A Review on Reclamation and Management Practices of Wind Erosion and Salt – Affected Soils of Sudan

Motasim Hyder Abdelwahab

Associate Professor, Department of Arid Land and Desert Agriculture, Faculty of Agriculture, Omdurman Islamic University, Omdurman, Sudan

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Abstract: Wind erosion and salt–affected soils are predominant desertification processes in Sudan, particularly in the northern part, and have adverse impacts on agricultural lands in the arid and semi-arid lands characterized by erratic rainfall, high temperature, high wind velocity and consequent high rates of evapotranspiration. The main objective of this paper is to present research review on combating, control, reclamation and management practices in areas affected by wind erosion and salt–affected soils. The study showed that the principal measures for controlling wind erosion depends on minimizing certain conditions that can be accelerated wind erosivity (winds ≥ 5.4 m/sec) and vice versa maximizing soil erodibility by creation a suitable condition for generate of non–erodible soil particles (NEP) versus soil surface detachment and transport by wind. Wind erosion research requires high financial support, thus this cost should be borne by government. The strategy of management practices of salt-affected soils aimed to sustain a level of salinity tolerable to the cultivated crops through good manages to water and crop. Assessment and mapping of wind erosion and salt-affected soils is urgent need to determine the inherent risk in the affected areas included in investment map of agricultural land capabilities of the country. Encourage studies on stabilizing soil particles by various natural or synthetic cementing and flocculation materials which are friendly to soil environment to increase NEP on the soil surface. Practical programs on reclamation of salt–affected soils should be included in national development programs and national strategy for scientific research in the State.

Keywords: Wind erosion, salt– affected soils, combating, reclamation, wind erosivity, soil erodibility and non-erodible soil particles (NEP).

1. Introduction

Desertification is defined as land degradation processes that must be combated at all levels, nationally, regionally and internationally. Degradation refers to a reduction of the current and the potential of the land to produce (quantitatively/qualitatively) goods or services by various processes: including soil erosion, biodiversity loss, salinity, sodicity, soil compaction, nutrient and organic matter depletion, and accumulation of pollutants toxic to plants and animals (Alzubair *et al.* *2020)*. Desertification being the main environmental problem and major constraint of biological production in Sudan (Mustafa, 2008) deserves top priority in research. In Sudan, the hyper-arid, arid and semi-arid lands constitute 41.2, 33.4 and 25.2% of the total area of Sudan, respectively. Thus, all states are subjected to wind erosion (Mustafa, 2008). Inspite of many researches, have been conducted in some states of Sudan to assess intensity wind erosion (Abdelwahab and Mustafa, 2013; Abdelwahab *et al., 2014;* Abuzeid *et al.,* 2017; Rizgalla *et al.* (1999); Farah, 2003; and Haikal, 2005). But there were two main constraints observed in assessing and combating of wind erosion: Firstly, the researches dealt with partial areas of affected states; secondly, there was no oriented government financial support for wind erosion study and research, this situation forced the researchers to fund their own research. Thereby, wind erosion and salts- affected soils researches in Sudan were monitored in few spot areas using field observations, remote sensing and geographical information system. These conditions may attribute to absence of national strategy for sustainable land management, mapping of wind erosion, and salt-affected soils, resulting in poor agricultural investment map for the country. Although Sudan used to describe as one of most famous agricultural country worldwise, no attention was given to study the impact of wind erosion and salt-affected soils on agriculture and socio-economic development.

Wind erosion occurs in a two-step process, namely detachment of primary soil particles from the soil mass and their transport by erosive winds V ≥ 5.4 m/sec (Skidmore and Woodruff, 1968). Certain conditions can be conducive to wind erosion include: lack or sparse vegetative cover, large and extensive field, loose, dry, and dispersed soil particles, smooth surface soil, and erosive winds. Wind erosion researches are widely acknowledged (Aleksandar *et al. 2019*; Javadi *et al. 2020*; Qi Luo *et al. 2020*; XinLyu *et al. 2021* and Guocheng Yang *et al. 2021*).

