow experienced a reduced trend, yet that of ground water and open collectors showed an increasing trend. 6- Glover-dumm

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performance index was calculated as 0.035 7- salt outlet index (SEI) was negative and 8- the amount of salt entering the environment decreased.

KEY WORDS: drainage coefficient, Glover-dumm, salt outlet index, sub drain depth

Introduction

The drainage coefficient is defined as the amount of discharge of ground water, arising from losses due to deep percolation of irrigation water, rainfall, losses from canals and seepage from nearby areas, which should be drained from plant root zone within a specified time. The Subsurface drainage coefficient is used for determining the spacing and capacity of subsurface drains. In order to precisely determine the subsurface drainage coefficient in any region, the identifying of thesources of deep percolation is of prime importance. Due to the slightness rainfall in arid and semi-arid regions, losses and deep percolations from irrigation water are the most important factors contributing to the recharge of ground water.

In most parts of the Khuzestan province, due to the scarcity of rainfall , the irrigation requirements of various plants with different cropping patterns is supplied from irrigation. Therefore, the main factor in determining the drainage coefficient in the region is considered to be deep percolation from the application of irrigation water.

In a study conducted by Safwat and others,(1998), the North Eastern regions of the Nile Delta were assessed. They concluded that the amounts of real drainage coefficient and the depths of the impermeable layer exceeds the estimated amount obtained in the design.

In a research conducted by Mansoori(2005), for assessing the performance of the drainage system in the regions where sugar cane development is taking place in the Khuzestan province, he concluded that by reducing the depth of the sub surface drains,the volume of drainage water will be reduced and as a result environmental impacts on the downstream side can be mitigated.

In other study, Mansoori, (2005) in assessing parameters for designing drainage system in sugar cane development plantations has shown that drains perform exceedingly well in controlling water level depth.

Naseri and Arvahi, (2009), assessed the performance of subsurface drainage at a pilot palm date farm in the Abadan area, using 4 different envelopes including locally available sands, standard sand cover, and poly propylene synthetic cover (PP700 and PP 450). They indicated that by implementing a subsurface drainage system using propylene synthetic covers with a 450 index in addition to using standard sand cover, results into the desirable performance for the controlling of the water level and salinity. In addition, subsurface drainage with drains at a depth of less than 1.5 meters, using synthetic filters of PP450, have been shown to provide good performance and to produce less drainage water.

In other study conducted by Feser et al. (2010), in Minnesota ica, on a field with loamy soil, a comparison was made between two subsurface drainage systems, one with controlled drainage ,and the other with free conventional drainage systems, where the amount of drainage discharge the amount of nitrogen and phosphate was compared and measured. The study concluded that the amount of discharge and the annual volume of outflow of nitrogen and phosphate in the controlled drainage system when compared to an uncontrolled system was significantly reduced.

Materials and methods

The Khuzestan province with an area of 64000 km^2 is situated in the South west of Iran. Due to the abundance of water resources and fertile agricultural soil it is considered to be potential major agricultural zone in the country .Nevertheless, due to high water table and salinity, crops grown in the area, experiences low yields as compared to potential yields. Therefore, for improving crop yield and production of different crops grown in the area, it is vital to implement subsurface drainage projects and assess the performance of existing subsurface drainage systems and better utilization of these systems in areas prone to and encountered with salinity built up and rising water table.

During recent years, the Jihad-e-Nasr, as the implementing agency for rehabilitation of 550000 hectars of land in Khuzestan and Illam provinces, has started to construct subsurface drainage networks. For construction of drainage system the drain spacing is determined based on recommended cropping pattern and the calculated drainage coefficient. In contrary with the designed specification, the implementing agency has made some changes in the network, inter alia, the most important one is reduction of the depth of laterals installation, from average 1.5 – 1.7 to 1.3- 1.5 meters. Based on the calculations, drain spacing is inversely proportional to the square root of drainage coefficient. Nevertheless, no change was made for subsurface drain spacing during the installation of drains.

In this research for assessing the impact of reducing the subdrain depth on calculated drainage coefficient and drainage water salinity loads. Two implemented subsurface drainage network laterals in Mianab-e-shushtar and shoeibieh plains with areas of 14000 and 10000 respectively were selected. In order to measure the drainage coefficient and compare it with the calculated drainage coefficient, some parts of the above mentioned plains were selected. In addition, by measuring the water level between the sub drains, the role of drainage for reducing ground water table was evaluated. For this purpose, from Mian Ab Shushtar two farm, with subdrain spacing of 35 and 70 meters and two farms in east of Shoeibieh with subdrain spacing of 50 and 95 meters were selected. The soil texture in these lands are loamy clay or silty clay loam and were under cultivation of wheat. Drainage system in the above said farms were equipped with perforated PVC carrugated pipes and synthetic cover of PP450 type of 100mm diameter. Drains outflow was measures from early November 2015 to 4 February 2016. During this period all farms were irrigated 4 times. Measurement of drains outflow was carried out from the beginning of flow in the drain till the end of flow, on daily basis and two times (morning and afternoon) per day. The specification of the farms is given in the table1:

Table 1. Farms specifications

Plain	Area (ha)	Farm name	Lateral Spacing (m)	Lateral length(m)	Slope	Crop
Mianab	14000	Farm 1	35	400	0.001	Wheat
		Farm 2	70	325	0.001	Wheat
Shoeibieh	10000	Farm 3	50	200	0.001	Wheat
		Farm 4	95	275	0.001	Wheat

The hydraulic head between laterals in farm1 in the Mian e-Ab-e –Shushtar was measured during the irrigation period. In addition, the electrical conductivity of the ground water in farm 1 was also measured. The EC of the outflow from the subsurface lateral and the outflow of the open collectors in all farms were measured. The design of the subsurface drainage in the above mentioned farms was based on the drainage coefficient of 3 mm/day with the depth of installation at 1.5 m and a 1 m water table depth.

Results and discussion

Drainage coefficient:

Tables 2 through 5 illustrate the results of measuring the drainage coefficient in the 4 envisaged farms with different lateral spacing, carried out over 4 irrigation periods, from early November 2015 to 4 February 2016. Figures 1 to 4 indicates a decreasing trend of drainage intensity during the period after irrigation. As shown, in all four farms the amount of measured drainage coefficient is less that of the designed one.

