Physical assessment and social judgement of wind erosion and possible restoration in the drylands of western Sudan

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Abstract
This study was conducted in July 2022 in North Kordofan State (latitudes 11.15° - 16.45°N; longitudes 27.05° - 32°E) in western Sudan on an inherently impoverished sandy soil highly vulnerable to wind erosion. The aim of the study is to assess wind erosion and its social and environmental impacts and the use of shelterbelts as erosion control measures. Various sand traps were used for measuring the sand accumulation. Social surveys were conducted to assess the drivers of land degradation and avoiding it these reasons. The results reveal the highest soil accumulation (70.0ton ha^{-1} year^{-1}) was obtained at the 15 cm trap height. Soil accumulation at the 30cm and the 45cm high traps was also high (>40ton ha^{-1} year^{-1}). The study proved that wind is blowing at different levels carrying the soil particles. Disc-ploughing on sandy soils, is the main driver of land degradation followed by overcutting of trees. However, drought, lack of improved seed and poverty are the main constraints to agricultural production.

Key words: wind erosion, Soil accumulation, sand traps, shelterbelts. Social impacts, environmental impact

Introduction

Wind erosion is a natural phenomenon that has occurred over the millennia as part of geological processes and climate change (Roger and Michel, 2013). Erosion is becoming more severe and it is accelerated by adverse human activities. Wind erosion is an important land surface process occurring in many countries. The eroding of the finest and most valuable soil particles lead to the degradation of agricultural lands besides polluting the atmosphere (Roger and Michel, 2013). The problem of wind erosion has received wide concern especially when climate change and its associated effects on human society and agriculture is regarded as a global problem (Funk and Reuter, 2006). More attention is given to wind erosion as a process responsible for an accelerated decrease in soil fertility and as a source of atmospheric pollution (Oldemann *et al.,* 1990; Gobin *et al*., 2003; Warren and Bärring, 2003). Soil is essential in sustaining humankind, but it can be rendered infertile when the topsoil or the fine soil particles are eroded by wind. The removed soil particles may be deposited downwind to become part of the new landscape or may be transported to oceans where the nutrient-rich dust enhances aquatic life (Morales, 1977). Shelterbelts and windbreaks are major components of successful agricultural systems in wind-erosion-prone areas throughout the world. Previous research on the effect of shelterbelts against moving sands showed that 44.4% of farmers interviewed at Namla village in North Kordofan emphasized the role of shelterbelts in curbing wind erosion (Mutwali *et al*., 2018).

In Sudan, the main degraded zones are the arid and semi-arid areas where 76% of the population of the country lives (Ayoub, 1998). Dregne *et al.* (1991) estimated that nearly 70 million hectares of

Sudan land are very severely degraded. North Kordofan State which is located between latitudes 11.15^o and 16.45^{o}N and longitudes 27.05^o to 32^{o}E is highly affected by wind erosion. The majority (about 70%) of the soil is sandy composed of coarse and fine sand with low nitrogen and organic matter contents. The rainfall is variable in amount and distribution with an average of 318 mm occurring between May-October with the peak in August. The climate is hot characterized by high temperatures reaching up to 45^{o}C and an average daily temperature ranging between 10-35^{o}C. However, within North Kordofan, Namla village and its surroundings is facing serious sand movement burying most of their agricultural land (Mutwali *et al.* (2015). The wind direction in the study area is from north to south and the sand accummulation occus during the windy months of March, April, May and up to mid of June. Accordingly, a sand dune fixation program was initiated to help protect the agricultural farms by planting some indigenous over- story (underground vegetation) and under- story species which can control sand movement and wind erosion. the three-row, 22-meter-wide, shelterbelt consisting of *Leptadenia pyrotechnica* “Markh”, *Acacia tortilis* “Syal”, *Acacia senegal* “Hashab”, *Balanites aegyptiaca* “Hegleeg”, *Fedaherbia albida*, “Hraz” and *Panicum turgidum* “Tomam” was established.

