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Soil crusting in agriculture: Mechanism, contributing factors, evaluation techniques and management strategies

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Abstract

Soil crusting is a form of surface soil degradation, especially prevalent in *Alfisols*. It significantly constrains agricultural productivity, particularly in arid and semi-arid regions. The formation of soil crust involves complex physical, chemical, and biological processes, initiated by raindrop impact, breakdown of soil aggregates, dispersion of fine particles, and subsequent drying. These crusts reduce soil infiltration rate, increase surface runoff and erosion and severely impede seedling emergence and early crop establishment. Based on their formation mechanisms, soil crusts are grouped into physical, biological, and chemical crusts. Each crust has a distinct morphological and hydrological characteristic. The formation, strength, and impacts of the crust is evaluated by a wide range of field, laboratory, and modern analytical techniques, including rainfall simulation, infiltration measurement, aggregate stability analysis, micromorphology, image analysis, remote sensing, and modelling, etc. Soil crusting may be effectively managed by an integration of mechanical measures, organic and chemical amendments, biological methods and improved cultural operation. It is important to understand the processes, factors influencing, evaluation methods, and management strategies of soil crusting to ensure sustainable crop production under changing climatic conditions.

Keywords: Soil crusting, surface sealing, infiltration and runoff, aggregate stability, *Alfisols*, rainfall impact, soil management strategies

Introduction

Crusting is a serious problem especially in *Alfisols*, which cover more than 35% of the semi-arid tropical region of India. These soils are characterized with thin sandy top layer, clay-rich subsoil, argillic (Bt) sub-surface horizon and often a hard stony layer called “*murrum*” (Bekele and Birhan, 2021; Cogle *et al.*, 1997) [7, 6]. Soil crusting favours the surface runoff and soil erosion but reduces water infiltration, thus affecting the seed germination (Bajracharya *et al.*, 1996) [6]. Because of crusting, a large part of early-season rainfall is lost as runoff, leading to soil erosion and moisture stress for crops (Assouline, 2004) [3]. Crusts reduce pore size, number, and arrangement, which further limit water movement. Field experiments on *Alfisols* have shown that crusting greatly reduces infiltration, with rates as low as 9.6 mm/h under no-tillage conditions, and this slow infiltration continues throughout the season. Soil chemicals such as exchangeable sodium, iron and aluminium oxides, and low organic carbon also make the crust stronger and more cohesive.

In initial stage crusting is known as soil sealing, which is formed by the breakdown of soil aggregates and the movement of broken fine particles towards the surface due to the impact of raindrops or flowing water. Later on, when the surface dries, it becomes a soil crust with a hard layer of high density and low porosity. Soil sealing and crusting are found in various soil types in around the world. They are very common in arid and semi-arid regions with clayey or silty soils containing smectite (2:1) clay minerals. Crusting also happens in temperate regions, where crusts form quickly on ploughed loamy soils after rainfall. Similar problems occur in tropical regions as well (Armenise *et al.*, 2018) [1].

As soil crusting is a serious challenge for agriculture, it is important to understand the crust formation, the factors affecting, its measurement and management strategies to protect the soil health and the improve crop production.

Surface soil crust

A surface soil crust is a thin, hard and more compact layer than the soil of lower horizon. Its thickness varied from 1 mm to 10 mm depending on the soil's clay and silt content (Bresson and Valentin, 1994; Bresson *et al.*, 2004) ^[14, 15]. In sandy, silty-sand, or sandy-loam soils, crust density may range from 1.75 to 1.95 Mg-cm⁻³, whereas loess-derived soils usually show lower values of 1.65-1.75 Mg-cm⁻³. The top few millimeters of the crust have very low porosity, which gradually increases with depth. Soils with low organic matter (<1%) are more prone to crust formation.

Types of surface soil crust: Surface soil crusts are classified into three main types based on their formation processes: (i) biological crusts, (ii) physical crusts, (iii) chemical crusts.

