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Groundwater Quality in Sand Dune Area of Northwest Honshu Island in Japan

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Abstract: This study was conducted to evaluate the groundwater quality in sand dune area of northwest Honshu island, Japan. Three observation wells were installed with three plastic tubes to collect ground water of 2.0, 2.5 and 3.0 m depth. Groundwater samples were analyzed for EC, pH, DO, concentration of Fe, K and NO_3-N during the period of April, 2004 to March, 2005. Groundwater level and soil environment from 0.1 m through 3.0 m was also evaluated. The groundwater level of the study field was observed within a range of 114.43 to 169.33 cm below ground surface. The results showed that EC, pH, DO and K concentration in groundwater were decreased with increasing depth whereas the opposite trend was observed for Fe. The groundwater of the study area was found not to be suitable for irrigation since concentration of Fe was more than 5 mg L^{-1}. Average concentrations of NO_3-N in groundwater of the study area were 0.026 mg L^{-1}. Since concentration of NO_3-N was very low in groundwater, there would not be any threat to human health and environment.

Key words: Groundwater quality, iron, nitrate, sand dune area

INTRODUCTION

Groundwater is the major source of drinking water for human and animal and important source of water for the agricultural and the industrial sector. The natural state of groundwater is generally of excellent quality, although harmful concentrations of certain ions e.g., iron, sodium etc. can occur naturally and lead to problems (Daly, 1994). Groundwater quality is a function of natural process as well as anthropogenic activities. Groundwater quality is a measure of its suitability as a source of water for human and animal consumption, irrigation and other purposes. It influences physical and chemical properties of soil, development of best management practices as well as surrounding environment.

Groundwater level also is of concern for sustainable crop production. A shallow groundwater level can affect plant growth in various ways. Shallow groundwater level may lead to negative effects on plant growth by displace of oxygen from the soil pore space and root respiration is inhibited. As a result roots begin to rot and eventually die. Above the ground plant parts, unable to absorb soil water, begin to show the symptoms of water stress like reduced vigor, chlorosis and death in the worst instance. On the other hand, areas where saline groundwater level is within 1.5-2.0 m of the surface has the greatest risk of salinization due to capillary action sucks up the saline water and dissolved salts invading the root zone and the soil surface (Murray-Darling Basin Commission, 2002).

Nonpoint source pollutants such as nitrate, potassium from fertilizer applications may cause groundwater pollution because of their high leaching ability. There is a high potential of groundwater contamination from fertilizer application in sandy soil due to sandy soils have relatively large pore space. Nitrate contamination of a shallow groundwater is of concern because of potential adverse effects on human and animal health and its potential to contribute to eutrophication of the sea or ocean (Weli *et al*., 1990). Groundwater nitrate contamination may occur due to over application of manure (Komor and Anderson, 1993; Wassenaar, 1995) and application of inorganic fertilizer at a greater rate than recommended (Herbel and Spalding, 1993; Exner and Spalding, 1994). Human consumption of water containing high nitrate has been linked to cases of methemoglobinemia, also known as blue baby syndrome (Comly, 1945; Gelberg *et al*., 1999). World Health Organization (WHO, 1993) set the maximum permissible limit of nitrate concentration in water at 10 mg L^{-1}. Unlike macro-nutrients, trace elements typically do not originate in groundwater from fertilizer application (Bianchi and Harter, 2002). Iron concentration in groundwater is of concern due to subsurface drainage pipe may be clogged by deposition of iron. In a previous study Sasaki *et al.*

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(2000) observed that efficiency of subsurface drainage system was decreased in the sand dune area due to clog of drainage pipe by accumulation of sediments which may cause increase of groundwater level. High iron concentration in sprinkler irrigation water may hamper the crop production. Purves (1972) and Rhoads (1971) reported that sprinkler irrigation water, which contain >1.5 mg L^{-1} Fe may cause foliar injury in tobacco.