Table 2. Measured Drainage coefficient in Farm 1 (mm/Day)

Irr.No \ Day	1	2	3	4	5	6	7	8
1	4.145	3.275	2.222	1.918	1.261	0.936	0.317	0.228
2	4.606	4.146	2.547	2.192	1.540	1.019	0.349	0.256
3	3.951	3.692	2.772	1.886	1.235	0.935	0.309	0.216
4	3.800	3.065	2.006	1.756	1.188	0.957	0.198	0.046

Table 3. Measured Drainage coefficient in Farm 2 (mm/Day)

Irr.No \ Day	1	2	3	4	5	6	7	8	9
1	3.057	2.570	2.222	1.902	1.704	1.401	0.541	0.430	0.276
2	3.735	3.272	2.926	2.374	2.099	1.837	0.932	0.417	0.108
3	3.025	2.624	2.340	2.056	1.769	1.485	0.580	0.185	0.000
4	3.781	3.192	2.466	2.028	1.614	1.130	0.790	0.253	0.059

Table 4. Measured Drainage coefficient in Farm 3 (mm/Day)

Irr.No \ Day	1	2	3	4	5	6	7	8	9
1	3.293	2.599	0.915	0.540	0.395	0.292	0.257	0.232	0.232
2	4.414	3.494	1.142	0.685	0.624	0.549	0.444	0.414	0.278
3	3.679	3.649	2.698	1.296	1.080	0.667	0.191	0.093	0.000
4	3.105	2.976	2.476	1.346	0.969	0.580	0.198	0.136	0.056

Table 5. Measured Drainage coefficient in Farm 4 (mm/Day)

Irr.No \ Day	1	2	3	4	5	6	7
1	2.822	1.796	0.599	0.525	0.429	0.380	0.321
2	4.661	4.309	3.161	2.167	1.210	0.605	0.241
3	2.741	2.797	2.395	1.951	1.278	0.673	0.136
4	3.482	3.260	2.945	1.352	0.747	0.284	0.086

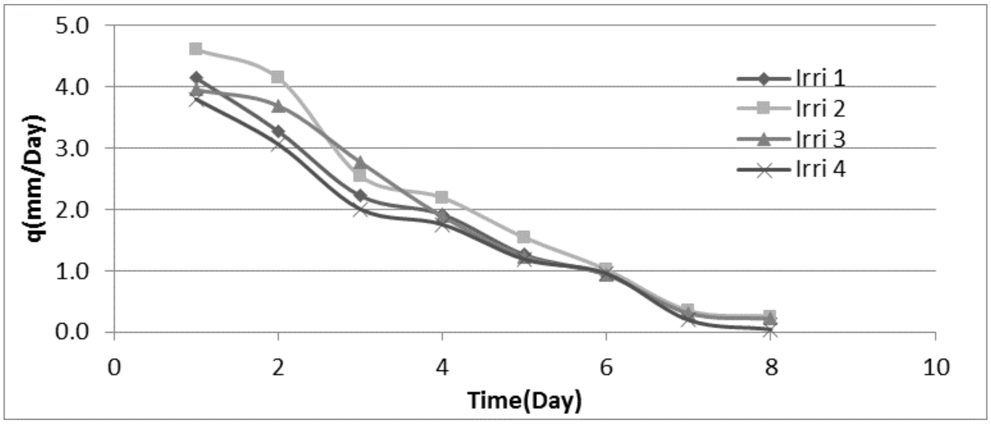


Figure1. Drainage coefficient in Farm 1

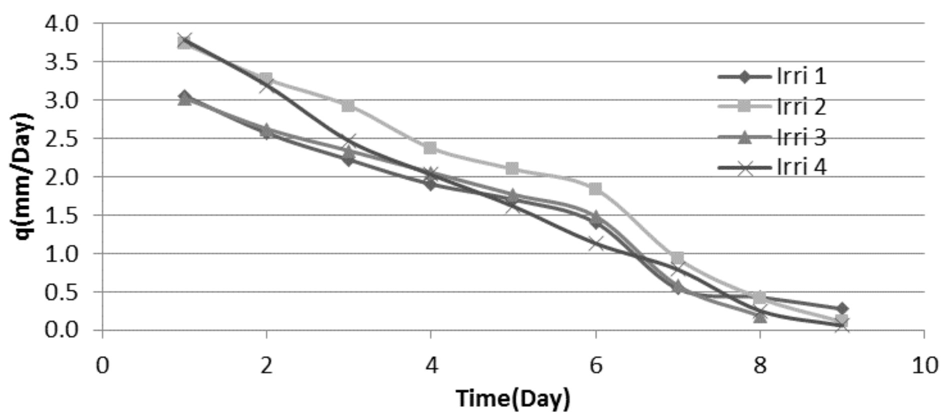


Figure2. Drainage coefficient in Farm 2

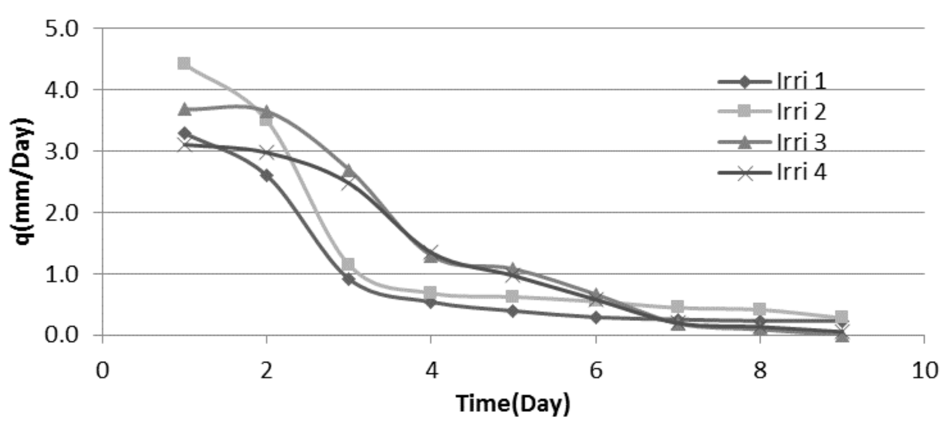


Figure3. Drainage coefficient in Farm 3

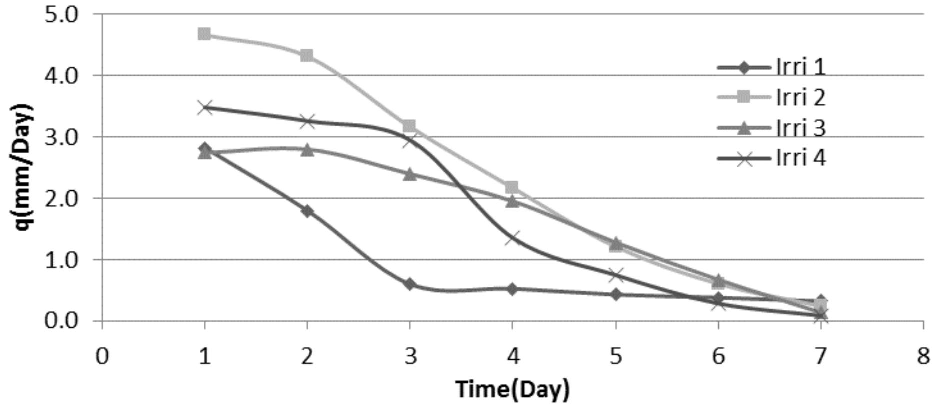


Figure4. Drainage coefficient in Farm 4

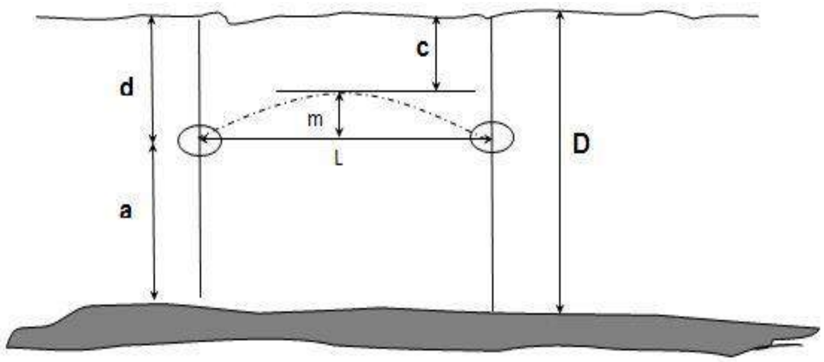
Hydraulic head

The fluctuation of water table in farm 1, in Mian Ab, during the test was recorded. Table 6 illustrates the results of the water table fluctuations. Moreover, fig.5 reveals that during the early days after irrigation, the water table remains at its highest level and gradually decreases and finally stands at depths of 89 cm from ground level.

