Tillage, Manure and Gypsum Use in Reclamation of Saline-Sodic Soils

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Summary

Soil degradation resulting from soil salinity and sodicityis a major problem under arid and semiarid climates. Nearly 831 million hectares of land are salt-affected worldwide. The high salt concentration negatively affects soil physical and chemical properties as well as soil microbial activity, thus causing a decline in soil productivity. It has led to the depletion of soil organic carbon, decline in biomass production, contamination of water resources, and emission of greenhouse gases such as CO_2 at an accelerated rate. The initial hydration of sodic clays leads to slaking and swelling while continuous hydration results in dispersion of clay particles. Saline and sodic soils usually suffer from poor physical properties, including high bulk density, low macroporosity and aggregate stability. Therefore, management of such soils is challenging. The fundamental issue of soil quality improvement may in a long-term have a aim to restore an earlier state for the required crop production purposes or to limit and/or slowing down the further deterioration, in order to reservations the original values and features of the soil properties. Appropriate tillage is key factor for mitigation of negative effect, while application of organic matter through various sources is another amelioration strategy for salt-affected soils. These procedures affect soil physical, chemical and biological properties. Tillage improves aeration and alleviates compaction while organic matter promotes binding soil particles into aggregates. Present paper present positive aspect of tillage and amendment addition (gypsum, farmyard manure, sulfur) on properties of saline-sodic soils using available literature.

Key words

management, aggregates, amelioration, gypsum, manure

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Introduction

The soil represents a layer between the lithosphere and atmosphere and serves as the medium of numerous biogeochemical processes and cycles, which combined enable the growth and development of plants. There are several major roles of soil: ensuring reciprocity of cycling particles, regulating biosphere processes and chemical composition of the atmosphere and accumulates active organic matter (Kovda and Rozanov, 1988; Bašić, 2013). The plant growth and development in the agroecosystems requires appropriate soil conditions to obtain yields that generate economic benefit (Birkás et al., 2008). To ensure the effective production, the acquisition of an appropriate knowledge of its soil physical, chemical and biological properties, its soil limitations and behaviours in various external factors (climate), and possibilities of improving it without any damage is crucial (Jug et al., 2015).

Nowadays, occurrence of degradation processes led to undesirable soil condition often connected with regulation of water and air movement, nutrient uptake, adequate drainage and other parameters essential for proper plant growth and development (Birkás et al., 2015; Kisic et al., 2002; Bogunovic et al., 2014, 2016; 2017a). Key factor for majority of degradation processes lies in inadequate management (Basic et al., 2004; Bogunovic et al., 2015; Kisic et al., 2017) connected with loss of organic matter (Bilandzija et al., 2016; Birkás et al., 2008a). Tillage (Geeves, 1997; Bogunovic et al., 2018), machinery traffic (Beccera et al., 2010; Abdollahi et al., 2014), overgrazing (Yu et al., 2010), mining (e.g. Dudka and Adriano, 1997), irrigation (Qadir et al., 2003; Surapaneni and Olsson 2002), forest fires (Malvar et al., 2016; Hosseini et al., 2016), commercial forestry (Oldeman, 1994), extensive use of agrochemicals (Rayudu et al., 2013; Bogunovic et al., 2017b,c) are some of examples non-sustainable soil management that have negative implications on soil quality. In some cases, such degraded soil due to its inadequate physical properties need to be tilled (Gardner et al., 1999; Birkás et al., 2008b). Different tillage affects the soil physical properties by changing conditions in the soil, and thus has a direct impact on the crop growth and the cost of yield production (Jabro et al., 2011). Tillage of soils with expressed limitation in physical-chemical complex, like saline and/or sodic soils is especially challenge. The major problem of saline soils occurs when Na^+ cations, which are very soluble and weakly attracted, start to accumulate and dominate over the Ca^{2+} cations. It causes structural deterioration by physical processes such as slaking, swelling and dispersion of clay which leads to compaction (Bethune and Batey, 2002; Qadir et al., 2003) and increasing the accessibility of organic C for the microbial biomass (Wong et al., 2008).