Shallow groundwater quality of sand dune area in Aomori prefecture of Japan is an inevitable factor not only for crop production but also conservation of water bodies and surrounding environment. As the soil characterized with light textured, the sand dune area of Aomori has the greatest risk of nitrate contamination in groundwater, which may contribute to eutrophication of Japan Sea. Recently the farmers of this area experienced that root crops such as burdock, radish etc., had been decayed for increase of groundwater level. In order to develop best management practices for sand dune area, well designed experimental data are needed on shallow groundwater quality. This study was initiated to evaluate the groundwater quality in agricultural field of sand dune area.

MATERIALS AND METHODS

Study area and soil: The study was conducted in an agricultural field of Tsugaru city under Aomori Prefecture (northwest Honshu island). The investigated field was located at 40°55' N latitude and 140°19' E longitude with an elevation of 29 m above sea level and about 2 km away from Japan sea. Usually the farmers of the study area cultivate the crops from April to November. During the winter most of the fields become fallow due to heavy snowfall. Wheat, radish, melon, shallot, Chinese yam, water melon, burdock, potato, tobacco, garlic, asparagus, pumpkin, leek, carrot etc., are main cultivated crops of the study area. Areas covered by different cultivated crops are shown in Table 1. Overhead sprinkler irrigation system is used in crops field of the study area except melon field where drip irrigation system is used. Water of Yamada river is used for irrigation in the crop fields. Irrigation water and rain water quality of the study area is shown in Table 2. Subsurface drainage pipe had been also installed in cultivated field. The recommended fertilizer doses for this sand dune area are shown in Table 3. Monthly total precipitation and average temperature of the study area are shown in Fig. 1. The soil of this area is characterized by sand. Some physico-chemical properties of soil of the investigation field are shown in Table 4.

Sample collection: In this study three observation wells were installed in an agricultural field to collect the groundwater samples. In every well three plastic tubes were installed to collect the groundwater sample from 2.0, 2.5 and 3.0 m depth. The sampling was performed every month from April 2004 to March 2005. First groundwater was pumped by syringe to rinse the pipe and syringe and thereafter samples were collected in plastic containers. The samples were then immediately transported to the laboratory of Hirosaki University, Japan and kept refrigerated until chemical analysis was carried out.

Table 1: Cultivated area covered by different crops in the study area, 1996-2005

	Area covered by respective crops (ha)									
Crops	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Wheat	202.9	202.2	189.1	173.7	132.1	142.8	152.2	138.8	96.8	109.1
Radish	203.7	162.0	162.8	163.8	157.2	155.0	134.0	134.2	77.3	77.2
Melon	87.7	80.1	69.2	60.7	58.3	50.8	47.6	32.8	39.8	34.8
Shallot	0.7	2.2	0.6	0.6	-	-	-	-	-	0.7
Chinese yam	58.7	78.5	91.3	91.8	65.0	94.8	106.0	115.2	128.6	130.6
Water melon	25.1	20.6	15.9	17.3	18.5	21.2	18.3	16.2	16.2	15.5
Burdock	46.0	40.3	38.0	46.4	40.7	41.8	43.8	52.1	54.9	55.5
Tobacco	14.4	13.3	16.2	16.4	58.8	16.9	19.6	17.9	21.0	22.4
Potato	18.8	30.7	19.5	19.0	23.9	31.0	32.3	21.6	18.7	20.0
Garlic	0.8	4.3	3.4	5.1	9.9	17.1	13.1	13.8	17.9	24.7
Asparagus	-	-	-	-	-	-	-	-	2.9	5.4
Pumpkin	10.4	13.7	19.8	18.5	16.9	20.5	21.1	35.4	33.5	21.7
Leek	59.7	60.0	70.8	70.1	72.0	58.3	58.3	55.4	52.5	49.4
Carrot	10.8	3.9	3.5	6.1	9.0	8.9	7.6	11.7	11.8	13.3
Others	37.6	56.6	60.0	54.5	80.7	135.7	107.0	74.3	127.0	115.6
Total	777.3	768.4	760.1	744.0	743.0	794.8	760.9	719.4	698.9	695.9

