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Amelioration of Salt Affected Soils

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Abstract: The amount of salt-affected soils in Pakistan varies in different places. In humid regions the salt problem is limited unlike arid and semi-arid areas, salt accumulation and water logging mainly threaten Agriculture. Our country exports agriculture commodities, but its exporting quantity is going to be low day by day due to salt problem. It is economical to undertake salinity/sodicity in control limits in order to use that land for agricultural production as well as buildings could be safeguard from the hazard of salt and water logging. The soluble salt that occurs in the soils consists mainly of ions: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), chloride (Cl^-), sulfate (SO_4^{2}), bicarbonates (HCO^-_3) and carbonate (CO_3^{2}). As a result of chemical decomposition and physical weathering these constituents (salts) are generally released and exists on the soil surface or on the crop root zone. A high concentration of such salts interfere the growth of plants, reduces the crop production and land value. The control of this problem is prime important for maximizing and sustainable agriculture. The control of the salts can be through soil applied amendments like gypsum, acids, sulfur, HCl, pressmud, molasses and various field practices including plowing, irrigation, surface flushing, leaching and drainage practices.

Keywords: Soil salinity, Amelioration, Management

Characteristics of salt affected soils: According to U.S. Salinity Laboratory (1954) there are three main categories of salt affected soils, namely saline, saline sodic and sodic soils. The term saline-sodic is commonly used for soils, which have a high content of soluble salts and high Sodium Absorption Ratio (SAR 15) in the saturation of soil extract. It has been argued (Bhumbia and Abrol, 1979; Abrol and Bhumbia, 1978) that the soil so called saline-sodic and saline are not different from each other and that both should be categorized as saline because in these soils plant growth is not likely to be affected owing the adverse effect of the excess exchangeable sodium on the physical properties of the soil. Saline-sodic soils have usually more than 40% exchangeable sodium and very low or nil permeability (Rafique, 1975). Michael (1978) defines saline soil as one which shows electrical conductivity (EC) of the saturation greater than 4 m.mhos/cm at 25C° and has exchangeable saturation percentage (ESP) value of less than 15. The absorbed (exchangeable) ions in saline soils are principal Ca^{2+} and Mg^{2+}. Calcium and magnesium of saturated soils are stable in water, are flocculated and are easily worked into granules and crumbs, their soil permeability are equal to or higher than those of similar non-saline soils and they usually provide a effect of salinity percent (Reeve and Fireman 1990). Alkali (sodic) soils contain sufficient adsorbed (exchangeable) sodium to interfere with the growth of most crop plants. Alkali soils (ESP>15) may be highly alkaline in reaction (pH =8.5 or above), but do not contain excessive amount of soluble salts. Israelsen and Hansen (1962) also reported that these soils contain excess soluble salts that make the soil solution sufficiently concentrated to injure and consequently impair crop productivity. Salt injury depends on species, varieties, growth stage and environmental factors (Ponnamperuma and Bandyopadhya, 1980). However, researchers fully recognize saline soil as it has ECe more than 4 m.mhos/cm. Sodic soils have poor physical condition characterized by low infiltration rate and hydraulic conductivity several times less as compared to unaffected soils (Abrol *et al.*, 1978).

Salinity problem in agriculture: Living things depends upon land and water as biological sustenance. To meet the challenge of increasing the agriculture production of the country, it is not only essential to increase the production per unit area but also to utilize unproductive lands for agriculture. In Pakistan out of 14 million ha of land, 8.5 million ha are salt affected (Shafique and Skogerboe,1983). Nearly 60% of these are saline-sodic in nature (Hassan *et al.* 1975). In Sindh salt affected area is 85% in upper Indus Basin (Zaidi *et al.* 1968) or salt affected area of Sindh is equal to the cultivated area. In irrigated areas, soil salinity is almost a universal problem and soil salinity would go increasing with the passage of time with application of irrigation. Thus, soil salinity is a wide spread problem in canal irrigated tracts of Pakistan; about 23% of salt affected soils fall within canal command area (NCA, 1987). The accumulation of salts on the lands of Sindh, Pakistan is the most common problem. This complicates the water management practices and reduces the land value in the irrigated areas; resulting unsatisfactory and uneconomical yield or failure of crop in these regions due to adverse effects or preventing owing to the effect of excess exchangeable sodium directly on plant growth or through its effect on physical and physiochemical properties of soils. Inadequate drainage is another factor intimately associated with the development of soil salinity. Some times soil salinity develops in spite of good quality irrigation water and good irrigation practices (Michael, 1978). Since the high concentration of salts acts adversely on the physical, chemical and biological properties of the soil. The accumulation of salts usually takes place during germination upto harvesting period in the crop root zone and was reported in less or non economic productivity of crop. It is due to improper drainage, soil, cultural practices, and unsuitable cropping sequences. The physical properties of soil may be improved or deteriorate despite the presence of salts depending upon the nature and amount of salts, soil amendments, and the initial physical and chemical conditions of the soil. The main physical properties influencing the air-water relationships in irrigated agriculture are markedly influenced by the nature and amount of exchangeable cations and swelling characteristics of the soil (Kovada, 1960). Cultural and drainage practices were also considered to be effective in the amelioration of the problem soils. These soils if brought under cultivation can contributed a tidy sum to total agriculture production of the country.

