Success Story No. 6

Drainage Technology for Land Improvement

Indian Agricultural Research Institute
New Delhi - 110012

Printed : August, 2005

Guidance
S. Nagarajan
Director

Nodal Scientists
A.K. Bhattacharya
Man Singh

Working Group
K.D. Srivastava
Srinivasan
G. Narayanasamy
A.K. Bhattacharya
Madhuban Gopal
K.Vijayaraghavan
A.K. Vasisth
S.K. Singh
C. Thomas

Assistance
D.K. Parashar
Aman Kumar

Correct citation: IARI, 2005. Drainage Technology for Land Improvement. Indian Agricultural Research Institute, New Delhi -110012, India

Copies printed: 1000

Success Story No. 6

ICN: 33/2005

Published by the Director, Indian Agricultural Research Institute, New Delhi-12, and printed at Royal Offset Printers, A-89/1, Naraina Industrial Area, Phase-I, New Delhi-110 028.

Drainage Technology for Land Improvement

Historical Background

For centuries, land drainage has been practised on the basis of local experience. After the experiments characterising the subsurface water flow conducted by a French Engineer, Henry Darcy in 1856, several drainage design theories have been propounded and land drainage has developed as an engineering science. These theories now form the basis of designing the modern agricultural land drainage systems. Yet, it is not possible to determine a unique solution for a land drainage problem merely with the help of these theories. The real challenge lies in the application of engineering judgement and local experiences to develop design criteria that are sound, convenient and readily adaptable by practising engineers and agricultural land users.

Why Land Drainage?

Excess water and salts in the soil forming the crop root zone are injurious to plants. Crop yields may drastically reduce on poorly drained soils. Under prolonged waterlogged conditions, the crops eventually die owing to lack of oxygen in the root zone. The main purpose of drainage is to provide a favourable root environment, which is conducive to the proper growth of plants. Artificial drainage is essential on poorly drained agricultural fields to ensure an optimum air-water-salt regime in the crop root zone.

Technology of Land Drainage

Broadly, there are two types of drainage systems, namely, surface drainage and subsurface drainage. The surface drainage clears the land surface of excess water that is commonly found over flat and low-lying agricultural lands under a monsoon-dominated climate. The subsurface drainage controls water table and salinity in shallow water table regions, mostly in the irrigated lands. There are about 15 million hectares of agricultural lands in India affected by waterlogging and salinity causing substantial loss in crop production.

Land Drainage Endeavours in India

India has lagged far behind the developed and many developing nations in adopting drainage technology in agricultural lands. Sporadic efforts were made during 1940 – 1980 in the design and execution of drainage systems. These were mostly confined to surface drainage but did not give much benefit due to lack of maintenance. Subsurface drainage systems for water table control and land reclamation were very little and in small areas addressing only the local problems of waterlogging and salinity. During the early to late nineties of the 20th century, a large subsurface drainage project was executed in 14,000 hectares of the saline land in the Chambal Command Area around Kota, Rajasthan.

Land Drainage Initiative by IARI and ICAR

In the late 1970s, a comprehensive surface drainage plan was developed and executed over 125 ha area of the IARI research farm having serious problems of surface water congestion and shallow water table. The work involved large-scale land grading and shaping, besides the construction of a drainage network including drainage structures. On a research-cum-demonstration scale, the Indian Council of Agricultural Research (ICAR) has been sponsoring projects on land reclamation mainly through sub-surface drainage from the mid-seventies at different places. Systematic research and pilot scale demonstration on various aspects of drainage were started during the early eighties by the ICAR and continued through 2002 in five states under an All India Coordinated Research Project (AICRP) on Agricultural Drainage, with the Coordinating Centre located at the Water Technology Centre of IARI. The experience gained through the operation of this project was utilized in commissioning different kinds of drainage systems in some other states also with the financial input from the user agencies.

Research in Surface and Subsurface Drainage

The surface runoff estimation procedure suiting the rainfall pattern under monsoon climate over India was refined and standardized. It was adopted for working out a revised surface drainage design in the Mahi Right Bank Canal (MRBC) Command Area of Gujarat. The designing and execution of surface drainage in the black soils of the farmers' fields in the Barna and Tawa Command Areas of Madhya Pradesh were done using this approach. As a result, the farmers got higher crop yield and the rising trend of the groundwater table was reversed. It also facilitated the availability of more working days to the farmers to timely complete the field operations. Physical model studies were done to develop a design standard for mineral filters used in subsurface drainage which has been adopted by the Bureau of Indian Standards. The standard and the designed clay tile drains were adopted for subsurface drainage execution in the tea gardens in Assam resulting into higher leaf tea production. The benefit of adopting sub-surface drainage in the chemically degraded soils, in terms of producing a favourable salt and nitrogen balance, increasing crop production and in improving the physical condition of the soil, were demonstrated in the farmers' fields in Andhra Pradesh and Kerala.