Table 2: Quality of irrigation water and rain water of the study area

Water source	pH	DO (mg L^{-1})	EC (mS cm^{-1})	Na (mg L^{-1})	K (mg L^{-1})	Ca (mg L^{-1})	Mg (mg L^{-1})	Fe (mg L^{-1})
Irrigation water	7.25	4.98	0.30	41.85	10.63	12.55	5.55	1.43
Rain water	6.01	4.75	0.05	4.90	1.21	2.78	0.96	0.06

Table 3: Recommended fertilizer doses for agricultural crops in sand dune area

	Basal dose (kg ha^{-1})			Additional dose (kg ha^{-1})		
Crops	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	80	120	100	60	-	-
Radish	100	200	100	100	25	100
Burdock	250	250	250	-	-	-
Melon	80	180	80	50	20	40
Water melon	80	180	80	50	20	40
Potato	120	220	120	50	13	50
Chinese yam	100	180	100	230	58	230
Leek	150	260	150	150	40	150

Table 4: Physico-chemical properties of soils in study field

						Exchangeable cations (meq 100 g^{-1} soil)			
Soil depth (cm)	Taxture	Porosity (%)	ρ_b[1] (Mg m^{-3})	ρ_p[2] (Mg m^{-3})	pH	Na	Ca	Mg	K
0-10	Sand	43.05	1.50	2.63	6.34	0.13	3.19	0.39	0.48
45-55	Sand	44.90	1.47	2.67	6.44	0.29	3.33	0.49	0.30
95-105	Sand	45.81	1.47	2.71	6.31	0.67	3.99	0.50	0.28
195-205	Sand	45.66	1.48	2.72	6.36	0.34	1.73	0.35	0.23

[1]Bulk density; [2]Particle density

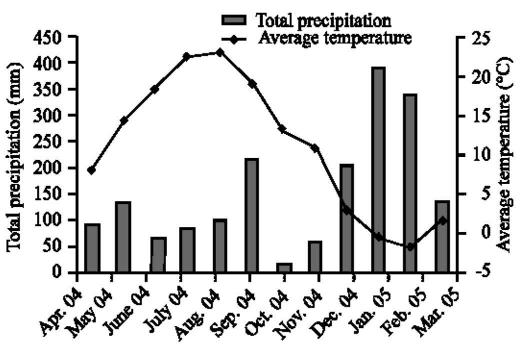

Fig. 1: Monthly total precipitation and average temperature of the study area

For measuring the groundwater level 12 observation bores were installed in the experimental field with 3 columns in east-west direction and 4 rows in north-south direction. The distance between two-observation bores was maintained 18 m in east-west direction and 7 m in north-south direction. Thermo recorders were installed at 0.1, 0.2, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 m depth to record soil temperature. Platinum electrodes were installed at 0.1, 0.5, 1.5 and 2.5 m soil depth to measure oxidation-reduction potential (Eh).

Measurements: Groundwater level was measured by using a rope water level meter (Rope water level WR type, ALFA, Japan). Groundwater level, soil temperature and oxidation reduction potential were measured every month. The water samples were analyzed for pH, electrical conductivity (EC), dissolved oxygen (DO), soluble iron (Fe), potassium (K) and nitrate nitrogen (NO_3-N). pH was measured electrometrically by using a pH meter (UC-23 digital pH/ORP meter, Central Kagaku Corporation, Japan) Electrical conductivity (EC) was measured at 25°C by using a EC meter (pH/Cond meter D-54, HORIBA Ltd. Japan). Dissolved oxygen was measured electrometrically by using a DO meter (UC-12 digital DO/O_2/temp meter, Central Kagaku Corporation, Japan) immediately after collection of samples. The concentrations of Fe and K were determined by using atomic absorption spectrophotometer (Z8200 Hitachi, Tokyo, Japan). NO_3-N was measured by using NP autoanalyzer in every month.