In spite of assuming that the design for the spacing and depth of the drain are based on a "Dynamic Balance"method and the tolerance of the fluctuation of the water table is considered as being 5 cm. The results indicate that the magnitude of the observed fluctuation is 46 cm which is more than the design allowance.

Table 6. Measured Hydraulic head in Farm 1 (m)

Day / Head	1	2	3	4	5	6	7	8
m	**0.850**	**0.760**	**0.690**	**0.620**	**0.580**	**0.530**	**0.450**	**0.390**



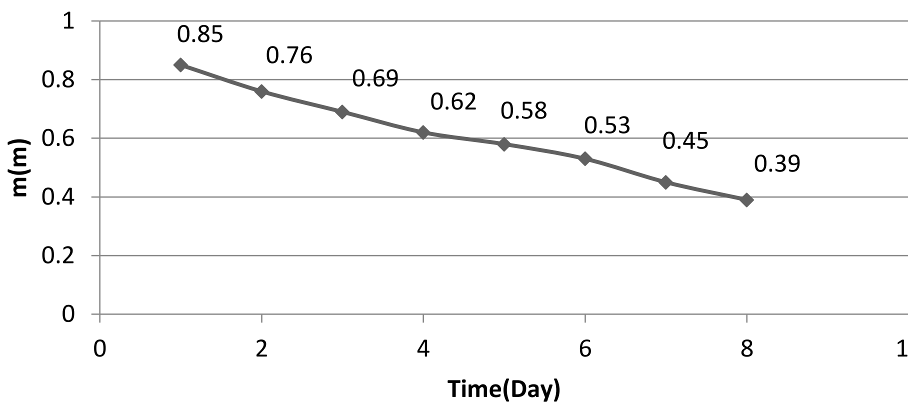


Fig.5. Fluctuation of water table in farm 1

Electrical conductivity

Tables 7 to 10 show the results of the measured EC of outflow from the laterals and open collectors in each farm and the EC of ground water in farm 1. The results reveal that the EC of the outflow in the laterals during the early days was at its highest level and gradually decreased; however, it was observed that this event occurred inversely in open collectors and ground water. In fact, observations show that in the early days the EC density from the outflow was low and after cutting off irrigation water, the EC density gradually showed an increasing trend.

Table 7. EC (ds/m) Measured in Farm 1

Day / Outlet	1	2	3	4	5	6	7	8
Lateral	**22.00**	**20.90**	**17.60**	**15.20**	**11.90**	**11.40**	**11.02**	**10.58**
Collector	**2.88**	**3.10**	**3.41**	**3.92**	**4.52**	**4.54**	**4.87**	**5.60**
Ground water	**2.90**	**3.41**	**3.92**	**4.57**	**5.32**	**6.50**	**7.90**	**8.50**

Table 8. EC (ds/m) Measured in Farm 2

Day / Outlet	1	2	3	4	5	6	7	8	9
Lateral	21.6	19.07	17.1	16	15.99	14.92	10.54	10.41	10.4
Collector	5.2	4	4.65	4.2	5.02	6.58	4.3	4.2	4.12

Table 9. EC (ds/m) Measured in Farm 3

Day / Outlet	1	2	3	4	5	6	7	8	9
Lateral	15.3	17.1	19.4	16.44	12.94	11.6	11.97	11.01	10.33
Collector	3.6	3.8	4.6	4.65	4.65	5.5	5.5	8.55	7.42

Table 10. EC (ds/m) Measured in Farm 4

Day / Outlet	1	2	3	4	5	6	7
Lateral	16.04	16.14	12	14	10	10.62	10.32
Collector	3.55	3.85	5.52	4.81	4.76	4.25	4.87