An irrigation system may be called successful, if apart from favourable social and economical aspects, the technical operation of the irrigation enables good crop growth for an indefinite period. The main causes of failure of an irrigation system are the possibility of waterlogging and stalinization of the soil. In recent years, the ill planning of last decade has created problems of drainage, salinity, and waterlogging and its adverse effects appeared on soil productivity. Many good books and papers have been written dealing with genesis, properties and dynamics of salt-affected soils (Bressler *et al.*, 1982), (Dent, 1986), (Szabolcs, 1989), management of salt affected soils and quality of irrigation water (Ayers and Westcot, 1985), (Chhabra, 1996), (Gupta and Abrol, 1995), (Mashali, 1999), (Pizarro, 1985), (Rhoades *et al.*, 1992), (Szabolcs, 1997) and (USSL Staff, 1982), among many others. Scientists have compiled a wide knowledge on salt affected soils in the past decades. Anyway the extension of soils affected by stalinization increases year after year due to cause of different nature i.e. (a) pressure for increasing food production has lead to intensive cropping using agrochemicals, with increasing demand of water and solute mobilization, (b) water sources increasingly scare, have worsened their quality by depletion of the best quality resources (in many cases with salinity induced by resultant saline ground water or marine intrusion), (c) correct management is not performed by several reasons (Mashali, 1999). Moreover the problem have been complicated by superposition of other like waste water use as irrigation water in many areas (Chhabra, 1996), heavy metals pollution and other (Ongley, 1996). It seems that there are some technological solutions capable of maintaining the rate of production under worsening conditions, but the access to such technologies is not always ensured for people dealing with the problems. There are new tools necessary for assessing and modeling future scenarios. In the past several indicator parameters (SAR or ESP, EC, pH, Ca/Mg ratio etc.) have been experimentally derived to easy assess the degree of salinity, its nature and for keeping track of the dynamics of salt accumulation/salt leaching and evaluation of conditions, in general, for such soils (Batlle Sales, 1999). New technologies derived from geophysics (electrical resistively survey, induced electromagnetic survey, time domain reflectometry (Rhoades, 1992) and others, provided valuable information in quasi-real time and allow for quick and easy treatment of the information required for "precision agriculture" in Geographical Information System, interfacing with remote sensors and existing database (Batlle Sales, 1999). Modeling at several sales has become a usual practice with purposes of research (Suarez, 1999), screening or management, using either deterministic models at point, plot or regional scale (Drever, 1997).

Sources of salt: Saline, saline sodic and alkaline soils are essential elements of arid zone landscapes.The drier the climate; the greater is the intensity of soil salt problem. The maximum salt problem can be found in the soils of complete desert. However, the formation and accumulation of salts in soils is due to a large number of geochemical process taking place in the upper strata of the earth's crust, with the weathering of the various rocks, the former links between the chemical elements are broken, giving place to new combination which may be in the form of either secondary clay minerals or various kind of oxides, or simple compound (Egorov, 1954).

The main elements, Ca^{++}, Mg^{++}, Na^{+} and K^{++} and its combinations give rise to the formation of salt affected soils. As Bouwer (1969) reported, nearly all known acids form salts which are found in varying quantities. The nature of salts however, may vary depending on the location of the soil as influenced by environmental factors and mineralogy of the soil.

Causes of salinity and alkalinity

- Use of saline irrigation water.
- Deposition of salts on soil surface from high subsoil water table.
- Seepage from the canals.
- Arid climate
- Poor drainage
- Back water flow or intrusion of sea water in costal areas.