Unfortunately, soil degradation resulting from soil salinity, sodicity, or combination of both, is a major problem of land resources under arid and semiarid climates (Qadir, 2007). Nearly 831 million hectares of land are salt-affected worldwide, while 340 million hectares suffer from sodicity (Szabolcs, 1994) in 75 countries (Martinez-Beltran and Manzur, 2005). Globally, about 95 million hectares of soils are under primary salinization (salt accumulation through natural processes), while 77 million hectares are under secondary salinization (human-induced and ever-rising groundwater) (Metternicht and Zink, 2003; cited by Amini et al., 2016). The high salt concentration negatively affects soil microbial activity as well as soil chemical and physical properties, thus causing a decline in soil productivity. Decline in vegetation growth, due to salt toxicity and detrimental osmotic potential, results in lower carbon inputs into these soils and further deterioration of their physical and chemical properties (Wong et al. 2009; cited by Amini et al., 2016).

Most of the saline soils are classified as Solonetz or Solonchaks in WRB. Solonetz as soils having a *natric* horizon within 100 cm of the soil surface. The *natric* horizon has an ESP of 15 or more in the upper 40 cm of the horizon. This horizon is made by clay illuviation that is dense and strongly structured (FAO, 2001). Solonchaks have a total salt concentration of the soil extract, expressed as the electrical conductivity (EC) > 15 dS m^{-1} (or mS cm^{-1}) within a depth of 125 cm of the surface. Solonchaks have subdued or non-existent faunal activity, while the vegetation is restricted to halophytic species (Chesworth, 2008). In Soil Taxonomy they belong to great groups of Inceptisols, Alfisols, Mollisols or Verisols that show *aquic* conditions and have a *natric* or *salic* horizon (Várallyay, 2001). Sodic soils usually suffer from deficiencies of macronutrients, such as nitrogen (N), phosphorus (P), and potassium (K). However, their high pH (>8.5) also adversely affects the availability of micronutrients such as Fe, Al, Zn, Mn, and Cu (Pessarakli and Szabolcs, 1999; Lakhdar et al., 2009; Amini et al., 2016). Reduction of vegetative growth due to salt toxicity, high osmotic suction, and degraded soil structure of salt-affected soils results in lower carbon inputs and also cause considerable erosive losses of organic matter, so organic matter is low in these soils due to both low input and high losses (Qadir et al., 1997; Nelson and Oades, 1998; Wong et al., 2009; Amini et al., 2016). Saline-sodic soils have the both combination of negative properties from saline and sodic, so they are considered to be the most degraded form of salt-affected soils (Rengasamy, 2002; Amini et al., 2016).

As Blaskó (2017) noted, the chemical improvement aims at maintaining the soil pH between 5.5 to 8.2 values keeping and making dominance of the exchangeable calcium. The physical improvement means loosening procedures, which alleviate compacted soil state to the deeper layers (≥ 60 cm). The biological repair concept includes all the procedures that increase soil biological activity and source of organic material by applying green manure crops and/or microbial preparations thereby enhancing the physical, chemical and colloidal soil properties.

We may outline that the improvement of saline-sodic soil can only be successful if the remedying method take into consideration to the diversity of saline soils and that aimed at the eliminate the cause of the salinisation/sodification or at least mitigation of the most serious problem. In this study we will describe mechanisms that have effect on degradation and disruption of physical properties on saline-sodic soils, the physical properties of alkaline and salt affected soils and their changes due to different tillage management and under various amendments. Despite the expressed difficulties, plant production on such soils can be performed but consequences of over salinization and practices for amelioration are various and needed to be summarized. As a real threat to agricultural productivity, this work fill focus on medium which supports life in its broadest sense and that is soil, and its characteristics.