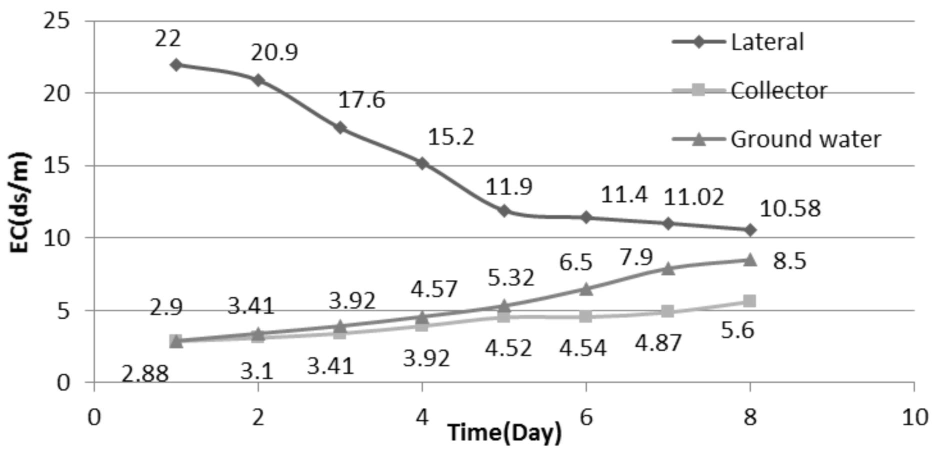


Fig.6. Electrical conductivity in farm 1

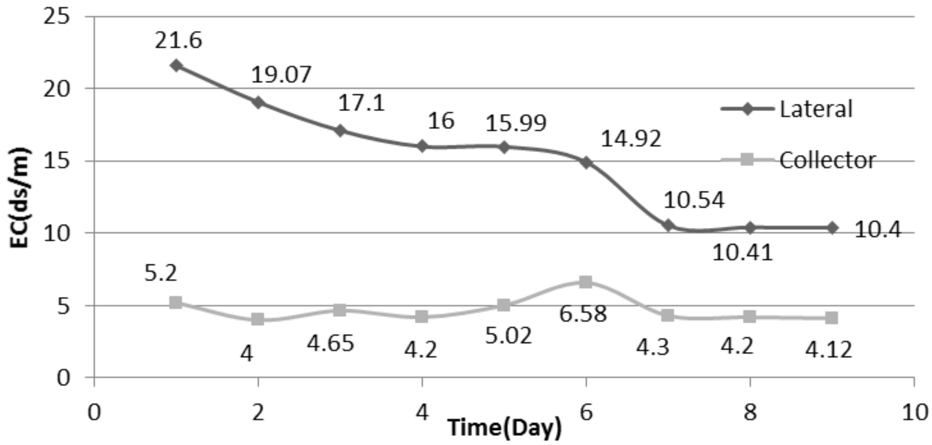


Fig.7. Electrical conductivity in farm **2**

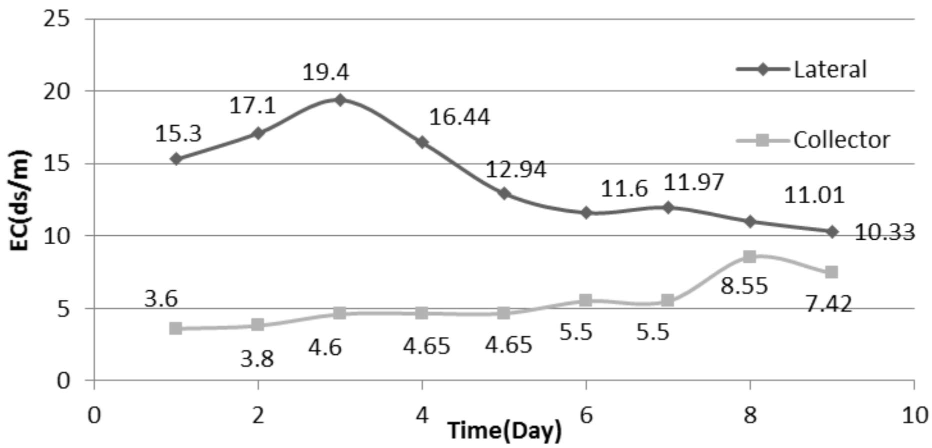


Fig.8. Electrical conductivity in farm 3

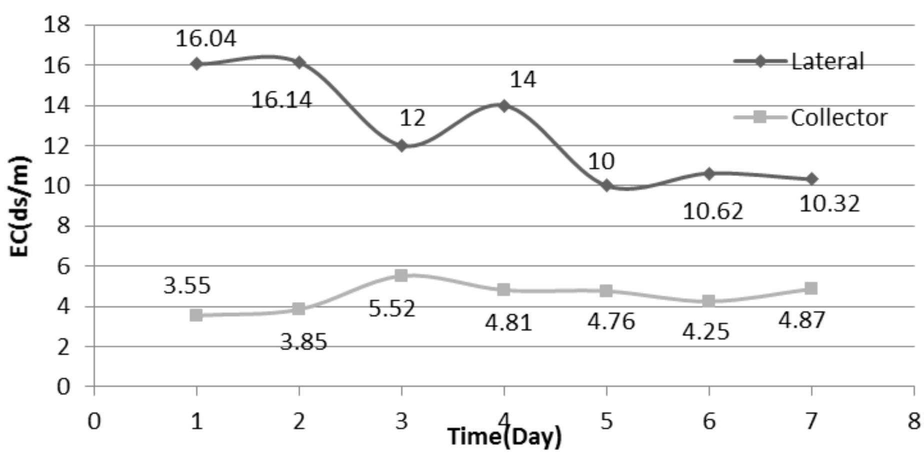


Fig.9. Electrical conductivity in farm 4

Salt outlet index (SEI)

$$\text{SEI} = \frac{inflow\ salt - outflow\ salt}{inflow\ salt} \quad (1)$$

SEI is a dimensionless index which is either negative or equal to zero, meaning that outlet salt is more than inflow salt. Considering the fact that the source of irrigation water in the area under the study is the Karunriver and the EC of the river in the vicinity of the study is less than 2 ds/m, therefore, based on the results of this research, the SEI for the area under consideration is always negative, which in itself is an indication of the suitable performance of subsurface drains in removing salt from the soil profile in the root zone.

The Glover - Dumm reaction coefficient

$$\alpha = 2.3 \left[\frac{\log(h2) - \log(h1)}{t2 - t1}\right] \quad (2)$$

Considering the data on fluctuation of the water table in farm 1, the decline of the water table is shown in fig.5

Where

α = Glover- Damm reaction coefficient

h_1 and h_2= hydraulic head at t_1 and t_2 in m

The amount of reaction coefficient for farm 1 was determined as 0.035. This is an index, indicating changes in drainage intensity due to recharging and in areas with low reaction; this coefficient varies from 0.20 to 0.30.

The results obtained from farm 1 reveals that the farm has low transmissibility and high drainage porosity.

Conclusion and Recommendation

With due regards to the reduction of the lateral depth installation, without any change to the lateral spacing , in addition to the results of the measurements carried out, the following observations were made:

- The water table rise is more than the design's permissible level
- As a result of the reduction in the depth of installation, the drainage coefficient is reduced

- The designed water table depth was considered as being 1m, while in practice it remained at 89 cm
- The electrical conductivity of laterals showed a decreasing trend over time, but the electrical conductivity of the collector outlet and ground water experienced a decreasing trend
- The reduction of the depth of drain installation, resulted into a reduced drainage coefficient which consequently mitigated the load of salt content and pollutants
- In terms of implimentation, installing laterals at lower depths is more convenient
- In the study, crop yield was not taken into consideration, it is recommended that in future studies crop yield measurement be considered and both cases (ie., different depths of lateral installation) be compared.

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EGYPTIAN EXPERIENCE IN AGRICULTURAL DRAINAGE IN MORE THAN 40 YEARS AND FUTURE NEEDS

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Abstract

In arid countries such as Egypt, irrigation and drainage are essential factors for the sustainability of agricultural production. The need for drainage of agricultural lands in the Nile Valley and the Egyptian Delta was realized once the conversion to the perennial cropping system occured.

Among developing countries, Egypt is considered as a country with subsurface drainage systems extending over large areas th. At the time strategic vision and governmental planning were behind the decision to launch a program to develop drainage infrastructures to cover all the irrigated lands (then about 6 million acres).

The implementation of a phased program starting in 1970 and continuing to cover more than 5.8 million acres up to the present time has been carried out consecutively. The implementation of such a large scale program imposed huge financial, institutional and technical challenges. It also involved significant operational challenges including the necessary implementation capacity and the need to complete the construction in cropped fields without interruption the growing season, mainly for social and economical reasons. Experience has shown that drainage has many effects and multiple impacts that go beyond the sole objective of agricultural productivity.

More than four decades have passed since the government of Egypt initiated its present program to develop effective drainage systems to cover almost all the agricultural land. Nowadays Egypt is facing great challenges such as water shortage, drought, water quality deterioration, climate change and its unexpected impacts, all of which are threatening the sustainability of the irrigated crops. This paper identifies and synthesizes the Egyptian experience in the field of agricultural drainage and the future need to cope with global challenges.

KEY WORDS: Subsurface drainage, Drainage materials, Controlled drainage, Drainage design criteria, Drainage technology, Future Vision and Developments in Drainage

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Introduction

The total area of Egypt is 1.001,450 km^2, the majority of which is desert lands representing 96%. The present population of Egypt is strongly concentrated in the Nile Valley and the Delta. 97% of the population lives on 4% of land of Egypt. Egypt's climate is hot, dry, desert and is getting warmer. During the winter season (December– February), Lower Egypt's climate is mild with some rain, primarily over the coastal areas, while Upper Egypt's climate is practically rainless with warm sunny days and cool nights. During the summer season (June-August), the climate is hot and dry all over Egypt.

