Effect of Soil Management on the Formation, Prevention and Control of Surface Crusts

Toko Manna[1], Meraj Ahmed[2]

[1]Ph. D Scholar, Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Jalandhar, Punjab, India, 14441

[2]Assistant Professor, Department of Soil Science and Agricultural Chemistry, Lovely Professional University, Phagwara, Jalandhar, Punjab, India
Email: *tokomanna1[at]gmail.com*

Abstract: ***Surface Soil crusting (SSC) is global phenomena that occur in variety of soil types and conditions prevalent in agricultural lands. The physical degradation results in a low hydraulic conductivity with problems of runoff and erosion and reduction in crop production due to reduced water infiltration and seedling emergence. Several factors influence the type and properties of soil crusts. These include surface roughness, soil water content, slope angle, topographic position, rainfall intensity, and crop cover. The SSC are generally divided into three main types, viz., structural crusts, sedimentional crusts, and Biological soil crusts. Soil crusting causes specific modification to the physical or structural properties of the soil surface. It causes decrease in steady - state water infiltration, induces soil erosion and soil degradation, physical impedance in seedling emergence and poor root growth, poor soil aeration in rhizosphere, affects nodule formation, frequent tillage requirement and delay in farm activities. Therefore, crusts decrease infiltration, accelerate ponding and runoff, causes inefficient irrigation and soil erosion. Soil aggregate stability is probably the single most important property affecting the rate of crust formation and final crust properties. Management of surface crusts can be best achieved by combining strategies that address both the physical processes of aggregate disintegration due to raindrop impact and the chemical process of dispersion. Anthropogenic soil crusting causes desertification and impedes vegetation establishment. Although surface crusting has been the subject of considerable research over the past 50 years or more, the practical management of soil crusts remains a challenge for many dryland communities.***

Keywords: Surface crusting, soil aggregates, humus, infiltration, Biological crust, erosion

1. Introduction

Soil is a three phase dynamic system that performs ecosystem services, numerous functions, and highly heterogeneous to sustains life on earth. Soil surface crust is the structural disintegration of top soil aggregates caused by natural calamities such as raindrop impact, followed by drying process. Compact thin impermeable layers with thickness ranging from less than 1 mm to 5 cm at the soil surface are formed and widely spreaded in arid and semiarid regions ((Šimanský *et al*., 2014). Soil structure, soil physico - chemical and biological processes of soil is formed by the aggregation of soil particles (Parent *et al*.2011). Thus, soil aggregation is a closely packed structure of clay, silt, sand and organic matters (Cambardella 2006). Surface crusts occur on unstable loamy soils in temperate regions (Mucher and De Ploey, 1977). In tropical region, it is a serious issue occurring on wider range of soil and throughout the range of climatic regimes. And in humid regions, there is a reduction in sustainment of biomass production and the extent of bare land increases due to intensive cultivation (Valentin and Janeau, 1989).

Soil type with greater silt and fine sand content and lesser aggregate stability are more prone to the crusting process (Le Bissonnais & Bruand, 1993). There is a specific modification in arrangement of pore system along with decrease in the size and the number of pores (Pagliai et al., 1983a; Bresson and Boiffin, 1990; Norton, 1987; Valentin and Ruiz Figueroa, 1987; West et al., 1992). Epstein and Grant (1973) found that soil erodibility is a function of the rate and extent of crust formation, noting that soil loss reached a maximum during the initial 10 min of rainfall, then decreased to a constant. Thus, the observed decreases in soil erosion that accompany increases in water erosivity suggest decreasing soil erodibility associated with crust formation (Moore and Singer, 1990).