Results and discussion

Mechanism of structural degradation and disruption of physical properties on saline-sodic soils

When very soluble and weakly attracted Na^+ cations start to dominate over Ca^{2+} cations, soil pH increases, which induces soil physical degradation. The clay fraction of the soil has a particle size of <2 mm diameter and is an important component of the soil matrix (Carter and Stewart, 1995), because of its charge properties and its surface area per unit mass is large in comparison to those of the soil's silt and sand fractions (Qadir et al., 2006). As initially forces between clay particles are powerful, sodicity affects infiltration rate, hydraulic conductivity, as well as shrinking pore volume, soil-air and soil-water capacity, which combined decrease the force between clay particles and form aggregate breakdown. The initial hydration of sodic clays leads to slaking and swelling while continuous hydration results in the releasing of clay particles, i.e. their dispersion (Rengasamy and Sumner, 1998; cited by Amini et al., 2016).

First mechanism of aggregate breakdown, slaking, takes place during soil wetting when the entrapped air expands, and results in breaking up of the individual weak aggregates. Swelling shrinks pore sizes and prevail the attractive forces of the clay particles. Ultimately, they are dispersed into individual clay particles.

Dispersion represents an irreversible process, which leads to the translocation of individual soil particles and plugging of water pores. Both slaking and dispersion represent irreversible mechanisms, which have a negative impact on the soil's hydraulic properties. In this context Kosmas and Moustakas (1990) showed that plugging of pores by dispersed organic and clay particles was the main reason of reduced hydraulic conductivity, while dissolution of organic substances was the major cause for increased hydraulic conductivity. Salt concentration increased with soil depth first in an exponential and later in a double linear relationship. The mechanism can be explained by diffuse double layer theory whereby intermolecular and electro statistic forces attract and repulse between ions in soil solution and soil particles. When Na^+ increases on the exchange sites of the soil particles, the repulsive forces are increased which in turn enlarges the interparticulate distance in the diffuse double layer and brings about dispersion and breakdown of soil aggregates which negatively affects soil structure (Oster and Shainberg, 2001; cited by Amini et al., 2016). Schmitz (2006) concluded that changes in double layer thickness will lead to unique interpretations and predictions of changes in hydraulic conductivity (negatively in Na^+ dominant soils).

Soil flocculation is favored by high electrolyte concentration of the soil solution, so higher levels of salinity can improve permeability and positively affect soil structure, conversely from high sodicity, which causes slaking and dispersion (Quirk and Schofield, 1955; McNeal et al., 1968; Frenkel et al., 1978; Shainberg and Lety, 1984; Quirk, 2001; Dikinya et al., 2006, Amini et al., 2016). These negative mechanisms cause similar consequences that are surface crust and hard setting of affected soils. Hard setting occurs in the lower depths of salt-affected soil unlike surface crust, and it is recognizable due it´s high bulk density (Birkás et al., 2014). Such soils with high Na and unfavorable physical properties are not provided for crop production and an increase in Ca^{2+} is indispensable (Greene et al., 1988; Southard et al., 1988; cited by Qadir et al., 2006) to improve aggregation, structure stability and improve soil fertility. Organic matter proved to be positive for improving soil aggregation. Increased aggregation is primary concern for sustainable plant production. It can be achieved through increase amount of carbon input into the soil, which additional decrease disturbances and the rate of carbon loss by decomposition and erosion. The best way is using amendments like organic matter (e.g. Abdollahi et al., 2014) compost, proper crop rotation (e.g. Jug, 2014), mulching, using other proper fertilizers (Bronick and Lal, 2005) or agroforestry interventions (inclusion of leguminous trees). The grass plantation may be useful in moderately degraded soils, however in highly degraded soils gives usually short-term solution, while the extinction of the grass species makes the surface again exposed to the weather elements (Blaskó, 2012).