The growing population of Egypt and related industrial and agricultural activities has increased the demand for water and land to a level that reaches the limits of the available supply. The population of Egypt has been growing in the last 50 years from 19 million in year 1947 to about 91 million in the year 2016. The annual increase is about 1.8 million and it is expected to be about 105 million by the year 2025.

Food security of a fast growing population in Egypt required measures to intensify crop production within the already irrigated area. The construction of the High Aswan Dam (HAD) allowed year round irrigation in the Nile Delta and Valley. This put the limited fertile land at risk of water logging and salinity. To relieve the pressure on the Nile Valley and Delta the government has embarked on an ambitious programme to increase the inhabited area by means of horizontal and vertical expansion projects in agriculture and the creation of new industrial areas and cities in the desert. All these developments require water and reclamation of both old and new lands

In Egypt there is a long history of irrigation. During last decades there has been a development in irrigation in conjunction with the construction of reservoirs. Aside from huge benefits of the irrigation projects they have also resulted in water logging and salinization. Therefore drainage systems are required at a large scale to enable irrigated agriculture on a sustainable basis.

Provision of effective drainage systems was an obvious mitigation measure included in the early planning of the HAD construction in the early sixties. A strategic vision and political decision were behind the decision to launch a program that covers all the irrigated lands (about 6 million acres at that time) with drainage infrastructure. The implementation of a phased program started in 1970 and continued to cover more than 5 million acres at present. Implementation of such large scale program imposed huge financial, institutional and technical challenges. It also involved significant operational challenges including the necessary implementation capacity and the need to complete the construction in cropped fields without interruption the growing season mainly for social and economic reasons.

Drainage benefits went beyond the direct objective of increasing agricultural productivity to improving health conditions, protecting built-up structure and archeological sights against rising water tables, and improving sanitation conditions in the rural areas. The impact of the drainage program is felt at local, regional, and national levels. Experience has shown that drainage has many effects and multiple impacts that go beyond the sole objective of agricultural productivity. The effects and impacts extend beyond the borders of the project to the whole drainage basin. Many stakeholders other than farmers share the benefits and may pay the cost of drainage inventions.

This paper identifies and synthesizes the Egyptian experience in the field of agricultural drainage and future needs to cope with great challenges

Development of Land Drainage in Egypt

Planning of drainage system

Planning of drainage projects is done according to a 5-years planning cycle. For each 5-year plan a number of main catchment areas of drainage pumping stations are earmarked for subsurface drainage implementation. A prerequisite for implementation is that the drainage pumping station is operational and that the network of main open drains is upgraded to cope with the increased drainage discharge from the drainage project areas.

A sub-surface drainage system is required, when the following drainage conditions exist:

- Water table depth is less than 1 meter below ground level in more than 10% of the surveyed area;
- Soil salinity of the saturation extract, expressed in ECe is more than 4 dS/m (mmhos/cm) in more than 10% of the surveyed area;
- A decline in crop yield of more than 20% as a result of poor drainage is reported in the considered area.

Pre-drainage investigations are made in sub-catchment areas of about 5000 to 7000 acres (2000 – 2800 ha) each and the need for drainage installation is assessed according to the above mentioned criteria. After the areas are selected for drainage implementation, the detailed design is made and tender documents are prepared.

The actual construction is done by contractors, who are supervised by Egyptian Pulic Authority for Drainage Projects (EPADP) staff of one of the five Regional Directorates of Drainage Projects. The total target of the surface drainage is 7.2 million acres, 4.9 million acres in the Nile Delta and 2.3 million acres in Upper Egypt.

Automation of the design of drainage projects

Automation of the design of drainage system becomes an important process for many reasons, mainly to reduce the manual computations and errors related to the design of the drainage system. Steps were taken to improve the quality of maps for the drainage design. Also the storage and retrieval of data were improved and the further improvement of quality of maps, by using digital basic maps and up grading drawing technique.

Introduction of (GIS)

The introduction of GIS causes a number of changes in the way the automation is organized. The main task of a GIS is the production of maps, delineating the design of a drainage network, which includes providing assistance in the design and computation of the drainage design parameters. The software was developed for drainage design into what is called "Drain GIS". The set up of the main menu of Drain-GIS follows the step of the manual design process. The Drain GIS programme is the Core program of the design activities. It combine the computation of the longitudinal profiles with the drawings of the layout of a drainage system in an Arcinfo-GIS .

Rehabilitation of subsurface drainage systems

EPADP started to develop criteria to assess the need and priority for rehabilitation of drainage systems. Initially, EPADP would renew those systems, whose economic life time was exceeded more than 30 years and which were performing very poorly. Farmer complaints and difficulties of maintenance are important factors in deciding on the need for renewal.

Subsurface Drainage construction

The implementation of subsurface drainage consists of installation of covered collector pipes and the installation of buried lateral drains of corrugated PVC pipes with envelopes. The total area to be provided with subsurface drainage is 7.2 million acres. Some 4.6 million acres of this area is in the Nile Delta and the rest 1.8 million acres in Upper Egypt and the total executed area up till 31/12/2016 is 5.9 million acres**.**

Materials and machines used in drainage construction

At the beginning of the 1970's, important development have taken place in the use of : drainage materials, drain envelopes, and installation techniques (grade control equipment, drainage machinery).

Drain materials

Lateral pipes were first made of 10-cm diameter clay pipes (30-cm long), replaced in 1963 by concrete pipes (10-cm and 50-cm long), and in 1979 by plastic PVC pipes (ID 72 mm) were introduced and took over. PE lateral pipes (ID 75 mm) were later introduced. Laying the plastic corrugated pipe (rolls) improved both speed of installation and quality control. PE/PVC collectors were introduced in 1985. Since 1998 all new collector systems are to be constructed with PVC or HPPE pipes, which is suitable for installation in the unstable soils (sandy with upward seepage) in the reclaimed areas and on the fringes of the old lands. With the shift from concrete to plastic pipes, the connecting pieces between laterals and collectors also changed.

Connection between lateral and collector drain

The type of connections has changed with the introduction of the corrugated PVC/PE pipes. An improved connection was introduced in 1980's with the use of a plastic T-joint (figure 1).