In Sudan research on wind erosion studied by several authors e.g. (Mukhtar, 1995 and Ibrahim *et al. 2003*). Abdelwahab *et al. (2014)* assessed wind erosion in river Nile state by remote sensing images, the data revealed that during the period 1987-2005, loose and shifting sand dunes increased by 1.3%, 110% and 34.4% in southeast Atbara, north Atbara and south Atbara, respectively. Moreover, the total area of irrigated tree crops decreased by about 11.6% and 8.2% in southeast Atbara and north Atbara respectively. Remote sensing is a successful technique for monitoring and assessing spatiotemporal variation of degraded natural resources and wind erosion. Thus, numerous works have been done in Sudan (Ali *et al. 2012;* Biro *et al. 2013*; Adam *et al. 2014;* Abdelwahab, *et al. 2014*; Fadl *et al. 2014*; Mohammedzain, *et. al. 2015*; Elhaja, *et al. 2017;* Abuzied, *et al. 2017).*

Saline and sodic soils occur naturally in arid, semi-arid and dry sub-humid regions of the world. Climate change namely relative sea level rise (RSLR) or hydrological change beside evapotranspiration patterns will promote the pressure on coastal systems, resulted in accelerating groundwater depletion qualitatively by increasing the mineralized groundwater level and quantitatively (Pérez-Martín et al. 2014).

However, secondary salinization occurs when the concentration of dissolved salts in water and soil is increased by anthropogenic processes, mainly through poorly managed irrigation schemes. Salinization induced by sea level rise and sea water intrusion is amplified by climate change. About 250,000 hectares in northern Sudan were affected to varying degrees by salinity and sodicity (Mustafa, 1986). Still there is a lack of studies on wind erosion and salt-affected soils practices in Sudan, accordingly this paper is step toward defining the interventions needed to manage and combat the two study issues through achieving the following objectives:

1. To present review of scientific theories and approaches (strategies, objectives, and management practices) that can help in the treatment of the wind erosion and salt-affected soils in study area.
2. To present review of research on wind erosion, salt-affected soils and their management and combating in study area.
3. To identify the research gap and constraints facing wind erosion and salt-affected soils in Sudan.

2. Materials and Methods

2.1. Study area

The study area was Sudan (1,882,000 Km²). is a northeast African country at latitudes 14 and 22° North and longitudes 22° and 38° East. Increasing temperature as a result of the greenhouse effect (global warming) is an important factor in climate change, leading to increasing temperature across the country. A change of 0.5-3ºC temperature was recorded (Taha *et al. 2013*). Vegetation biomass is seriously affected by this change, with a high variation in spatial and temporal distribution of rainfall in Sudan. Harison and Jakson, 1958 were used lines of equal rainfall (isohyets) to classify the vegetation zone of Sudan. Sudan is dominated by two types of winds, the dry northeasterly wind in winter (October, November, December, January and February) and the humid southerly wind in rainy season during (May, June, July, August and September). Aridity index (AI) is defined as a measurement of precipitation divided by evapotranspiration. Five degrees of aridity were defined (0.03 - 0.65) by (Dregne *et al.* 1991) in and become a global measure (Alzubair *et al. 2020***)**.

2.2. Source of data

This a review paper relay upon collection of research and studies that published in a national and international refereed scientific journals, Ph.D. thesis, internet and some scientific reports that gave consideration with wind erosion and salt- affected soils in sudan.