1. Biological crust

Biological soil crusts form through a close interaction between soil particles and a diverse community of microorganisms, including cyanobacteria, green algae, fungi, bacteria, lichens, and bryophytes. These organisms inhabit or lie directly on the top few millimetres of the soil surface, where they bind soil particles together and create a cohesive, living layer. Through their growth and metabolic activities, they contribute to soil stability, nutrient cycling, and moisture retention, playing an essential role in maintaining the health and functioning of arid and semi-arid ecosystems (Belnap and Gardner, 1993) ^[8].

2. Physical crust

A physical crust is a dense layer formed on the surface of the soil after rain, which is an important stage of erosion caused by the splash of raindrops. It has been found that the physical properties of crusted soils can change greatly, regardless of whether or not the crust is mature such as an increase in bulk density, a decrease in the number of macropores, and a decrease in porosity, which prevents water from penetrating further downward, contributing to an increase in surface runoff, altering the hydrological processes of the soil, increasing the likelihood of inducing erosion, and affecting agricultural production. Physical crust is classified into two sub-types on the basis of their formation process: (i) structural crust, formed by the direct impact of raindrops and breakdown of soil aggregates, and (ii) depositional crust, formed by the accumulation and compaction of fine particles transported by runoff or water movement.

- **Structural crust:** Structural crusts develop directly from rainfall when raindrop impact and sudden wetting break down soil aggregates into fine particles that settle and form a compacted surface layer, reducing pore space, restricting infiltration, and increasing runoff (Assouline, 2004) ^[3]. Morphologically, four main types of structural crusts can be distinguished based on their formation process. Slaking crusts are thin, apedal surface layers with relatively porous but poorly connected voids, limiting water movement and producing moderate infiltration of 5-20 mm/h over a 1-3 mm thickness. Infilling crusts form when loose silt grains clog the spaces between soil aggregates, creating a 2-5 mm low-porosity layer that reduces infiltration to 5-8 mm/h. Coalescing crusts are thicker and denser (3-15 mm) layers where void convexity increases toward the surface, restricting gas exchange and water entry,

with infiltration rates of 3-9 mm/h. Sieving crusts have a stratified structure that influences water movement and soil stability. Two-layered sieving crusts consist of a sandy top layer over a thin seal of fine particles, 1-3 mm thick, with infiltration of 5-15 mm/h, while three-layered sieving crusts have a coarse sandy top, vesicular fine sandy middle, and fine-particle bottom seal, resulting in very low infiltration (0-5 mm/h).

- **Depositional crust:** Depositional crusts, also called sedimentary seals, form indirectly from rainfall when runoff carries fine particles such as silt and clay across the soil surface. These particles settle in small depressions, creating a thin, compacted layer that reduces pore space and limits water infiltration, which over time can increase surface runoff and contribute to soil degradation (Assouline, 2004) ^[3]. Depositional crusts are further categorized into three types based on their formation. Runoff crusts develop from flowing water that deposits alternating sandy layers and fine particle seals, forming a 2-50 mm low-porosity surface with infiltration rates of 1-5 mm/h. Still-water crusts form under standing water conditions, where heavier particles settle on top and finer particles accumulate below, creating a 2-50 mm layer with very low porosity and extremely low infiltration (0-2 mm/h). Erosion crusts occur when the topsoil is stripped away, leaving an exposed thin (<1 mm) compacted layer of fine particles that allows almost no water entry, with infiltration rates of only 0-2 mm/h.

3. Chemical crust

Soil salt crusts are special layers at the soil surface which are mainly formed by soluble salt such as Sodium sulphate, Sodium chloride, Magnesium sulphate etc. crystallizing soil particles. Salt crusts have high salt content, higher hardness and strong resistance to wind erosion. Under natural conditions at the shallow groundwater level regions, water and soluble salt move upwards to soil surface because of soil capillarity action, water evaporates and loses, but the salt accumulates and crystals at the soil surface and forms soil salt crusts.

