Salinity and sodicity management in Pakistan

BACKGROUND

Salinity is traditionally associated with irrigated agriculture in Pakistan. Three main causes can be identified:

- Genetic salinity due to weathering of saline parent material
- Capillary rise of salts due to a rise in groundwater tables
- Use of poor quality groundwater for irrigation

The massive development of private tube wells in Pakistan, estimated to exceed 500,000 at the moment, makes the threat of salinisation through the use of groundwater an important challenge.

Salinity mainly affects the water root uptake of plants and thus the yield of crops. *Sodicity* degrades the soil structure, impacting on crop yields. WAPDA estimated that 10.7% of the soils in the Indus Basin are saline, 23.6% are saline-sodic, and 3.5% sodic. These figures emphasises the importance of sodicity, in addition to salinity.

Measures that have been taken to control salinity and sodicity have mainly focused on drainage. Recently, the government of Pakistan has encouraged the joint implementation of irrigation and drainage measures (e.g. FESS project). The IIMI-Cemagref research project focused on the identification of irrigation policy and management options that would mitigate salinity and sodicity, thus providing support for the implementation of these options.

Policy issues

Groundwater exploitation
How to make optimal use of the available groundwater resources in conjunction with canal water, to avoid land degradation?

Economic and environmental impact
How to find a balance in agricultural productivity and environmental sustainability and how to assess the impact of proposed interventions on these issues?

Reallocation of canal water
In the present context of water scarcity, adequate supplies are not available for all farmers. The question becomes then how to allocate canal water, keeping in mind the agricultural productivity, but also its sustainability (salinity, sodicity, groundwater mining). The political and technical feasibility of reallocating and distributing canal water needs to be studied.

Information system
How to ensure an adequate and continued flow of information on environmental issues between the field, managers, researchers and policy makers?

Financial costs of irrigation versus drainage measures
In the present context of financial scarcity, a solution package has to be determined that minimises the costs of intervention by combining irrigation and drainage, and at the same time that maximises the benefits.

RESEARCH RESULTS

Salinity and sodicity are natural pher omena, but are influenced by human interventions. The research, therefore, focused on analysing both bio-physical processes as well as farmer management. In addition, a methodology was developed for large scale salinity and sodicity surveys.

BIO-PHYSICAL PR OCESSES

- Irrigation with groundwater rich in sodium and bi-carbonates, leads to the sodificatior of the soil profile
- Land degradation occurs at fairly low levels of sodicity (Exchangeable Sodium Percentage (*ESP*) of 4) due to the illitic nature of the clay minerals. This corresponds with recent findings in Australia, but is much lower than earlier assumptions, which was based on American research (Richards in 1954 presented a critical limit of *ESP* 15).
- Sodification oc curs rapidly; the first signs of soil degradation (surface crusts, hard soil layers) appear after 1-2 irrigations.
- Salinisation th ough capillary rise occurs when the groundwater table is at 2 m or les s.
- Irrigation watc r quantity and quality are determinant factors for soil salinity and so licity.