The major process in the development of soil salinity and alkalinity in irrigated areas is transpiration evaporation and poor drainage. Various investigations have revealed that most of the watercourses are improperly designed, poorly maintained and carelessly operated, this results in considerably water loss, which in turn has adverse effects of salt accumulation on the plow layer. If the watercourses are lined properly the maximum efficiency and reduced water loss risks and salt accumulation on the surface can be minimized (Mirani, *et al.*, 2001). Accumulation of salts also happens due to application of saline waters. Appropriate water quality application would be possible, if, soil and water management practices would be improved and adequate water for leaching the salts is available. Water quality of tube wells has detoriate with time due to upcoming population and production pressures. The re-use of saline water is possible only by controlling the dilution ratio below the determintal effects on soils and crops (Bhutta *et al.*, 1996). Recently, Oad *et al.*, (2001d) from his various studies proved that saline water having ECe 3.0 m.mhos/cm can be used successfully by mixing with canal water in the proportion of 76%: 24% and 57%: 43% respectively. Other possibilities should be considered, such as excessively applied fertilizer or manure, or wind-blown saline water spray and particles.

Reclamation of salt affected soil by leaching: Leaching is the usual way to reclaim salt affected soils because plant solute uptake removes insignificant amounts of salt. It can be performed to areas where water for leaching is available. Nonirrigated areas only rely on natural precipitation for leaching. Salt leaching involves the dissolution of soluble salts in the soil, the passage of water through soil profiles, and the removal of salt from the root zone. Thus, soils to be reclaimed must be permeable and have outlets for drainage. Drainage systems may need to be established before soils with high water tables are leached. (Keren, 1990). Ramzan *et al.*, (1987), however reported that amelioration of saline sodic gypseferous could be achieved by simple leaching where as non-gypseferous soils could not be reclaimed without addition of amendments along with leaching. The extent of leaching requirement depends largely on initial salt problem, the salt tolerance of the crops, and the depth of the water table. The prevailing idea in earlier reclamation trials was to leach all excess salts from the entire depth of the root zone. However, under good drainage conditions the aim is to reduce salts in the top 45 cm to 60 cm of the soil below the threshold values of the crop. To reclaim salt affected virgin land the leaching may be conducted for several months or more. To reclaim cropped fields e.g. pastures and orchards, the leaching may take place in short time period by avoiding lack of aeration. Leaching generates highly saline drainage water, which can contaminate water and contribute to rising water tables. Evaluation of environmental and legal implications must be the part of any reclamation program (Keren, 1990). Recently, Mangio *et al.*, (2001) reported the mechanism of stalinization in water logged conditions that maximum salt concentration was specific rather than the surface which might happened due to non-uniform distribution of wind and varying water depths. The stalinization rate depends very much on the distance of ground water table from surface soil, soil moisture content and evaporation rate of the surface soil.

Leaching requirements: The amount of leaching needed to maintain a viable irrigated agriculture depends on the salt content of the irrigation water, soil, ground water table, the salt tolerance of the crop, climate and soil and water management practices. The only economical way to control soil salinity is to ensure a net downward flow of water through the root zone to a suitable disposal site. If leaching is inadequate harmful amounts of salt can accumulate within few cropping seasons.

The leaching requirement may be defined as the fraction of the irrigation water that must be leached through the root zone to control soil salinity at any specified level. This concept has greatest usefulness when applied to steady state water flow rates or to total depths of water used for irrigation and leaching over a long period of time. The leaching requirement will depend upon the salt concentration of the irrigation water and upon the maximum concentration permissible in the soil solution. The maximum concentration except for salt crusts formed by surface evaporation will occur at the bottom of the root zone and will be the same as the concentration of the drainage water from a soil where irrigation water is applied with aerial uniformity and with no excess leaching. During reclamation of salt affected soils, different depths of irrigation water are required depending upon the salt concentration, and depth of soils to be reclaimed. Qayyum and Malik (1983) reported that while reclaiming a saline sodic non-gypseferous medium textured soil found about 90% salt was leached down from upper 30cm layer by passing 19-28 cm depth of water and 80% salts moved down from upper 60 cm soil column by supplying 17-27 cm water. A saline sodic soil after the removal of excess soluble salts through leaching presents problem peculiar to sodic soils. For reclaiming such soils it is essential to improve their structure by replacing Na^+ on the exchange complex by Ca^{++} (U.S, Salinity Lab. Staff, 1954; Pearson, 1960).

Surface flushing: High concentrations of soluble salts are often found at and near the surface of the soil, especially in soils with shallow water tables. It is desirable to remove surface accumulated salts instead of leaching into the soil prpfile. However, Reeve *et al.* (1955) found that passing water over the surface by sheet flow failed to remove the salts. When plowed fields with a clay substratum are bedded and the alternate row leaching technique is used and the efficiency may improve. The physical removal of salt crusts by mechanical means is an alternative (Keren, 1990).