RESULTS AND DISCUSSION

Groundwater level: The groundwater level of the study area was observed within a range of 114.43 to 169.33 cm throughout the investigation period. According to Murray-Darling Basin Commission (2002) this area has a greatest risk of salinization due to such high groundwater level. Groundwater level was decreased slightly from May to September and then increased in both east-west and north-south direction until March except February (Fig. 2). The reason might be that crops cultivated in this field from April to September resulted in higher evapotranspiration. On average the highest groundwater level (123.06 cm) was observed in March and the lowest (159.85 cm) was observed in September. Since groundwater level was gradually decreased in east-west direction and more or less same in north south direction irrespective of month we can assume that the groundwater discharge and recharge were occurred in east-west direction.

Soil temperature: The soil temperature at 0.1, 0.2 0.5, 1.0 and 1.5 m (Fig. 3) was gradually raised with time from the month April to August. Thereafter the soil

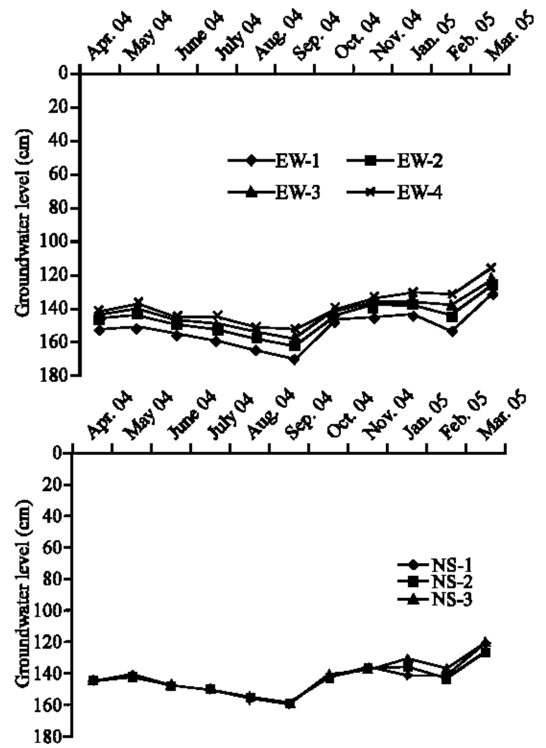

Fig. 2: Fluctuation of groundwater level in East-West direction (A) North-South direction (B)

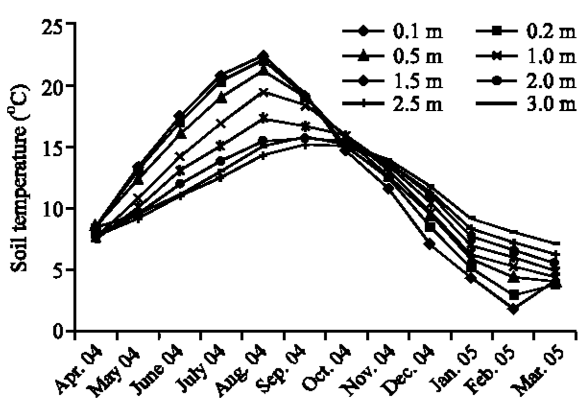

Fig. 3: Soil tempetature at different depth of soil

temperature was decreased sharply at the upper soil until February. On the other hand, soil temperature at 2.0, 2.5 and 3.0 m were increased until the month of September and thereafter decreased slowly until March. In August the highest (22.3°C) and the lowest (14.2°C) soil temperature was observed at 0.1 and 2.5 m depth, respectively. Whereas in February the highest soil temperature (8.0°C) was observed at 3.0 m depth and the lowest (1.8°C) at 0.1 m depth. From March temperature of upper soil was increased again. These results showed that the subsoil temperature is generally warmer in winter and cooler in summer and the outcome supported the statement by Brady (2000).

