# Nitrate Movement in the Soil Profile under Irrigated Agriculture: A Case Study

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## ABSTRACT

The study was conducted at the research station of Sindh Agriculture University Tandojam where four irrigation methods installed during 2000 were utilized. The irrigation methods included traditional flooding (through basins and furrows) and micro irrigation (through trickle and sprinklers). The soil samples were collected at 0.3, 0.6, 0.9 and 1.2 m depths for nitrate nitrogen analysis. The results from two-year study showed high $NO_3$-N concentrations at all sampling depths under basin and furrow methods, which could be attributed to free percolating water under these methods. In contrast, the $NO_3$-N concentrations remained concentrated only in the top 0.3 and 0.6 m depths under trickle and sprinkler irrigation methods due to insignificant water movement towards deeper depths. The results further demonstrate that the $NO_3$-N concentrations exceeded the threshold limit (i.e. 10 mg $l^{-1}$ set by EPA) under basin and furrow irrigation methods but remained below the threshold limit under trickle and sprinkler irrigation methods, at 1.2-m depth. The availability of $NO_3$-N at 1.2-m depth suggests that it will continue to move towards deeper depths under traditional methods, and consequently contaminate the shallow groundwater. The people drinking this contaminated groundwater are likely at substantial health risks.

**Keywords:** Nitrate leaching, traditional irrigation methods, micro irrigation methods, shallow groundwater, nitrate nitrogen, Pakistan

## 1. INTRODUCTION

Around the world, the fresh groundwater resources continue to deteriorate due to accelerated application of synthetic fertilizers, high slurry application, and organic pollution (Mirjat et al. 2007). The excessive use of fertilizers in agriculture is recognized as a major contributor to this deterioration (Laegreid et al., 1999). Since, the agriculture sector uses over 70% of the available fresh water resources around the world; hence they always remain at the risk of contamination. In Pakistan, the agriculture sector utilizes over 90% of available freshwater. It receives water through a huge and contiguous irrigation network that comprises three major storage reservoirs, 19 barrages, 12 link canals, 45 irrigation canals, over 107,000 watercourses and millions of farm channels and field ditches. This system irrigates about 16.2 million hectares of the land (Mirjat et. al., 1997; Mirjat and Chandio 2001). The irrigation is traditionally practiced using conventional flooding methods through borders, basins and furrows. The fields are either partly flooded, in case of furrow irrigation method or completely flooded under basin or border irrigation methods. The flooding of entire field requires large amounts of water. It increases infiltration opportunity time that allows deep percolation. The deep percolation is uncontrollable under flooded conditions, hence free and fast movement of applied chemicals towards deeper depths is possible. Nitrate-nitrogen ($NO_3$-N), a water-soluble nutrient, is transported to shallow groundwater as a leachate that consequently contaminates it. A study conducted in the central region of Thailand suggests that application of fertilizers increased $NO_3$-N concentration by five-fold in the groundwater bodies (Pathak et al., 2004). The inhabitants' drinking water containing nitrates exceeding the safe drinking water standards always experience health problems. The major problems linked to $NO_3$ contamination are methemoglobinemia (blue baby syndrome) in infants (Ray, 2001) and human birth defects (Fletcher, 1991).