Adoption of Drainage Technology

The research outputs and their successful adoption in the areas of surface drainage and sub-surface drainage are described below:

Surface drainage

Runoff estimation and surface drainage coefficient. Runoff is estimated to fix the design capacity of the surface drains. The currently used method was suitably modified to take care of the runoff produced from extended duration of rainfalls, which occur due to the monsoon climate over India. The modified method was adopted to redesign the capacity of the surface drains in the 12,000 ha Tarapur Drainage Block in the Mahi Right Bank Canal Command (MRBC) Area in Gujarat. At this place, the existing drainage system was inadequate resulting in surface waterlogging and shallow water table. The modified drainage coefficient values are given in Table 1.

Table 1. Surface drainage coefficient for Tarapur Drainage Block in MRBC for 5-year recurrence interval

Consecutive days/crop tolerance period	Surface drainage coefficient, mm/day
1	71
2	47
3	34
4	30
5	25

The recommended surface drainage coefficient values of Table 1 were much higher than the adopted values of 10 to 15 mm/day for surface drainage design in the command area. The adopted values had proved inadequate. Simultaneously, it was suggested to the command area authority to enhance the groundwater use in irrigation.

Modified drainage system and increased groundwater use proved to be beneficial in the MRBC command area. The region of shallow water table in the critical range of less than 1.5 m to 3 m from the ground level decreased, while the region in the safe range of 3 to 6 m water table depth increased after the introduction of surface drainage improvement and enhanced groundwater use in irrigation. Figure 1 shows the increase in the safe water table regions in the MRBC command area after drainage improvement and more groundwater use. Till the early eighties, before the adoption of improved drainage and enhanced groundwater use, almost 95% of the area had water table shallower than 3 m and 80% had water table shallower than 2 m.

Production increase due to surface drainage. Surface drainage systems were designed and commissioned in the farmers' fields in five villages in the Barna Command Area and in one large village in the Tawa Command Area, both in Madhya Pradesh. Surface drains had carrying capacities of 6 to 7 Lps/ha (52 to 60

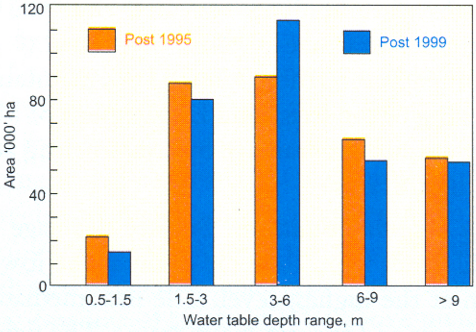

Fig. 1. Reduction in waterlogging due to surface drainage and increased groundwater use in the MRBC command area

mm/day). The drainage performance was evaluated through crop yield, water table fluctuation and the number of days to bring the clay soil dominated fields under workable condition after an irrigation or a heavy rainfall. In the surface drained fields in the Barna Command Area, *kharif* soybean and *rabi* wheat yields increased by 81 and 28 per cent, respectively, over the respective yields in the undrained areas. The rising trend of the water table prior to the construction of the surface drains was reversed after the construction of surface drains. Satisfactorily functioning surface drains prevented runoff accumulation, restricted water table rise and allowed more working days to the farmers to timely complete their field operations. The benefits of drainage were reflected through the increased yields of soybean and wheat in the area served by well-maintained surface drains (Table 2).

Table 2. Effect of drain maintenance on water table, soil condition and crop yield (Baikhedi village, Tawa Command Area, M.P.)

Treatment	Evaluation parameters			
	No. of days in a year when water table < 100 cm from surface	Time (days) for field to become workable	Yield, t/ha Soybean	Yield, t/ha Wheat
Before drainage or ill-maintained drains	120	20	1.12	2.54
Well maintained drains	101	13	1.55	3.08

Feedback data analysis revealed that the farmers, who maintained their drainage systems, continued to get better crop yields in comparison to those who did not maintain their systems. The local wing of the Irrigation Department of Madhya Pradesh facilitated field surface drainage by constructing and maintaining additional link drains.