Mechanism of soil crust formation

Formation of the soil crust depends on intensity and amount of precipitation, soil texture, aggregation, and structural stability (Choudhury *et al.*, 2014; Chen *et al.*, 2020) ^[20, 18]. Several mechanisms contribute to the development of structural crusts.

1. The beating action of raindrops breaks down soil aggregates and separates soil particles. The effect is high in clay and Silty clay soils with low aggregation stability due to insufficient organic matter, iron oxides, lime, or other binding agents. Separated soil particles are washed, moved below in soil surface and clog soil pores (Chen *et al.*, 2013) ^[17].
2. The falling raindrops compressed the soil surface and formed a thin, dense layer with high bulk density and low porosity.
3. Saturated topsoil develops cohesion during drying, which helps bind soil particles together. The drying and re-orientation of these particles consolidate the topsoil.

Collectively, these processes lead to the formation of compacted surface layers that affect water movement, runoff, and soil stability.

Factors responsible for soil crust formation

Important soil physical properties include soil texture, structure, clay content, and moisture level (Opoku-Kwanowaa *et al.*, 2020) as well as soil chemical properties, such as organic matter content and exchangeable sodium percentage, directly influences the crust formation. Other external conditions like raindrop impact, sprinkler irrigation pressure, temperature, and the rate of surface drying also strongly affect crust development.

1. **Soil texture and particle size distribution:** Fine-textured soils, especially clay and silty clay, characterized by high density and low infiltration rate, are susceptible to dispersion and thus more prone to crusting than coarse-textured soils. Similarly, soils with high silt content have weak aggregate stability and become susceptible to soil crusting when subjected to alternate wetting and drying.
2. **Rainfall intensity and raindrop impact:** The possibility of the crust development increases with rainfall intensity and impact of the raindrops. Rainfall with high intensity generates strong rain drop impact, which readily breakdown the soil aggregates through kinetic energy. The dispersed soil particles then lead to surface sealing and form a structural soil crust upon drying. Such crusts reduce infiltration and increase runoff, making rainfall characteristics a major driver of crust formation (Assouline, 2004) [3].
3. **Organic matter content:** Soil with low organic matter content lose the natural binding ability of soil particles and become more susceptible to dispersion. Organic matter enhances soil aggregation by enhancing microbial activity, increasing polysaccharide production, and providing structural binding agents. As a result, higher organic matter content promotes better soil structure and greater resistance to crusting.
4. **Clay mineralogy:** Due to the swelling and dispersion characteristics of smectitic clays, black soils are more prone to crusting. Smectitic clays readily break down into finer soil particle which clogs soil pores and forms a compact and impermeable crust layers. The swelling-shrinkage property of these clays also contributes to the formation of dense surface crusts.
5. **Exchangeable sodium and salinity:** Sodic soils characterized by a high exchangeable sodium percentage (ESP) have serious deflocculating issue. Sodic soils often develop dense, hard crusts because dispersed clay moves into pore spaces and blocks them, reducing infiltration and soil aeration. Thus, sodium-affected soils are highly susceptible to crust formation.
6. **Land use and tillage practices:** The choice of land management practices directly influence the soil structure and potential of the crust formation. Minimum tillage operations have minimal effect on soil aggregation. In other hand, continuous and intensive tillage operations disrupt the soil structure and breaks aggregates into dispersed finer particles. The practices like overgrazing and machinery-induced compaction also degrade soil structure and increase the chances of surface crusting.
7. **Biological activity:** Soil aggregation is also influenced by microbial activity. Microbial and root activity increases the production of natural binding agents such as polysaccharides, glomalin, and humic substances which strengthen soil aggregates and reduce crust

susceptibility. In contrast, microbes like cyanobacteria, algae, lichens, and mosses binds the soil particles and form biological soil crusts.