In Pakistan, the fertilizers are used as an essential source to maintain the fertility and the productivity of cultivated lands. Different types of nitrogenous, phosphatic and potassic fertilizers are used to increase the food production. During 1970–71, the nitrogenous fertilizer was applied at an average rate of 15 kg ha$^{-1}$ which has gradually increased to 147 kg ha$^{-1}$ in 2004 with total production reaching to about 2500 thousand metric tons (Agricultural Statistics of Pakistan, 2003-04). Its use has resulted in tremendous yield increases during past thirty five years. The wheat yield has gone up from 3.9 million metric tons to 21.7 million metric tons. The rice production has increased from 1.3 million metric tons to 4 million metric tons, while, the sugarcane has progressed from 22 million tons to 45 million tons and maize yield from 0.7 million tons to 1.3 million tons. The nitrogenous fertilizer is applied in the form of urea as a top dressing at the time of planting followed by irrigation. Urea being highly soluble quickly moves towards deeper depths. The applied urea, as soon as, enters the soil it hydrolyzes into ammonium carbonate by enzymatic reactions. Hydrolyzes and oxidation is finally converted to nitrates. The nitrates ions thus formed are either taken up by the plants and micro organisms, or move downward. Under traditional irrigation methods, the entire soil surface is flooded that expedites the leaching of nitrates towards deeper depths and results in build up of high nitrate levels in the shallow groundwater. Many developed countries have engaged their scientists to resolve the problem of shallow groundwater contamination. Active research is being carried out in the United States (Logan et. al., 1980; Bengtson et. al., 1984; Kanwar and Baker, 1991; Mirjat et. al., 1993) to figure out the best possible alternatives that will not hamper the crop production either quantitatively or qualitatively, but will reduce the potential threat to the environment. The controlled drainage and sub-irrigation have been recognized as the best methods that reduce nitrate losses (Willis et. al., 1998). In the places where crops are irrigated through micro-irrigation such as, trickle and sprinkler methods, the nutrients are spoon-fed to the crops to accurately meet their nitrogen needs. Under these modern methods, water is sprinkled or only the area around the plant is wetted thus deep percolation becomes insignificant which does not allow the chemicals to move freely towards deeper depths, hence the potential for groundwater contamination is negligible (Lamm et. al., 2001). The best water management practices to control nitrate leaching particularly, under irrigated agriculture, require better understanding of interaction between irrigation system performance and the movement of water and solutes through the soil (Rice et al., 2001). The management practices include, improved irrigation methods, efficient water application, amount and appropriate timing, improved tillage practices and cropping pattern. All these practices are regarded as the best management practices for agricultural sustainability. The goal of this study was to determine the leaching potential of nitrates under current traditional irrigation methods and compare them with modern micro irrigation (trickle and sprinkler methods) and suggest the best possible irrigation methods that can reduce nitrate leaching.

## 2. MATERIALS AND METHODS

The experiments were conducted at the research station located near the Faculty of Agricultural Engineering, Sindh Agriculture University Tandojam. At this station, four irrigation methods installed during 2000 were utilized. The irrigation methods included, traditional flooding (through basins and furrows) and micro irrigation (through trickle and sprinklers).

### 2.1. Traditional Flooding Methods (Furrow and Basin)

A plot measuring 25 x 14.5 m was used for furrow irrigation method. A total of 25 furrows, each 14.5 m long, 0.6 m wide and 0.3 m deep were prepared with a 0.6 m row-to-row spacing. The furrows were supplied water through gated pipes having 10 cm diameter. Each gated pipe had an opening spaced at an equal distance of 60 cm. The pipes were connected to a 5 cm diameter supply line directly connected to the pumping station. The irrigation amounts applied to each furrow were measured by a flow meter installed in the main pipeline. The seeds of cotton variety Nayyab-78 were manually sown at the ridges of each furrow with a 30 cm plant-to-plant spacing.

Three plots each measuring 76.5 $m^2$ were used for basin irrigation method. Each plot was bounded by levees to form a basin. The cotton-seeds of Nayyab-78 variety were sown using a hand drill. They were sown at a row-to-row spacing of 60 cm and plant-to-plant spacing of 30 cm. The cotton sowing took place in the early May and the picking started during early October and continued until the end of the November, during both study years.