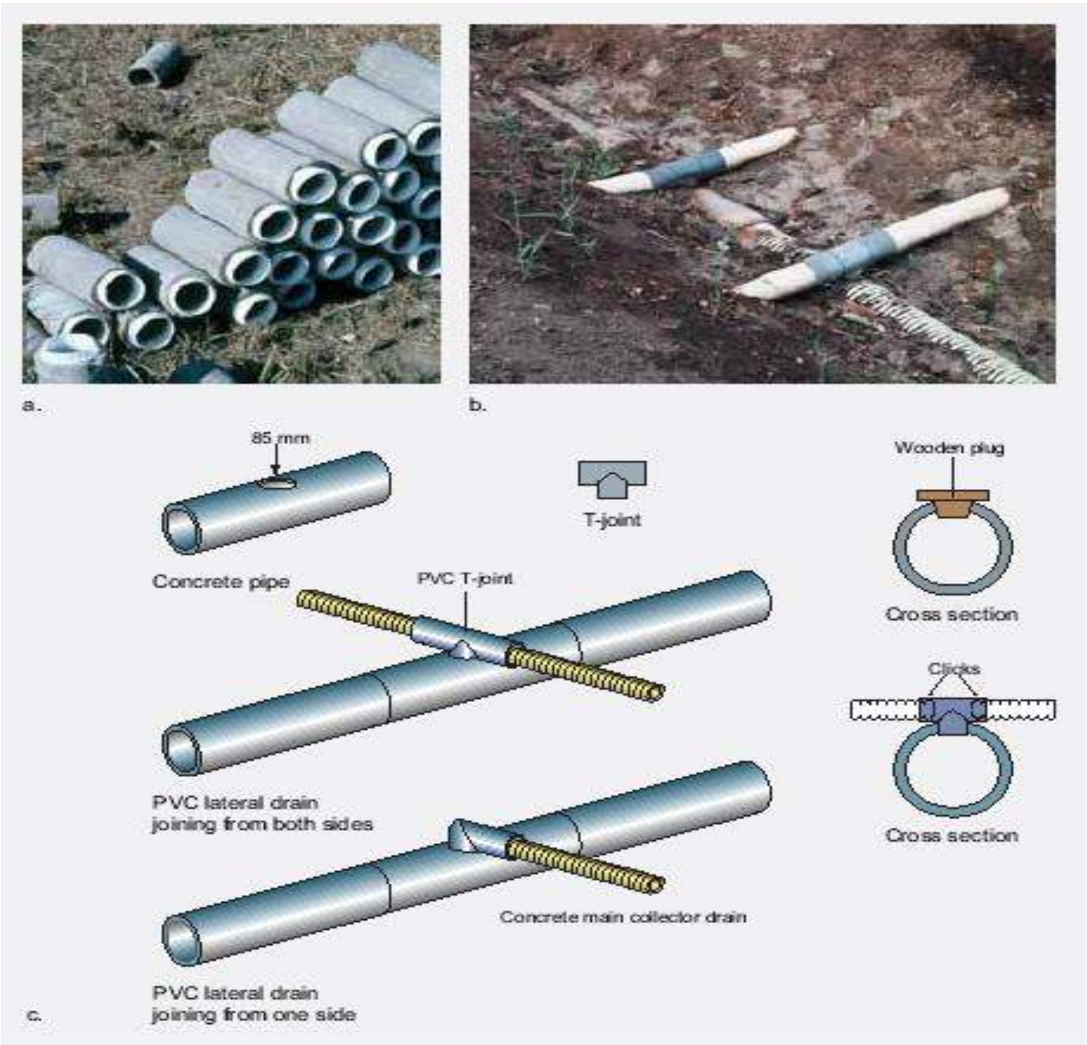

Figure 1. Connections between (a) field drains and (b) collector drains

Manholes

Manholes are constructed along the collector lines at a maximum distance of 180m so far, only manholes of plain concrete with diameter of 75 to 100cm have been installed on large scale.

Manholes were originally cast in situ; later, prefabricated elements were used. Plastic manholes are also being experimented with (much lighter in weight and quicker installation but expensive).

Installation techniques

Since the late seventies, all drainage construction is done by lateral-laying machines and collector laying machines. Hydraulic excavators are used for the installation of very large diameter collector pipes. Since 1997, a trenchless lateral laying machine had been engaged in construction of laterals in silty soils and quick Sand area soils in the North-west Delta. Before 1988, the leveling and grade control was done manually, using standard survey instruments and simple sights. The use of laser-guided grade control was 1992 mandatory equipment on every lateral and collector laying machines. Different drainage machines(figures 2-a,b)

Figure 2-a. Lateral machine

Figure 2-b. Laser with Lateral machine

Drain Envelopes

Graded gravel has been widely used to protect the laterals against the intrusion of soil particles that can clog pipes laid in soils with a clay content of less than 30 percent. Because gravel is costly to apply, there has been a shift to using pre-wrapped synthetic envelopes for the laterals. The use of pre-wrapped synthetic drain envelopes was introduced successfully in 1990 on a pilot scale. In 2000, it was decided to use only synthetic envelopes, where needed. Drain envelopes are mainly required in silty soils, that have less than 30% day fraction. Currently the pre-wrapped synthetic envelopes are applied in large scale implementation and are replacing the gravel envelopes in new contracts (figure 3, 4).

Figure 3. Envelopes can be made of wrapped polypropylene fibres (a, f & g), polystyrene granules (b) and coconut fibres (c), non-woven nylon (d) and woven typar (e)

Figure 4. Pre-wrapping drain pipes manually (a) and mechanically (b

Drainage Machinery

Mechanized installation started in the 1960s with three imported lateral laying machines. Large-scale use started in the 1970s, and many more drainage machines have since been imported. These were of the trencher type with a digging chain to dig a trench in which the pipe was laid in one operation and subsequently backfilled. A modification was made because of the sticky clay soil and water tanks were installed on the machine. Since 1976, collector-laying machines (deeper installation depths and bigger pipes) were introduced (figure 5). The trenching type of installation causes considerable crop damage. At the end of the 1990s, trenchless installation was introduced for lateral laying with a V-plough type and may well continue to be used. Grade control of the laid pipes was greatly improved with the introduction of laser-guided grade control equipment in 1990.

Criteria for Water Table Control in Egypt

A typical criterion to satisfy objectives of water table control is indicated in figure (6). The criteria for leaching H – 1.0m and q=1-2mm/day are satisfactory for groundwater drainage projects in the Semi-arid areas of Egypt. The criteria for capillary salinization control also apply to the fairly typical case where there is a small seepage coming from canal leakage and the soils have fine sandy or silty subsoil's with high capillary capacity.

For aeration drainage the criteria H=0.80 and q=4mm are fairly typical. Suitable drain depths have also been indicated for all cases where there are no objections. The drain depth (W) has been taken equal to the least cost depth, generally to be in the order of 1.40m. For aeration drainage, W=1.25m

(see table 1)

Table 1 Water Table depth criteria

Objectives	Water table depth H(m)	Design discharge q(m/d)	Drain depth W(m)	Differential water table h(m)
Leaching	1.0	0.002	1.40	0.40
Salinity Control	1.25	0.005	1.40	0.15
Aeration	0.80	0.004	1.25	0.45

- Modification of the required water table depth should involve rate of evapotranspiration during the season. The water table depth will be affected and will result in larger drain design spacing.

