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SOIL SURFACE CRUST: ITS SIGNIFICANCE, TYPES AND MECHANICS OF FORMATION. A REVIEW

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ABSTRACT

Most of the agricultural soils around the world suffer from increased soil degradation and erosion and reduce moisture conservation, which is the decisive factor in agricultural crop production, and among these problems is the phenomenon of Surface Soil Crusting (SSC), which is spread in a wide range of climates, especially in dry and semi-arid soils. In this review, the focus was done on the significance of SSC, its formation mechanisms, stages of emergence, types of crusts, methods used to estimate crust hardness and its resistance to penetration. It was noted that SSCs are formed when raindrop falls on newly plowed soils or soils without vegetation, followed by periods of drought, thus destroying soil aggregates and splashing there fine particles, these particles enter the inter-pores, Leading to formation of hard thin layers at the soil surface with thickness ranges from several millimeters to several centimeters or these particles moved by surface runoff water to deposit in the bottom of valleys, forming a sedimentary crust of five to seven centimeters thick. The SSC are generally divided into three main parts, namely, structural crusts, sedimentional crusts, in addition to the Biological soil crusts, which is formed over the previous two types and consists of fungi, algae, lichens and bacteria. Crust hardness can be measured or estimated by two main methods, which are Modulus of Rupture, and crust Penetration Resistance.

Keywords: surface crust, Soil structure, Biological crusts, Resistance to penetration

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INTRODUCTION

The continuous increase of world's population needs food resources sufficient to meet the growing needs for food, at the time the world suffers from climate changes and the deterioration of agricultural lands (Šimanský *et al.*, 2014), agricultural land degradation occurs escalating pace and affect areas inhabited by more than one third of the world's population (Valentin and Bresson, 1992), the consequences of this have negatively affected soil productivity due to salinization or desertification the soils (Sela *et al.*,2012).

Recent studies have tended in many countries around the world to search for new means and methods to improve soil structure, organic carbon and moisture conservation by making use of the remains of previous crop (El-Naggar *et al.*, 2018) or adding agricultural residues and animal waste (Fan and Wu, 2020) and adding some low-cost natural rocks as phosphogypsum or lime (Borselli *et al.*, 1996 and Al-Nasser and Al-Khalid, 2020) to improve soil health and its sustainability (Choudhury *et al.*, 2014, Opoku-Kwanowaa *et al.*, 2020).

Most agricultural soils, especially in arid and semi-arid regions, suffer from some physical and chemical problems, such as salinization, alkalinity, structure deterioration, low aggregations and low organic matter content (Sela *et al.,* 2014 and Acir and Gunal, 2020), and to reduce these problems or reduce their negative effects on soil and agricultural production (Pires *et al.,* 2017). Many researchers in the field of soil management and conservation (Agassi *et al.,* 1985, Pagliai *et al.,* 2000b, Sela *et al.,* 2012 and Pires *et al.,* 2017) recommended that more experiments and research be conducted in order to improve the properties of degraded soils that suffer from some problems and constraints that affect their productivity to obtain the best economic return. From exploiting these lands while preserving their properties from degradation (Wilhelm *et al.,* 2010 and Fan and Wu, 2020). One of these problems is the phenomenon of SSC, which is widespread in a wide range of soils, especially in soils of arid and semi-arid regions with a clay or silty texture that contain extended clay minerals from smectite group 2:1 (Scott *et al.,* 2015).

SSCs are occur in the soil surface layer resulting from natural conditions such as the effect of raindrops strikes followed by drying process (Fox et al., 2004), leading to formation of a thin, solid layer on the soil surface, its thickness usually ranges from less than 1 mm to 5 cm (Šimanský *et al.,* 2014), and when it dries up, these appearances become stiffer than the lower soil materials (Fajardo *et al.,* 2016). This dense layer not only reduces the size and number of pores, but also changes pores arrangement (Pagliai *et al.,* 2004, Neave and Rayburg 2007). Soil crusting occurs in a wide range of soils and causes danger not only in very dry areas but also in all climatic systems (Armenise, *et al.,* 2108). In temperate regions, soil crusts develop rapidly after rainfalls on plowed soil with loamy texture, the same problem arises in soils of tropical regions (Nciizah and Wakindiki 2014 and Mahesh *et al.,* 2018).