Anthropogenic Soil crusting causes desertification due to reduction in infiltration rate, acceleration of runoff and erosion, and inhibition of vegetation establishment having negatively impacting soil productivity (Sela *et al*., 2012). The major disadvantages of soil crusts are that it influences the seedling emergence and water infiltration. Especially small seeds cannot germinate on the hard pan formed by soil surface crust. There is a decrease in water infiltration due to soil crusting obliging the farmers for rational consumption policy adoption. Decrease in water infiltration increases the surface run - off causing both environmental and erosion risks due to the pollution of surface waters consequently the possible nutrient losses by the increased run - off. Also there is a reduction in soil atmosphere gaseous interchanges contributing to decrease of crop yields.

2. Formation of Surface Crust

Soil surface crusts are formed by various processes such as raindrop impact, aggregate breakdown, slaking, dispersion, redistribution and sediments of disintegrated soil particles (Le Bissonnais 1996). Bresson and Cadot (1992), classified soil crusts as structural and depositional. Structural crusts are defined as thin impermeable layer on soil surface formed by smaller particles due to disintegration of macro - aggregates from top soil. While, crust formed from the transport and deposition of minute soil particles dislocated from their point of origin is called depositional crust (Boiffin 1986).

Soil structural crusts formation occurs in three stages. Firstly, breakdown of macro soil aggregates by effect of rain droplets. Followed by drowning of fine particles by the infiltrating rainwater into the soil causing pore clogging and then formation of a compact thin impermeable layer on the soil surface (Chen *et al*.1980)

The single most important factors influencing crust formation is aggregate stability. Hence, intensity of surface crust formation is measured by aggregate stability (Le Bissonnais 1996, Materechera 2009). It can be measured by different methods, such as wet sieving, rainfall simulation, ultrasonic disruption and clay dispersion (Kemper & Rosenau 1986, Le Bissonnais 1996, Emerson 2002, Fristensky & Grismer 2008).

Mechanisms of aggregate breakdown include
a) Breakdown due to raindrop impact (Nearing & Bradford 1985);
b) Slaking due to air compression while wetting (Le Bissonnais &Arrouays 1997),
c) Slaking from differential clay swelling (Le Bissonnais *et al*.1989); and
d) Physico - chemical dispersion by osmotic stress (Emerson 1967, Shainberg 1992, Sumner 1992).

The degree of soil crusting depends on soil physical properties (soil moisture content, soil texture, soil structure, and clay content) (Opoku – Kwanowaa *et al*., 2020), soil chemical properties (organic matter content and amount of exchangeable sodium ratio) (Wakindiki and Ben - Hur, 2002 and Rabot *et al*., 2018), and external factors (intensity of pressure created by the impact of raindrops and sprinkler irrigation, temperature, and the speed of surface drying) (Taha, 2016).

Recent studies found that crust formation is not always accompanied by reductions in total porosity, hydraulic conductivity and soil water retention. The eventual runoff formation from tropical soils with loamy and clayey texture seems to be more related to a reduction in the soil surface roughness, that would reduce the surface water storage, than to changes in porosity and reduction of the soil hydraulic conductivity (Castilho *et al*.2011)

3. Types of Surface Crust

Binding of the soil particles because of colloidal oxides of aluminium and iron present in soils under wet conditions subsequently drying to form hard compact mass causes surface crusting. It is prominent in Alfisols and occurs in varied soil type too. There are three main categories of soil crust: Disruptional crust, Sedimentional Crust and Laminar Crust (Arshed and Mermut, 1988). Based on mechanics, Soil Surface Crusting is divided into three main types viz., 1. Physical/Structural, 2. Biological and 3. Chemical/Sedimentional crusts (Rattan & Shukla 2004)