Figure 5. Collector machine

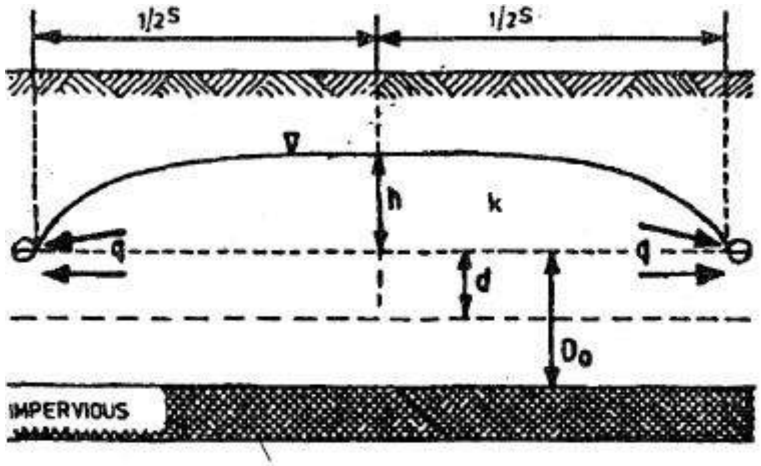

Figure 6. Water table depth criteria

Current Drainage Practices

A horizontal composite subsurface drainage system is used. The lateral drain spacing currently varies from 20m – 80m and is dependent on specific drainage design criteria and soil hydraulic properties. Lateral depth is approximately 1.35m. Average lateral slope is between 0.1 and 0.2%, with a length of 200m. The drainage coefficient for calculating drain spacing is 1mm/day for a dewatering zone of 1.0m. Pipe capacity is calculated according to a drainage coefficient of 3mm/day in non-rice areas, and 4 mm/day in rice areas.

There are 7 pipe factories producing subsurface drain pipes, all owned and controlled by the Egyptian Public Authority for Drainage Projects (EPADP). Lateral drain pipes have a diameter of 80mm, and are made of PVC, although HDPE is now being produced at the Aga Pipe plant. Collector drain pipes with a diameter of 15 to 40 cm were until 1997 generally constructed of plain concrete pipes, but since 1998 the Tanta pipe plant produces sufficient PVC collector pipes to supply all the ongoing drainage contracts. Moreover, the Aga pipe plant produces HDPE collector pipes as well. Reinforced concrete pipes are used when the collector diameter exceeds 40 cm. Collectors can be up to 2km in length. It should be noted that EPADP is both a producer and user of drainage pipes. In areas of sand and silt soils, synthetic, pre-wrapped envelopes are installed with the pipes during installation.

Rehabilitation of the System

The life time of drainage systems have been estimated between 30 and 40 years. Since drainage started in Egypt more than 30 years ago, the existing drainage systems are gradually due for rehabilitation. The lifetime of the systems depend on the quality of the used material, quality of the construction, design factors and external factors, such as vandalism, penetration of plant root in pipes, rodents, etc.

Normally a drainage system has to be renewed when:

- Groundwater table is rising to unacceptable levels;
- Soil salinity is increasing;
- Costs to maintain the hydraulic performance of the system become unacceptably high.

Decisions to rehabilitate a drainage system are based on actual information about the lifetime and the performance of the system. Regions in which pipe drains installed before 1970, need to be assessed on its drainage performance. It is expected that the pipes and associated material have deteriorated due to age and need to be renewed. Renewal will be done according to the current drainage criteria.

Changes in cropping patterns and rotations might also impose new irrigation and drainage regimes. New information on drainage coefficients, pipe, and envelope materials and installation equipment and techniques should be incorporated in system design.

Technology and Research Development

Egypt is the first country outside Europe and North America to implement large-scale agricultural drainage projects. It was therefore necessary at all times to seek and use the latest technical and technological development in implementing its drainage projects. Research over the past sixty years was behind the successful progress of drainage projects, the development of design criteria, and design concepts and specifications for machinery and materials.

The use of heavy drainage machinery, the Egyptian experience has played an important role in more powerful machines being produced. It is true that Egypt's drainage projects stand behind many of the technological developments made by the international drainage industry. The benefits have not only been limited to drainage in Egypt, but have extended to many other parties around the globe. The local production of drainage pipes and envelope materials has developed and increased to meet the project needs, and can also cover the requirements of other countries in the region.

Behind Research development support is the Drainage Research Institute (DRI) which was established on January, 1975. The institute is considered the supporting arm to the Drainage Authority for implementing projects i.e. (EPADP). As a result of research improvement on drainage survey and design has been taken place. Introduction of computerizing the drainage system started since 1987, on wards. Research on drain performance, varying depths and spacings revealed that change in the conventional design criteria. Therefore a range of drain spacing adopted by (EPADP) in its projects has been increased from 40-60m to 20,30,40,50,60,70,80m.

After with the research conducted by DRI, (EPADP) stopped applying gravel envelopes around the drain pipes in 1978 in heavy clay soils with a clay content of 40%. After further research, the clay content limit was decreased to 30%, in 1985. This resulted in cost saving during a research for almost 10 years. The application of a modified layout for drainage system in rice growing areas was included. The study revealed that the restriction of the out flow from sub collector unit with rice would save about 2.5m/day. Saving of water would be approximately 10 million m3 per day per/million acres of rice areas.

Farmer's Contribution to cost of drainage

Cost of drainage (main infrastructure and subsurface drains) is borne by the Government. However, farmers repay the cost of subsurface drainage system in 20 years interest free annual installments, which only starts 3 years after installation.

Economic benefits from drainage

Benefits of improved drainage have a direct positive affect on the income of farmers. The project's key benefits will be: (a) Increased crop productivity and production; (b) Increased land area available for agriculture; and (c) Increased household incomes for the farmers. Crop productivity is expected to increase by between 17-21% for a number of key crops. Financial analysis done during project preparation showed that for a typical one acres farm model, the annual net farm income of the traditional farm increased by US$200/ha to US$375/ha, depending on the initial level of salinity before providing subsurface drainage. With total construction costs of US$1500/ha and maintenance costs of US$20/ha/year, the payback period is only four years.

Re-use of drainage water (non-conventional water resources)

The main and almost exclusive source of water in Egypt is the River Nile. The available annual water available from High Aswan Dam is 55.5 billion m3. Agriculture accounts for the largest share of water use in Egypt. The total which amounts to 84% of available water resources, this share corresponds to about 50 billion m3 per year. The other uses of water cover industrial, municipal and navigational demands. Current estimates indicated the total annual water use is expected to increase in the year 2025 to about 75.3 billion m3.

The gap between the available water resources by the River Nile and the different demands was partly filled by abstraction of groundwater (2.6 billion m3/year). Drainage water emerged as an important source to provide the rest of water needed to meet the demands on short term basis. The amount of water that return back to drains from irrigated lands is relatively very high. The agricultural drainage water of the southern part of Egypt returns directly to the Nile River Nile where it is mixed with the Nile fresh water. The drainage water in the Delta region is emptied to the Sea and Northern lakes via drainage pump stations. The amount of drainage water pumped to the Sea was estimated as average to be 12.41 b.c.m and the total amount of drainage water of official re-use was 7 b.c.m per year .

Controlled Drainage

Controlled Drainage for rice areas

The concept of controlled drainage for the purpose of controlling the water table depths in rice areas is another way to save water.