### 2.2. Micro Irrigation Methods

#### 2.2.1. Sprinkler Irrigation Method

The sprinkler irrigation system was installed on a plot with 25 m x 21.4 m dimensions. The plot was divided into four equal sized subplots, in which the sprinklers were installed and spaced at a 10 m distance. Depending on the operating pressure, each sprinkler covered a radius between 5 and 6 m, hence they overlapped each other. A 5-cm diameter Galvanized Iron (G.I.) pipe was laid-down that served as mainline and supplied water to four sub-mains each with 2.54 cm diameter. The riser pipes with 1.27 cm diameter were fixed in sub-main pipes. The sprinklers were fixed initially in the 75-cm high risers and then the riser heights were elongated to 150 cm as soon as the cotton plants attained a 75 cm height or exceeded. A pressure-measuring gauge was installed in the mainline to monitor the actual operating pressure. The pressure was controlled through a gate valve installed in the mainline along with a flow meter that measured the flow rate. The seeds of cotton variety Nayyab-78 were sown at a 60-cm row to row and 30-cm plant-to-plant spacing using a manually operated hand drill during early May during the two study years. The cotton picking was done during October and November for the two study years.

### 2.2.2. Trickle Irrigation Method

A plot measuring 25-m X 14.5-m was equally divided into three subplots and the trickle irrigation system was installed in it. The system comprises a mainline with 5 cm diameter and 45 m long that supplied water to sub-mains having 2.54 cm diameter. Eighteen laterals each 7.6 m long and equally spaced at a distance of 60 cm were installed in each subplot. Polyethylene rubber tubes with 12-mm diameter were laid down in each subplot that served as laterals. The emitter tubes with 3.2 mm diameter were fixed in the lateral pipes near the plants. A flow meter with a control valve was installed at the head of each sub-main to measure and regulate the water flow to the laterals. The pre-soaked cotton-seeds were sown during early May and the cotton picking started in October and ended in November during the two study years.

### 2.3. Soil Sampling and Analysis Procedures

The soil samples under each treatment were collected at 0.3, 0.6, 0.9 and 1.2 m depths. Nine samples per treatment (three samples at each replication) were randomly collected from each plot. The samples were mixed together to yield a composite sample per replication. In this way three composite samples per treatment at each depth were analyzed. The samples were collected using a zero contamination core sampler. The sampler was pushed into the soil, each core slide into a clean liner made of polyethylene terephathalate glycol-modified (PETG) plastic that protected the sample from contamination. The collected samples were preserved promptly for later analysis.

### 2.4. Analysis Procedure

A 100-gram sample of wet soil was mixed with 435 gram of 2N (normal) KCL. The mixture was shaken for 65 minutes, and then allowed to settle for overnight. On the following day, solvent was filtered and poured into a 100 ml test tube. The $NO_3$-N in the solvent was analyzed using an Ion Selective Electrode Meter (Jenway Model-3345). This meter directly displays the readings on the screen which are recorded. A calibration curve was established and the actual concentration in the sample was calculated.

## 3. RESULTS AND DISCUSSION

Two sets of soil samples were collected at different soil depths before and after fertilizer application, and a third set of samples at the time of harvest. The samples were analyzed for $NO_3$–N and the data is shown in Figures 1 through 3 for the year 2002. Figure 1 shows that the $NO_3$–N concentration was very low in the samples taken before fertilizer application at all depths under furrow, basin, trickle and sprinkler irrigation methods. Such trends are expected, because there wasn't any activity at the experimental site before this experiment. The concentrations ranged between 0.5 and 1.34 mg $l^{-1}$ under four treatments.