1) **Structural crust**: Crust of 1 - 3mm thick formed by the direct effect of raindrops strikes on the soil surface (William *et al*., 2018). It further consists of two layers: (a) Seal layer, thinner layer with approx.1 mm thickness (Arshed and Murmut, 1988). (b) washing layer, formed by soil fine particles those carried with infiltration water and accumulated directly in the interfacial pores of the sub - surface layer, leading its blockage (Bowker et al., 2016). The sub - types structural crusts are: i) Slaking crusts, ii) Infiltrating crusts, iii) Coalescing crusts, iv) Sieving crusts.
2) **Sedimentional Crust**: the dissolved and fine soil particles being carried by surface runoff and gets deposited in the Interfacial pores or at the end of the slopes rarely formed in the micro - relief topography of the land (Carmi and Berliner, 2008). Thickness estimated between 0.6 - 20 mm having very low porosity. The Sedimentional crust is sub divided into erosion crusts and depositional crusts (Bresson *et al*., 2004).
3) **Biological Crust**: renown as Cryptogamic or Cryptobiotic or Microbiotic Soil Crust (Fan and Wu, 2020). Its Surface crust formed by thin layer of micro organisms on top of soil in extremely dry and cold areas such as algae, fungi, lichens, algae and bacteria (Chen *et al*., 2020). Biological soil crusts improve soilmoisture retention, soil stabilization and fertility. It is the vital sources of carbon in regions with meagre vegetation cover (Belnap and Büdel 2016). Organic compounds are leached into the surrounding soil formed through the conversion of atmospheric nitrogen by Cyanobacteria and lichens, also slowdowns water runoff and increases water infiltration into the soil rough surfaces of crusts (Ferrenberg *et al*., 2017). In the recent years the significance of biological crusts have gained widespread popularity (Eldridge *et a*l., 2000; Belnap and Lange, 2001)
4) **Effect of Surface Crust-** Soil crusting causes specific modification to the physical or structural properties of the soil surface (Algayer *et al*.2014). It causes mechanical barrier to seedling emergence resulting decrease in crop yield. The degree of crust formation and their effects on water movement and seedling emergence, differs due to soil type, surface characteristics and rainfall strikes (Carmi & Berliner 2008)

Soil aeration below the crust is curtailed by surface crusting which significantly reduces porosity and permeability (Chartres and Greeves, 1998). Lack of aeration causes poor germination of seeds causing hindrance in seedling emergence (Wakindiki and Ben - Hur, 2002). Soil surface sealing and loss of roughness during surface crusts formation are the sub processes responsible for surface runoff and soil erosion (Darboux*et al*., 2001). Also run - off and erosion are triggered by low hydraulic conductivity and low infiltration rate (IR). Thus, hydraulic conductivity and infiltration rate (IR) are vital indices to monitor soil crusting (ISSS 1996). It has been reported by Souza et al. (2014) that for crusted soil the time required for infiltration to reach 113 mm depth ranged between 1140 to 2880 seconds while only 400 to 670 seconds for non - crusted soil. Infiltration and erosion processes can inhibit vegetation establishment and contribute significantly to desertification. However, Soil crust reduces the sensitivity of the soil to wind erosion (Zobeck, 1991).

Soil crusting is impeditive to many environmental and agronomic problems. Some of common effects can be listed as decrease in steady - state water infiltration, induces soil erosion and soil degradation, physical impedance in seedling emergence and poor root growth, poor soil aeration in rhizosphere, affects nodule formation, frequent tillage requirement and delay in farm activities. Therefore, crusts decrease infiltration, accelerate ponding and runoff, causes inefficient irrigation and soil erosion (Hardie *et al*.2013).

Yonter and Yagmur (2011) determined soil loss from a simulated rainfall experiment. They found that rainfall event on non - crusted soil resulted in 276.52 g/m^2 to 100.44 g/m^2 soil loss and in second event the soil loss on crusted soil was 701.76 g/m^2 to 243.61 g/m^2. Concluding Soil loss by the second event was attributed to crust formation and the reduction in water movement. Erpul and Çanga (1999) also concluded that, consecutive rainfall applications accelerated runoff and soil loss, and significantly lowered percolation by crusting. Single rainfall event can decrease in soil infiltration of 50 to 100 % and infiltration rates are higher in sloped regions where high erosion rates minimize crusting (Morgan, 2005)