Reclamation of sodium affected soils by soil amendments

Concepts and Principles: Reclamation of sodium-affected soils usually involves replacing exchangeable Na^+ with Ca^{2+}. This Ca may originate from the dissolution of Ca^{++} containing minerals in the soil. Such amendments as gypsum and calcium chloride or Irrigation water with Ca^{++} ions. A significant factor in reclaiming sodic soils is the maintenance of hydraulic conductivity (HC) by providing a sufficiently high electrolyte concentration in the soil solution to counter the influence of exchangeable Na^+. Generally the higher the electrolyte concentration the higher the exchangeable Na^+ fraction at which a relatively high permeability can be maintained (Quirk and Schofield, 1955). McNeal and Coleman (1966) showed that soils responded differently to the same combination of electrolyte concentration and each soil has a unique threshold of salinity concentration. The electrolyte concentration affects the HC less when the contents of the soil water are low (Russo and Bresler, 1977). If the electrolyte concentration of the percolating solution is adequate to reduce clay swelling the permeability of the soil remains high. When low saline water (or rainwater) follows the saline water, permeability can be maintained by applying an electrolyte source on the surface of the sodium-affected soil. Applying a slow dissolving salt adds sufficient electrolytes to the rainwater to prevent clay dispersion (Keren and Shainberg, 1981), even if the Na-Ca exchange process in the adsorbed phase is limited (Keren *et al.*, 1983). The effectiveness of amendments in reclaiming sodic soils depends on their dissolution properties (Kemper *et al.*, 1975; Keren and Conner, 1982).