- A temporary closure of the subsurface drains in rice fields was practiced, with the following advantages saving of water.
- Saving of other crops from damaging effects of a blocked system.
- The modified layout of the drainage system was introduced, as shown in Figure (7)

The saving from this system stem from the fact that they operate without allowing excessive water losses during the rice season. The areas provided with this system required approximately 35% less irrigation water compared to the area with a conventional layout.

Irrigation improvement water use efficiency

Controlled drainage has the potential to improve water use efficiency, maintain crop yields in periods of water stress and ensure that land drainage systems work to the maximum benefit of farmers.

A new perspective for managing the drainage system as a key part of integrated water resources have been developed to improve irrigation water use efficiency. The management concepts were:

- To change the effective drain spacing between drains.
- To change drain depth from soil surface using water table control device (figure 8).

These management options were applied and compared with the conventional drainage system. The result indicated that it is possible to improve the existing irrigation water use efficiency by 15-20% without any yield reduction.

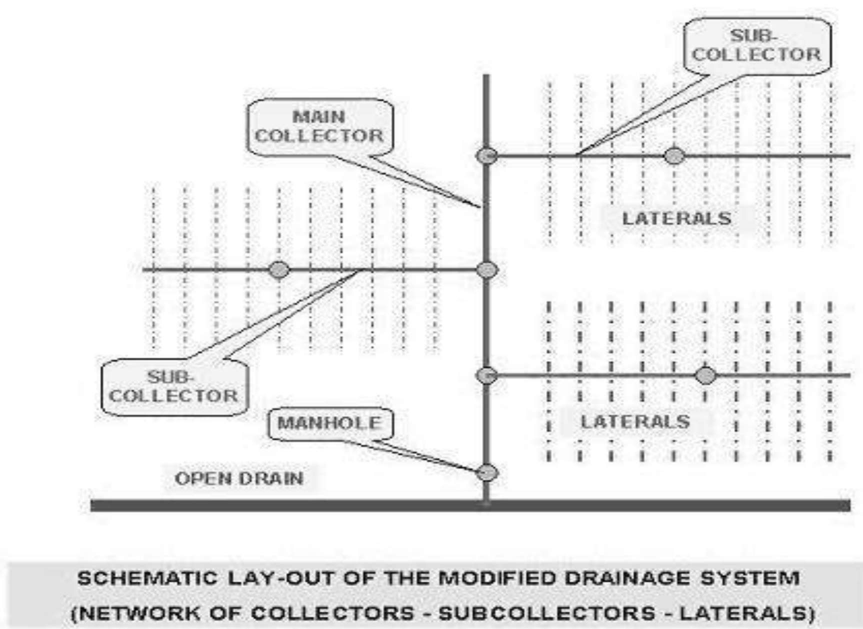

Figure 7. Modified drainage system

Figure 8. Water table control device

Challenges for future drainage system

- Gaps in capacity building in the field of irrigation and drainage
- Lack of understanding the multi-functions of Agricultural drainage
- Needs for innovative technology
- Climate change effects
- Water scarcity
- High cost of agricultural drainage system
- Lack of a sustainable maintenance for the drainage systems
- Water quality degradation

Future Vision & Developments in Drainage

Improved Information and Installation technology

Application of new technology will lead to a longer lifetime of drainage networks and less maintenance requirements. Throughout the last 30 years, Egypt has acquired the latest drainage technology. However, further developments of the (MIS) management information system that were defined in the basic system design have to be made. The production of plastic lateral and collector pipes with the latest pipe extruder plants guarantee high quality pipes larger diameter collector pipes can be used. The application of synthetic Envelope material, pre-wrapped around the lateral pipes minimizes the incidence of sedimentation. The introduction of pre-fab modules for manholes and the application of plastic connectors between manholes and collector pipes are still an area for improvement.

Drainage of Oasis and closed basins

The New Valley is a large depression located between the Nile Valley and Libya. In this depression there are five main Oasis which are Paris, Kharaga, Dakhla, Farafra and Bahariya. The total area of the New Valley is 458,000 km^2. Generally drainage problems are created from excess irrigation water discharged from free flowing springs and uncontrolled wells. This causes increases in subsurface water level and soil salinity of top soil layers. Disposal of drainage water in the Oasis depends mainly on the topographic features of the depressions. This poses and creates serious drainage problems. The need to develop unconventional drainage systems in these areas is highly important.

Drainage of the New Lands

The areas of the "New Lands" are rather different than the flat and homogeneous soils in the Old Lands. The main characteristics of the new lands differ from the old Delta lands. Facing these differences with all its complications, there is a needs to develop a new and flexible approach to pre-design investigations, inter-disciplinary planning, design and implementation that ensures the efficient and effective performance of the water management infrastructure. Moreover, it will be essential to ensure that any intervention is environmentally sound and sustainable. Therefore, any development plan should commence with a comprehensive Environmental Impact Assessment.

Future Research Requirements

Development of research needs in subsurface drainage would cover mainly the future vision and drainage developments issues which can be summarized as :

- A new design criteria for agricultural drainage under drought and water scarcity conditions must be considered and its effect on water quality.
- Improvement in information, installation technology, and operation, management and maintenance.
- Management of subsurface drainage systems in the arid and semi-arid areas as it is developed in humid areas
- Farmer's involvement in drainage planning and operation, maintenance and management of drainage system.
- In already drained lands, evaluation of the performance of existing drainage systems will also be needed in order to determine the need for rehabilitation.
- Field research is necessary to examine modern water management for agricultural production focuses on the management and enhancement of existing drainage systems to benefit water quality and the profitability of agriculture
- Protection of drainage water quality for the re-use of irrigation.
- Disposal of drainage water in the oasis and closed basins.
- Environmental and ecological impacts of drainage system.
- Application of new technology for Bio-drainage and dry drainage
- Impact of climate change on drainage planning, design, construction, operation and management.

Conclusions and recommendations

- In spite of the great achievements and benefits of agricultural drainage in Egypt, there are many challenges which threat the sustainability of agricultural drainage and drainage has to break out of its isolation caused by narrow agricultural perspectives and make itself instrumental in meeting many different objectives and interests.
- A new role for private and governments sector is needed. The private sector can offer a wide range of products and services which can promote agriculture production and growth.
- Farmers association and participations is a key elements for future development and management of drainage system
- GIS can be a very useful and helpful decision making tool at the pre-investigation stage for technical and financial analysis with limited funds.
- Integrated management of irrigation and drainage would mean:
  - Acknowledging the multiple objectives served by the management of shallow water tables and the disposal of excess surface water, and the need to maintain the resources system over time (resources sustainability)
  - Improving the scientific knowledge base through a major move from operation and maintenance of drainage system toward the fields of management, sustainability, multifunctionality, and stakeholder representation in governance and decision making.
- New approaches for water table control must be developed. The use of modified land drainage systems or dual-line irrigation/drainage systems may also afford the recycling of nutrients and chemicals that would otherwise leach to the water table, providing another tool to reduce chemical / nutrient leaching.
- There are usually several water management alternatives that can be used to satisfy agricultural objectives. The challenge is to select those methods that will minimize negative environmental impacts.

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