微量地下水涵養に伴う浅層地下水位の変動

Laboratory investigations of short-term fluctuations of shallow groundwater in response to recharge events

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1. INTRODUCTION

Shallow water tables are a common feature of many irrigation areas due to high recharge rates and, frequently, reduced drainage rates [1]. Their management requires a precise estimation of their recharge rate. Such estimation is usually based on the specific yield of the soil material. Nevertheless, many researchers quoted that groundwater recharge calculations based on the specific yield are, to some extent, erroneous under shallow water table environments [2]. The reason is that a disproportionate water level rise is observed in response to water input. Kayane and Kaihotsu (1988) [3] noted that the rise in the water table in response to rainfall or irrigation is frequently much greater than would be predicted on the basis of water balance calculations using fillable porosity and net groundwater recharge. This phenomenon has been reported to occur in a variety of environments. For instance, Drabsh et al. (1999) [4] mentioned its occurrence in intertidal sand flat, Tyler et al. (2006) [5] reviewed numerous studies reporting the occurrence of this phenomenon in playas and sabkha systems. In the present study, laboratory simulations of shallow water table response to water input have been conducted in order to investigate the impact of different factors affecting shallow groundwater level response.

2. MATERIALS AND METHODS

Two Japanese soils were used in the present study: Toyoura sand and Chiba light clay, from Yamaguchi and Chiba prefectures, respectively. Toyoura sand has a particle density of 2.65 g/cm^3, a bulk density of 1.60 g/cm^3, a porosity of 40 % and a saturated hydraulic conductivity of 1.4 10^{-2} cm/s. Chiba soil classified as light clay (ISSS classification) has a particle density of 2.68 g/cm^3, a bulk density of 0.9 g/cm^3, a porosity of 66 % and a saturated hydraulic conductivity of 5.15 10^{-4} cm/s. These two soil types were packed homogenously into two plastic columns with 50 cm length and 7.5 cm inner diameter. The Toyoura sand column was equipped with 17 plastic porous cups along the profile. Nine of these cups were connected through water filled flexible tubing to a water manometer. The rest eight cups, numbered T1 through T8, were connected to a series of pressure transducers with a 0 to 100 kPa range. The transducers were connected to a Data logger (CR10X, Campbell Scientific Inc.). The Chiba soil column was equipped with 11 ceramic porous cups connected to 11 pressure transducers which have been calibrated and connected to a Data logger. The water table level inside the column was monitored by means of a U-Tube water manometer. Two experiments (Exp 1 and Exp 2) have been conducted using Toyoura sand and Chiba clay, respectively. For both experiments, initially, the soil in the column was slowly saturated from the bottom using deaired water. After water was ponded on the entire upper surface, the water table was lowered to the desired position. After waiting for hydraulic equilibrium to be established, water addition was initiated. The hydraulic head and water table level were then monitored. The whole experiment was conducted in a constant temperature room (20^o C).

3. RESULTS AND DISCUSSION

3.1. Experimental observations

During the Exp 1, the initial water table position below soil surface was at 20 cm. After waiting for equilibrium, 1 mm rainfall was applied to the soil surface. Following this application, a very rapid rise of water inside all manometers' tubes has occurred. The water table level indicator showed a rapid water table rise reaching 17.2 cm below soil surface within approximately 40 seconds. The WT level then continue rising until a maximum height of about 16.7 cm below surface after which it started falling to a level of 17.2 cm at which the WT level remained stable. Starting from this new water table level and after waiting for equilibrium we moved to the second experimental Run by applying 2 mm rainfall. Following this addition the water table exhibited the same behavior as in the first experimental Run but with higher velocity. In fact, the water table level reached a depth of 11 cm within 30 seconds. The

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water table level continued rising to reach a maximum height of 12 cm and finished at 11.6 cm depth. The third experimental run in which 5 mm rainfall was added brought about a water table rise reaching approximately 1 cm above soil surface.
Table 1 summarizes the results of the laboratory simulation of rapid water table responses to rainfall events during the Exp 1. When the water table was at distances of 20 and 17.2 cm from the surface the addition of 1 mm and 2 mm of water resulted in immediate large responses of magnitude 140 mm for each case. At greater depths of 40 and 37.1 cm the addition of 1 mm and 2 mm resulted in water table responses of magnitudes 145 mm and 130 mm respectively.

Table 1. Laboratory simulation of SWT responses to variable rainfall events during the Exp 1.

Run No	Simulated rain (mm)	WT level (cm)	Response magnitude*
1	1	20	140
2	2	17.2	140
3	5	11.6	106
4	1	40	145
5	2	37.1	130
6	5	31.9	113
7	10	19.5	38

* Response magnitude = (water table rise/rain)

In the case of Chiba light clay experiment (Exp 2), water table was initially at 23.2 cm below surface. After the application of 0.5 mm rainfall, WT rose gradually to reach a level of 20.3 cm below surface. Starting from this level, the application of 1 mm rainfall brought about a WT rise to 17.3 cm depth. Then, the WT, started falling to a depth of 19.6 cm and remained stable at this level. The maximum WT rise was observed after the application of 2 mm rainfall. In fact, starting from a depth of 18.7 cm, WT rose almost to 12 cm below soil surface. After approximately 6 hours during which WT level remained relatively stable, there was a gradual decline to a depth of 13.4 cm.

3.2. Pressure head variations

Pressure head values exhibited instantaneous fluctuations of decimeters due to the addition of millimeters of water (Fig. 1). For instance, in the case of Toyoura sand, the response of tensiometer T1 located 3 cm below surface, was rapid, with change in head of 17 cm occurring within 10s after the addition of 2 mm water. In the case of Chiba light clay the tensiometer T4 located 2 cm below soil surface indicates a change in head of 15 cm occurring within 1 min following 2 mm water supply.

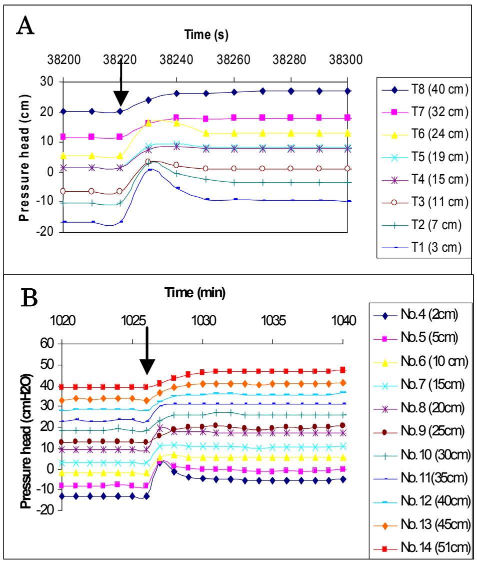

Fig. 1. Temporal changes in pressure head following 2 mm water. A: Toyoura sand; B: Chiba light clay.

4. CONCLUSION

Laboratory simulations of shallow groundwater fluctuations inside sandy (Toyoura sand) and clayey (Chiba light clay) soils, in response to recharge events revealed a rapid and large water table rise following water application. The magnitude and the velocity of the response depend on the water table depth, the soil type as well as the amount of added water. Hence, in the case of Toyoura sand, water table rose by hundred times the depth of added water while in the case of Chiba LiC, the water table rise was relatively less pronounced and slower. These observations were supported by monitoring temporal changes in pressure head values which exhibited immediate fluctuations of decimeters due to the addition of millimeters of water.

5. REFERENCES

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