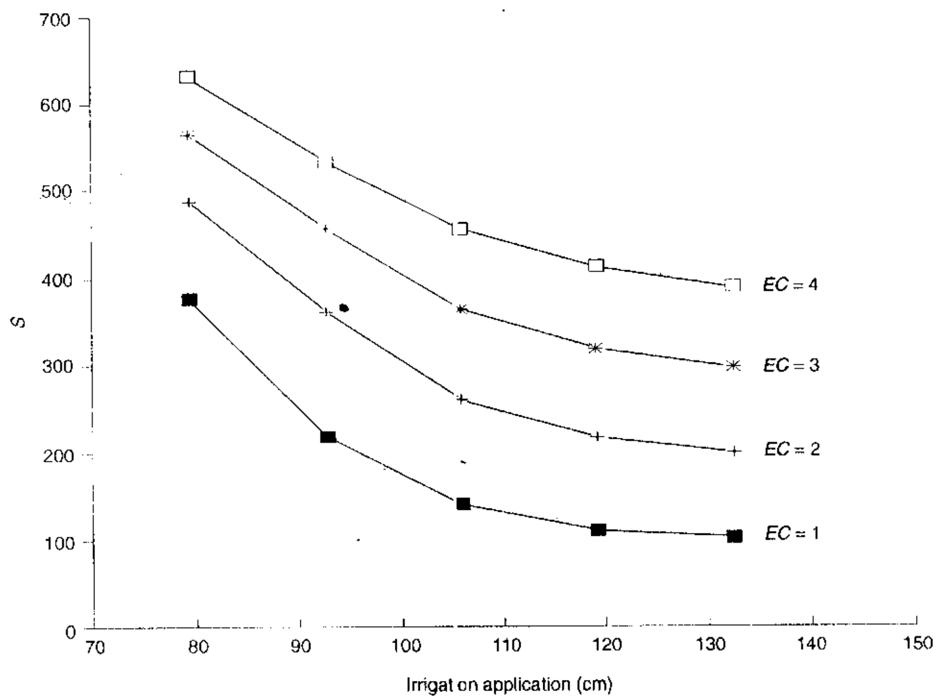

Figure: Irrigation water quantity and quality are determinant factors explaining soil salinity and sodicity. Here the total number of salts, *S*, in a soil profile (in mg/cm^2) of sandy loam is presented as a function of the water quality (in electrical conductivity, *EC* in dS/m) and water quantity (in cm).

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Research Issues

- *Salinisation and sodification* are two distinct processes with different causes and requiring different policy and management interventions. These processes, therefore, need to be analysed separately.

- Salinity is traditionally associated with irrigated agriculture due to weathering of saline parent material and capillary rise of salts due to a rise in groundwater tables. A more recent threat is posed by *the use of poor quality groundwater* for irrigation. The recent deployment of more than 500,000 private tube wells in Pakistan makes this threat an important research issue. The use of groundwater in conjunction with canal water should, therefore, be studied for its impact on salinity and sodicity.

- Due to the *spatial heterogeneity* in environmental factors (depth to groundwater table, soils, groundwater quality, canal water allocation) and the *diversity in farmers* (objectives, resources, constraints), special attention needs to be given to formulating research that captures this diversity.

- Different policy and management options can be considered to address salinity and sodicity. To evaluate the effectiveness of these options, *tools* need to be developed to quantify the impact of these options on salinity and sodicity.

- Salinity and sodicity exhibit *dynamic properties*, related to climate, hydrology and soils. Capturing the salinity and sodicity at a given time does not have much value. Instead, the factors explaining the state and the dynamic of salinity and sodicity should be determined.

- *Canal water* is singled out by farmers as the most important factor for salinity and sodicity control. The feasibility of reallocating and redistributing canal water should be investigated.

- *Assessing salinity and sodicity for large areas* is not an easy task given the dynamics of these phenomena and the fact that the determination of salinity and sodicity levels is rather cumbersome, involving laboratory analyses. A methodology for a large scale survey needs to be developed to take these problems into account.

RESEARCH METHODOLOGY

- Physical and chemical processes leading to salinity and sodicity were studied at the field level by employing deterministic models that are based on physical laws that have been proven to govern these processes. These deterministic models (separate models for salinity and sodicity) were calibrated and validated for the existing situation.

- Once calibrated and validated the models were used to carry out sensitivity analyses in order to quantify the relative impact of the different physical factors that cause salinity and sodicity, showing the importance of the quantity and quality of irrigation water. Another important finding was the dynamic of salinity and sodicity, depending on the irrigation regime, the climate, and the soils.

- Land degradation as a function of the sodicity level was quantified through physical measurements of the soil structure, providing evidence of soil degradation at ESP levels as low as 4. In addition, this process was found to be rapid with signs of soil degradation appearing after 2-3 irrigations.

- The models were also used to evaluate the impact of farmers' management on salinity and sodicity in order to determine whether farmers could contain salinity and sodicity if more canal water would be made available to them. The physical model describing salinisation is easier to use than the geo-chemical model describing sodification. The latter model incorporates both physical and chemical processes, complexifying the studied relationships.

- *Farmers' salinity and sodicity management* was studied in the larger context of the farming systems to understand their constraints in managing salinity and sodicity in order to formulate matching policy and management interventions.

- The results of the salinity and sodicity analyses were combined with studies of the canal irrigation system in order to assess the technical feasibility of reallocating canal water through simulation models in order to mitigate salinity and sodicity.

- *Large-scale surveys* were undertaken for the entire study area (70,000 ha) through different means: remote sensing, visual observations (in collaboration with Directorate for Land Reclamation), and a Soils/Hydrological survey (in collaboration with the Soil Survey of Pakistan). The strengths and weaknesses of these approaches could thus be established.

- The information collected was stored in a *GIS*, combining soils and physiography data with information on depth to groundwater tables and groundwater quality. This provides a good means for analysing the salinity and sodicity risk and providing opportunities for discussing these analyses with researchers, managers, and policy makers. The data collected provide an interesting scope for continued efforts in this field.