Agriculture systems in terms of crop production are affected by crust formation negatively. In cultivated land, higher soil strength on drying results in pathetic seedling emergence and poor crop yield (Nabi *et al*.2001). At top layer few millimetres of the crust, porosity is less and it increases with depth (Mahesh et al., 2018). So it is difficult to grow field crops. The erosion process consists in the detachment, transport and deposition of soil particles (Pimentel et al., 1995)

4. Soil Management for prevention and control of Surface Crusting

Management of surface crusts can be best achieved by combining strategies that address both the physical processes of aggregate disintegration due to raindrop impact and the chemical process of dispersion, mainly in sodic soils. Management systems those restore soil organic matter, increase electrolyte concentration and reduce raindrop impact are likely to reduce aggregate disintegration and crust formation (Portella *et al*.2012).

4.1 Vegetation

Increase in vegetation cover is directly proportional to increase in infiltration rate, burrowing animals and insects help in restoring macro - pores in crusted soils (Langmaack *et al*., 2001; L´eonard and Rajot, 2001). There is direct impact of vegetation on reduction of crusting and increasing infiltration (the crop canopy and residues protects from raindrop impact, crust disruption by stems) and indirectly crusting severity is reduced by impacts like increased soil organic matter content and faunal activities a (Dunkerley, 2000). Hence, surface crusting be decreased through increased carbon content via application plant residues or organic wastes. Agronomically bold grained seeds can be used for sowing on the crusted soils and resistant crops like cowpea can be sown.

4.2 Surface Protection

The surface can be managed to be protected from raindrop impact by vegetal mulches in rainfed while stone cover in dryland.

4.3. Aggregate Stabilization

Aggregate stability is the capability of soil aggregates to withstand disaggregation to fine fragments when rapidly moistened. Aggregate stability is usually related to soil properties including; organic carbon, texture, structural and clay mineralogy. So, aggregate stability can be achieved by organic matter addition, phosphogypsum, or synthetic soil conditioners to prevent disaggregation. Phosphogypsum and gypsum are rich in calcium. Calcium replaces sodium on the exchange complex, resulting in improvement of aggregate stability and infiltration rate in sodic - dispersive soils (Shainberg *et al*., 1989; Shainberg, 1992). Surface crusting can be potentially managed by improved electrolyte balance generally through gypsum application.

Higher clay content can also decrease crust formation as the clay particles bind and protect the soil aggregates against the destructive effects due to raindrop impact (Chenu *et al*.2000; Boix – Fayos *et al*.2001). Phosphoric acid increases aggregate stability and total porosity, and reduce soil crusting (Thein 1976, Ortas & Lal 2012)

Humic acid treatment improve aggregate stability, as the humic substances have the ability to penetrate between clay particles and displace cemented agents with weaker bonded clay particles (Piccolo et al.1997). Aggregate stability can also be improved by using composted sludge

4.4 Soil Conditioners and Polymer Application

Soil conditioners and polymers controls surface crusting. Studies revealed that polyvinyl alcohol (PVA) impacted crust strengths (Page and Quick, 1979). Zhang and Miller (1996) found that surface materials treatments by 64%, gypsum treatments by 28%, and gypsum + surface material treatments by 88% decreased soil loss, respectively and these applications also decreased crust formation than controls, significantly. Lime or gypsum [at]2 t ha^{-1} can be uniformly spreaded and another ploughing be done for mixing of amendment with the top soil. The capability of gypsum and compost to ameliorate soil surface crusting has been widely reported (Haynes 2000, Rasse *et al*.2000). Gypsum application reduces clay dispersion and crust formation in sodic soils (Chorom & Rengasamy 1997). Application of gypsum acts by replacing Na^+ with Ca^{2+}, and by increasing electrolyte concentration in the soil water (Valzano *et al*.2001), that results in decreased clay dispersion and crust formation (Ilyas *et al*.1997). Polyacrylamides significantly increases infiltration rates when sprayed on the surface of crusted soils (Shainberg *et al*.1990). Yönter and Yağmur (2011) found thatAgri - SC application with very low doses on soil effectively minimized soil erosion by water as runoff, soil loss and crust strengths

The Soil Organic Matter acts as a binding agent for soil particles and water - absorbing agent, hence reducing clay wetting and subsequent aggregate disintegration (Blanco - Canqui and Lal 2004). Thus, soil physical crust formation reduces with an increase in SOM content.