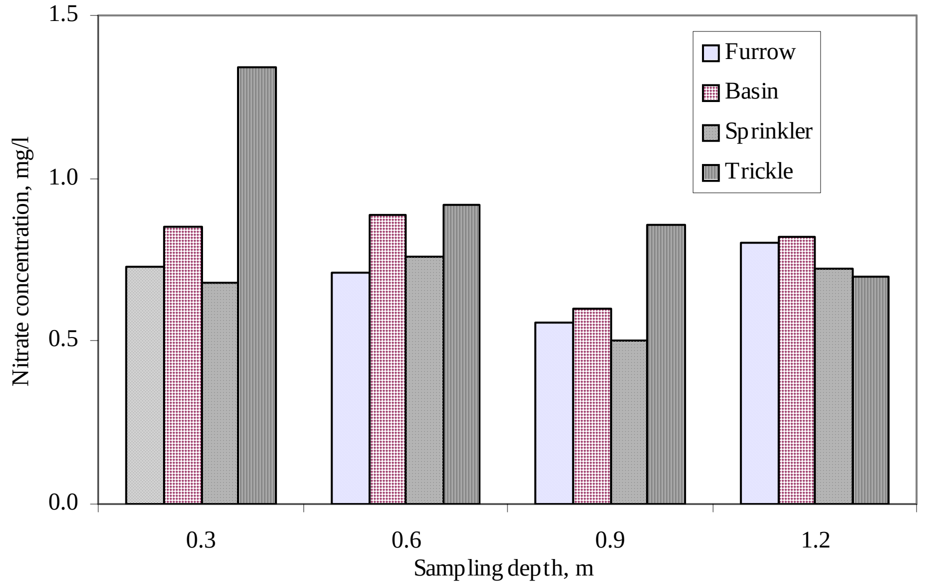


Figure 1. Nitrate concentrations observed at different soil depths before fertilizer application during 2002

Figure 2 shows nitrate concentrations observed at various depths in the samples collected after fertilizer application. The impact of fertilizer application is quite clear in the figure, which shows that the concentrations varied at different depths. The concentrations were rather high in the top 0.3 m depth under all treatments, but the trends at deeper depths were different for trickle and sprinkler irrigation methods. Under the furrow and basin methods, the concentrations were fairly high at 0.6, 0.9 and 1.2 m depths, which suggest that nitrate was moving towards deeper depths with water seeping through the micro pores. Since surface area is completely flooded under basin irrigation with a water application depth of 7 to 10 cm that imposes free draining conditions under this method and expedites nitrate leaching. Similarly, under furrow irrigation even more ponding depth is provided in the furrow channels that causes deep percolation and increases nitrate leaching. The concentrations under basin irrigation were 71, 53, 39 and 15 mg $l^{-1}$ at 0.3, 0.6, 0.9 and 1.2 m depths, respectively. Similarly, the concentrations observed under furrow irrigation were 59, 68, 53 and 23 at 0.3, 0.6, 0.9 and 1.2 m depths, respectively. In contrast, the nitrate concentrations remained concentrated in the top 0.3 depths under trickle and sprinkler irrigation methods. Since, there is limited movement of water below root zone under these methods, thus the nitrate movement towards deeper depths is very slow and is governed by unsaturated hydraulic conductivity and soil water potential differences in the soil profiles.

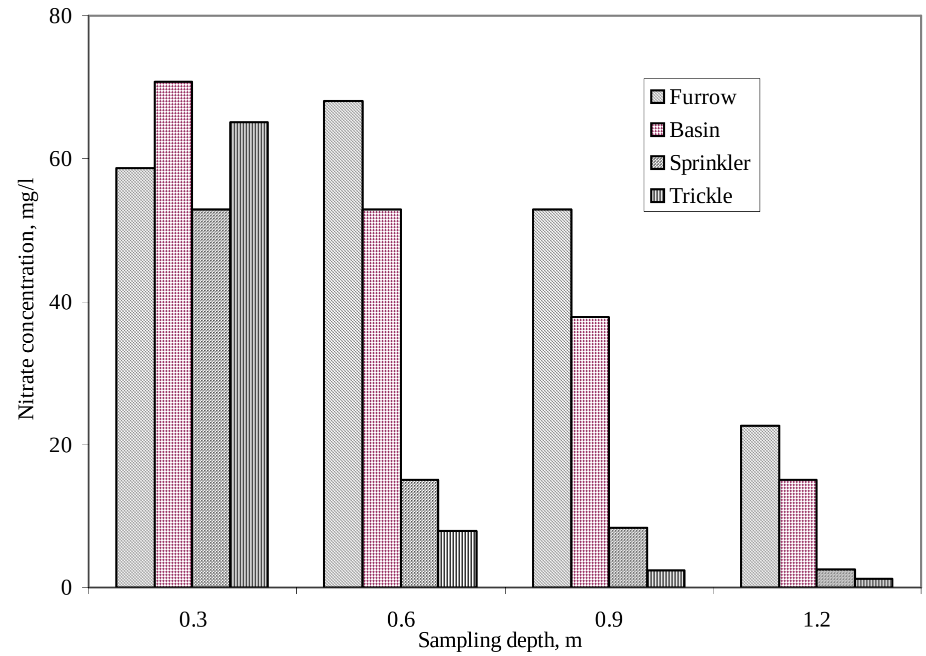


Figure 2. Nitrate concentrations observed at different soil depths after fertilizer application during 2002