SURFACE SOIL CRUST

SSC is generally thin layer soil ranging in thickness from 1 mm by (Bresson et al., 2004) to more than 10 mm (Bresson and Valentin, 1993), more densely packed than the underlying horizon, ranged from 1.75 to 1.95 Mg cm^{-3} for soils with silty sand loamy, sand or sandy loam textures, crusts of loess-derived soils showed lower values, ranging from 1.65 to 1.75 Mg cm^{-3}, In the top few millimeters of the crust, porosity is low and it gradually increases with depth (Mahesh *et al.,* 2018). Strong crusts with high bulk densities may impede aeration under moist conditions by preventing effective diffusion of oxygen into the soil. Lack of aeration becomes a problem for germination of seeds which led to decrease in seedling emergence (Wakindiki and Ben-Hur, 2002).

Soil capability for crusting depends on different soil physical properties (soil texture, soil building, clay content and moisture content) (Opoku-Kwanowaa *et al.,* 2020), soil chemical properties (organic matter and exchangeable sodium ratio in soil) (Wakindiki and Ben-Hur, 2002 and Rabot *et al.*, 2018), and external factors (degree of pressure generated by the effect of raindrops or sprinkler irrigation, temperature, and the speed of surface drying) (Taha, 2016).

The crust occurs when rain falls on lands with less vegetation cover or newly plowed lands, and after the soil dries up, the surface layer of it hardens, forming a hard crust with little porosity, which impedes the emergence of seedlings and adversely affects agricultural production (Graef and Stahr, 2000), reduces infiltration rate, moisture storage, and increased surface runoff (Carmi and Berliner, 2008) and increased soil erosion (Fox *et al.,* 2004, Sela *et al.,* 2014, and Al-Naser, 2018), the presence of a layer of high bulk density above the soil surface reduces the aeration of the soil and negatively affects the growth of young plants inside the soil body (Fox *et al.,* 2004 and Graef and Stahr, 2000) in addition to the rupture of roots and young plants sometimes when the crusts dry up and crack (Giannetta *et al.,* 2018).

Chen *et al.,* (2013) reported that SSCs have both internal and external morphological differences depending on soil texture, type of clay minerals, bonding materials, rain intensity and drying speed (Scott *et al.,* 2015). Soils newly plowed or devoid of vegetation are affected to different degrees by raindrop energy according to the content of organic matter, clay, iron and sodium oxides present in the exchange complex (Bresson *et al.,* 2004) that affect the aggregate stability. When soils are exposed to rain storms, the falling raindrops can generate a number of different responses, as shown in the table (1):

Table (1): The response of soil surface to raindrops

INPUT RAIN DROP ENERGY	Rain splash erosion	Removal of macro aggregates
		Removal of discrete particles
	In situ surface processes	Breakdown of structural units
		Surface of particle sorting
		Surface compaction
	Input rain drop energy	In wash of material in to soil

Stages of Crust Formation

Scott *et al.,* (2015) indicated that crust formation, the occurrence of runoff and soil erosion passes through several stages, and that the response of the soil surface to the energy of the falling raindrops is divided into two main parts, the first part is the splashing of particles by the fallen raindrops (Romkens *et al.,* 1990 and Pulido Moncada *et al.,* 2014), and the fine particles enter the intermediate pores to create a crust with low porosity (Norton, 1987). The second part is when the soil is wetting (Bresson and Valentin, 1993 and Pagliai *et al.,* 2004), and the soil aggregates dissolved and their parts expanded by swelling (Bronnikova, 2011), sometimes air is trapped in large pores, resulting in air vesicles that may open to the outside (air explosion) (Neave and Rayburg, 2007), this condition occurs when rain falls on dry soils, which leads to clogging of the soil surface, increased runoff, and soil loss (Fajardo *et al.,* 2016). It increases the process of clogging the pores and increasing the surface run-off, thus increasing soil erosion. The following table illustrates this:

Table (2): The effect of raindrops on crust formation, runoff, and soil loss

<table>
<tr><td rowspan="4">Rainfall</td><td>Splash</td><td>Crusting</td><td rowspan="4">Sealing</td><td rowspan="4">Runoff</td><td rowspan="4">Soil loss</td></tr>
<tr><td rowspan="3">Wetting</td><td>Swelling</td></tr>
<tr><td>Slaking</td></tr>
<tr><td>Air explosion</td></tr>
</table>

Mechanism of Soil Crust Formation

SSCs differ in their mechanism and composition from one region to another according to the intensity and amount of precipitation, soil texture, soil aggregation and structural stability (Choudhury *et al.*, 2014 and Chen *et al., 2020)*. Water and dissolved solutes determine the spatial arrangement of soil particles, therefore, a saturated or near saturated soil is essential for crust formation. As soil dries out, soil water tension increases, bringing the particles closer together (Fajardo *et al.*, 2016). Thus the combined effects of increased soil water tension, reduced pore size and increased number of contact points enhance bond formation. The nature of exchangeable cations also affects the particle distribution and packing (Neave and Rayburg, 2007).

McIntyer (1958) stated that the SSC is formed as a result of effect of two processes: the first is mechanical by the action of direct raindrops falling on the soil. The second is a process of physiochemical dispersal of soil aggregates (Romkens *et al.*, 1990), and in this process the transferred particles of clay and silt contribute to the clogging of pores, especially large pores, and upon drought this layer becomes solid with a high apparent density and low permeability to water and air as well as reducing the emergence of small seedlings (Nciizah and Wakindiki, 2014). The following mechanisms play an important role in formation of structural crusts as reported by Fox *et al.*, (2004) and Fan and Wu (2020):

1- The topsoil aggregations are mechanically destroyed by the direct effect of rain drops, which work to break down soil aggregates and separate soil particles from each other. This process occur in most type of soils, especially in clay and silty clay soils, when the aggregations stability is very low, due to lack of organic matter, iron oxides, lime and other binders (Šimanský *et al.*, 2014 and Scott *et al.*, 2015).

2- Washing and transferring of fine soil particles and depositing them in the underlying soil pores (Chen *et al.*, 2013).

3- Compression of the soil surface by the direct effect of falling raindrops, thus forming a thin layer with a high bulk density and low porosity that reduces the entry of water into the soil pores (Taha, 2016). So, the fine soil particles move with the tip of the water and are deposited in the inter-pores forming the washed-in layer and when it dries up and hardens, the surface crust is formed (Wakindiki and Ben-Hur, 2002 and William *et al.*, 2010) consisting of two parts: the first layer is approximately 0.1 mm thick resulting From the pressure resulting from the impact of direct raindrops (Scott *et al.*, 2015), the second part is the fine soil particles that are dispersed by the raindrops and enter the inter-pores with the infiltration water, causing clogging under the first layer with a thickness of 2 mm and McIntyre (1958) called it the washed-in layer.

3- The cohesion of the topsoil saturated with water after drying and redirecting the soil particles (Fox *et al.,* 2004).
4- The topsoil layer consolidates upon drying and re-orientation of surface soil particles after what was saturated with water, which causes the hardness of the soil crusts (Fox *et al.,* 2004).

Types of Soil Crusts

Arshed and Mermut (1988) mentioned that there are three main categories of soil crust:
A- Disruptional crust: It is formed immediately after the destruction of soil aggregates under the influence of raindrops in silty soils.
B- Sedimentional Crust: It is formed in soils with surface runoff at the bottom of slopes or within the micro relief of soil surface.
C- Laminar Crust: It is formed in soils with a high content of exchangeable magnesium and sodium.
A surface sealing layer is the dissolution of soil weak surface layer formed as a result of irrigation or during rainstorms on clay or silty clay soils (Rabot *et al.,* 2018). This processes is attributed to collapse or breakdown of fragile soil aggregates, leading to clogging the pores and formation of a thin layer about 0.1 mm thick (McIntyre, 1985). In wet months the silty soil disperses, especially in the depressed parts of the field, resulting in the formation of a clogging layer up to 7 cm thick, and during the following dry conditions the surface clogs transformed into SSC (Aubert *et al.,* 2011).