8. **Soil moisture and drying cycles:** The repetition of alternate wetting and drying cycles enhances the strength and likelihood of soil crusting. In wetting, aggregates slake and disperse, while drying they shrink and compact, leading to formation of hard, cemented layer on the surface. This process aggravates crust hardness and decreases soil permeability over time (Bresson and Boiffin, 1990) [13].

Soil crusting evaluation techniques

Various techniques are used to evaluate formation, strength and impact of the soil crusting under the field and laboratory conditions as discussed here.

(A) Evaluation techniques for soil crusts under field conditions

These methods are essential for studying soil crusting under natural conditions.

1. **Rainfall simulation and runoff measurement:** It allows controlled studies of soil sealing and crust development using rainfall simulators that produce the natural impact of raindrops (Arndt, 1965) [2]. It also measures runoff generation, soil loss, and infiltration decline due to crusting. Double-ring infiltrometers and runoff plots are also used to assess infiltration rates before and after crust formation.
2. **Seedling emergence tests:** Through seedling emergence studies, the impact of soil crusting on plant growth is evaluated. Hanks and Thorp (1956) and Lemos and Lutz (1957) observed that the thickness and hardness of surface crusts significantly restrict seedling penetration. It is measured by the relative study of seeding emergence percentages with soil crust strength and moisture content.
3. **Crust strength and thickness measurement:** Field penetrometers are used to determine the mechanical resistance of the crust layer, which indicates its hardness and the degree of compaction. Measurements are taken at multiple points to estimate spatial variation. A portable penetrometer to quantify crust resistance, establishing relationship between crust strength and seedling emergence.

(B) Laboratory Evaluation Techniques for Soil Crusting

Physical and chemical properties of the soil during the formation of soil crust can be analyzed under controlled laboratory conditions.

1. **Controlled rainfall simulation:** The kinetic energy, drop size, and duration of rainfall can be precisely controlled to simulate natural rain impact in laboratory rainfall chambers. This method helps to assess the impact of raindrop on rate of crust formation, sealing intensity and infiltration loss under variable soil texture.
2. **Aggregate stability and disintegration tests:** On the basis of aggregate stability, the likelihood of soil crusting is estimated. Weak aggregates easily disintegrate and are more prone to crust formation. Aggregate stability analyzed by the wet-sieving method, developed by Kemper and Rosenau (1986), is used to study the stability of soil aggregates when exposed to water. Soil structural stability and resistance

to crusting are estimated by mean weight diameter (MWD).

3. **Penetration resistance and hydraulic conductivity:** The mechanical resistance of crusts and reduction in infiltration help in assessing the severity and persistence of crusts (Bagarello *et al.*, 2004) ^[5]. The mechanical resistance of crusts formed in trays or cylinders is measured by the penetrometers and shear strength devices. Likewise, reduction in infiltration due to crust sealing is quantified by the hydraulic conductivity tests (constant head or falling head methods).
4. **Soil chemical and mineralogical analysis:** Soil electrolyte concentration, sodium adsorption ratio (SAR) and clay mineralogy are direct influence the crust formation mechanisms. High dispersive clays (*e.g.*, montmorillonite) and low electrolyte concentrations favour sealing and crusting.

(C) Analytical and Modern Techniques

Analytical and advanced methods provide high-resolution and quantitative insights into crust morphology, composition, and spatial variability. These techniques bridge the gap between micro-scale processes and field-scale implications.

