Irrigation induced soil degradation in semi-arid India and its management: A case study

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India has made significant investments in creating an irrigation potential of > 50 M ha. However, the irrigated areas, which have contributed significantly in increasing food grain production are now facing serious problems of rise in ground water-table and soil salinization. The impact of soil degradation processes is not limited to national boundaries. There are evidences to show that the land degradation processes, such as loss of organic matter and increase in carbon dioxide contents are contributing to global changes affecting adversely the humanity at large. In order to understand the menace of irrigation induced land degradation in arid and semi-arid zones of India a case study was carried out with the objectives. i)To study the changes in hydro-physical behaviour of dominant soil series with change in irrigation intensity and irrigation induced salinisation and alkalization, ii) To study the effect of irrigation induced salinisation and alkalization on dispersion and swelling behaviour of these soils and iii) To develop agro-techniques to reclaim saline and alkaline soils for enhanced productivity.

Most of the soils of head reaches were alkaline, those of middle reaches were saline and those of tail reaches were normal in reaction. Fine textured soils outside the command area were normal in reaction, calcareous in nature with normal swelling and dispersion behaviour. If these soils are brought under stressed irrigation in tail end, the soils remain normal with accumulation of some salts in upper layers. Because of frequent irrigation soils became saline in reaction with EC > 8.0 dSm^{-1}. However, under intense and heavy irrigation situations, as at head end, soils tern alkaline with pH>8.5. This observation is well supported by the data obtained on Ca^{2+}+Mg^{2+}, Na^{+} and $CaCO_3$ content. Calcium carbonate played a major role in degradation of these soils. As the intensity of irrigation increased, exchange sites occupied by calcium and magnesium were replaced by sodium resulted in precipitation of calcium as $CaCO_3$. This observation also indicates that development of salinisation and alkalization starts simultaneously but the hazard of salinisation appears much earlier than alkalization. Infiltration rate was determined near the profiles using double ring infiltrometers. Clay, clay loam and sandy clay loam soils outside the command area had steady state infiltration rate of 4.5, 9.2 and 54.0 mm h^{-1}, respectively. Infiltration rate reduced drastically with the intensity of irrigation. Such reduction was large in clay as compared with clay loam and sandy clay loam soils. Saturated hydraulic conductivity values also showed the similar trend. In fine textured alkaline soils of head reach, it was difficult to determine saturated hydraulic conductivity even with falling head methodThe tendency of retaining more water with increase in intensity of irrigation was more prominent in fine textured soils than medium and coarse. This is mainly because of (i) increase in alkalization facilitated higher dispersion of clay and silt particles and (ii) relatively higher swell-shrink potential of these soils. Dispersion and swelling increased the total surface area exposed by the clay minerals resulted in higher water retention. A net decline in unsaturated hydraulic conductivity of all the soils was observed with increased intensity of irrigation over the respective soils outside the command area. This showed that the intensive irrigation practices lead to poor hydraulic conductivity and may result into waterlogging. Irrigation induced changes were more prominent in clay soils under low water content range and in sandy clay loam in high water content range. However, clay loam soils exhibited little changes only in low water content range. Soil-water diffusivity data also showed the similar behaviour to that of unsaturated hydraulic conductivity data. Degree of deterioration was much less in clay loam than the clay soil. This may be because of differences in clay mineralogy of the two soils. The case study clearly brought-out the ill effects of injudicious use of irrigation water on fine textured soils of semi-arid India.

Keeping in view the fact that plant growth can be restricted or entirely prevented by increased levels of salinity and alkalinity in the soil, these soils have to be reclaimed so that they become productive. The processes of accumulation of salts and build-up of ESP have to be reversed. To achieve these objectives, provision of adequate drainage, replacement of Na^+ ions from the exchange complexes and leaching out of soluble salts below root zone were ensured. For reclaiming these soils different methods were tried e.g. physical, chemical, hydro-technical and biological. Physical methods include deep ploughing, sub-soiling, sanding, profile inversion, scrapping etc. Hydro-technical methods include leaching of salts, provision of drainage, use of leaching curves etc. Under chemical methods, application of gypsum was the prominent one. Other chemical techniques include application of calcium chloride, calcite, phospho-gypsum and iron pyrites etc. Biological methods include green manuring, addition of FYM and other organic manures, incorporation of crop residues and press mud. Within a period of 3-5 years large areas affected by salinization, and alkalization were reclaimed. Among the various management practices, use of green manuring was proved to be highly effective in rapid reclamation of irrigation induced degraded soils. Reclaimed soils showed similar hydro-physical and chemical properties as that of normal soils with significant yield increase. Water and nutrient-use efficiencies were considerably higher in the case of reclaimed soils than that of degraded soils.