Oxidation-reduction potential (Eh): Oxidation-reduction potential is one of the important chemical characteristics of soil that affect the availability of different nutrients such as iron, manganese and nitrogen. The Eh value was measured at 0.1, 0.5, 1.5 and 2.5 m soil depth. Oxidation reduction potential values were observed greater than 300 mV at 0.1 and 0.5 m depth throughout the investigation period other than in June at 0.5 m depth (Fig. 4). On average the highest Eh value (711.00 mV) was observed at 0.1 m followed by 0.5 m and the lowest Eh value (-77.90 mV) was observed at 2.5 m. Eh value at 1.5 m depth was >300 mV in the month of April, July, September, October, January, February and March and <300 mV in the month of May, June, August, November and December. Oxidation-reduction potential value at 2.5 m depth was below 300 mV throughout the investigation period, which was an indication of reduced state. The gradual decrease in Eh value with soil depth might be a result of decrease in oxygen diffusion rate in deeper soil.

pH: pH values of the collected water samples were found within a range of 6.16 to 6.99 which indicated that groundwater of the study area was slightly acidic to nearly neutral irrespective of sampling time and soil depth (Fig. 5). The highest and lowest pH values were observed at 2.0 and 3.0 m depth, respectively throughout the investigation period. On average the highest pH value was observed at 2.0 m followed by 2.5 m and the lowest pH value was (6.33) at 3.0 m depth. This result indicated that the pH value of water decreased with an increase in soil depth. Results suggested that the shallow unconfined groundwater of the study area was suitable for crops since the accepted pH range of water for agriculture is 6.0 to 8.5 (Ayers and Westcot, 1985).

Electrical conductivity: Electrical conductivity of groundwater was found also different at different soil depth (Fig. 6). On average the highest EC value of 0.32 mS cm^{-1} was observed at 2.0 m depth followed by 2.5 m depth and the lowest value of 0.26 mS cm^{-1} at 3.0 m depth. The EC value, irrespective of soil depth, was gradually decreased with time during the period of April to July and thereafter, it increased and maintained a steady state up to the end of the investigation period. The value for EC of groundwater was decreased with soil depth might be due to slow rate of vertical diffusion of solutes in groundwater.