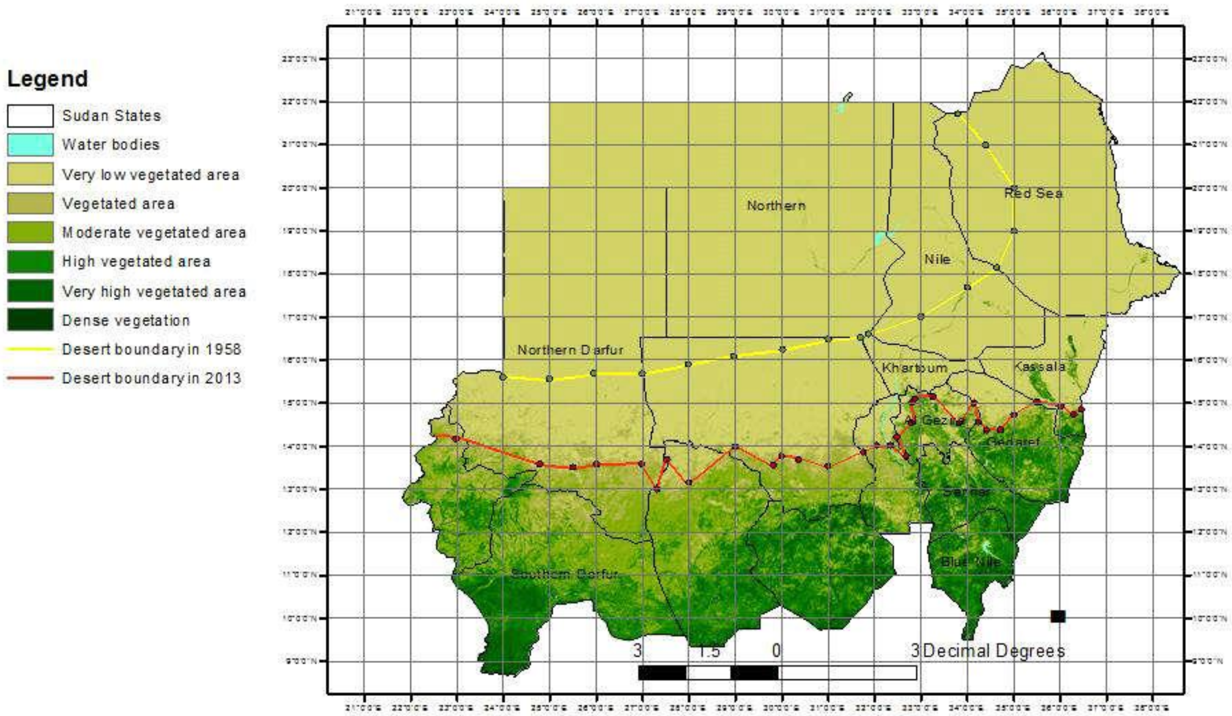

Fig.1. vegetations map of Sudan produced from MODIES EVI5 2013

Source: (Eltoum *et al.*, 2015).

3. Research in wind erosion

Wind erosion is the predominant process in Sudan and has adverse impacts on agricultural lands in the arid and semi-arid lands characterized by low, erratic rainfall, and high temperature, high wind velocity and consequent high rates of evapotranspiration. Many historical estimations were made by some scientists (Lamprey, 1975; UNEP,1977; FAO/UNEP,1984; Dregne,1991; Salih,1996; Ayoub,1998 and Mustafa, 2008). Numerous works has been done in many states to assess intensity of wind erosion (IWE) in parts only of the affected states (Abdelwahab and Mustafa, 2013; Abdelwahab *et al., 2014;* Abuzeid *et al.,* 2017; Rizgalla *et al.* (1999); Farah, 2003; and Haikal, 2005). A national research project on the assessment and mapping of wind erodibility in various states was undertaken in the Desertification and Desert Cultivation Studies Institute (Medani and Mustafa 2003; Mustafa and Medani 2003; Mohammed and Mustafa, 2005; Rehan and Mustafa, 2005; Abdelwahab *et al.*, 2009; Mohammed and Mustafa, 2011; Hassan and Mustafa, 2011 and Abdelgadir *et al.*, 2013).

3.1. Combating wind erosion

Wind erosion may be controlled by (a) stabilizing soil with various natural or synthetic cementing and flocculation materials that increase the non-erodible soil particles (NEP) on the soil surface, (b) by producing a rough and cloddy surface, (c) by maintaining sufficient vegetative cover and (d) reducing effective field length traveled by the wind by the establishment of barriers or shelterbelts barriers. In addition, there is no national strategy for combating wind erosion. Mapping of wind erosion is urgent need to determine the inherent risk in the affected areas. These principles for controlling wind erosion were summarized by the general functional relationship given by Woodruff and Siddoway (1965) as a wind erosion equation in the form:

$$E = f(1, K, C, L, V)$$

Where E is the average annual soil loss per unit area (tons/ha), I is a soil erodibility factor, K is a soil ridge roughness factor, C is a climatic factor, L is the unsheltered distance traveled by the wind and V is equivalent amount of vegetative cover. Rizgalla *et al. 1999*, used this relationship for estimating potential wind erosion (PWE) in three locations near El-Obeid differing in surface cover. His finding revealed that fallowing and burning reduced PWE by 98.7 and 26.3%, respectively. The fenced yard within the fallow reduced PWE of the fallow by 33.3%. The silt plus clay content in the soil drift was 15.8% less and sand content was 2.4% greater than in the virgin soil. Furthermore, wind erosion showed pronounced spatial and temporal variation (Rizgalla *et al., 1999*).

3.2. Objectives of wind control practices

All wind erosion control practices aim to accomplish one or more of the following:

3.2.1. Reduction of wind velocity at the soil surface

This is done with vegetation, crop residues, reducing field length, enhancement of surface roughness, strip cropping, establishment of windbreaks and shelterbelts (Woodruff, et al., 1972).

3.2.2. Trapping soil particles

This is accomplished by maintaining crop residues on the soil surface and/or by ridging or roughening the soil surface (Woodruff, et al., 1972).

3.2.3. Enhancement of non-erodible soil aggregates (Tatarko, 2001)

The size and stability of aggregates have major effects on a soil's susceptibility to wind and water erosion (Kemper and Chepil, 1965). Enhancement of non-erodible soil aggregates can be achieved by:

Using crop rotations that include grasses and legumes, growing high-residue crops and returning crop residues to the soil, applying manure, and using emergency tillage, which can create stable clods on the soil surface if soil moisture and texture allow.

