UNLOCKING THE POTENTIAL OF NANOGYPSUM FOR SODIC SOIL RECLAMATION

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Land degradation of different kinds is a severe problem challenging agriculture and sustainable crop production worldwide. In India, about 97.8 Mha (29.7%) of land area are considered degraded (SAC, 2021). ICAR-National Bureau of Soil Survey & Land Use Planning grouped land degradation into various classes viz., water erosion, wind erosion, chemical deterioration, physical deterioration etc. Chemical degradation comprises of salinization/alkalization and acidification (<5.5 pH). Alkalization results in the formation of sodic soils. Sodic soils are characterized by a pH of saturated soil paste greater than 8.2, electrical conductivity of saturated soil extract generally less than 4 dS/m at 25°C, exchangeable sodium percentage (ESP) of 15 or more, and contain soluble carbonate and bicarbonate ions of sodium.

Major processes responsible for the formation of sodic soils include weathering of rocks and minerals, alternate wet and dry seasons, use of ground water containing carbonates and bicarbonates, desalinization and the reduction of sulphate ions under anaerobic conditions. Majority of the sodic soils in Indo-Gangetic plains seems to have formed due to alternate wet and dry seasons. Sodic soils exhibit unique structural problems as a result of certain physical processes (slaking, swelling, and dispersion of clay) and specific conditions (surface crusting and hard setting) (Qadir and Schubert, 2002). Low fertility status, poor drainage, soil erosion, high ESP and poor microbial activity are the major factors affecting crop stand, growth and productivity in sodic soils (Shirale et al., 2017 & 2018).

EXTENT OF SODIC SOILS IN INDIA

In India, around 6.74 Mha of area is salt-affected, of which 2.96 Mha is saline soils and the rest 3.78 Mha is sodic soils. Major share of sodic soils found in the states of Uttar Pradesh (35.6%), Gujarat (14.3%), Maharashtra (11.2%) and Tamil Nadu (9.4%) in India. In Madhya Pradesh, sodic soils occupy nearly 1,39,860 ha area Mandal et al. (2018). Verma et al. (2006) reported that about 21,965 ha black soils in the Malwa and Nimar regions of south-west Madhya Pradesh have sodicity due to natural factors. Shirale et al. (2018) observed that the basic nature of the parent material, aridity of the climate, nearness to sub-soil water, poor drainage condition and topography have an effect on development of sodicity in Vertisols and associated soils. Incidentally, the Malwa and Nimar regions falls in the semi- arid tropics with low leaching intensity and alternate wet and dry seasons.

RECLAMATION OF SODIC SOILS

In most arid and semi-arid regions, salinity or sodicity imposes a serious threat to soil health, affecting the germination, growth, and productivity of agricultural crops as well as forest trees. Common methods for sodic soil reclamation include chemical amelioration, providing sub-surface drainage, leaching and flushing of salts, and growing salt-tolerant trees, shrubs, and grasses. Generally, sodic soils are ameliorated using a readily available source of Ca^{2+} to replace the excess Na^+ on the cation exchange complex (Figure1). The displaced Na^+ is leached from the root zone through the application of excess irrigation water. Replacement of Na+ on the exchangeable complexes can be achieved through application of chemical amendments. Though gypsum, calcium chloride, sulfuric acid, pyrite, and ground limestone are the commonly used amendments for sodic soil reclamation, gypsum has emerged as the most preferred chemical amendment for sodic soils due to its relatively easy availability and low cost.

Gypsum requirement for restoring a sodic soil depends on the initial ESP, texture and mineralogy of the soil, depth of the soil to be reclaimed, and tolerance of crops to sodicity (Verma et al., 2006). Good correlation exists between soil pH and gypsum requirements. Although gypsum is used in large quantities for amending soils, due to its low solubility, activity of gypsum is generally limited to its degree of homogeneity in the soil, which varies depending on the quantity applied and particle size. However, to keep the sodium content below the critical level repeated application of gypsum is required. In due course, the insoluble portions of gypsum settle at the subsoil layer lead to the formation of calcareous sodic soil and gypsum application becomes pointless thereafter. In this context, Nano-gypsum is the best possible alternative strategy for the reclamation of sodic soils. Nano-gypsum with its finer particle size not only resolves the low solubility issue of conventional gypsum but also decrease the soil sodicity more effectively with much low quantity (Kumar and Thiyageshwari, 2018).