The humic acid is the fundamental material that promotes soil aggregation (Shephera *et al*.2001). Humic acids protect soil aggregates from disintegration by the creating clay - humic complex over bridging polyvalent cations adsorbed on clay surface (Piccolo & Mbagwu 1994). Also there are many surfactants, wetters and permeants, which are known to reduce soil crusting by improving infiltration.

Composted sludge contains plant nutrients and has high water retention capacity, and studies have shown that matured sludge is highly stable on steep slopes and gives a fertile substrate for re - vegetation in severely degraded bad lands (Fox *et al*., 2002).

Farm yard manure or composted coir pith[at]12.5 t ha $^{-1}$ or other organics improves the physical properties of the soils. Organic matter play role of an aggregating agent, decreases wetting rate, escalates electrolyte concentration and increases soil hydrological properties (Leelamanie*et al*.2013).

However, management of crust control and prevention is labor and/or capital intensive.

References

[1] Algayer, B., Wang, B., Bourennane, H., Zheng, F., Duval, O., Li, G.,. . . &Darboux, F. (2014). Aggregate stability of a crusted soil: differences between crust and sub-crust material, and consequences for interrill erodibility assessment. An example from the L oess P lateau of C hina. *European Journal of Soil Science*, *65* (3), 325 - 335.

[2] Alkhafagi, Q. D. (2020). SOIL SURFACE CRUST: ITS SIGNIFICANCE, TYPES AND MECHANICS OF FORMATION. A REVIEW. *Mesopotamia Journal of Agriculture*, *48* (4), 75 - 85.

[3] Arshad, M. A., &Mermut, A. R. (1988). Micromorphological and physico-chemical characteristics of soil crust types in northwestern Alberta, Canada. *Soil Science Society of America Journal*, *52* (3), 724 - 729.

[4] Belnap, J. (2001). *Biological soil crusts: structure, function, and management* (Vol.150, pp.241 - 261). O. L. Lange (Ed.). Berlin: Springer.

[5] Belnap, J., &Büdel, B. (2016). Biological soil crusts as soil stabilizers. In *Biological soil crusts: an organizing principle in drylands* (pp.305 - 320). Springer, Cham.

[6] Bergsma, E., Charman, P., Gibbons, F., Hurni, H., Moldenhauer, W. C., &Panichapong, S. (1996). *Terminology for soil erosion and conservation*. ISSS: ITC: ISRIC.

[7] Blanco - Canqui, H., & Lal, R. (2004). Mechanisms of carbon sequestration in soil aggregates. *Critical reviews in plant sciences*, *23* (6), 481 - 504.

[8] Boiffin, J. (1986). Stages and time - dependency of soil crusting in situ. In *Assessment of soil surface sealing and crusting* (pp.91 - 98). Flanders Research Center for Soil Erosion and Soil Conservation Ghent.

[9] Boix - Fayos, C., Calvo - Cases, A., Imeson, A. C., Soriano - Soto, M. D., &Tiemessen, I. R. (1998). Spatial and short - term temporal variations in runoff, soil aggregation and other soil properties along a Mediterranean climatological gradient. *Catena*, *33* (2), 123 - 138.

[10] Bowker, M. A., Belnap, J., Büdel, B., Sannier, C., Pietrasiak, N., Eldridge, D. J., & Rivera - Aguilar, V. (2016). Controls on distribution patterns of biological soil crusts at micro - to global scales. In *Biological soil crusts: an organizing principle in drylands* (pp.173 - 197). Springer, Cham.