3.3. Field control practices (Woodruff et al., 1972)

The field practices adopted to achieve these principles include:

3.3.1. Crop residues

Crop residues reduce wind erosion by reducing wind speed and by preventing much of the wind force from contacting soil particles. Vegetative matter on the surface also traps moving soil particles and reduces the avalanching effect. The amount of crop residue required to lessen wind erosion varies with residue type, height, position in relation to wind direction, and soil type (Lyon and John, 2004). In Sudan some farmers leave crop residues for animal grazing as a traditional practice in irrigated schemes (e.g. Gezira scheme in central Sudan). This practice is not studied as a method of wind erosion control, but Omer, 2018 described this practice as future energy option in Sudan.

3.3.2. Conservation tillage

Reduces wind erosion by leaving crop residues on the soil surface and reducing soil pulverization, which may occur if soils are tilled when dry. Each tillage operation reduces surface residue quantity and dries the soil, making the soil more susceptible to wind erosion. If soil moisture is adequate, tillage may bring erosion-resisting clods to the soil surface, but generally, this is only a short-term solution (Lyon and John, 2004). The effect of different vegetative covers on wind erosion can be compared by converting to the percent of the soil surface that is covered. The effect of surface cover on soil erosion is the same regardless of residue type. Fig 1 shows the effect of non-erodible soil cover (crop cover, %) on relative soil loss reduction compared to bare soil (%).

Many research activites have conducted on conservation tillage in Sudan (Abubaker,*et. al., 2017*; Abdalla,*et. al.,2007*; Ahmed,*et. al. 2020*; Khalil,*et. al., 2021*).

Photo.1. Conservation tillage

Source: https://www.shutterstock.com/search/conservation tillage

Standing residues are more effective at slowing the wind speed at the soil surface than the same quantity of residue flat on the soil surface. The higher the standing residues are, the more they reduce soil movement by wind. To determine the effect of standing stubble on soil erosion, the height (H, m), diameter (D, m), and number of stalks in a given area (for example, per square meter) must be estimated. The product of these three values gives the plant silhouette area (m^2/m^2), which is used in *Figure 2* to determine the effect on soil erosion. Fig. 2 shows soil loss ratio as a function of silhouette area (plotted from research data of Lincoln Extension, Institute of Agriculture and Natural Resources, University of Nebraska).

$$SLR = 0.0013\ X^{-1.4894}$$

Where SLA = soil loss area and X = silhouette area. In Sudan, some farmers leave crop residues

Photo.2.Tall wheat stubble (Nebraska)

Source: http://digitalcommons.unl.edu/extensionhist/1341

3.3.3. Strip cropping

The practice of farming land in narrow strips on which the crop alternates with fallow is an effective aid in controlling wind erosion (Chepil, 1957). Strips are most effective when they are at right angles to the prevailing wind erosion direction, but also provide some protection from winds that are not perpendicular to the field strip. Strip cropping reduces erosion damage in the following ways: (a) It reduces the distance the wind travels across exposed soil, (b) localizes drifting that starts at a focal point, and (c) reduces wind velocity across the fallow-strip when adjacent fields are covered with tall stubble or crops. Many farmers leave plant residues, whether they are grain crops or legumes, but the effect of these residues on reducing wind erosion and comparing it with uncultivated lands has not been studied.

3.3.4. Tillage and ridging

Stable non-erodible soil-clods formed by tillage help reduce wind erosion. They should be large enough to resist the erosive force of the wind and protect smaller material (Colazo and Buschiazzo, 2010)

Clod stability depends on soil moisture content at the time the clod is formed, soil density, soil texture, particle-size distribution, and microbial activity. Soils that produce the most stable clods are silt loams, clay loams and silty clay loams. In general, erosion of a land surface continues until a sufficient number of non-erodible soil particles are uncovered at the surface. At this stage, the non-erodible elements provide direct cover and shelter to the remaining erodible particles on the surface (Colazo and Buschiazzo, 2010)

This condition may alter with change of wind direction. The point at which this cover is sufficient to prevent particle movement from continuing or starting is called the critical surface barrier ratio and originally called the critical surface roughness constant. The use of this concept is extended to include other roughness elements, such as ridges and strip crops. This ratio is defined as the distance between the non-erodible clods, ridges or barriers and the height of either. It was found to vary between 4 and 20 on cultivated soils, depending upon the wind shear velocity at the time and the threshold shear of the erodible fractions. The higher the shear velocity and the lower the threshold, the lower is the critical surface barrier ratio. Chepil and Milne (1941a), investigating the influence of surface roughness on drifting dune materials and cultivated soils, found that the initial intensity of drifting was always much less over a ridged than a smooth surface. Ridging of cultivated soils reduces the severity of drifting, but ridging of highly erosive dune materials is less effective because the ridges will disappear rapidly. Serious and sincere work must be done to fill the lack of field control practices in order to reduce wind erosion and thus reach peaceful management of soil resources.