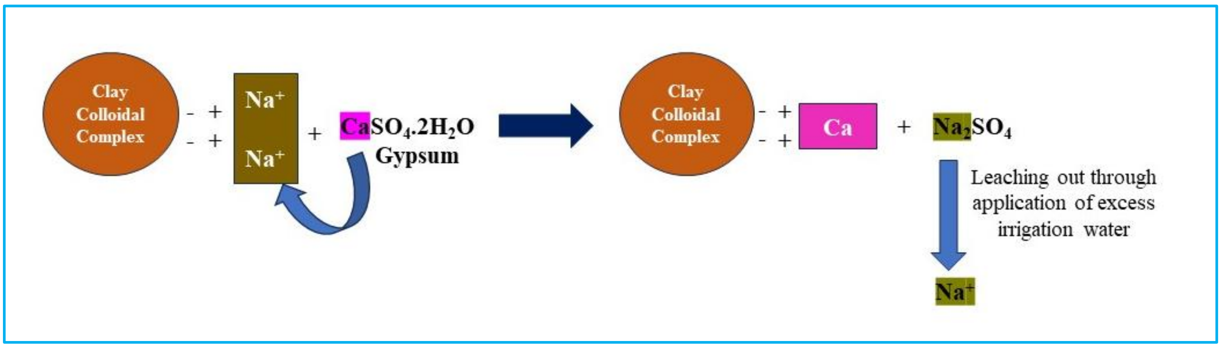


Figure 1. Equation showing mode of action of application of gypsum in sodic soils

SYNTHESIS OF NANOGYPSUM

An array of methods is available in the literature that is being used to synthesise nanoparticles. However, fundamental approaches in nanoparticles synthesis can be categorised into two groups: top-down approaches and bottom-up approaches. In a top-down approach, macroscopic particles are reduced to nanoscale by different physical methods like high-energy ball milling, mechano-chemical processing, physical vapour deposition, electro-explosion, sonication, sputtering, or laser ablation. High energy ball milling is a non-equilibrium process. In this method, powdered material placed inside a ball mill is subjected to high-energy collisions from balls. It uses very efficient, cost-effective, and simple techniques for the preparation of nanoparticles at very high production rates. In the bottom-up approach, nanoparticles are prepared by a build-up of material from the bottom: atom-by-atom, molecule-by-molecule, or cluster-by-cluster. This method is more often used for preparing most nano-scale materials because it has the ability to generate a uniform size, shape, and distribution. The sol-gel method is one of the simplest methods and has the ability to control particle size and morphology through systematic monitoring of reaction parameters. Synthesis of nano-gypsum using top-down approach (Rawat, 2017) consist of the following steps

Grind raw gypsum repeatedly with specific material (neem leaves, parthenium, fym, vegetable peels, vermicompost, clay or biocahar) in mortar and pestle

↓

Over dry the ground material at 80°C for 24 hrs & deep freeze at -20°C for 24 hrs simultaneously (repeat the process 10 times)

↓

Centrifuge at 4000 and 8000 rpm for 10 minutes

↓

Collect nano-gypsum

↓

Characterization of nano-gypsum with zeta analyzer, XRD and SEM

Synthesis of nano-gypsum using bottom-up approach: Co-precipitation method (Mehrabi et al., 2014) consist of the following steps

Dissolve 0.3954 g of calcium acetate in 100 ml distilled (DI) water and stir for 5 minutes on the stirrer

+

Dissolve 0.3954 g of ammonium sulfate in the 100 ml mixture of ethanol and DI water and stir for 10 minutes

+

Dissolve 4.5 g of Brij 35 in 50 ml DI water and stir for 5 minutes on the stirrer