Water Management in Problematic Soils of Canal Commands

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The scientific water management aims at providing suitable moisture environment to crops for obtaining optimum yields with corresponding economy in the use of irrigation water and maintenance of soil productivity through check on rise of ground water table and secondary salinisation. During the periods when actual evapotranspiration (ET_a) exceeds precipitation(P) and their being no contribution from the ground water table to crop ET, the crops need irrigation, if the soil moisture stress exceeds a thresh hold value. Irrigation requirement of crops is highly location specific and is influenced by the climate, soil, choice of cropping systems and other factors. In problematic soils, the irrigation management is very much different from that practiced in normal soils because of differences in their physical and chemical properties. Amongst problem soils also, there are wide variation in the properties requiring different irrigation management practices for crops. In alkali soils, which are relatively less permeable, light and frequent irrigations are required whereas on saline soils, the major consideration is to reduce the salt concentration through leaching to maintain the salt balance in the root zone profile below the critical value.

Soil characteristics considerations for water management

The problem soils of Sutlej-Ganga plains generally form a part of some what low lying, flat terrain and predominantly sodic with excess of exchangeable sodium. The sodium saturation on soil exchange complex may be as high as cent percent. The excess soluble salts comprise chiefly of carbonates and bicarbonates which cause high pH of these soils. Usually the pH ranges between 8.5 and 10.5. The sodic soils in the Vertisol region of Gujarat and Maharashtra generally have excess of chlorides and sulphates of sodium in the solution phase and because of their high buffering capacity, their pH is usually less than 9.0.

These soils lack adequate amounts of soluble and exchangeable calcium to support normal crop growth. Owing to high value of exchangeable sodium percentage (ESP), these soils are structure less and highly dispersed. The fine clay particles when settle down, seal the pore spaces thereby imparting very poor transmission characteristics. The intake rate of water determined over prolonged period has been found to be as low as 9 mm/day. The corresponding figure on normal soils is several times more. It is a common observation that on sodic soils, water accumulates following a rain storm or a heavy irrigation. It remains on the soil surface for long periods until it is evaporated and hardly penetrated few centimeters in the soil profile. During the drying process, particularly in the periods of high atmospheric evaporative demand as in summer months, the soil surface gets dried up very quickly but there is practically no change in the water content below 15 cm depth. This indicates a very poor upward water flux to replenish the water loss taking place at the surface. Although low soil permeability of sodic soils is a desirable feature for rice cultivation yet other crops suffer badly.

The water holding capacity of a soil is a function primarily of soil texture but increasing sodicity in the soil results in greater moisture retention at higher soil suction thereby reducing the available water capacity of the soil for crop water use. Presence of a compact sub-soil layer of bulk density as high as 1.7 g/cm^3 in these soils does not permit crop root growth deeper in the profile. Exposition of roots of wheat, raya and castor have indicated that the roots hardly go 20cm deep whereas, in a normal soil, they have been observed to be more than a meter deep. Thus, the volume of soil from which the moisture can be tapped by crop roots further shrinks. Poor permeability characteristics, typical drying pattern, presence of compact subsoil layer, low available soil moisture storage capacity of sodic soils coupled with restricted root growth calls for a very careful water management for successful crop production.

In saline soils, the major problem is of reducing the salt concentration through effective leaching. In case saline soils have been developed as a result of high water table of poor quality, drainage will be inevitable.

Irrigation Scheduling in Crops

Rice is the principal crop to be grown in sodic soils during kharif season. It being a semi-aquatic plant, needs submerged moisture regime for optimum grain yield. High yielding, dwarf rice varieties require only shallow submergence (about 5 ± 2); deeper submergence reduced crop yield. Highly dispersed condition of sodic soils, obviates the need for puddling, which is inevitable on normal soils. Poor moisture transmission characteristics of these soils help maintain submerged moisture regime with ease as compared to normal soils. The total irrigation requirement is also considerably reduced when compared with normal soils. Field experiment conducted for 4 years revealed that during lean periods, application of 7cm irrigation after one day of disappearance of ponded water produced as much grain yield as the treatment of continuous submergence but with a saving of about 27% in irrigation water. Delaying irrigation to four days after disappearance of ponded water, though economized irrigation water by 56%, yet the grain yield was reduced significantly as compared to continuous submergence. Besides adverse moisture stress effect in the former treatment there was also more loss of nitrogen through volatilization there by resulting in low nitrogen use efficiency. Moisture stress during tillering and heading stages as monitored by with holding irrigation for one week, resulted in significant reduction in grain yield.