[11] Bresson, L. M., &Cadot, L. (1992). Illuviation and structural crust formation on loamy temperate soils. *Soil Science Society of America Journal*, *56* (5), 1565 - 1570.

[12] Bresson, L. M., Moran, C. J., &Assouline, S. (2004). Use of bulk density profiles from X-radiography to examine structural crust models. *Soil Science Society of America Journal*, *68* (4), 1169 - 1176.

[13] Cambardella CA (2006) Aggregation and organic matter. In: Encyclopedia of Soil Science (Ed. Lal, R.) Boca Raton, FL, Taylor and Francis. pp.52 - 55.

[14] Carmi, G., & Berliner, P. (2008). The effect of soil crust on the generation of runoff on small plots in an arid environment. *Catena*, *74* (1), 37 - 42.

[15] Castilho, S. C. D. P., Cooper, M., &Juhász, C. E. P. (2011). Influence of crust formation under natural rain on physical attributes of soils with different textures. *RevistaBrasileira de Ciência do Solo*, *35*, 1893 - 1905.

[16] Chamley, F., Hardie, M., Lambert, S., & Doyle, R. (2012). Consequences of soil crust formation on soil hydraulic properties and irrigation performance. In *5th Joint Soil Science Australia and New Zealand Society of Soil Science Conference* (pp.221 - 224).

[17] Chartres, C. J., & Greeves, G. W. (1998). The impact of soil seals and crusts on soil water balance and runoff and their relationship with land management. *Advances in GeoEcology*, *31*, 539 - 548.

[18] Chen, Y., Tarchitzky, J., Brouwer, J., Morin, J., &Banin, A. (1980). Scanning electron microscope observations on soil crusts and their formation. *Soil Science*, *130* (1), 49 - 55.

[19] Chorom, M., &Rengasamy, P. (1997). Carbonate chemistry, pH, and physical properties of an alkaline sodic soil as affected by various amendments. *Soil Research*, *35* (1), 149 - 162. da Silva, J. G. Problem soils and their management.

[20] Darboux, F., Davy, P., Gascuel - Odoux, C., & Huang, C. (2002). Evolution of soil surface roughness and flowpath connectivity in overland flow experiments. *Catena*, *46* (2 - 3), 125 - 139.

[21] Dunkerley, D. (2000). Hydrologic effects of dryland shrubs: defining the spatial extent of modified soil water uptake rates at an Australian desert site. *Journal of Arid Environments*, *45* (2), 159 - 172.

[22] Eldridge, D. J., Zaady, E., &Shachak, M. (2000). Infiltration through three contrasting biological soil crusts in patterned landscapes in the Negev, Israel. *Catena*, *40* (3), 323 - 336.

[23] Evans, R. D., & Johansen, J. R. (1999). Microbiotic crusts and ecosystem processes. *Critical reviews in plant sciences*, *18* (2), 183 - 225.

[24] Fan, W., & Wu, J. (2020). Short - term effects of returning granulated straw on soil microbial community and organic carbon fractions in dryland farming. *Journal of Microbiology*, *58* (8), 657 - 667.

[25] Ferrenberg, S., Tucker, C. L., & Reed, S. C. (2017). Biological soil crusts: diminutive communities of potential global importance. *Frontiers in Ecology and the Environment*, *15* (3), 160 - 167.

[26] Fox, D. M., Bryan, R. B., & Price, A. G. (2004). The role of soil surface crusting in desertification and strategies to reduce crusting. *Environmental monitoring and assessment*, *99* (1), 149 - 159.

[27] Fox, D., Flourou, S., &Daideri, M. (2002). The use of composted sludge for the rehabilitation of soils degraded by erosion. In *Man and soil at the Third Millennium. Proceedings International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March - 1 April, 2000. Volume 2* (pp.2127 - 2139). GEOFORMA Edicions, SL.