In spite of the documented effect of the electrolyte concentration in the soil solution on the permeability of the soil, the main criteria for determining the sodic hazard is the soil Era and the sodium adsorption ratio (SAR) of the saturation extract or irrigation water. However, soil sodicity cannot be assessed without information on the total electrolyte concentration of the soil solution (Keren, 1990). Amendments commonly used to provide soluble Ca^{++} include gypsum ($Ca\ SO_4.2H_2O$) and calcium chloride dehydrate ($CaS_{12}.\ 2H_2O$). Amendments used in calcareous soils include gypsum, sulfuric acid, sulfur, and iron most commonly used for reclamation due to their relatively low cost and effectiveness. Chemical amendments may improve water penetration caused by excessive sodium, if the texture of the soil, compaction or water restricting layers are not the cause of low permeability (Keren, 1990). Gypsum due to its solubility low cost and availability is the most common used amendment for reclaiming sodium-affected soil and reducing the harmful effects of high sodium irrigation water. Gypsum comes from both mines and as a by-product of the phosphate fertilizer industry. Under comparable conditions, the rate of dissolution of industrial gypsum is much higher than that of mined gypsum. (Keren, 1990). Gypsum has been a conventional supplier of the Ca^{++} ion for replacing excessive sodium on the exchange complex in saline sodic soils. In Pakistan large a proportion of saline sodic soils are calcareous. Dissolution of the free Ca CO_3 by acid dissociates Ca^{++}, which then is capable of replacing Na^+ on the exchange complex. This process has been used for reclaiming saline sodic calcareous soils (Poonia and Bhumbia, 1974; Prather *et al.*, 1978; Rashid and Majid, 1983). Gypsum added to sodic soil increases permeability by increasing electrolyte concentration and by reducing exchangeable Na^+ (Keren and Shainberg, 1981; Loveday 1976). Shainberg *et al.*, (1982) evaluated the relative significance of the electrolyte effect and the cation exchange on the HC by comparing the effects of gypsum and CaS_{12} in chemically equivalent amounts. Infiltration of distilled water into the non-calcareous soil initially treated with CaS_{12} decreased and eventually stopped. The gypsum treatment maintained high hydraulic conductivity. They observed no difference between the two amendments in a calcareous soil. Since both amendments had similar Na^+ replacement, they attributed the gypsum particles must be sustained to maintain the high HC of soils irrigated by waters with a low electrolyte concentration (Keren, 1990). As the soil depth increases the concentration of Ca^{++} and Na^+ in the soil solution decreases and increases, respectively because of Ca^{++}-Na^+ exchange. Eventually, the SAR of the soil solution reaches a value in equilibrium, with the existing Na^+. The remaining soluble Ca^{++} will not react with exchangeable Na^+ and is removed by drainage. The efficiency of applied Ca^{++} to remove absorbed Na^+ varies with ENa. It is much greater at high ESP values (Chaudhry and Markentin, 1968). The efficiency of ENa exchange at ENa levels below about 10 is low (about 30%), because a greater fraction of applied Ca^{++} displaces exchangeable Mg^{++} (Greenes and Ford, 1955; Loveday, 1976), efficiency may also be low (20% to 40%)in fine textured soils due to the slow kinetics of Na/Ca exchange inside the structural elements (Manin Pissarra *et al.*, 1982). A factor seldom considered is that applying large amounts of gypsum may temporarily reduce HC because small gypsum particles lodge in the soil pores (Keren *et al.*, 1981). Gypsum must dissolve to effect reclamation. Gypsum contents and the velocity of the soil water influence the gypsum dissolution rates (Kemper *et al.*, 1975; Keren and Conner 1982). The net result is a decreasing dissolution rate with increasing velocity. Thus lowering the rate of water application whenever possible, for example with sprinkler irrigation, is preferable. It increases the rate of gypsum dissolution and enhances the efficiency of exchange. Generally soil water penetrates too slowly to reclaim sodium-affected soils in a single leaching. For example a 50-cm depth of water applied for leaching can only dissolve about 12 mg/ha of gypsum. Larger gypsum treatments should not be made unless sufficient soil water penetrates to allow larger applications of water. Thus sodium-affected soil normally can only be reclaimed to a limited depth in the first year, will often permit a shallow rooted crop to be established after leaching (Keren, 1990). Dutt *et al.*, (1971) considered gypsum to be an efficient amendment for reducing ESP, and stated that the amount of gypsum to be applied depends on the amount of Na^+ to be displaced. Ramzan *et al.* (1982) observed that 100% gypsum requirement (G.R) of soil plus farm yard manure (FYM) has maximum reclamation efficiency, followed by 50% G.R plus FYM. They however, recommended that press-mud is also a cheap source of reclamation, which decreases the ECe of the soil significantly. Ahmed (1991) advocated that gypsum is most commonly used amendment for reclamation of sodic soils because of its low cost and easy availability. It produces the desired changes by increasing permeability through both electrolyte concentration and cation exchange effect. Malik and Mohammad (1992) disclosed that gypsum takes less time to improve the problem soil as compared to biological methods of reclamation. Due to its solubility, low cost and availability; gypsum is the most commonly used amendment for reclaiming sodium-affected soil and reduce the harmful effects of high sodium irrigation waters. Gypsum comes from both mines and as a by-product of the phosphate fertilizer industry. Under comparable conditions, the rate of dissolution of industrial gypsum is much higher than that of mined gypsum (Keren, 1990). $CaSo_4$ is frequently added as a soil amendment to reclaim sodic soil and maintain soil permeability. It is moderately soluble and readily precipitated when its solubility is exceeded such as when irrigating with high sulfate water. The dissolution reaction for gypsum is: $Ca\ So_4\ 2H_2O \leftrightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$ Gypsum has been utilized for many years with varying success as $Ca2^+$ source to replace Na^+ from the soil exchange complex and thereby reclaim salt affected soils. Several empirical formulae based upon different exchange efficiencies have been used, through none of them has been constantly accurate. The application of computer models has enhanced our ability to simultaneously consider more factors influencing sodic soil reclamation and hence to better predicts gypsum or other Ca^{2+} source requirements

Oster and Frenkel (1980) discussed the chemistry of sodic soil reclamation with gypsum and lime and suggested that gypsum requirements for sodic calcareous soils be increased by a factor of 1.1 to 1.3 depending upon the desired final exchangeable sodium percentage. Surface applied gypsum generally increases infiltration rates and reclaims sodic sails, but the process is sometimes rather slow because the gypsum moves slowly into the soil. Sharma (1971) reported that water penetration, relative hydraulic conductivity, aggregate stability and water disruption characteristics had each improved to depth of 30 cm after 40 months surface application of gypsum to some sodic soils. Mixing the gypsum with the soil usually accelerates the reclamation process, however, because the Ca^{++} is physically placed where it will react. The addition of gypsum to deep mixed soils has not been shown more beneficial than deep mixing alone (Loveday, 1976; Rasmussen *et al.*, 1972). The two processes can be described by combining a one-dimensional convection dispersion equation with a first order kinetic expression. Gypsum can also be added to the irrigation water to improve the Ca^{2+}/Na^+ ratio of the water and subsequently to enhance the reclamation of sodic soils. Kemper *et al.*, (1975) measured the dissolution rates of gypsum in water flowing through beds of gypsum fragments. They found that dissolution rates were high enough to distribute significant quantities of gypsum to the soil through the irrigation water. Gypsum is the commonly used amendment for the reclamation of salt affected soils. Leaching with water invariably follows the application of gypsum to dissolve these applied amendments and to remove the soluble reaction products from the root-zone. For this purpose the addition of 90 to 120 cm of irrigation water has been recommended for an application of 9.9 to 12.4 tones per hectare of the agricultural-grade gypsum of such fineness that 85 percent of the material would pass through a 100 mesh sieve (Richard, 1954). Dutt, (1962) and Dutt *et al*., (1971), using a simulation model, developed a computer programme based on the solubility of gypsum and sodium-calcium exchange equation. They predicted that 52 to 72 cm of water was required to dissolve 16.5 to 23.9 tones of gypsum per hectare, when applied to the soil surface. A tenfold increase in the solubility of gypsum occurs when the amendment is mixed with highly sodic soils. The solubility of gypsum must also be affected by the degree of sodium saturation of the soil and the fineness of the amendment owing to the increase in the contact area.