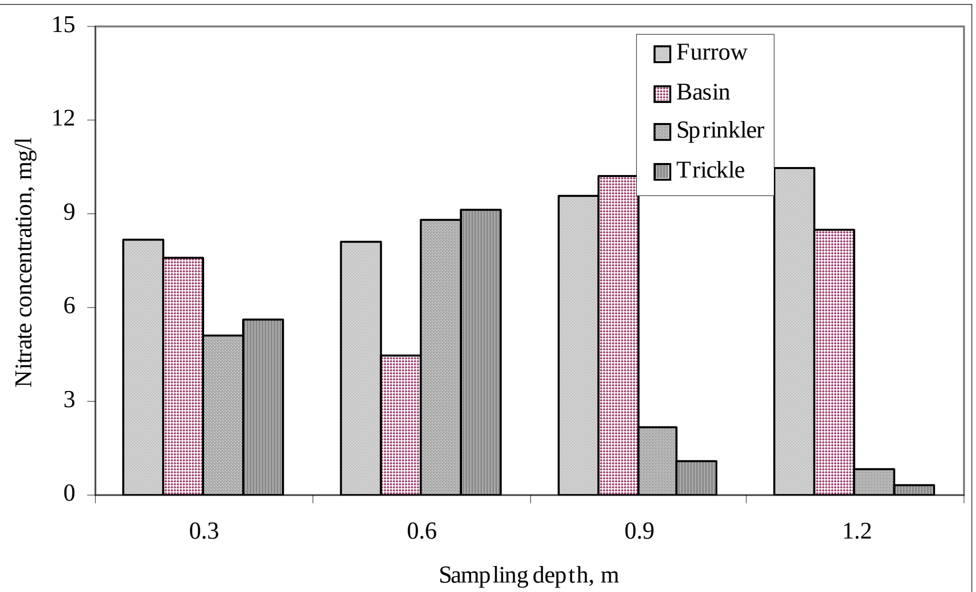


Figure 3. Nitrate concentrations observed at different soil depths after harvest during 2002

Figure 3 shows the nitrate concentration observed in the soil samples taken at the time of harvest for the year 2002. The results show that generally the nitrate concentrations have decreased at all depths, however flooding of basins or furrows expedited movement of nitrates into the soil profile, which resulted in higher concentrations available at deeper soil depths at the time of harvest. The amounts in excess of 10 mg $l^{-1}$ were found at 1.2 m depth that consequently will keep moving towards deeper depths and might contaminate the shallow groundwater. Under trickle and sprinkler irrigation methods, the amounts were well below EPA's threshold limit (10 mg $l^{-1}$) at all depths thus does not pose any threat to groundwater contamination. The amounts available at the time of harvest under trickle and sprinkler were 0.3 and 0.8 mg $l^{-1}$ at 1.2 m depth, respectively.

Figures 4 through 6 show the average nitrate concentrations for the year 2003 under all treatments. The concentrations in the soil profile before experiment (Figure 4) were slightly