1. **Micromorphological and structural analysis:** Micro-morphological techniques involve preparing thin sections of crusted soils and observing them under optical or scanning electron microscopes (SEM). These analyses reveal pore blockage, particle rearrangement, and compaction features responsible for crust sealing. SEM provides detailed imaging of the fine structural arrangement and binding agents within the crust.
2. **Image processing and surface profiling:** Roughness, porosity, and crust thickness can be evaluated using digital image analysis and laser scanning. Three-dimensional surface models generated from high-resolution photographs are used to quantify crust microtopography and its effects on infiltration (Le Bissonnais and Arrouays, 2000) ^[19].
3. **Remote sensing and GIS-based assessment:** Using satellite imagery, hyperspectral data, and UAV (drone)-based sensing, it is possible to map crusted areas at regional scales. Crusted zones can be identified using spectral indices related to surface reflectance and soil brightness, especially in semi-arid regions (Ben-Dor *et al.*, 2003) ^[9].
4. **Modelling and predictive analysis:** Mathematical models such as HYDRUS, SWAT, and infiltration models integrate field and laboratory parameters (aggregate stability, texture, hydraulic conductivity) to simulate crust effects on runoff and soil erosion (Bagarello *et al.*, 2004) ^[5]. These analytical approaches help predict crust susceptibility and guide soil conservation practices.

Strategies for managing soil crusting

(A) Mechanical and physical management

1. **Tillage and surface roughening:** Light tillage, harrowing, and surface roughening are effective mechanical methods for breaking existing soil crusts and improving water infiltration. Implements such as rotavators, harrows, and chisel ploughs help increase the roughness of the soil surface and promote aggregate

stability, thereby reducing the likelihood of crust formation before rainfall events. However, excessive or frequent tillage can negatively affect soil structure by destroying aggregates and depleting organic matter, ultimately making soils more vulnerable to crusting in the long term.

2. **Mulching:** Mulching with organic materials such as crop residues, straw, and compost or with synthetic options like plastic films and geotextiles, plays an important role in protecting soil from raindrop impact and reducing surface evaporation. Mulches create a protective layer that maintains soil moisture, moderates temperature fluctuations, and fosters biological activity, all of which contribute to enhanced aggregate stability. By minimizing direct exposure of the soil surface, mulching significantly lowers the risk of crust formation and improves soil health.
3. **Crust disruption:** Once crusts have formed, they can be mechanically disrupted using tools such as rotary hoes, crust breakers, or spiked rollers. These implements help break the hardened surface layer, allowing better aeration, water infiltration, and seedling emergence. This practice is especially beneficial for crops like maize and cotton, whose germination and early growth are often hindered by crusted soil surfaces. Timely crust disruption ensures improved crop establishment and reduces early-season stress.

(B) Chemical management

1. **Soil Amendments:** Soil amendments such as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) play a crucial role in improving the physical condition of sodic and dispersive soils by replacing exchangeable sodium (Na^+) with calcium (Ca^{2+}), which promotes flocculation and enhances aggregate stability. In acidic soils, lime application helps improve soil structure by reducing acidity and strengthening aggregates. Additionally, chemical conditioners like polyacrylamide (PAM) and natural polysaccharides increase particle cohesion and improve water infiltration. These amendments collectively reduce surface sealing and crust formation by strengthening the soil's physical framework.
2. **Organic matter Application:** Adding organic materials such as biochar 15-60% increase in mean-weight diameter (MWD); 20-70% increase in water-stable aggregates (WSA) depending on dose 5-20 t/ha (Blanco-Canqui, 2017) ^[11], farmyard manure 15-45% increase in MWD; WSA increase 20-50% when applied 5-20 t/ha annually (Manna *et al.*, 2005), compost 20-50% improvement in aggregate stability; WSA increase by 25-60% with 10-30 t/ha (Bhattacharyya *et al.*, 2020) ^[10] and green manure 10-40% increase in WSA; 15-35% increase in MWD after 1-3 seasons. Significantly improves soil aggregation and enhances biological activity. Organic matter serves as a binding agent, promoting the formation of stable aggregates through the action of microbial polysaccharides, fungal hyphae, and root exudates. Increased microbial activity leads to greater secretion of polysaccharides that help cement soil particles together, thereby reducing the susceptibility of the surface layer to crusting. Over time, the enrichment of organic matter strengthens soil structure and resilience against degradation processes.