↓ Add it slowly to calcium acetate solution to adjust pH to 4

Mix calcium acetate and ammonium sulphate solution and stir for 15 minutes on the stirrer

↓

Collect the solid part by centrifuging the mixture

↓

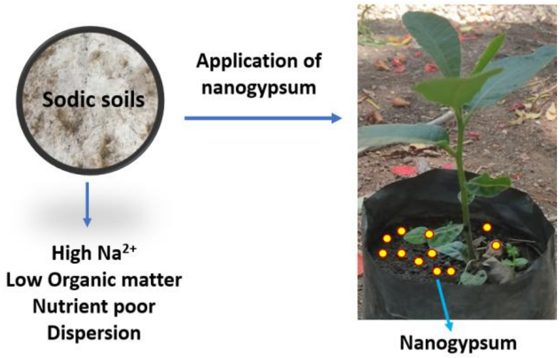
Dry in oven at 90°C for 2 hrs followed by annealing at 350°C for 1 minuet under nitrogen atmosphere

↓

Characterization of nano particles

MODE OF ACTION OF NANOGYPSUM

Nanomaterials are composed of very small particles (≤100 nm) with a high surface-to-volume ratio, which helps increase their reactivity and possible biochemical activity (Chaudhary et al., 2021). Nano-gypsum with its large surface area, improves the retention and release of exchangeable cations (Ca^{2+}, Mg^{2+}, and K^{+}) for an extended period. These cations can attract soil particles and form very stable soil structural units through the coalescence of micro-aggregates, preventing clay dispersion, leading to a decrease in bulk density and an increase in saturated hydraulic conductivity. This results in faster leaching of Na+. In turn, this also results in a reduced exchangeable sodium ratio of the soil, reducing the effects of Na toxicity as well as soil salinity, as summarized in Figure 1. This will result in good growth for the plants.



☞ Decreased ESP

☞ Increased nutrient availability

☞ Decreased soil reaction

☞ Decreased bulk density

☞ Increased saturated hydraulic conductivity

☞ Good plant growth

☞ Flocculation

Figure 4. Advantages of the application of nano-gypsum on sodic soils

SUCCESS STORIES

Very limited studies are available on the utilization of nanogypsum for the reclamation of sodic soils. Table 1 gives a brief summary of the successful amelioration of sodic soils through the use of nanogypsum.

Table 1. An outline of studies on nano-gypsum for reclamation of sodic soils

TREATMENTS	SALIENT FINDINGS	REFERENCES
Nanogypsum at 10.8% (960 kg ha^{-1}) of conventional gypsum requirement (CGR)	Decreased the bulk density (16.4%), soil reaction, electrical conductivity and exchangeable-Na percentage by 15.9%, 39.7% and 71.4%, respectively. Increased stable soil structure (46.2%), soil hydraulic conductivity increased by approximately 2.4 times, which helped increase the Na-removal efficiency by 68.9%.	Abd El-Halim et al (2023)
75 % RDF along with nano-sized gypsum or clay based nano-sized gypsum	Nano-sized gypsum produced significantly higher yield (4.07 t/ha) of wheat.	Rawat (2017)
Nanogypsum along with *Pseudomonas taiwanensis*	Significantly improved soil physico-chemical properties, enzyme activities and microbial population. Metagenomic study of the treated soil revealed that application of Nanogypsum was beneficial for the growth and survival of bacteria belonging to different phyla.	Chaudhary et al (2021)
Nanogypsum as 100 % gypsum requirement (GR)	Significantly reduced pH of the soil to 7.43 and exchangeable sodium percentage (ESP) to 10.37 compared to the unamended control soil and it is very effective over 100% GR as conventional gypsum.	Kumar and Thiyageshwari (2018)

CONCLUSION

Under the scenario where cultivable lands are shrinking due to increased urbanization, the restoration and management of salt-affected soils offer a potential hope of land expansion and production enhancement for future food security in the country. Therefore, Nano-gypsum may introduce a novel and alternative application strategy for reclamation of sodic soils. The effects of Nano-gypsum in field trials in a wide range of types of sodic soils should be investigated in the future.

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