[28] Hardie, M., Doyle, R., Cotching, W., Holz, G., &Lisson, S. (2013). Hydropedology and preferential flow in the Tasmanian texture-contrast soils. *Vadose Zone Journal*, *12* (4), 1 - 14.

[29] Haynes, R. J. (2000). Interactions between soil organic matter status, cropping history, method of quantification and sample pretreatment and their effects on measured aggregate stability. *Biology and Fertility of Soils*, *30* (4), 270 - 275.

[30] Ilyas, M., Qureshi, R. H., &Qadir, M. A. (1997). Chemical changes in a saline - sodic soil after gypsum application and cropping. *Soil technology*, *10* (3), 247 - 260.

[31] Lal, R., & Shukla, M. K. (2004). *Principles of soil physics*. CRC Press.

[32] Langmaack, M., Schrader, S., & Helming, K. (2001). Effect of mesofaunal activity on the rehabilitation of sealed soil surfaces. *Applied Soil Ecology*, *16* (2), 121 - 130.

[33] Le Bissonnais, Y. L. (1996). Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. *European Journal of soil science*, *47* (4), 425 - 437.

[34] Le Bissonnais, Y., &Arrouays, D. (1997). Aggregate stability and assessment of soil crustability and erodibility: II. Application to humic loamy soils with various organic carbon contents. *European Journal of Soil Science*, *48* (1), 39 - 48.

[35] Le Bissonnais, Y., Bruand, A., &Jamagne, M. (1989). Laboratory experimental study of soil crusting: Relation between aggregate breakdown mechanisms and crust stucture. *Catena*, *16* (4 - 5), 377 - 392.

[36] Leelamanie, D. A. L., Karube, J., &Samarawickrama, U. I. (2013). Stability analysis of aggregates in relation to the hydrophobicity of organic manure for Sri Lankan Red Yellow Podzolic soils. *Soil Science and Plant Nutrition*, *59* (5), 683 - 691.

[37] Léonard, J., &Rajot, J. L. (2001). Influence of termites on runoff and infiltration: quantification and analysis. *Geoderma*, *104* (1 - 2), 17 - 40.

[38] Mahesh, C., Malavath, R. N., Balaguruvaiah, D., &Vidyasagar, G. E. C. H. (2018). Genesis, classification and evaluation of some sugarcane growing black soils in semi arid tropical region of Telangana. *Journal of Pharmacognosy and Phytochemistry*, *7* (3), 81 - 92.

[39] MORGAN, R. P. C. Soil erosion and conservation.3. ed. New York, Blackwell Publishing, 2005.320p.

[40] Moss AJ (1991): Rain - impact soil crust.1. Formation on a grainite - derived soil. Australian Journal of Soil Research 29, 271 - 289

[41] Nabi, G., Mullins, C. E., Montemayor, M. B., & Akhtar, M. S. (2001). Germination and emergence of irrigated cotton in Pakistan in relation to sowing depth and physical properties of the seedbed. *Soil and tillage research*, *59* (1 - 2), 33 - 44.

[42] Nearing, M. A., & Bradford, J. M. (1985). Single waterdrop splash detachment and mechanical properties of soils. *Soil Science Society of America Journal*, *49* (3), 547 - 552.

[43] Parent, L. E., Parent, S. É., Kätterer, T., &EgozcueRubí, J. J. (2011). Fractal and compositional analysis of soil aggregation. In *Proceedings of CoDaWork'11: 4th international workshop on Compositional Data Analysis, Egozcue, JJ, Tolosana - Delgado, R. and Ortego, MI (eds.) 2011*. CIMNE.

[44] Piccolo A, Mbagwu JSC (1994): Humic substances and surfactants effects on the stability of two tropical soils. Soil Science Society of America Journal 58, 950 - 955

[45] Piccolo, A., Pietramellara, G., &Mbagwu, J. S. C. (1997). Use of humic substances as soil conditioners to increase aggregate stability. *Geoderma*, *75* (3 - 4), 267 - 277.