(C) Biological and ecological management

- 1. Vegetative cover and crop residues:** Maintaining continuous vegetative cover through practices such as cover cropping, intercropping, or retaining crop residues greatly reduces the direct impact of raindrops on the soil surface, thereby minimizing crust formation. Root systems, especially those of deep-rooted or fibrous-rooted species, improve soil porosity and enhance aggregate stability by fostering root-microbe interactions. These biological processes contribute to stronger soil structure, improved infiltration, and greater resistance to surface sealing.
- 2. Biological soil crust:** In arid and semi-arid regions, biological soil crusts composed of cyanobacteria, lichens, and mosses play a critical role in stabilizing the soil surface and preventing erosion. These crusts bind soil particles through filament networks and organic secretions, forming a protective layer against wind and water erosion. Restoration techniques, such as controlled inoculation with cyanobacteria like *Microcoleus vaginatus*, have been shown to accelerate crust recovery and enhance soil stability in degraded landscapes (Chamizo *et al.*, 2012) ^[16].
- 3. Microbial and enzymatic enhancements:** Microbial inoculants and biopolymers offer an effective biological approach to improving soil aggregation and reducing crust susceptibility. Beneficial microbes such as *Azotobacter* and *Bacillus* species stimulate the secretion of extracellular polysaccharides, which act as natural binding agents that cement soil particles together. These microbial products enhance aggregate stability, increase water infiltration, and strengthen the soil's structural integrity, making the surface less prone to crusting.

(D) Agronomic and land management practices

- 1. Conservation tillage and No-till farming:** Conservation tillage practices, which retain crop residues on the soil surface, help protect the soil from raindrop impact and reduce the chances of crust formation. By minimizing soil disturbance, these practices maintain organic matter and promote the development of a stable soil structure. No-till farming further enhances soil health by increasing biological activity, improving root channels, and promoting the accumulation of organic carbon. Together, these benefits strengthen soil aggregates and improve infiltration, thereby lowering the risk of crusting (Blanco-Canqui and Lal, 2008) ^[12].
- 2. Contour farming and terracing:** On sloping landscapes, contour farming and terracing are effective management strategies that reduce the velocity of surface runoff. By following the natural contour lines or creating stepped terraces, these methods slow down water movement, allowing greater infiltration and minimizing soil displacement. Reduced runoff decreases the likelihood of aggregate breakdown and surface sealing, which in turn helps prevent crust formation and soil erosion.
- 3. Irrigation management:** Proper irrigation management plays a key role in minimizing soil surface sealing. Gentle irrigation techniques such as drip and sprinkler systems reduce the kinetic energy of water hitting the soil surface, thereby lowering the risk of slaking and crust formation compared to flood

irrigation. Additionally, pre-wetting the soil before full irrigation can help stabilize aggregates and prevent their breakdown. These approaches improve water distribution, enhance infiltration, and protect the soil structure from crusting.

Conclusion

Soil crusting is a critical barrier to sustainable land and crop management, particularly in semi-arid and arid regions where fragile soils are highly vulnerable. It results from the breakdown of soil aggregates, leading to dense, compacted surface layers that severely restrict infiltration and enhance runoff. The widespread occurrence of crusting in *Alfisols* and related soils of the semi-arid tropics highlights its significant impact on agricultural productivity. Evidence from field studies shows that crusts persist over time, limiting water entry and contributing to moisture stress and soil erosion. The formation of structural, physical, biological, and chemical crusts is governed by complex interactions of soil texture, mineralogy, rainfall intensity, and land-use practices. Crusting also alters soil pore structure, affects seedling emergence, and disrupts hydrological processes essential for crop establishment. A combination of field, laboratory, and analytical techniques is vital for accurately assessing crust behaviour and severity. Effective management requires integrated mechanical, chemical, biological, and agronomic strategies to improve soil structure and resilience. Overall, addressing soil crusting is essential to enhancing infiltration, reducing erosion, and ensuring long-term soil productivity and environmental sustainability.