During rabi season, whet, barley, barseem, raya, sugarbeet maybe grown with success in the problem soils. Wheat, barley and rant can't tolerate standing water and also relatively wet moisture regime whereas barseem and sugarbeet, will perform better with the latter moisture regime. In view of poor moisture transmitting properties of alkali soils, light and frequent irrigations to these crops are desirable. Heavy irrigation may result in water stagnation on soil surface. For wheat at Karnal in early years of reclamation, 8 to 9 irrigations have been found optimum in sodic soils as against only4 to 5 irrigations in normal soils. The irrigation interval for wheat may be of three weeks during November, December and January; two weeks during February and 10 days during March. As against the common belief of first irrigation at CRI stage, this could be delayed to 30-35 days without any reduction in crop yield.

In barseem, more frequent irrigation is necessary for higher green and dry fodder yields but on the basis of water productive efficiency, irrigation at 60 mm CPE was better than the schedule of 40 mm CPE.

At certain places excess soluble salt also occur alongwith high ESP which necessitates adoption of special planting methods such as planting on sides of ridges in a ridge and furrow layout. During winter months, the position of the sun remains southwardly thereby resulting in more water evaporation from southern face of the ridges which are oriented in East-West direction vis-à-vis higher salt accumulation on the southern face of the ridge. Accordingly, to avoid salt damage to crop a plant, planting is done on the northern face of the ridge where the salt concentration remains low. In a field trial with sugarbeet, raised flat beds alternated with a narrow furrow and oriental in North-south direction, produced higher root yield of sugarbeet and also effected economy in irrigation water to the extent of 17%. Irrigation application at 40 mm CPE (Cumulative Pan Evaporation) value produced the highest beet yield. Delaying the irrigation beyond this value resulted in significant reduction in crop yield. the response to irrigation was amplified with addition of nitrogen; the magnitude being higher in raised flat beds than in ridge and furrow layout.

Dhaincha is a good green manure crop in sodic soils during summer months after harvest of rabi crops. Irrigation water source is available; it should be grown to hasten the process of alkali soil reclamation. The irrigation requirement of dhaincha is, however, more. About 15 irrigations at 50 mm CPE have been found optimum at Karnal.

Choice of Irrigation Method

Adoption of a suitable method of irrigation in salt affected soils is of a paramount importance in view of the poor moisture transmission characteristics of sodic soils and higher concentration of soluble salts in saline soils. Invariably, surface methods of irrigation; result in excess irrigation even under best design of the method and regulation of the water supply. Graded borders, about 90 meters long with 0.1% slope, have been found suitable for irrigation of wheat in alkali soils. With low cut-off ratio, there was higher application efficiency and it reduced with increase in the ratio. Since rice is an important crop in sodic soils and which require submergence during its growing cycle, it is necessary to have level plots for optimum efficiency thus, an irrigation method which has been found suitable for wheat is not good for rice. A field trial where compartmentalization of graded borders into 1, 2 and 3 compartments was made, has shown that three compartments of a border gave higher crop yield and higher uniformity co-efficient.

Sprinkler method of irrigation may be used on sodic soils because the application rate can be regulated by changing the size of the nozzle in order to match the intake rate of the soil. This method will avoid stagnation of water on soil surface even for a smaller period which is a common feature in surface method of irrigation. In saline soils, sprinkler irrigation will maintain only downward flux of salts, since the surface layers remain relatively moist due to frequent irrigation. The initial investment on the system is the only hurdle in its quick adoption. For wide row crops, such as horticultural crops (Ber, Guava etc.), use of drip irrigation will be desirable. This will not only maintain wet moisture regime in the soil profile but also keep the soluble salts away from the root zone. Drip irrigation method is being widely used in some of the developed countries on a large scale and also in India. Despite its many advantages, the prohibitive cost of the system and subsequently delicate maintenance, restrict its wider use under Indian conditions, at present.