Photo: Proper ridging protects soil from wind erosion

https://www.shutterstock.com/search/conservation tillage

Ridges 10 to 20 cm tall reduces wind erosion by sheltering and trapping soil particles when the wind blows at right angles to them. This effect is reduced when the wind blows parallel to them. Ridges consisting of only erodible particles are of little value because they are easily flattened. Tall ridges expose the top most particles to stronger winds and increased erosion.

3.3.5. Barriers

Use of wind barriers is an effective method of reducing wind erosion. A properly oriented barrier, when winds predominate from a single direction, will decrease wind erosion forces by more than 50 percent from the barrier leeward to 20 times its height; the decrease will be greater for shorter distances from the barrier (Hagen, 1976). Besides the more conventional tree windbreak, different combinations of trees, shrubs, tall-growing crops, and grasses were used as barriers. They include annual crops like small grains, corn, sorghum, sudan grass, sunflowers (Karreker, 1966; Fryrear, 1963, 1969; Hagen *et al. 1972*; Hoag and Geiszler, 1971), tall wheatgrass (Aase *et al. 1976*;

Black and Siddoway, 1971), sugarcane and rye strips on sands in Florida. No consideration was given to this practicein Sudan.

3.3.6. Shelterbelts

Shelterbelts are vegetative barriers usually made up of one or more rows of trees or shrubs to reduce wind speed, provide sheltered areas on the leeward (the side away from the wind) and windward (the side toward the wind) sides of the shelterbelt and prevent wind erosion. Shelterbelts reduce wind erosivity, air temperature, and emissions of green house gases and trap dust storms. As such, they provide comfortable habitat for livestock. Furthermore, they protect the farm from trespassing of animals, people, and road traffic hazards and noise etc. (Gregory,1995). Human induced establishment of trees, shrubs and grasses over large areas appears extremely difficult due to water requirements. Studying and investigating the impact of existing shelterbelt on reducing wind erosion in Sudan received very little attention. Thus designing and implementing of shelterbelts, specify type of trees and number of rows must deserves top priority in research.

3.3.7. Aerodynamics of a shelterbelt

Farm-shelter play vital role in producing stable and high crop yield, stabilizing the farmland ecosystem, improving the micoclimate of agriculture field and reducing windstorm disasters (Kowalchuk and Jong, 1995; Zheng *et al.*, 2016a,b; Zhu *et al.*, 2017; He, *et al.*, 2017). When the wind approaches the shelterbelt, air pressure increases (loosely speaking, air piles up) on the windward side and conversely decreases on the leeward side. As a result the air stream approaching the shelterbelt is retarded, and a proportion of it is displaced up and over the shelterbelt, resulting in a jet of higher wind speed aloft. The remainder circulates through the shelterbelt to its downstream edge, pushed along by the decrease in pressure across the shelterbelt's width. These air streams are now further retarded by an adverse pressure gradient, because in the leeward side of the belt, the air pressure recovers again to the ambient level, with increasing downwind distance. Research on aerodynamics of a shelterbelt plays a vital role in reducing wind erosion. Unfortunately no research has been conducted in this field especially specify type of trees, number of rows and aerodynamics of a shelterbelt.

3.4. Research gab in wind erosion

Despite numerous relevant studies, still there is substantial gaps on the extent and severity of wind erosion at national scale in quantitative and qualitative studies such as: Stabilizing soil particles by various natural or synthetic cementing and flocculating materials that increase the non- erodiable soil particles (NEP) on the soil surface; producing a rough and cloddy surface; maintaining sufficient vegetative cover; and establishing barriers or shelterbelts barriers to reduce effective field length traveled by the wind. Furthermore there is a lack in studies focused on measuring sand encroaching into the Nile, winds data analysis, impact of wind erosion on agriculture and socioeconomic development, losses estimation of nutrients and organic matter particularly that caused by wind erosion. (Alzubair *et al. 2020*). The impact of climate change studies for dust and sand storm effects remain a critical gap, because the effects of dust and sand storms on human welfare, ecosystems, crop productivity and animal health are not measured, in Sudan and in the highly affected regions such as the Sahel, North Africa, the Middle East and Central Asia (Painter *et al.,* 2018). Climatic factor (C) is one of the five Wind Erosion Equation (WEQ) components. The relative soil loss for specific regions as determined based on the distribution of (C). Estimation values of (C) are essential for drawing (C) value maps for region under consideration, unfortunately in Sudan the (C) value maps are not done yet, reflecting in very little knowledge on wind erosion susceptibility and severity in all states of Sudan. Financial studies (cost expenses) are indispensable studies should be carried out in future for impact of wind erosion on agriculture and socioeconomic development in Sudan.