SSC can generally be divided into three main types in terms of its mechanics:
1- Structural crust: This type of crust formed by the direct effect of raindrops on the soil surface (William et al., 2018), Usually these crusts are very thin 1-3 mm thick and have more porosity than the depositional crusts (Aubert et al., 2011). These crusts consist of two layers: the first is called Seal layer, which is a thin layer with a thickness of approximately 1 mm (Arshed and Murmut, 1988), and it formed as a result of the dissolution of soil aggregates and their compaction by action of falling raindrops. The second is called washing layer, and it is formed when the soil fine particles are transported with infiltration water and deposited directly in the interfacial pores of the sub-surface layer, causing its blockage (Bowker et al., 2016). The sub-types of this type of crust (structural crust) are: a) Slaking crusts, b) Infiltrating crusts, c) Coalescing crusts, d) Sieving crusts.
2- Sedimentional Crust: These crusts are formed when soil aggregates are dissolved after rain falls and fine soil particles (coarse clay and fine silt) are transferred by surface runoff and deposited in the Interfacial pores or deposited at the end of the slopes, and they also form in the micro-relief topography of the land (Belnap *et al.,* 2004 and Carmi and Berliner, 2008). The thickness of these crusts reaches several centimeters (Chen *et al.,* 2013). Chahinian *et al.,* (2006) mentioned that the thickness of these crusts ranges between 0.6-20 mm with very low porosity, while Bronnikova (2011) and Laker and Nortj (2019) mentioned that the thickness of these crusts is more than 50 mm and consists of several microebed layers (thin laminate layer) and each layer represents one rainstorm. The Sedimentional crust is divided into two secondary types, namely; erosion crusts and depositional crusts (Bresson *et al.,* 2004).

3- Biological Crust: This type of crust also called Cryptogamic or Cryptobiotic Soil Crust. It is surface crust formed from algae, fungi, lichens, algae and bacteria over Structural crust (Chin *et al.,* 2013 and Chen *et al.,* 2020) or above erosional or sedimentation crusts, and because it is composed of a microbiological layer known as Microbiotic Soil Crust (Wakindiki and Ben-Hur, 2002 and Fan and Wu, 2020). Since these crusts are formed due to the proliferation of microbes on the above crusts, they are sometimes not considered as soil crust (Belnap *et al., 2004*).

Biological Crust is a thin layer of living materials that forms in the upper millimeters of soil, where soil particles are collected by a community of microorganisms. It is primarily found in open spaces in extremely dry and cold regions of all continents, where extreme conditions prevent the growth of many plants (Bowker et al., 2016). In many areas, biological soil crusts are important for soil stabilization, moisture retention and soil fertility, and have a major impact on global ecosystems, as they are important sources of carbon in areas with little vegetation cover (Belnap and Büdel *2016*). Cyanobacteria and lichens in crusts convert atmospheric nitrogen into organic compounds that leach into the surrounding soil, as well as crusts with rough surfaces that slow down water runoff and increase water infiltration into the soil (Ferrenberg *et al.,* 2017).

Soil Properties Related to Crust Formation

Soil susceptibility to crusts depends not only on external factors such as the effect of falling raindrops, but also on the following internal soil factors (Laker and Nortj, 2019):

1) **Soil Texture:** the particle size distribution of soil, especially clay and silt, affects the formation of soil crusting. The high clay content encourages the development of soil aggregates and reduces the rate of crust formation. The medium-textured soils (less than 20% of the clay) very susceptible to crusting, and that the coarse particles on the surface of the soil protect smaller soil aggregates from the influence of direct raindrops, in the same way that mulching works, thus increasing infiltration and reducing erosion (Carmi and Berliner, 2008; Chen *et al.,* 2013 and Al-Naser, 2018).

2) **Clay Minerals:** Soils containing Smectite, Illite, and Muscovite are more prone to crusting, while Kaolinites minerals are less prone to crusting (Nciizah and Wakindiki, 2014 and Opoku-Kwanowaa et al., 2020).