Role of tillage and its effect on soil physical properties

Since ancient times, tillage has been the main soil operation with three major tasks: (i) to improve soil tilth; (ii) to combat weeds; (iii) and incorporate plant residues and organic manures. Until today, it has remained the major soil operation (Lal et al., 2007). Tillage affects soil´s physical, chemical and biological properties. Soil´s bulk density, porosity, water holding capacity, air capacity, and soil´s resistance are indicators of tillage effects on soil´s physical and hydraulic properties (Strudley et al., 2008). Mouldboard and disc ploughing have been the most obvious way for meeting these demands and are still the most widely used primary tillage methods in many countries worldwide (Schjønning and Rasmussen, 2000).

Choice of tillage system can affect soil properties depending on site, crop species, climate, and the time the tillage system has been used. Nevertheless, tillage can have both favorable and unfavorable effects on different physical properties of treated topsoil (Bogunovic et al., 2018).

Conventional tillage (CT) accelerates oxidation of organic matter by soil microorganisms through changes in soil moisture and aeration (Moussa-Machraoui et al., 2010). This led to compaction (Bogunovic and Kisic, 2017), root inhibition (Birkas et al., 2010) and promotes soil erosion by water (Kisic et al., 2017). It also affects soil temperature, soil mechanical impedance and soil porosity (Hamza and Anderson, 2005). Intensive tillage can affect soil structure and cause excessive break down of aggregates (Cerda et al., 2009), thus enhancing the potential for further degradation. It induces carbon loss, contributes to greenhouse gas emissions, and decreases production capacity (Horn et al., 1995; Bilandzija et al., 2016).

Conservation tillage present interesting alternative to CT, especially for salt-affected soils. Moussa-Machraoui et al. (2010) improved organic carbon concentrations and microbial biomass with addition of straw mulch on salt-affected silty clay and sandy clay soil surface in northwestern Tunisia. In addition to that, mulch reduced water evaporation and even increased infiltration. Choudhury et al. (2014) have proved that direct seeded rice with no tillage in wheat (with residue) treatment has the highest potential to secure sustainable yield increment and good soil health by improving soil aggregation and soil organic carbon (SOC) sequestration with respect to the conventional tillage with transplanted rice after five years of continuous rice–wheat cropping in sandy loam reclaimed sodic soil in India.

The adaptable tillage method on saline soils depends by the occurrence of the clay, salt and exchangeable sodium in the profile. Thus, in solonetz type of saline soils the inverting tillage can not be deeper than the depth of A-level leached earlier. Otherwise, plowing inverts the materials of the solonetzic B-level, which due to the higher clay, exchangeable Na^+ and a water soluble salt content has extremely unfavorable chemical and physical properties, since it is particularly important applying ploughless, loosening procedures (Blaskó, 2017).

Wang et al. (2014) reported that no tillage with subsoiling and straw cover (NTSC) reduced bulk density for about 10%, while soil organic matter is increased, such as total porosity for 20% in the clay-loam topsoil in Northern China. In all four layers (0–5, 5–10, 10–20 and 20–30 cm), water-stable aggregates of the largest size class (>2 mm) were 63.1%-80.3% ($p < 0.05$) greater under NTSC than under conventional tillage with plowing after straw removal (CTSR). NTSC soil management significantly reduced soil salinity (from 2.84% to 1.55% after 12 years) and water stress, and parallel improved soil structure.

However, Singh et al. (2014) noted significant decrease in bulk density (BD) in tilled treatments (moldboard plowing) compared with NT. This research on silty clay loam soils showed positive effect of tillage on BD of sodic soils in India. In this context, Dao (1996) also observed a decrease in BD under ploughed treatments silt loams of Oklahoma (US). It's probably because of loosening the soil and thus temporarily forming macropores. Sodic soils are confirmed as compact soils because of swelling of clay particles, dispersion and formation of quasicrystals (Sumner, 1993; cited by Singh et al., 2014). Birkás et al. (2014) outlined that the effects of loosening do not last long, in many cases they vanish by the end of the growing season. Attention should therefore be paid to regularly improving the state of deeper layers of the soil. The depth of ploughing is limited to the depth to which the soil may be inverted. A field that has deeply soaked through should not be ploughed, or tilled with any other implement in fact. Surface forming in the autumn is not recommended because these soils are prone to settling heavily. Indeed even primary tillage in the autumn is not recommended in fields of saline soils that are prone to liquefy under rainwater.