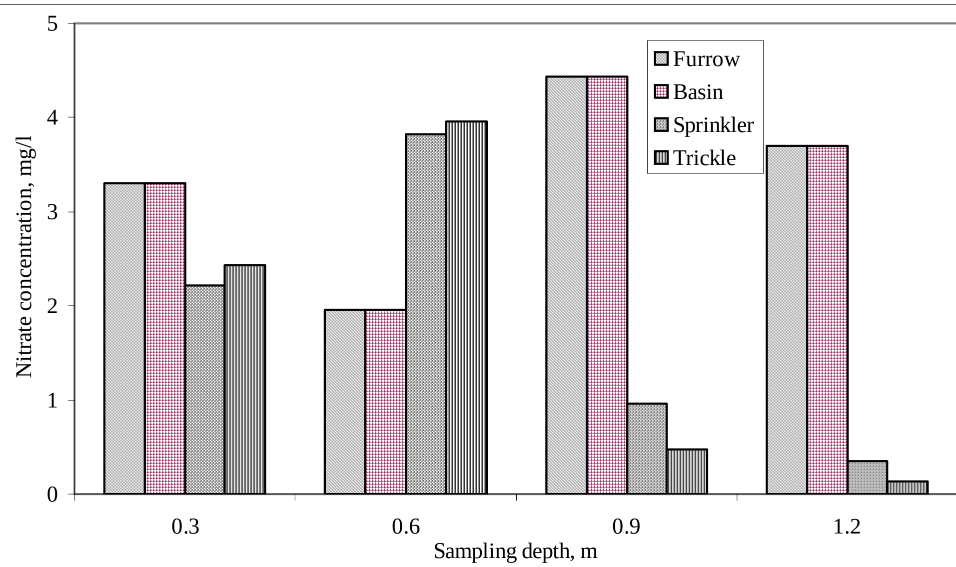


Figure 4. Nitrate concentrations observed at different soil depths before fertilizer application during 2003

higher during this year as compared to previous one. This might be the result of residual effect from the previous year, a maximum of 4.57 mg $l^{-1}$ was observed under furrow and basin irrigation methods at 0.9 m depth while it was only 0.95 mg $l^{-1}$ under sprinkler and 0.45 mg $l^{-1}$ under trickle irrigation methods at the similar depth, which is insignificant.

Figure 5 shows the concentration observed after fertilizer application during 2003. Almost similar trends those of 2002 were observed. The conventional flooding through basin and furrow irrigation methods resulted higher concentrations at all depths, whereas the nitrate concentrations were higher only in the top 0.3 depth under trickle and sprinkler irrigation methods. The nitrate concentrations ranged between 24 and 67 mg $l^{-1}$ under furrow irrigation and between 17 and 62 mg $l^{-1}$ under basin irrigation methods.

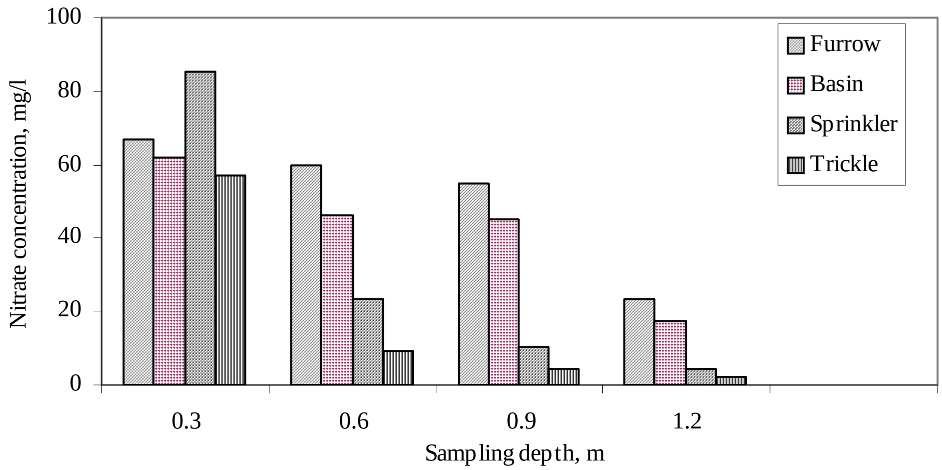


Figure 5. Nitrate concentrations observed at different soil depths after fertilizer application during 2003