Generally, for effective biological control of wind erosion, some studies suggest that shelterbelts should be designed to contain 10 or more rows of trees and shrubs to provide maximum benefit to wildlife and land/ homeowners (IOWA, 2010). The most effective shelterbelt will be composed of semi-permeable tree crowns to provide a barrier to wind over their full height and from the ground to the crowns of the tallest trees. In biological control, field investigations indicated the effectiveness of trees and shrubs to suppress moving sands compared to other mechanical measures (Al-Amin *et al.*, 2006; Al-Amin *et al.*, 2010; Shulin *et al.*, 2008; Mohammed *et al.*, 1999).

Therefore, the overall objective of this study is to assess wind erosion in terms of sand accumulation and to understand the local peoples’ perceptions of the social and environmental impacts of wind erosion and control measures using shelterbelts for improved agricultural production and improved livelihood of the people.

Specific objectives

1. To assess the amount of windy soil erosion in ton/ha/ year.
2. To understand peoples’ views on causes of land degradation.
3. To determine the constraints to agricultural production and the role of active institutions in support of the local people to achieving restoration and overall environmental protection.

Methodology

Assessment of wind erosion

Horizontal and vertical sand traps were used for measuring wind erosion at Namla village (Fig 1) in terms of sand accumulation in the sand traps. The horizontal sand traps are plastic cans, 21*21cm wide and 40cm high, erected in the windward and leeward directions of the shelterbelt (Fig 2) and arranged in three replications in the northern and southern wind directions. The traps were erected, after 5 years from our previous measurements presented in Mutwali *et al*. (2018), at distances of 1.0, 10, and 20 m from the shelterbelt belt. The traps were discharged every three months and the accumulated soils weighed. Similarly, the traps were erected in the northern and southern wind directions with the shelterbelt. The vertical trap is supported by a metal pipe with three levels: 15cm, 30cm, and 45cm from the ground surface. The trap has two windows, each is 1cm*1cm, in opposite directions. One of the windows is open and the other is covered with mesh to control the sand particles entering through the open one. Similarly, these traps were discharged every three months and the deposited soil is weighed. The accumulated sand in the horizontal and vertical traps in tonnage ha^{-1} $year^{-1}$ was calculated using the soil loss equation (Farah, 2003) adapted from Woodruff and Siddways (1965):

$$\text{Soil loss (Tons ha}^{-1}\text{ year}^{-1}\text{)} = \frac{\text{Weight of soil sample (g) x 100}}{\text{Area of trap (cm)}}$$

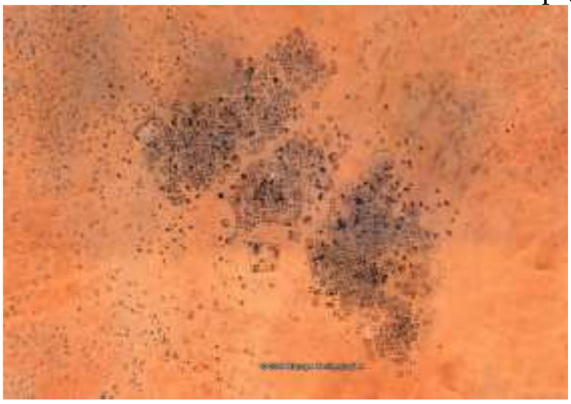

Fig (1): Map of Namla village

Focus group discussion and interviews with the local community

Focus group discussions were conducted with a gender-balanced group of village farmers to understand the village context and the community views concerning environmental and social vulnerabilities in the area and the role of restoration in mitigating adverse impacts. A structured questionnaire was also used to collect more detailed data and information on farming practices based on 50 households. A multi-disciplinary team of experts with relevant skills leads the discussions and some interviews with key informants. Native administration, other community leaders, and lead farmers participated in the interviews to understand their views for causes of land degradation, the production constraints to agricultural production, and active institutions in support of the local people in achieving restoration and overall environmental protection. The collected data and information were analyzed using SPSS and Excel statistical software.