The reclamation of saline sodic soils involves the leaching of salts and the replacement of exchange Na^+ with Ca^{++}. The cultivation of rice and the application of gypsum have, therefore been frequently recommended. Singh and Nijhawan, (1932) recommended the application of gypsum at the rate of about 5 tones per hectare. Yadav and Agarwal, (1959) reported that 60 to 70 percent reduction in exchange Na^+ content would constitute the economic application of such an amendment. Kanwar and Chawala, (1963) from pot experiments on a sodic soil, with graded doses of gypsum reported that the application of gypsum in quantities higher than 30 percent of the gypsum requirement was not necessary. It has also been reported that calcareous saline sodic soils can be reclaimed easily once a plant cover is established (Kelley,1951). Recently, Oad *et al*., (2001a) reported that 100% GR and 50% GR are the best to reclaim the saline-sodic soils of Sindh Province. Further, he reported that adding FYM, pressmud and continuous flooding are the supporting practices to carry soil towards amelioration process.

Acid and Sulfur: Sulfuric acid is an amendment that treats sodium-affected soils. In some areas, acid waste products from mining and industrial activities are available. Using these waste products as amendment may provide a safe way to dispose of them (Miyamoto *et al*., 1975). The acid reacts with soil calcium carbonate to form gypsum (using H_2SO_4) or calcium chloride (using HCl). Sulfur requires an initial phase of microbiological oxidation to produce H_2SO_4. (Keren, 1990).

In soil column studies, Yahia *et al*., (1975) and Prather *et al*., (1978) found that H_2SO_4 increases the penetration of water into calcareous sodium affected soils more effectively than gypsum. Field experiments on yield response have generally shown results in favor of H_2SO_4 (Overstreet *et al*.,1951). Equivalent amounts of gypsum reduced soluble and exchangeable Na^+ in the surface soil.

The concentrated acid applied directly on the surface of the soil results in better distribution, less destruction of soil aggregates and more efficient in leaching the salts (Miyamoto *et al*., 1975). Another technique used commercially is direct application by chiseling into the soil in bands about 45 cm apart. H_2SO_4 and SO_2 being highly corrosive should not be added to water that would pass through metal or concrete irrigation systems. The amount of acid required can be calculated from equation using EC and concentrations of Na^+, Ca^{++} and Mg^{++} in the saturation extract made with the leaching water (Miyamoto *et al*., 1975).

Acidualants that first must be oxidized, such as sulfur, pyrites and polysulfides act more slowly than H_2SO_4. Their effectiveness in field experiments has varied. It may relate to the presence or absence of microbial populations. For elemental sulfur application, dust posses a problem. This can be overcome by using conventional fluid fertilizer equipment to apply water suspensions containing 55% to 60% sulfur (Thorup, 1972) or granulated sulfur. Acids applied at high rates lower the soil's pH in the root zone and consequently increase the availability of P, Zn, Mn and Fe. This is important in obtaining improved crop responses (Miyamoto *et al*., 1975).

Irrigation and salt control: Irrigation must be adequate over the long term to prevent harmful accumulation of salts in the root zone. To prevent high water table, which often contribute to salt accumulation at the soil surface, irrigation applications must not be excessive. Infiltrated depths of water must be relatively uniform to meet the crop's needs and leach salts adequately without excessive surface run-off or deep percolation. To meet such depth and uniformity, irrigation systems must be suited to the site, well designed, and well managed (Kruse, 1990). Recent studies on varying water depletions applied to saline soil showed that value of soil chemical properties viz. pH, ECe, SAR and ESP increase with the water deficit (90-70% soil moisture depletion SMD), however adequate irrigation application at 50% SMD or frequent irrigation leaches the salts downward from the surface. Salinity prominently becomes high in the water stress conditions (Oad *et al*., 2001c).