Nevertheless, tillage intervention, alone or in combination with incorporation of crop residues, induced the flocculation of clay particles and enhanced aggregation, macroporosity and infiltration (Singh et al., 2014). Presented results from international literature confirms idea that decreased compaction of sodic soils will lead to better aeration, water drainage, leaching of available salts from surface to deep layers and expansion of crop rooting systems, all factors that can further improve soil quality.

A significant part of saline soils belonging to the so-called solonetz, that is a *physical saline*. Therefore, the most important limiting factors related to the physical condition, is hydraulic properties of the soil. The classical authors stated in their experiments, that the deep loosening of soils without chemical treatment has a yield-increasing factor. It is important to note that the medium deep loosening, which is currently widely used nowadays, in their effect is not a substitute to the deep (≥ 60 cm) soil ripping (Blaskó, 2017).

Importance of soil organic matter in soil system

Application of organic matter is proved as one of the most important way of amelioration salt-affected soils by changing their chemical, physical and biological properties as organic matter improves binding soil particles into aggregates (Bronick and Lal, 2005; Cha-um and Chalermpol, 2011). The key is deprotonation of humic and fluvic acids, which leads to formation of large organic polyanions. They can bind clay particles into microaggregates by forming [(Cl-P-OM)x]y complexes where Cl, P, and OM are clay particles, polyvalent cations and organic matter (Edward and Bremner, 1967; Tisdall and Oades, 1982; Carter and Stewart, 1995; Six et al., 2000; Amini et al., 2016). The biological amelioration methods using amendments like crops, stems, straw, green manure, farmyard manure, compost, sewage sludge (Wang and Li, 1990; Matsumoto et al., 1994; cited by Mahdy, 2011), have few beneficial effects on the salt-affected soil amelioration, such as the improvement of the soil structure and permeability, thus enhancing salt leaching, reducing surface evaporation, and inhibiting salt accumulation in the surface layers. For salt-affected soils, the addition of organic matter (OM) can accelerate the leaching of Na^+, decrease the ESP and electrical conductivity (EC), and increase water infiltration, water-holding capacity, and aggregate stability (Lax et al., 1994; Qadir et al., 2001; Tejada et al., 2006; cited by Mahdy, 2011).

Lakhdar et al. (2010) studied an application of sewage sludge and municipal sewage waste on salt-affected soils in North-East Tunisia and found an obvious positive impact of municipal sewage waste compost and sewage sludge on soil physical and chemical properties and biological activities. In this context, all carbon rich materials and their repeated additions, like plant residues, could increase the supply of easily available carbon compounds (Elmajdoub and Marschner, 2015). Nowadays, biochar, has become a promising technique with great potential in soil amendment due to its confirmed positive effect including increasing soil cation exchange capacity (CEC) (Novak and Busscher, 2013; Luo et al., 2017), enhancing water and nutrient retention (Zheng et al., 2013; Soinne et al., 2014; Luo et al., 2017), and increasing crop yields (Zheng et al., 2013; Luo et al., 2017). Many researches agreed (e.g. Drake et al., 2016; Amini et al., 2016; Luo et al., 2017) that the utilization of biochar in ameliorating the saline-alkali soil have potential to assist in amelioration of saline-sodic soils.