4. The extent of salt-affected soils in Sudan

Salinity and sodicity are widely spread and have series adverse impacts on the productive capacity of agricultural lands, forestlands, and rangelands (Drenge *et. al.,*1991; Mustafa 2007). Salt-affected soils in Sudan fall under three soil orders: Vertisols, Aridisols and Entisols (USDA, 1999). They extend along vast areas at latitudes 14-22° N, including the White Nile, North Gezira, Khartoum state, crossing the River Nile and the Northern states. Elmubark, 2007 reported that about 268636 ha of the surveyed and mapped areas in Sudan –until 2007-were found to be affected by salinity and/or sodicity. Consideration to these studies, still there is tremendous gap in salt-affected soils studies in Sudan, including surveying and reclamation.

5. Research in soil salinity and sodicity

Saline and sodic soils occur naturally in arid, semiarid and dry sub-humid regions of the world. Climate change or hydrological change can cause soil salinisation by increasing the mineralized groundwater level. However, secondary salinisation occurs when the concentration of dissolved salts in water and soil is increased by anthropogenic processes, mainly through poorly managed irrigation schemes.

Hamid and Mustafa (1975), found that the relative hydraulic conductivity of the Vertisols and other Aridisols was increased while the dispersion index, decreased by decreasing the exchangeable sodium percentage (ESP) and increasing the total concentration of salts (C.) There was also a significant decrease in the relative hydraulic conductivity by increasing the dispersion index which indicated 80% variation of soil samples balanced with salts of sodium chloride and calcium chloride. The relationship between the sodium exchangeable ratio and the total salt concentration threshold showed that the saturated gypsum solution was initially active in Vertisols with ESP >9, and in the expandable Aridisols soil with ESP >16. Mustafa and Hamid (1977) found that the large swell of soil increased with increasing ESP and C decrease. The study showed that the swelling caused 87% and 71% variability of the relative hydraulic conductivity for the Vertisols and Aridisols, respectively. Elmahi and Mustafa (1980) conducted a laboratory experiment to study the effect of the concentration of electricity and the absorption sodium ratio on the phosphorus capture in three surface soil samples from different arid regions, one of which belongs to the Vertisols, and two were Aridisols. Dahab *et al. (1988)* studied the effect of irrigation periods (5, 10 and 20 days) and the amount of irrigation water 120, 240 and 480 mm added at (3 and 6 mm / day) on intermittent evaporation and distribution of soil moisture and redistribution of salt in columns of saline-sodic soil have irregular salinity. Malik *et al. (1992)* found an increase in the swell and dispersion of the Vertisols from the soil of central Sudan and the decrease in permeability and spread of water, by increasing SAR and decreasing C. Awad Elkarim *et al. (1995)* explained the low rate of urea hydrolysis by water due to increased soil salinity in the range of 40-200 meg/L especially at high level of SAR. A study was conducted on the effect of some organic and inorganic amendments on cumulative evaporation, moisture distribution and salt redistribution in saline (Vertic-natargid)(Abd Elrahman *et al. 1996*). Mohammed and Mustafa (2000) found a very significant increase according to the second degree polynomial equation in the size of the soil shrinkage by increasing the sodium exchangeable ratio at several fixed values of the total concentration of salts. The direction of these equations explained more than 90% of the variation in shrinkage size. The effect of salts on the physiochemical properties of soil was studied by several researchers (Mohammed and Mustafa 2001; Ishaq and Mustafa 2005; Saeed and Aissa 2002; Mustafa and Abdelmajid 1981, 1982; Dahab, *et al. 1988*). Many research studies were undertaken to evaluate the impact of Farm Yard Manure (FYM) and chemical fertilizers on some crop production (Alaagib, 1999; Alaagib, 2003; Alaagib and Babiker, 2004; Alkhazin and Khalid, 2013; *El Mahi et. al.*, 2002)

6. Management and reclamation of salt-affected soils

Reclamation of saline soils aims to maximize the productivity of a crop or crop sequence by leaching and/or replacing of the exchangeable sodium with calcium for development of soil aggregation process and better aeration status (Mustafa, 1986; 2008; Nachtegaele, 1976). In Sudan during 1970s, some experiments in the Gezira, Soba and Hudeiba research stations has been done by national research center in addition some research activities on salt-affected soils conducted by agriculture faculties especially Faculty of Agriculture in Khartoum University. Unfortunately there is no strong reclamation program established yet.