Irrigation management practices for salinity control

Crops: Different plant cultivars have different salt tolerances. Selecting the proper crop according to the site's salinity conditions can increase the profitability of crop production. Management of different irrigation methods often depends on the crop's characteristics. Temporary sprinklers are sometimes used to germinate and establish salt sensitive crops. Sprinklers can apply small depths of water uniformly keeping the seed bed adequately moist and salt-free (Robinson and Mayberry, 1976). Surface irrigation is then used to grow the established crop.

If the sprinkler irrigation water is saline the salt deposits on leaves may adversely affect some crops. Deciduous fruit trees are especially susceptible. The salts that accumulate on leaves are largely those that remains in solution in the intercepted water at the end of irrigation. As this water evaporates, the salts are concentrated and deposited on the foliage. Larger, less frequent irrigations may reduce the salt deposits relative to the volume of irrigation applied. Irrigation at night or another low evaporation period also minimizes salt concentration and absorption (Kruse, 1990). Irrigating the crops with canal water is better approach to gain maximum yield of the crops and to improve soil fertility. But, if, availability is scare in any crop growth phase, the pumped saline water can be used for plant growth and development. The irrigation pattern i.e. irrigating crops by pumped saline water during vegetative phase and canal water during reproductive and maturity stages is beneficial for maximum crop yield (Oad *et al.*, 200le).

Tillage: Deep plowing can redistribute salt in the soil profile. The practice should be evaluated on a small land area before plowing entire fields. Slowly permeable soil layers that prevent leaching water from flowing downward can be chiseled or ripped (Kruse, 1990). Recently, Oad *et al.* (200lb) has given the emphasis on planting practices of the crop that seeds should be planted few inches below the top of ridge to avoid the salt accumulation in the root zone, because due to capillary movement salts deposits on the surface soil and top of the ridge. The planting below the top of the ridge exhibits satisfactory growth and yield. The furrow accumulated salts are flushed with the water application. In another study Oad *et al.* (1996) also chalked out method of wheat planting that instead of drilling seeds in saline soil, the seeds should be broadcasted in standing water. Because standing water dilutes the salt concentration and provide the favorable condition for seed germination.

Timing of irrigation: Irrigation scheduling is important when management includes salinity considerations. Proper timing can help to avoid low levels of soil water that cause salts in the soil solution to become highly concentrated. Frequent water applications maintain low matric water stress, which can compensate for the osmotic stress caused by saline water. Frequent irrigations also keep the salts moving through and away from the root mass. If irrigations are applied frequently, each irrigation must be small. Small irrigations can seldom be applied as uniformly with surface methods as with sprinkler or micro-irrigation. Shainberg and Shalhevet (1984) reviewed the effect of the frequency of the saline water irrigation on yield, using saline water and concluded that higher frequencies result in higher yields.

Scheduling each irrigation application allows the depth of leaching water to be accurately determined and prevents excessive deep percolation. Jensen *et al.* (1970), Burman *et al.* (1980), and the American Society of Agricultural Engineers (1981) presented methods for estimating rates of ET by irrigated crops and scheduling individual irrigations. Limiting irrigation applications to amount necessary for replacement of root zone water and leaching also helps to minimize deep percolation and buildup of the water table. The frequent irrigation at the interval of 14 days showed decreasing trend in ECe, ESP, and SAR values (Soomro *et al.*, 2001). Soil salinity changes with application of irrigation. Since more frequent irrigation maintains better water availability in the active root zone that result in dilution of salts, which are then leached down, ultimately optimize the crop production. The method of irrigation has significant effect on salt accumulation in the soil (FAO, 1980). The under irrigation results in salt accumulation in the root zone. In contrast, over irrigation increases the ground levels that cause upward movement of salts (Rashid, 1994). However, frequent application of irrigation leaches the salts from the root zone and provide better environment for crop growth (Oad *et al.*, 200lb). Some times soil salinity develops inspite of good quality irrigation water and good irrigation practices (Michael, 1978). It is due to improper drainage, soil and conventional cultural practices and unsuitable cropping pattern. The accumulation of salts usually takes place during the germination upto harvesting period in the crop root zone which results in less economic productivity of the crop. No proper guidance is being provided to the farmers as to when a crop should be irrigated and how much water should be applied to optimize production. Thus, better irrigation management practices are required that would reduce soil salinity and produce high crop yields. Several studies have been conducted in this regard. In a study, Bordovsky *et al.* (1992) reported that it is not necessary to get high yields with high amount of water, their results show reduction in lint yield with increased amounts of irrigation. Soliman *et al.* (1976) reported that soil salinity as well as irrigation intervals significantly affected flowering and cotton yield. Thus, Memon *et al.*, (2001) in his recent findings suggested that irrigation should be applied according to Cumulative pan evaporation to avoid the waterlogging and salinity hazards due to excess evapotranspiration.