References

1. Armenise E, Simmons RW, Ahn S, Garbout A, Doerr SH, Mooney SJ, *et al.* Soil seal development under simulated rainfall: Structural, physical and hydrological dynamics. *J Hydrol.* 2018;556:211-219.
2. Arndt W. The impedance of soil seals and the forces of emerging seedlings. *Aust J Soil Res.* 1965;3(1):55-68.
3. Assouline S. Rainfall-induced soil surface sealing: A critical review of observations, conceptual models, and solutions. *Vadose Zone J.* 2004;3(2):570-591.
4. Awadhwai NK, Thierstein GE. Soil crust and its impact on crop establishment: a review. *Soil Tillage Res.* 1985;5(3):289-302.
5. Bagarello V, Iovino M, Elrick D. A simplified falling-head technique for rapid determination of field-saturated hydraulic conductivity. *Soil Sci Soc Am J.* 2004;68(1):66-73.
6. Bajracharya RM, Cogle AL, Lal R, Rao KPC, Smith GD, el DF. Surface crusting as a constraint to sustainable management on a tropical *Alfisol*: I. Soil physical properties. *J Sustain Agric.* 1996;8(4):25-44.
7. Bekele D, Birhan M. The characteristics, distribution and management of *Alfisols*. *Int J Res Stud Agric Sci.* 2021;7(6):1-6.
8. Belnap J, Gardner JS. Soil microstructure in soils of the Colorado Plateau: The role of the cyanobacterium *Microcoleus vaginatus*. *West North Am Nat.* 1993;53(1):40-47.
9. Ben-Dor E, Goldshleger N, Benyamini Y, Agassi M, Blumberg DG. The spectral reflectance properties of soil structural crusts in the 1.2-to 2.5- μ m spectral region. *Soil Sci Soc Am J.* 2003;67(1):289-299.

10. Bhattacharyya R, Prakash V, Kundu S, Srivastva AK, Gupta HS. Long-term effects of fertilization on soil aggregation, carbon stabilization, and productivity in subtropical India. *Soil Tillage Res.* 2020;197:104-112.
11. Blanco-Canqui H. Biochar and soil physical properties. *Soil Sci Soc Am J.* 2017;81(4):687-711.
12. Blanco-Canqui H, Lal R. Principles of soil conservation and management. Springer; 2008.
13. Bresson LM, Boiffin J. Morphological characterization of soil crust development stages on an experimental field. *Geoderma.* 1990;47(3-4):301-325.
14. Bresson LM, Valentin C. Soil surface crust formation: Contribution of micromorphology. *Dev Soil Sci.* 1994;22:737-762.
15. Bresson LM, Moran C, Assouline S. Use of bulk density profiles from X-radiography to examine structural crust models. *Soil Sci Soc Am J.* 2004;68(4):1169-1176.
16. Chamizo S, Cantón Y, Miralles I, Domingo F. Biological soil crust development affects physicochemical characteristics of soil surface in semiarid ecosystems. *Soil Biol Biochem.* 2012;49:96-105.
17. Chen L, Sela S, Svoray T, Assouline S. The role of soil-surface sealing, microtopography, and vegetation patches in rainfall-runoff processes in semiarid areas. *Water Resour Res.* 2013;49(9):5585-5599.
18. Chen N, Yu K, Jia R, Teng J, Zhao C. Biocrust as one of multiple stable states in global drylands. *Sci Adv.* 2020;6(39):eaay3763.
19. Chenu C, Le Bissonnais Y, Arrouays D. Organic matter influence on clay wettability and soil aggregate stability. *Soil Sci Soc Am J.* 2000;64(4):1479-1486.
20. Choudhury SG, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK, *et al.* Tillage and residue management effects on soil aggregation, organic carbon dynamics, and yield attributes in a rice-wheat cropping system under reclaimed sodic soil. *Soil Tillage Res.* 2014;136:76-83.