Design recommendations. Surface drainage network has a hierarchical order from the field drain at the lowest level to the main drain at the highest level. The intermediate levels are the collector drains and the sub-main drains. The field drains are 'V' shaped shallow channels, about 15-20 cm deep, with side slope of 1/8 vertical to 1 horizontal, constructed at an approximate interval of 100 m across the major slope of the field. The collector drains are normally of 40 cm average depth and of trapezoidal section with 1:1 or 1½:1 side slope and at least 20 cm bottom width. They are constructed along the field boundaries to receive the water delivered by the field drains. Their section is designed assuming a capacity of 5 to 7 Lps/ha of the drained area. The field drains should have ungated pipe outlets at the downstream to slowly discharge the runoff into the drain. The fields are bunded to avoid overland flow into a drain causing soil erosion and drain siltation. To allow proper drainage, the field surface has to be smooth and properly graded. The permissible longitudinal slope of the drains usually varies between 0.1 and 0.3 per cent. The sub-main and the main drains are designed for the sum of the discharges of the number of the corresponding lower order drains. As the total number of lower order drains joining a higher order drain increases from upstream to downstream, a higher order drain may have a smaller section to start with and may have increased section at suitable intervals towards the downstream.

The cost of construction of the surface drains is calculated based on the volume of earthwork involved and the unit earthwork cost. The costs of structures such as culverts, drops, pipe outlets, etc., are additional to the earthwork cost. If the land is to be leveled and graded to a desired slope and finish to facilitate drainage, additional costs to the tune of about Rs. 250/- per hour for self owned laser leveler and Rs. 350/- per hour for custom hired laser leveler are to be incurred. This works out to be about Rs. 2500/- per hectare for the former and Rs. 3500/- per hectare for the latter. The costs of leveling with conventional leveling equipment will be lower but the surface finish is better when laser leveler is used leading to higher water application efficiency during irrigation and better surface drainage. The cost of leveling will also depend on the earthwork involved, i.e., the existing surface features of the field. The above mentioned costs are for an average field condition and are based on the costs prevalent in 2005.

Subsurface drainage

Studies on subsurface drainage comprised the standardization of mineral filter design, the designing clay tile drains for small-scale execution work and their demonstration in the field followed by dissemination of the technology leading to its adoption by the user agency.

Design and placement of mineral filter. The design standard of mineral filter comprising various proportions of relatively coarser particles was developed through sector model studies. The Bureau

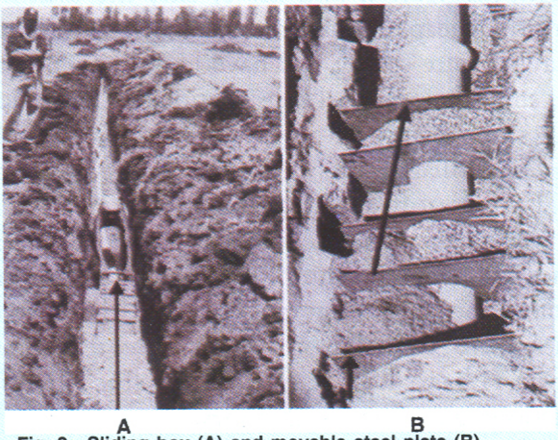

Fig. 2. Sliding box (A) and movable steel plate (B) used for selective filter placement

of Indian Standards adopted the result in the mineral filter design code of practices (IS: 9979 – 1981). The code was adopted with some further modification at the subsurface drainage installation site in the tea gardens of Assam. The filter placement technique was developed while installing the subsurface drainage system with a view to economizing on filter use. Two techniques were adopted for this, viz., the selective placement of the filter over the joints of the clay tiles, and the covering of the filter with a plastic sheet to avoid direct vertical flow of subsurface water into the drains. The mechanism of selective filter placement was accomplished by using movable separator steel plates and movable open steel box (Fig. 2).

The minimum possible trench size for manually installing the tile drains is large and needs more filter. A sliding open steel box (Fig. 2A) or a movable steel separator plate (Fig. 2B) is a useful device to place the filter where it is needed. The option of Fig. 2B was adopted in the subsurface drainage installation in the tea gardens of Assam and it reduced the filter need by 29%. A plastic sheet was placed over the mineral filter (not shown in the Figure) before the trench was backfilled to further reduce the chance of soil moving into the tiles.