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6.1. Management practices of salts-affected soils

6.1.1. Strategy

If it is not technically and economically feasible to remove the salt completely out of the root zone and drain it completely from the soil profile through natural waterways to seas or oceans. Soil, water and crop management may be relied upon to sustain a level of salinity tolerable to the cultivated crops. This strategy may be applied before, during and after soil reclamation while applying a suitable management plan during each of these stages (Hamid and Mustafa, 1975; Mustafa, 2014). This strategy conducted in small scale particularly in a farm at Shambat (Fac. of

Agric. University of Khartoum) and experimental fields in the Gezira, Soba and Hudeiba research stations (National research center). These studies are not applied on countrywise to reclaim salt-affected soils of Sudan. The technological management package consists of simple cost-effective techniques such as seeding appropriate salt-tolerant crops, applying pre-sowing irrigation, adopting frequent irrigation schedule, and alleviating seeding in high salinity spots etc. Whereas, soil reclamation requires relatively expensive techniques such as grading of rolling land, changing the irrigation system and the source of irrigation water, using subsurface drainage and modifying the soil profile (Mustafa, 2008, Mustafa, 2014).

6.2. Reclamation practices of salt-affected soils

6.2.1. Strategy

The strategy of reclaiming saline soils aims to maximize the productivity of a crop or crop sequence by leaching and draining the excess salts completely out of the root zone through natural waterways or by artificial subsurface drainage to seas or oceans (Mustafa and Abdel-Magid, 1981). In the case of sodic soils, the reclamation process includes, in addition to what has been mentioned for saline soils, the application of a calcium amendment to replace the excess exchangeable sodium by Ca^{++} and reduce the ESP to a tolerable level (Hamied and Mustafa, 1975; Mustafa and Hamid, 1977; and Elaagib, 1999). If there, is no natural drainage waterways an artificial subsurface drainage system may be installed to transport the drainage water out of the soil profile. The quantity of water required for reclaiming the saline soil depends upon the initial and the required final soil salinity, the water quality (mainly EC and SAR), the soil depth required to be leached, the actual evapotranspiration of the growing crop and the soil physical properties.

6.2.2. Continuous pounding

This method consisted of continuous flooding of the soil in basins for 60 to 100 days, after which it is left to dry. The drying of the soil promotes its structure and reduces microbial growth and allows soil sampling. At the appropriate stage of soil drying, crops that can tolerate salt and wet moisture conditions, such as rice, barley and wheat and sorghum grasses may be seeded. Growing crops will facilitate soil reclamation since crop residues will add organic matter to the soil and hence improve its structure and enhance water infiltration and conservation. Furthermore, CO_2 released directly by the roots and produced by microbial decomposition of organic matter may dissolve soil $CaCO_3$ and release Ca^{++} that will replace exchangeable Na^+ and enhance water movement. All these effects will facilitate the soil reclamation process. There is no attention was given to continuous pounding methods as reclamation practices of salt-affected soils in Sudan

6.2.3. Intermittent pounding

Several laboratory and field experiments showed that intermittent pounding is more efficient in salt leaching than continuous pounding. Further, studies by Mustafa and Abdel-Magid (1981) showed that under intermittent pounding salt leaching increases with more frequent irrigations. Some research has been carried out to investigate the effect of irrigation interval and soil amendments on some plant growth (Gabir,1984; *El-Tilib et. al.*, 1995 and Baraka *et. al.,* 1999 Mustafa and Abddel- Rahim, 2012)

6.3. Reclamation of sodic soils

Many research studies were undertaken to reclaim sodic soils in Sudan. The principle of reclaiming such soils is replacement of Na^+ on their exchange complex by Ca^{++}. The aims of this step are to alleviate the adverse soil physical effects of ESP, safe some crops from the toxic effects of Na^+ and the adverse nutritional imbalance caused by excessive sodium. The replacement of exchangeable Na^+ by Ca^{++} increases the soil hydraulic conductivity (HC), which promotes leaching of the replaced Na^+ out of the soil profile naturally or artificially (Mustafa and Hamid, 1977). When sodic soils are cultivated for a long period without reclamation, especially if they are swelling clay soils, they tend to develop hard massive structure, surface crusting, poor internal drainage and an overall poor soil quality that produces very low crop yields (Izzeldin, *et al. 1996;* Izzeldin *et al. 2000*). Before completing its reclamation, the soil may be properly managed to maximize its productivity. The addition of crop residues, farmyard and green manures and plowing cover crops under with tillage will enhance internal drainage and accelerate soil reclamation. Chisel plow and sub-soiling may be undertaken to shatter hard pans, if any (Mustafa, 2008). The natural sources of calcium include gypsum and calcium carbonate. Gypsum is the most important natural source of calcium, and it is usually used for reclaiming sodic soils. However, its use is limited by low solubility. A saturated gypsum solution has a concentration, which is nearly equal to 30.5me/l at 25 °C, which is equivalent to 2700 mg/l gypsum ($CaSO_4.2H_2O$) or 590 mg/l Ca^{++} (Hamid and Mustafa, 1975).