LARGE AREA SURVEYS

- The characterisation of the soil salinity and sodicity in an irrigation system must be *dynamic* and must be based on an *understanding of the processes* leading to these phenomena. A map representing the salinity/sodicity status for a given time period is not sufficient to take appropriate policy decisions to mitigate salinity and sodicity. Salinity and sodicity levels are fluctuating and there are multiple causes of these phenomena, which need to be considered to identify policy and management interventions. This was illustrated for a 14,000 ha command area. Supplying extra canal water to areas with high salinity levels was found to be less effective, in terms of mitigating salinity and sodicity, than supplying extra water to areas with poor quality groundwater.
- A salinity or sodicity risk map for the Indus Basin can be prepared by mapping the soils (soil physical and chemical properties, drainage capabilities), the groundwater quality, the depth to groundwater table and the canal water supply. These were the factors found to determine salinity and sodicity. Most of these data can be obtained from different government agencies.
- Salinity and sodicity in barren areas can be easily recognised through remote sensing. In cultivated areas this is much more difficult.
- The influence of farmer and irrigation agency management on salinity and sodicity is considerable. This factor should not be neglected while carrying out a large scale survey. Differences in farmers' objectives and constraints, such as tenancy, may explain certain salinity patterns, but will also require the formulation of different policy and management options.

FARMER MANAGEMENT

- Farmers have a long experience in dealing with problems of salinity and sodicity. They have a series of management practices to deal with these problems, including water management, crop choice, cultural practices, and biotic and chemical amendments.
- Modelling results showed that the water management practices of farmers have a considerable impact on salinity and sodicity. This is due to the fact that the irrigation water quantity and quality, generally resulting from a mix of canal and groundwater, are determinant factors for salinity and sodicity.
- Farmers' salinity and sodicity strategies are related to overall farm strategies (e.g. profit maximisation) and constraints (credit, labour, tenancy) and to their experience in dealing with these issues. Extension messages need to be adapted to these differences in farms.

TOWARDS AN INTEGRATED APPROACH: IRRIGATION AND DRAINAGE POLICY AND MANAGEMENT

- Irrigation management can contribute to the management of salinity and sodicity, by changing the quality and quantity of irrigation water available with farmers. This can help minimising (costly) drainage requirements.
- It is technically feasible to reallocate canal water resources. For an area of 14,000 ha it was shown that in doing this the area threatened by sodicity, could be reduced by 40%.
- Salinity and sodicity are directly managed by farmers. Irrigation and drainage measures should, therefore, aim to increase the capability of farmers to deal with salinity and sodicity. In irrigation management this means that farmers obtain a certain control over the water resources and are free to interchange water turns (e.g. through water markets). In drainage management this means giving farmers the possibility to regulate water levels.
- In order to deal with a highly variable environment (soils, groundwater quality, ..), a large set of policy and management interventions should be considered. To assess the impact of these different interventions in different contexts, it is important to have access to tools that can help in determining the impact on salinity and sodicity.

Policy implications

Extension on Salinity and Sodicity Issues
Training should be provided to extension agents on the distinction in causes and treatment between salinity and sodicity. This is required to provide extension services to farmers that are better adapted to farmers' constraints. There needs to be a range of extension messages to cater for the variety of environmental constraints farmers are faced with.

Environmental Monitoring System
Financial and human resources should be allocated to combine and analyse existing information collected through regular monitoring (soils, groundwater table depth, groundwater quality, canal water supplies) in order to provide maps displaying the salinity and sodicity risk, groundwater mining and other environmental issues. The data collection of individual agencies needs to be targeted towards the integration of information and the results directed towards policy makers for making appropriate decisions.

Canal Water Allocation
If a reallocation of water resources is considered, it is recommended to take the salinity and sodicity risk into account. The information provided by the environmental monitoring system will be of use for this. It is necessary to study the political and technical feasibility of reallocating water between canal commands of the Indus Basin.

Farmer management of salinity and sodicity should be analysed to better match potential policy and management interventions aimed at mitigating salinity and sodicity with farmers' needs and constraints.

FOLLOW-UP RESEARCH ACTIVITIES

- *Analysis*: The analyses of this project determining the origin, causes, and dynamic of salinity and sodicity need to be extended to the entire Indus Basin, thus facilitating the implementation of the Environmental Monitoring System. These analyses should include the determination of the different environmental and human factors influencing salinity and sodicity. These analyses will need to constitute a sustained effort even after implementation of SIS.
- *Large area surveys*: There is a need to develop a methodology for large area salinity and sodicity surveys. These surveys should focus on the environmental factors leading to salinity and sodicity, thus capturing the dynamics of salinity and sodicity.
- *Tools*: The use of tools, describing and simulating relationships between environmental factors and salinity and sodicity, should be enhanced to allow for a well functioning Environmental Monitoring System.
- *Extension messages*: Research results need to be translated into clear messages that extension agents can use in their interactions with farmers. These messages must be adapted to the large variability in environment (groundwater tables, soils, groundwater quality) and farming systems (credit, labour).