Still, addition of various carbon rich materials into soil should be careful and consider the specific environmental conditions. As an illustration, excessive use of some organic amendments, for instance chicken manure, can increase the risk of secondary salinization in regions with abundant rainfall (e.g. Li-Xian et al., 2007). Consequently, the proper selection of organic amendment and appropriate timing and correct method of application to the soil (Diacono and Montemurro, 2010; Lakhdar et al., 2010) is necessary during the remediation process.

Farmyard manure effect on physical, chemical, and biological soil properties in saline-sodic soils

Several organic materials, such as farmyard manures, agro-industrial by-products and composts can be used as amendments to enhance and sustain the overall soil fertility. These amendments are used for soil remediation in the salt-affected areas due to their high organic matter content (Diacono and Montemurro, 2015). Besides, farmyards manure (FYM) shows positive effect on soil physical properties. It counteracts the negative effect of exchangeable Na^+ (Qadir et al., 2007). The decomposition of cattle manure and plant residues release CO_2 and organic acids which help to dissolve any insoluble calcium salt in soil solution and neutralize the alkali present. This process improves soil permeability and bacteria present in it, increases stability of aggregates, slowly release the nutrients and protects soil against erosion (Gaur et al., 1984). The principle of reclamation processes can be explained with that soil organic addition can activate soil microbes to produce organic acids neutralizing soil alkalinity (Khorsadni and Nourbakhsh, 2007). Furthermore, positive effect of FYM is reported by Yu et al. (2010) through increased concentrations of nutrients and organic matter, while salinity and sodicity were decreased. Also, soil physical structure was improved and more efficient salt leaching was obtained with soil organic addition. Positive effect of FYM on soil was reported by Meng et al. (2016) who determined that FYM application combined with deep tillage management was more effective than conventional tillage. Likewise, Yu et al. (2010) noted that FYM increased corn yield and improve soil physical and chemical properties (pH, EC, ESP, BD) and enzyme activities. Above presented improvements of physical and chemical properties of saline-sodic soils are confirmed in numerous other experiments performed at all continents (Hussain et al., 2001; Liang et al., 2003; Kahlown et al., 2003; Tejada et al., 2006; Walker et al., 2008; Lakhdar et al., 2010; Cha-um et al., 2011; Mojiri et al., 2011; Wang et al., 2014; Oo et al., 2015; Diacono and Montemuro, 2015).

Overall effect of tillage and soil amendment on physical complex of saline-sodic soils

Gypsum ($CaSO_4$ x $2H_2O$) is considered for one of the most commonly used amendment for sodic-soil reclamation, primarily because of its low cost. As a by-product from phosphate industry, it is often produced in high quantities, and the costs for transporting, crushing process, and broadcasting are relatively low (Gharaibeh et al., 2009). Reclamation of sodium affected soils requires soluble Ca^{2+} for exchange of absorbed Na^+ and adequate flow of water through and beyond the root zone. As it removes Na^+ from saline-sodic soils, SO_4^{2-} in the gypsum can decrease the pH of alkaline soils in reclaimed tidal land (Lim et al., 2011) and improve bulk density, macroporosity, hydraulic conductivity (Emami and Astaraei, 2012) and other physical properties (Singh et al., 2014).