Drainage and salt control: Applying irrigation water to soil disturbs the natural hydrologic balance of the soil profile. Since irrigation water cannot be applied with total uniformity, some water percolates below the root zone. If the amount of deep percolation is less than the natural drainage capacity of the soil, the water table will remain low and the net movement of salt in the profile will be downward. If deep percolation exceeds the natural drainage capacity of the soil, the water table will rise. Soil layers of low permeability may restrict percolating water from flowing downward and cause perched water table. When the water table is too close to the soil surface in an arid region, water and salt will be carried upward by capillary action and the upper soil profile and surface may become salinized as the water evaporates. Annually, if enough irrigation water is applied for net downward movement of water through the profile, a favorable salt balance can exist, even in the presence of a high water table. The shallow the water table, the more care needs to be taken with water applications to assure a net downward movement (Kruse, 1990).

If the natural drainage capacity is so limited that normal deep percolation of irrigation water causes the water table to rise close to the soil surface, drains must be installed. Poor irrigation uniformity and excessive deep percolation increase the amount of water that drainage systems must remove. (Kruse, 1990).

Water table depths: Deep-rooted crops require a deeper water table than shallow-rooted crops. The water table should be deep enough to allow adequate aeration in the active plant root zone. The water table should be deeper in clay soils than in sandy soils as the capillary rise of water is greater in the clay soils. Salt deposits on the soil surface or crops that appear to be suffering from poor soil aeration may indicate a water table that is too shallow. The desired water table depth varies with crop, soil, and spacing of drains (Food and Agriculture Organization 1980). In arid regions, drains that are placed approximately 1.8 m deep and designed to remove 2.0 mm to 5.0 mm of water per day generally maintain the water table at a depth that prevents salinization of the root zone. Such drains also provide an adequately aerated root zone for all crops (Kruse, 1990).

Many of the salinity problems associated with ground water tables occur in dry land farming regions and are related to seasonal variations in water-table depths. In such regions with high winter rainfall and hot, dry summers salinity in the upper soil layers is often at it's lowest at the end of winter. During spring and summer, capillary movement of water concentrates salt in upper soil horizons and lowers the water table. This is especially true in summer-fallowed land. The salt concentration of soil at harvest time is markedly affected by the root system of the crop. The root system tends to accelerate water-salt movement from deeper soil horizons into the root zone, whereas fallow land tends to accumulate salt on the soil surface. Deeper water table control is generally recommended for salinity control than for aeration and trafficability control. While, for salinity control, the desirable depth depends on a number of factors, general agreement in the literature appears to exist that saline ground water may be tolerated at shallower depth in coarse-texture soils than in soils of intermediate texture, for which depths of 180 to 200 cm are most generally recommended.

Drainage of non-irrigated, saline fields: Non-irrigated cropped areas may need subsurface drains, depending on the annual amount and distribution of rainfall, soil and plant water use. Seeps or saline areas may develop when the amount of water present exceeds the natural drainage capacity of the soil. For example, if an area of natural vegetation is converted to cropland and then followed, excess water from precipitation that is not used by the crops may cause drainage and salinity problems. Saline seeps sometimes appear on non-irrigated arid lands when precipitation exceeds evapotranspiration during the process of soil fallowing. Excess water percolates down to the water table and then moves laterally to lower soil surfaces, dissolving salts in the material through which it flows. Substance conditions eventually force the flow to the surface, where it evaporates and results a saline seep (Kurse, 1990).

Recommendations

- The field before reclamation should be deep plowed and leveled in a manner to allow the equal spread of irrigation water.
- The availability of water is another factor for amendment reaction in those problem soils.
- Use of 100% GR & 50% GR is effective in amelioration of Saline Sodic Soils.
- The application of pressmud, FYM are the cheapest sources which have show tendency of making pH, ECe, SAR and ESP toward neutral.
- Continuous flooding should also be considered in those areas where gypsum is not available.

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