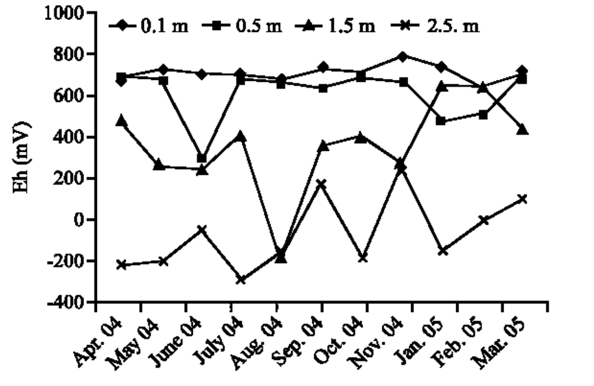

Fig. 4: Oxidation-reduction potential at different soil depth

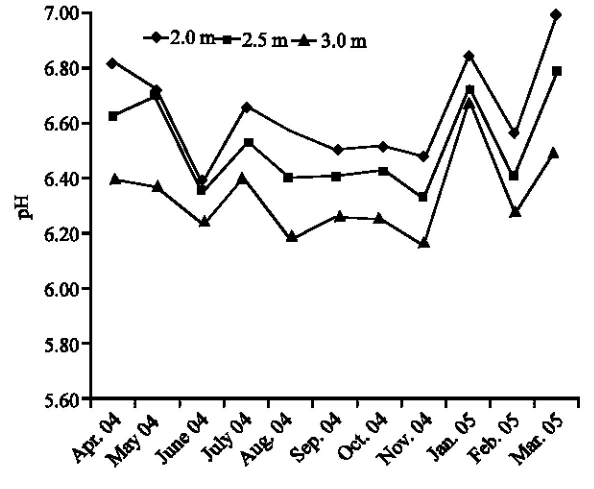

Fig. 5: Vertical variation in pH of groundwater

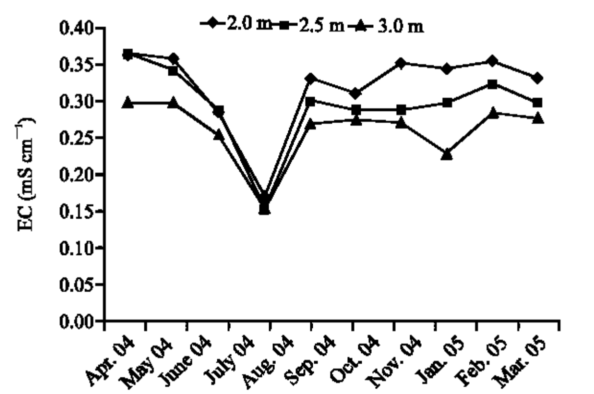

Fig. 6: Vertical variation in EC of groundwater

Dissolved oxygen: Concentration of dissolved oxygen was varied at different soil depth. The concentrations of dissolved oxygen at 2.0 and 2.5 m depth remained approximately identical during the period of April, 2004 to March, 2005 (Fig. 7). On average the lowest concentration of dissolved oxygen (4.57 mg L^{-1}) was observed at 3.0 m

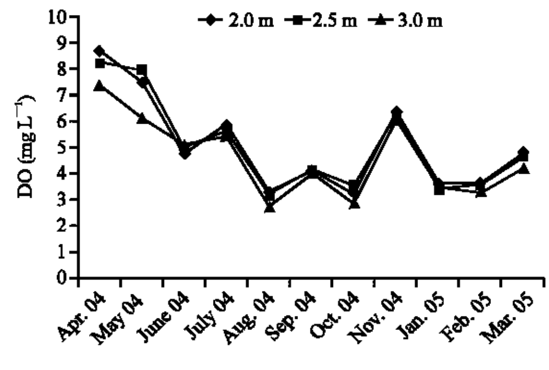

Fig. 7: Vertical variation in dissolved oxygen of groundwater

depth, which might be due to the decrease in oxygen diffusion rate with an increase of soil depth. And the highest concentration of dissolved oxygen (8.05 mg L^{-1}) was observed in April and lowest (3.06 mg L^{-1}) was observed in August. Groundwater of the study area was suitable for domestic use since water for domestic use should not have the dissolved oxygen concentration below 3 mg L^{-1} (CDPHE-WQCD, 2005).

Iron: Iron concentration was varied in groundwater of different soil depth (Fig. 8). The highest level of Fe was observed at 3.0 m depth followed by 2.5 m depth and the lowest level was observed at 2.0 m depth throughout the investigation period. The low Eh value (Fig. 4) and low pH (Fig. 5) might promote the availability of Fe in water at 3.0 m depth. Temporal variation of Fe concentration in groundwater was not remarkable at all soil depths investigated. On average the highest Fe concentration (38.51 mg L^{-1}) was observed at 3.0 m depth followed by 2.5 m depth and the lowest (13.31 mg L^{-1}) at 2.0 m depth. Soils serve as a source of iron in groundwater which, might cause such kind of high iron concentration in groundwater. In a previous study Sasaki *et al.* (2000) reported that total iron concentration in soils of this study area was varied from 0.79 to 2.4%. Groundwater of the study area was found not be suitable for irrigation since recommended Fe concentration in irrigation water 5 mg L^{-1} (Ayers and Westcot, 1985).