Kim et al. (2016) evidenced that gypsum application effectively improves the soil properties of reclaimed tidal soil by decreasing sodicity and salinity. Likewise, combined effect of mechanical intervention, organic inputs and other amendments (like gypsum and sulfur) often resulted with highest and fastest changes of soil physio-chemical complex. In this context, Singh et al. (2016) reported that amelioration of sodic soil in India by deep tillage with gypsum and green manuring, showed maximum improvement in the grain and straw yield. Ahmed et al. (2015) and numerous other researches (e.g. Choudhary et al., 2004; Khan et al., 2010) proved that combination of gypsum and FYM with chiseling, improved soil properties like BD, organic matter, hydraulic conductivity, pHs, ECe, SAR and increase fodder beet root and shoot biomass. Islam et al. (2015) concluded that three passing tillage with power tiller (6 cm depth) along with gypsum and organic manure should be right choice for managing silty-loam soils in Bangladesh. They reported higher soil aeration, reduced bulk density and increased organic matter content of soils which contributed increased concentrations of available plant nutrients and higher crop yield after intervention. Deep tillage by plowing or loosening with fertilizer combination (Rahman, 1997; Jeyasree and Rao, 2005; Xiong et al., 2012; Meng et al., 2016), or with combination of straw mulch (Zhao et al., 2014) also showed positive results on remediation of saline-sodic soils and improvement in grain yields. Similar results reported Costa et al. (2016) after the application of gypsum and disc harrowing to a 15 cm. Performed intervention improved BD, porosity, infiltration of water and decreased dispersion unlike no-till treatments. Furthermore, the performing a 15 cm depth tilling, without gypsum produce a SARs reduction because of the dissolution of the soil native carbonate. Presented research point out that in sodium affected soils, the addition of gypsum, as well as tillage without gypsum, increased the infiltration compared with no-till without gypsum, increasing sunflower crop yield. However, research showed no results of applying gypsum on physical properties, similar to Buckley and Wolkowski (2014).

Sulfur (S) is another important soil amendment and plant nutrient involved in plant growth and development. Its role is important in saline-sodic soils where implications are on: lowering soil pH and dissolution of Ca form carbonate soils. Also can improved a reclamation processes in non-carbonate saline sodic soils. Johnston et al. (2013) did a research of reclamation the saline-sodic irrigation water with gypsum (G), sulfur (S), and combination of both (GS). The best results were achieved after application of both amendments. Sulfur was proved as amendment which decreased pH. In addition to that Ali et al. (2012) significantly increase wheat grain yield by applying sulfur into saline-sodic soil managed as no-tillage. Nevertheless, Rezapour (2014) provided the best results for reclaiming the top 15 cm of saline-sodic clay loam soil in Iran by combining elemental sulfur with composted manure in contrast to separate effect of sulfur and manure. These reports are only part of numerous experiments with sulfur application all around the Earth (e.g. Modaihsh et al., 1989; Slaton et al., 2001; Velarde et al., 2005; Jaggi et al., 2005; Yang et al., 2007), but proves that addition of sulfur can increase positive effect in saline-sodic soils or even enhance tillage and manure addition in reclamation of such soils.

Conclusion

Soil degradation resulting from soil salinity, sodicity, or combination of both, is a major problem of land resources worldwide, under arid and semiarid climates. The high salt (especially sodium) concentration negatively affects soil microbial activity as well as soil chemical and physical properties, thus causing a decline in soil productivity. Furthermore, it affects the growth and yield of most crops through increased subsoil compaction and surface crust. Human intervention on such soils goes in two directions: 1) procedures that are based on the removal of exchangeable and soluble Na^+ and modification of the ionic composition of soils by adding chemicals paralleled with leaching of sodium salts out of the soil profile; and 2) physical amelioration (deep ploughing, sub-soiling, sanding, profile inversion) in combination with amending of soil with various reagents (gypsum, calcium chloride, limestone, sulfuric acid, sulfur) and biological products (crops, stems, straw, green manure, barnyard manure, compost, sewage sludge).

Mechanical interventions showed positive implications on most of investigated areas. Deeper tillage procedures have reported as beneficial compared to no tillage management. Nevertheless, addition of organic amendment like farmyard manure and/or gypsum or sulfur improves the remediation. In most researches combination of described measures improved physical, chemical and biological properties, and showed the best results in reclamation of saline-sodic soils. However, existence of some exceptions, indicate a need for site specific amelioration strategy and additional research.

It is clear that the complex amelioration associated with the large-scale transformation of nature is difficult to stand up in the economy, however the neglect of the soil reclamation, does not allow to preservation of the soil quality for future generations. Management in the unimproved soils involves waste of resources, because a serious deterioration of nutrient utilization and increasing the energy requirement of soil tillage.

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