Design, fabrication and use of clay tile drain. Clay tile drains are the cheapest sub-surface drainage conduits. Properly baked clay tiles are strong and have long life. They are ideally suited for small-scale manual construction of sub-surface drainage system. Perforated clay tiles were designed and the design was given to a local village potter near the drainage installation site in Assam. Clay tiles of 10 and 15 cm diameter were used. Coir rope winding was given at the tile joints as additional filter to avoid any chance of soil movement into the tiles. Perforations over the tile enhanced the water flow into the tiles. These were used for sub-surface drainage installation in a number of tea gardens varying in area from 11 ha to 60 ha (Figs. 3, 4a and 4b). The systems have been functioning for the last 20 years.

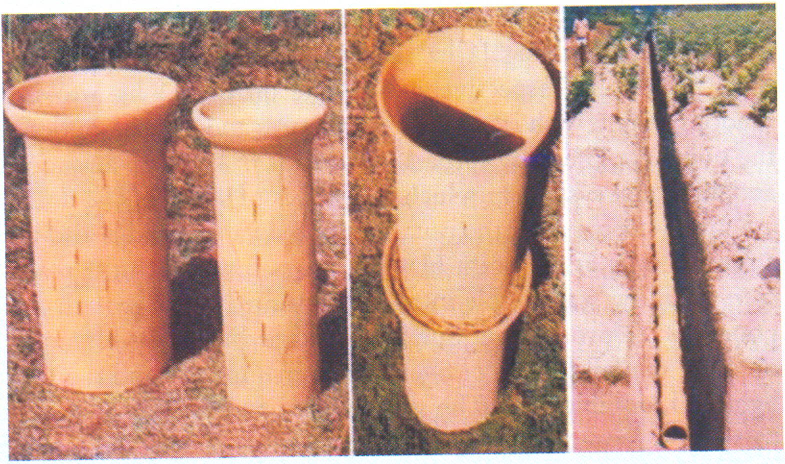

Fig. 3. Perforated baked clay tiles, their fixing, and layout

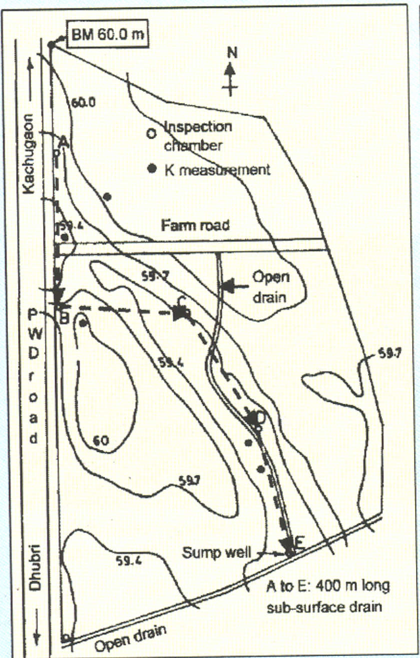

Fig. 4a. Random layout of subsurface drainage in an 11 ha tea garden in Assam

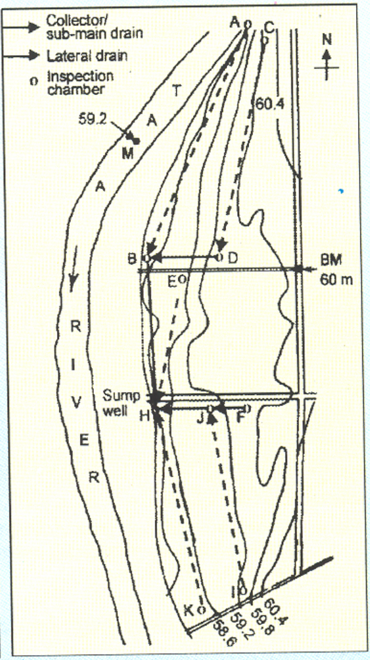

Fig. 4b. Near-parallel subsurface drainage layout in a 17 ha tea garden in Assam

Sub-surface drainage for water table control. Two layouts of the sub-surface drainage system for water table control in two tea gardens measuring 11 ha and 17 ha in Assam are shown in Figs. 4a and 4b, respectively. The one on the 11 ha area is a random system with intervening structures and a pump outlet at the point E. The one on the 17 ha area is in between a random and a parallel system in which the slopes of some of the drains are much steeper than the usually adopted values, and it also has a pump outlet at the point H. The problems at both the places were: shallow water table in patches, stunted plant growth and poor leaf tea production. Surface drainage was infeasible under the high rainfall feature of over 3600 mm annually and the very light and unstable soil. The stunted root and plant growth due to shallow water table in the absence of drainage, the fate of surface drain in such soils and the plant growth with sub-surface drainage are shown in Fig. 5. The intervention of sub-surface drainage resulted in an increased tea production varying from 20 to 30 per cent at different locations. Besides, the sub-surface drainage entirely eliminated the need and high maintenance expenditure of the deep open surface drains for water table control. The open drains used to be severely damaged every year during the monsoon season.