Potassium: The change in K concentration was not found distinct between 2.0 and 2.5 m soil depth (Fig. 9). Average concentration of K was found the lowest (13.24 mg L^{-1}) at 3.0 m depth as compared to 2.0 and 2.5 m depth, which might be due to the presence of high concentration of Fe at 3.0 m depth (Fig. 8). Higher Fe presence might promote the fixation of K as reported by Chen *et al.* (1987). K concentration in the groundwater of the study area was

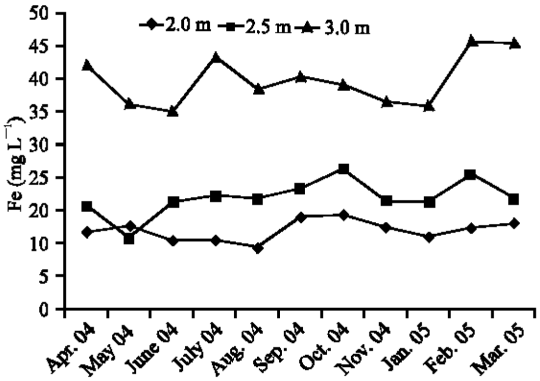

Fig. 8: Vertical variation in Fe concentration of groundwater

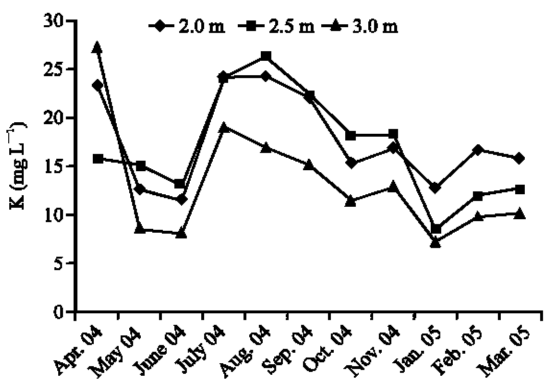

Fig. 9: Vertical variation in K concentration of groundwater

always higher than the normal range for irrigation water throughout the investigation period, since the normal range of K in irrigation water is 0-2 mg L^{-1} (Ayers and Westcot, 1985). The average concentration of K in river water of Japan is 1.19 to 1.64 mg L^{-1} (Yamane *et al*., 1982). So, the K concentration measured in groundwater of the study field was 11.27 times higher than that of the river water. It might be due to heavy application of potash fertilizer by the farmers (Table 3).

NO_3-N: Nitrate nitrogen concentration in groundwater was found between 0.0002-0.099 mg L^{-1} range. On average the highest NO_3-N concentration was observed in May followed by July and the lowest concentration in November. The average highest NO_3-N concentration (0.045 mg L^{-1}) was observed at 2.0 m depth followed by 2.5 m depth and the lowest concentration (0.014 mg L^{-1}) at 3.0 m depth. The results indicated that NO_3-N concentration was decreased with depth (Fig. 10) as reported by Toda *et al*. (2002). NO_3-N concentration in the

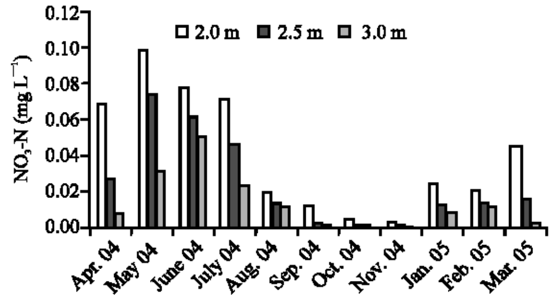

Fig. 10: Vertical variation in NO_3-N concentration of groundwater

ground water of the study area was found lower than the standard value (10 mg L^{-1} NO_3) for nitrate in drinking water. Therefore, the groundwater of the study area may impart no adverse effect on human health and surrounding water bodies.

CONCLUSIONS

According to the above results, EC, pH, dissolved oxygen, K and NO_3-N concentration in groundwater were decreased with increasing depth throughout the investigation period whereas Fe concentration was increased. Groundwater level of the study area can be considered as high level, which may hamper the root crops production under poor drainage system. Though pH of groundwater of the study area is suitable for agricultural crops, sprinkler irrigation may cause foliar injury due to high Fe concentration. Since concentration of NO_3-N was very low in groundwater, there would not be any threat to human health and environment.

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