If the root zone of a sodic soil contains an amount of gypsum equivalent to exchangeable Na^+ and the clay mineral is kaolinite or illite, reclamation can be achieved by leaching with water only provided soil HC is sufficient. Furthermore, the drying and wetting process along with growing a crop will facilitate the reclamation process.

Soil Hydraulics Conductivity (HC) through the soil profile is a very important factor in the reclamation process. Soil HC in a salt-affected soil depends on ECe, ESP and the relationship depends on the soil texture and clay mineral. Water with low salt concentration (C) causes dispersion of a sodic soil and hence it decreases HC, while water with high salt concentration causes flocculation of clay particles and hence increases HC. Thus, in sodic soils HC increases with increase of C and decrease ESP, especially in swelling soils (Hamid and Mustafa, 1975; Mustafa and Hamid, 1977). The presence of $CaCO_3$ in a soil does not affect significantly the concentration of Ca^{+2} in the soil solution because of its extremely low solubility. The solution saturated with $CaCO_3$ at atmospheric pressure and 25 °C has a concentration of 0.14 me/l or 2.7 mg/l Ca^{+2}. However, in the case of the presence of growing crops, their respiration produces CO_2, which reacts with $CaCO_3$ to form the water-soluble calcium bicarbonate (Mustafa, 2008).

6.4. Research gab in soil salinity and sodicity

The amount and type of salts presents in the soil play an essential role in determining the land productivity. Till now in Sudan experiments of reclamation which are conducted in small farm must be implemented in agricultural affected lands throughout the country. Moreover, insertion of scientific and practical reclamation programs for salinity and sodicity should be included in national strategy in the State.

7. Conclusions and recommendations

7.1. Conclusion

- Wind Erosion and salts–affected soils are prevalent in Sudan because of the presence of conducive, condition especially in northern part of country including high temperature, low and erratic rainfall and relatively high wind speed.
- The principles of wind erosion controlling measures depend on minimizing the certain conditions can be accelerated wind erosivity (winds $\geq$ 5.4 m/sec) and vice versa maximizing soil erodibility by creation suitable practices to obstruct soil particles to detachment and transport by wind.
- Limited financial resources for wind erosion research lead to weakness in implementing of wind erosion control practices and also wind erosion research not covers the whole targeted areas in the country.
- The strategy of management practices of salt-affected soils aimed to sustain a level of salinity tolerable to the cultivated crops through good crop and water management. This strategy may be applied before, during and after soil reclamation.
- The strategy of reclaiming saline soils aims to maximize the productivity of a crop or crop sequence by leaching and draining the excess salts completely out of the root zone through natural waterways or by artificial subsurface drainage to seas or oceans.
- In the case of sodic soils, the reclamation process includes, in addition to what has been mentioned for saline soils, the application of a calcium amendment to replace the excess exchangeable sodium by Ca^{++} and reduce the ESP to a tolerable level.
- The current strategy and practices for wind erosion and salinity management are not effective, which requires intervention to highlight what has accomplished and not accomplished, and then draw up a clear strategy for the whole country that covers shortcomings in affected areas that leads ultimately to agricultural development and natural resources sustainability.

7.2. Recommendations

- Assessment and mapping of wind erosion and salts-affected soils is urgent need to determine the inherent risk of affected areas which can considered as a major constraint for both land productivity and the country agriculture investment map.
- Inclusion of effective programs on soil reclamation of salinity and sodicity in the national development agenda.
- The country must invest in scientific research to ameliorate soil resilience to wind erosion and increasing of soil function, hence socioeconomic development.
- Encourage studies on stabilizing soil particles by various natural or synthetic cementing and flocculation materials which are friendly to the environment to increase the non- erodible soil particles (NEP) on the soil surface.
- Financial studies (cost expenses) are indispensable studies should be carried out in future for impact of wind erosion on agriculture and socioeconomic development in Sudan.

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