These results warn that presence of nitrate in excess of 10 mg $l^{-1}$ at deeper depths (1.2 m) might become a serious threat to shallow ground waters in the long run. Under traditional irrigation methods the nitrate will continue to leach-down with freely draining water. Figure 5 reveals that the higher nitrate concentrations were concentrated in the top 0.3 m depth both under trickle and sprinkler irrigation methods. As high as 85 mg $l^{-1}$ was observed under sprinkler irrigation whereas, 57 mg $l^{-1}$ was observed under trickle irrigation at this depth. However, the concentrations decreased with increasing depth and the lowest amounts of 2 mg $l^{-1}$ were observed at 1.2 m depth under trickle irrigation and those were 4.3 mg $l^{-1}$ under sprinkler irrigation methods.

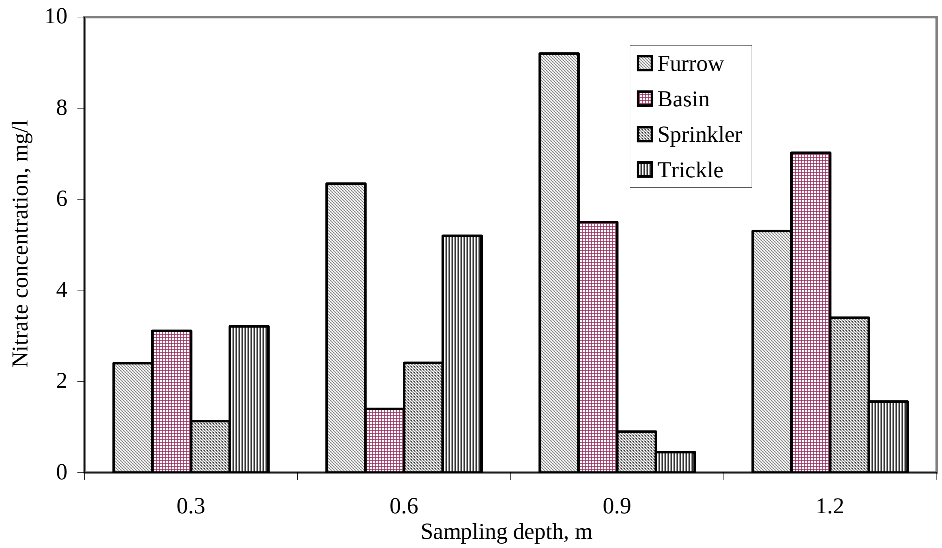


Figure 6. Nitrate concentrations observed at different soil depths at harvest during 2003

The concentrations observed at the time of harvest for the year 2003 are shown in Figure 6. This figure shows a significant decrease in concentrations at top depths under all treatments. Such trends are expected, because the nitrogen has either been utilized by plants or has been leached-down. It is apparent from the figure that under furrow and basin irrigation methods, the concentrations are still high as compared to trickle and sprinkler irrigation methods. In general, the concentrations ranged between 2.4 and 9.2 mg $l^{-1}$ under furrow irrigation, between 1.4 and 7 mg $l^{-1}$ under basin irrigation, between 0.9 and 3.4 mg $l^{-1}$ under sprinkler irrigation and between 0.5 and 5.2 mg $l^{-1}$ under trickle irrigation methods.

## 4. CONCLUSIONS

The study was conducted at the research station of Sindh Agriculture University Tandojam to determine the movement of nitrate nitrogen under traditional flooding (through basin and furrow) and modern micro irrigation using trickle and sprinkler methods. The study resulted in the following conclusions:

1. Basin and furrow irrigation methods showed high concentrations at all depths which is result of deep percolating water caused by surface flooding, in contrast, the nitrate concentrations remained concentrated only in the top depths under trickle and sprinkler irrigation methods. Since, water does move freely below the root zone under these methods thus the nitrate movement towards deeper depths is insignificant.
2. The results from two-year data reveal that the concentrations of $NO_3$-N in excess of 10 mg $L^{-1}$ (a threshold limit set by EPA) were observed at 1.2-m soil depths under traditional flooding through basin and furrow irrigation methods. However, trickle and sprinkler

irrigation methods did not show any potential threat of nitrate nitrogen leaching towards deeper depths.