Fig. 5. Stunted root and plant growth due to waterlogging, (A & B) damaged open drain under high rainfall in sandy soil (C) and good plant growth with sub-surface drainage in a tea garden (D) in Assam

Subsurface drainage for salinity control. All irrigation water contains dissolved salts and continuous irrigation keeps on adding salt to the cropland. Salts may also be added if there is seawater ingress as occurs in the coastal agricultural lands. Too much of salt in the root zone does not permit the plants to take up nutrients. This leads to over application of fertlilisers, which is harmful to the ecosystem. Subsurface drainage controls the water table and facilitates salt leaching from the root zone soil layer. Figure 6 shows the salt concentrations in the drainage effluent from a reclaimed land and from a land under reclamation by subsurface drainage in the farmers' rice fields in the coastal region of Andhra Pradesh near Machilipatnam. It is seen from Fig. 6 that owing to the operation of subsurface drainage system, the drainage effluent salinity came down to less than 5 g/l (≈ 5-6 dS/m), which is safe. In contrast, the prevalent condition at the start of subsurface drainage showed drainage effluent salinity close to or greater than 20 g/l (≈30 dS/m), which is unsafe even for moderately salt tolerant rice crop. While rice productivity was less than 1 t/ha before drainage, it increased to 5.6 t/ha after reclamation due to subsurface drainage.

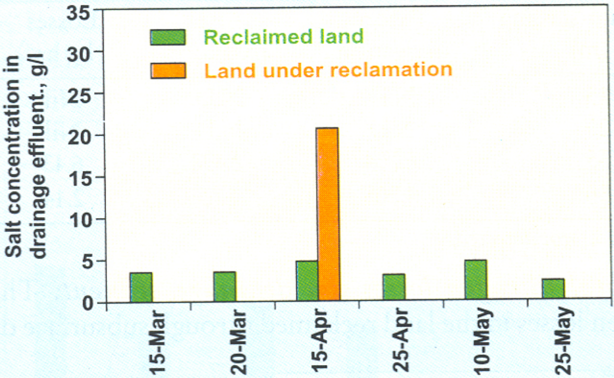

Fig. 6. Subsurface drainage effect on salt

Subsurface drainage continuously removes salt solutions from the drained land. It is, therefore, apprehended that nutrient solutions may also be lost through the drainage effluent. This was studied by analysing the drainage effluent samples collected at the inspection chamber (Fig. 7).

Ammonium losses through drainage effluent. In subsurface drained cropland, ammonium losses occurred via drainage effluent while reclaiming the saline-sodic coastal clay soils. The narrower the drain spacing, the higher was the loss (Table 3), with an average varying from 5 to 6 per cent of the total nitrogen loss. There was no ammonium loss from the already reclaimed areas with 15 and 25 m drain spacing. The losses would be more after applying the first dose of nitrogen at transplanting, as it coincides with the initial stage of plant development when the plant uptake of nutrient is low.

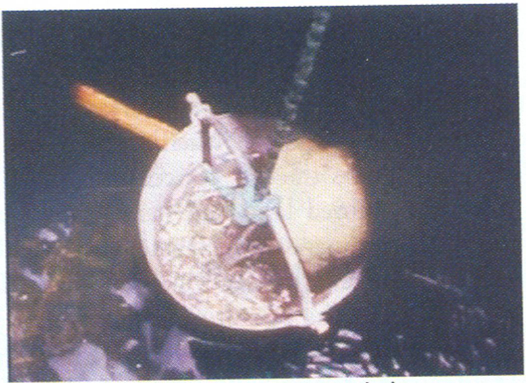

Fig. 7. Effluent sample collection for analysis

Table 3. Ammonium-N concentration (mg l^{-1}) in subsurface drainage effluent

Drain spacing (m)	Before irrigation	After irrigation	Losses (kg ha^{-1})
15	N.D.	N.D.	Nil
25	N.D.	N.D.	Nil
35	6.704	2.438	6.43
55	4.205	1.65	2.14

N.D.: not detected.