3) Organic Matter content: It is considered one of the most important stabilizing factors for soil aggregations (Duwig *et al.,* 2020), thus protecting the soil from dispersion under the influence of rain drops (Sela *et al.,* 2012).

4) **Sesquioxides Content:** Iron and aluminum oxides encourage the formation of soil aggregates (Graef and Stahr, 2000 and Aubert *et al.,* 2011).

5) **Exchangeable Cations:** Some cations (exchangeable sodium and sometimes magnesium) play an important role in crust formation due to their ability to disperse colloids and flocculate those (Choudhury *et al.,* 2014).

6) **Moisture Content:** when precipitation covers dry soil, the water moves to the pressure of the air in front of it due to swelling, so the aggregates are destroyed and air bubbles exit, and as a result, the aggregates collapse (Bronnikova, 2011).

Methods Used to Determine the Soil Crust Strength

There are three main Parameters that can be used to determine the strength of the surface soil crust:

1- Modulus of Rupture: This parameter gives indication of the hardness of the crust; it is estimated by placing a piece of crust of a certain dimensions and thickness under the influence of a special machine, and when the mold is broken. The force required to break the mold can be estimated according to Ashby (2011):

$M = (3 * F * L) / (2 * b * d^2)$

M: Modulus of Rupture (dyne / cm^2), F: force to break mold (dyne), L: distance between anchor points (cm), b: mold width (cm), d: mold thickness or height (cm^2).

2- Penetration resistance: The hardness of crust can be estimated by pocket penetrating device, which is a devise, with a flat head of a certain diameter that is pressed perpendicular to crust layer, and when the crust breaks under the influence of this pressure, the reading is determined directly from the device by the (dyne cm^{-2} or kg cm^{-2}) (Hadas and Frenkle 1982).

3- Seedling emergence examination: This parameter can be determined by measuring the ability of the seedlings to push the crust layer upwards by using different sizes of penetration to represent the emergence of seedlings of different diameters.

قشرة التربة السطحية: أهميتها وانواعها ميكانيكية تكوينها. بحث مراجعة

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الخلاصة

تعاني معظم الترب الزراعية حول العالم من زيادة تدهور التربة وتعريتها وتقليل الحفظ الرطوبي، الذي يعتبر العامل الحاسم في إلانتاج الزراعي المحصولي، ومن بين هذه المشاكل ظاهرة قشرة التربة السطحية (SSC) التي تنتشر في مجموعة واسعة من المناخات ، وبالاخص في ترب المناطق الجافة وشبه الجافة. في هذه المراجعة، تم التركيز على أهمية قشرة التربة السطحية والتاثيرات السلبية التي تحدثها، ومراحل نشوءها وانواع تقشرات التربة والطرق المستخدمة في تقدير صلابة القشرة ومقاومتها للاختراق. لوحظ عند مراجعة الموضوع أن قشرة التربة السطحية تتشكل عندما تسقط قطرات المطر على التربة المحروثة حديثًا أو التربة الخالية من الغطاء النباتي، مما تؤدي إلى تدمير تجمعات التربة وتناثر دقائق التربة ودخول هذه الدقائق الناعمة في المسامات البينية، مما يؤدي إلى تكوين طبقات رقيقة صلبة على سطح التربة بسمك يتراوح من عدة مليمترات إلى عدة سنتيمترات، أو تنتقل هذه دقائق التربة بواسطة مياه الجريان السطحي لتترسب في المنخفضات مكونة قشرة ترسيبية يتراوح سمكها من 5- 7 سم. تنقسم تقشرات التربة بشكل عام إلى ثلاثة انواع رئيسية، القشرة التركيبية والقشرة الترسيبية بالاضافة الى القشرة البايلوجية والتي تتكون فوق النوعين

السابقين وتتالف من الفطريات والطحالب والاشنات والبكتريا. يمكن قياس أو تقدير صلابة القشرة بطريقتين رئيسيتين، وهما فحص معامل الكسر وقياس مقاومة القشرة للاختراق بالاضافة الى طريقة بزوغ البادرات.

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