[46] Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M.,. . . & Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science*, *267* (5201), 1117 - 1123.

[47] Portella, C. M. R., Guimarães, M. D. F., Feller, C., Fonseca, I. C. D. B., & Tavares Filho, J. (2012). Soil aggregation under different management systems. *RevistaBrasileira de Ciência do Solo*, *36*, 1868 - 1877.

[48] Rasse, D. P., Smucker, A. J., & Santos, D. (2000). Alfalfa root and shoot mulching effects on soil hydraulic properties and aggregation. *Soil Science Society of America Journal*, *64* (2), 725 - 731.

[49] Ronald Page, E., & Quick, M. J. (1979). A comparison of the effectiveness of organic polymers as soil anti-crusting agents. *Journal of the Science of Food and Agriculture*, *30* (2), 112 - 118.

[50] Sela, S., Svoray, T., &Assouline, S. (2012). Soil water content variability at the hillslope scale: Impact of surface sealing. *Water Resources Research*, *48* (3).

[51] Shainberg, I. (1992). Chemical and mineralogical components of crusting. *Soil crusting: chemical and physical processes*, *1045*.

[52] Shainberg, I., Sumner, M. E., Miller, W. P., Farina, M. P. W., Pavan, M. A., & Fey, M. V. (1989). Use of gypsum on soils: A review. *Advances in soil science*, 1 - 111.

[53] Shepherd, T. G., Saggar, S., Newman, R. H., Ross, C. W., & Dando, J. L. (2001). Tillage - induced changes to soil structure and organic carbon fractions in New Zealand soils. *Soil Research*, *39* (3), 465 - 489.

[54] Šimanský, V., Polláková, N., &Halmo, S. (2014). Soil crust in agricultural land. *Actafytotechnica et zootechnica*, *17* (4), 109 - 114.

[55] Souza, E. S., Antonino, A. C. D., Heck, R. J., Montenegro, S. M. G. L., Lima, J. R. S., Sampaio, E. V. S. B.,. . . &Vauclin, M. (2014). Effect of crusting on the physical and hydraulic properties of a soil cropped with Castor beans (Ricinuscommunis L.) in the northeastern region of Brazil. *Soil and Tillage Research*, *141*, 55 - 61.

[56] Sumner, M. E. (1992). The electrical double layer and clay dispersion. *Soil crusting: chemical and physical processes*, 1 - 31.

[57] Valzano, F. P., Greene, R. S. B., Murphy, B. W., Rengasamy, P., &Jarwal, S. D. (2001). Effects of gypsum and stubble retention on the chemical and physical properties of a sodic grey Vertosol in western Victoria. *Soil Research*, *39* (6), 1333 - 1347.

[58] Wakindiki, I. and M. Ben - Hur (2002). Soil mineralogy and texture effects on infiltration, and crust micromorphology erosion. Soil Science Society of America Journal, 66 (3): 897. DOI: 10.2136/sssaj2002.8970.

[59] Yonter G, Yagmur B (2011): Effect of agri - sc as a soil conditioner on runoff, soil loss and crust strengths. African Journal of Biotechnology 10, 13292 - 13298

[60] Yönter, G., &Yağmur, B. (2011). Effect of Agri - SC as a soil conditioner on runoff, soil loss and crust strengths. *African Journal of Biotechnology*, *10* (61), 13292 - 13298.

[61] Zhang, X. C., & Miller, W. P. (1996). Physical and chemical crusting processes affecting runoff and erosion in furrows. *Soil Science Society of America Journal*, *60* (3), 860 - 865.

[62] Zobeck, T. M. (1991). Abrasion of crusted soils: Influence of abrader flux and soil properties. *Soil Science Society of America Journal*, *55* (4), 1091 - 1097.