3. The trend of nitrate leaching measured below root zone depth reveal that the concentrations will continue to leach-down towards shallow groundwater, and consequently contaminate this precious source, which is hazardous for human health, particularly, for the infants. The rural population using such contaminated groundwaters is likely at substantial health risks thus they may be warned of its effects.

## REFERENCES

Agricultural Statistics of Pakistan. 2003-2004. Government of Pakistan, Ministry of Food, Agriculture and Livestock, Food, Agriculture and Livestock Division, (Economic Wing), Islamabad.

Bengtson, R.L., C.E. Carter, H.F. Morris, and J.G. Kowalczuk. 1984. Reducing water pollution with subsurface drainage. Transactions of the ASAE. 27(1):80-83.

Fletcher, D.A., 1991. A national perspective, In.: Flleff, R.F., Keeney, D. R., Cruse, R.M.,(Eds.). Managing groundwater quality and farm profitability, SSSA, Madison, W.L.:9-17.

Kanwar, R.S., and J.L. Baker. 1991. Long term effects of tillage and reduced chemical application on the quality of subsurface drainage and shallow groundwater. In: Proceedings of the Environmentally Sound Agriculture, Orlando, Florida, pp. 121-129. Editors: A.B. Bottcher, K.L. Chambell, and W.D. Graham. Gainesville, University of Florida.

Laegreid, M., O. C. Bockman, and O. Kaarstad,., 1999. Agriculture fertilizers and Environment, CABI Publ., Wallingford and Norsk Hydro ASA, Oslo.

Lamm, F.R., T.P. Trooien, H.L. Manges, and H.D. Sunderman. 2001. Nitrogen fertilization for subsurface drip-irrigated corn. Transactions of the ASAE. 44(3):533-542.

Logan, T.J., G.W. Randall, and D.R. Timmons. 1980. Nutrient content of the tile drainage from cropland in the North Central Region. NC Regional Publ. 268. Res. Bull. 119. Wooster, OH: OARDC.

Mirjat, M.S., A.M.S. Shah, A.D. Brohi, G.R. Mari, and G.M. Memon.1997. Use of Poor quality groundwater with gypsum and its effect on soil properties. Gomal University Journal of Research. 17:63-70.

Mirjat, M.S. and A.S. Chandio. 2001. Water resources: present status and future strategies. Economics and Business Review. Appeared in Daily Dawn Karachi, May 7-13.

Mirjat, M.S., M. Rodgers, and P. Gibbons. 2007. Appropriate Slurry Application Rates and Timings: A Management Tool to Reduce Nitrate Leaching towards Groundwater. Agricultural Engineering International: the CIGR Ejournal. Manuscript LW 06 022. Vol. IX, September.

Mirjat, M.S., R.S. Kanwar, T.S. Colvin, and S.W. Melvin. 1993. Impact of subsurface drain installation methods on $NO_3$-N losses and crop yields. Agricultural Engineering Journal, 2(1&2):35-48.

Pathak, B. K., F. Kazama, and T. Iida (2004). Monitoring of Nitrogen Leaching from a Tropical Paddy Field in Thailand. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript LW 04 015. Vol. VI, December.

Ray, C. 2001, Managing nitrate problems for domestic wells in irrigated alluvial, aquifers, Journal of Irrigation and Drainage Engineering, 127 (1): 49-53.

Rice, R.C., D.J. Hunsaker, F.J. Adamsen, and A.J. Clemmens. 2001. Irrigation and nitrate movement evaluation in conventional and alternate furrow irrigated cotton. Transactions of the ASAE, Vol. 44(3):555-568.

Willis, G.H., L.M. Southwick, and J.L. Fouss. 1998. Nitrate in runoff and leachate from controlled-water-table plots on a Mississippi alluvial soil. Drainage in the 21st century, food production and the environment. In: *Proceedings of the Seventh International Drainage Symposium*, Orlando, Florida, USA, 559-566.