Total nitrogen losses via drainage effluent. The total nitrogen losses in the land reclaimed through subsurface drainage

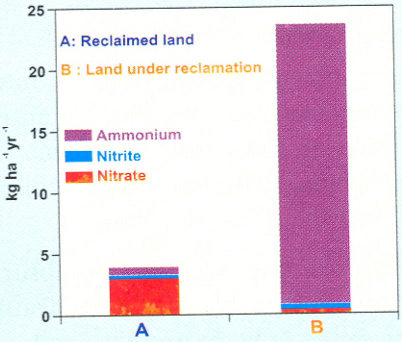

Fig. 8. Various forms of nitrogen loss via subsurface drainage effluent

was 3.744 kg/ha per year and the nitrate loss comprised 82% of the total nitrogen loss. The total nitrogen losses at the initial phase of reclamation by subsurface drainage were 4 to 8 times higher and comprised 90 to 96% as ammonium loss (Fig. 8). As a result, it was recommended that during reclamation, the basal dose of nitrogen (60 kg/ha) is to be applied in 3 equal splits separated by an interval of 10 days and the drainage operation is suspended for a few days after the nitrogen application.

Nitrate in groundwater of subsurface drained land. In a saline-sodic rice field reclaimed with 15 m drain spacing, after a decade of subsurface drainage and at a nitrogen application rate of 120 kg N/ha in each of the two rice cropping seasons in a year, the highest accumulation of nitrate in the groundwater was 1.5 mg l^{-1}. In the area under reclamation, with 35 and 55 m drain spacing, the usual dose of nitrogen was applied just for one year. In another area with 25 m drain spacing, the subsurface drainage was stopped for the purpose of investigation and nitrogen was not applied, as the field was left fallow. In both these cases, the nitrate in groundwater reached to about half the above value in just one year (Fig. 9).

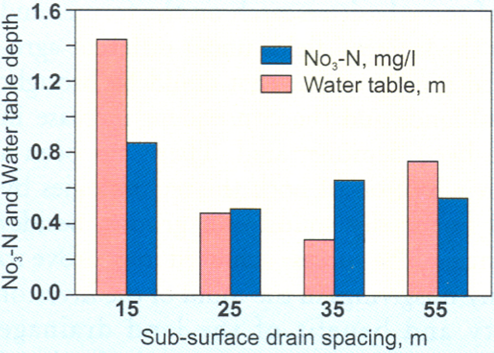

Fig. 9. Nitrogen in groundwater in a reclaimed land and that in a land under reclamation

Impact of subsurface drainage on nitrite accumulation. In waterlogged and saline-sodic soil, the process of nitrification is restricted due to the limited presence of nitrifying bacteria. This may cause nitrite toxicity to the plants due to nitrite accumulation on account of incomplete nitrification process. Sub-surface drainage enhances soil aeration and brings down salt concentration in the root zone, providing a better environment for the nitrifiers to function. This hypothesis was conclusively proved in the saline-sodic and waterlogged rice fields in coastal Andhra Pradesh. An earlier reclaimed rice field with 25 m drain spacing was deliberately left fallow without drainage operation for three successive years. As a result, the nitrite accumulation in the rice root zone grew exponentially (Fig. 10).

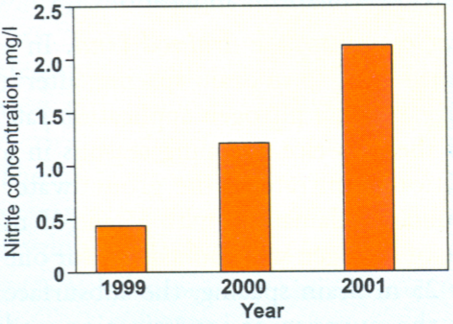

Fig. 10. Nitrite accumulation over time in the absence of drainage

Prospects of the Technologies

This success story revolves around two fundamental land drainage technologies, namely, surface drainage and subsurface drainage. On the basis of some basic research on the former and the adoption of both in the farmers' fields under different agro-ecosystems, the potential improvement that could be brought about in the agricultural lands and the consequent increase in their productivity have been demonstrated. There has been a reasonable success in the adoption of both the technologies by the knowledgeable and financially sound user groups, besides some governmental agencies. The success achieved may prove to be useful in removing any misgivings in the mind of the investor about the adoptability and benefit of the land drainage technology. In view of the increasing pressure on the land and the water resources, many a time leading to their deterioration and reduction in production potential, the land drainage technology holds promise for the future. It is useful in checking the degradation of the land and the water quality and is also capable of turning the degraded land into a productive land on a sustainable basis.