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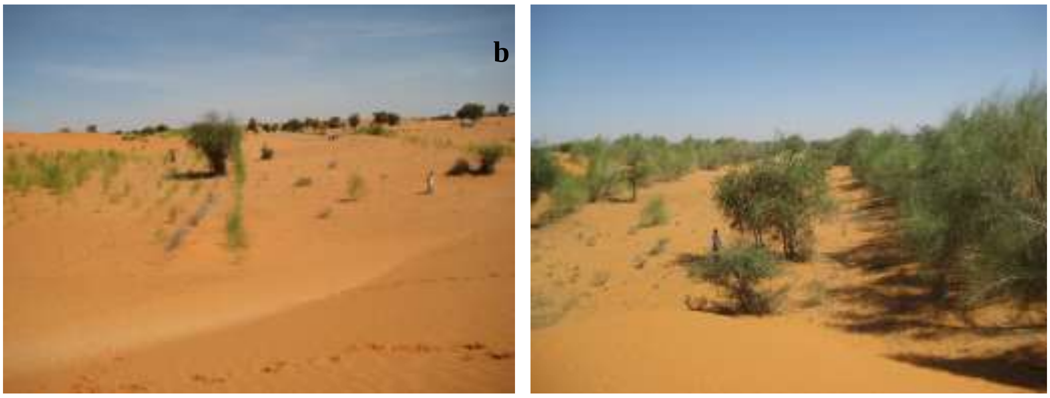


Fig (2): Early (left) and late (right) stages of establishment of Namla shelterbelt in North Kordofan, Sudan.

Results

Soil loss by wind erosion

the wind direction in the study area is from north to south and the sand accumulation occurs during the windy months of March, April, May and up to mid-June, i.e. a total of 107 days, and therefore, the accumulation per year was estimated by number of windy months in the year.

The amount of soil loss in ton ha^{-1} $year^{-1}$ accumulated in the vertical sand traps was presented in Table 1. From this table, the highest (70.0-ton ha^{-1} $year^{-1}$) soil accumulation was obtained at the 15 cm high trap at the windward side of the shelterbelt. However, the soil accumulation in the 30 cm high trap was also high averaging 63.4 tons $ha^{-1}year^{-1}$. On the other hand, the amount of soil loss decreased to about 47.6 tons ha^{-1} $year^{-1}$ in the 45 cm high trap indicating less soil loss with increasing trap height. This result proved that the wind in this area is blowing at different levels carrying soil and at varying heights, but at the same times it is also indicative of surface creep type, (there are three types of sand movement saltation, suspension and surface creep). The sand accumulation decreased by 17% south of the belt, i.e. the leeward side, at the 15cm trap height. However, the soil accumulation at the 30 and 45 cm trap heights was quite different. It reaches 60.2 tons ha^{-1} $year^{-1}$ and 37.8 tons ha^{-1} $year^{-1}$ under the 30 and 45cm trap heights, respectively. On the other hand, the reduction of soil accumulation decreased by 48% at the 45 cm trap height. These relatively high accumulations of soil are due to the very frequent filling of the sand trap during the three-month accumulation period.

Soil accumulation as measured by horizontal traps with distance from the shelterbelt in the windward and leeward directions is presented in Table 2. Accumulation of sand was found to decrease according to the distance from the shelterbelt both at the windward and leeward directions. The highest (300.0 and 209.7 tons $ha^{-1}year^{-1}$) accumulations were obtained at a distance of 1.0 m from the shelterbelt at the windward and leeward directions, respectively. This high accumulation is also due to the very frequent filling of the sand trap during the three-months period. The amount of sand accumulation decreased by 30.1% in the southern or leeward side of the belt. Similarly, at a 10 m distance from the belt, the amount of soil accumulation also decreased by about 30% in the north direction from the shelterbelt. In line with the above result, the amount of soil accumulation at the 20m distance from the belt decreased in both directions of the belt but the decrease was less than 30%.

Table (1): Accumulation of sand (ton ha^{-1} $year^{-1}$) in vertical traps at Namla village in North Kordofan State in western Sudan.

Trap height (cm)	Soil accumulation at north of shelterbelt (Ton ha^{-1} $year^{-1}$)	Soil accumulation at south of shelterbelt (Ton ha^{-1} $year^{-1}$)	Reduction (%)
15	70.0	62.2	17.0
30	63.4	37.8	40.4
45	47.6	24.4	48.7

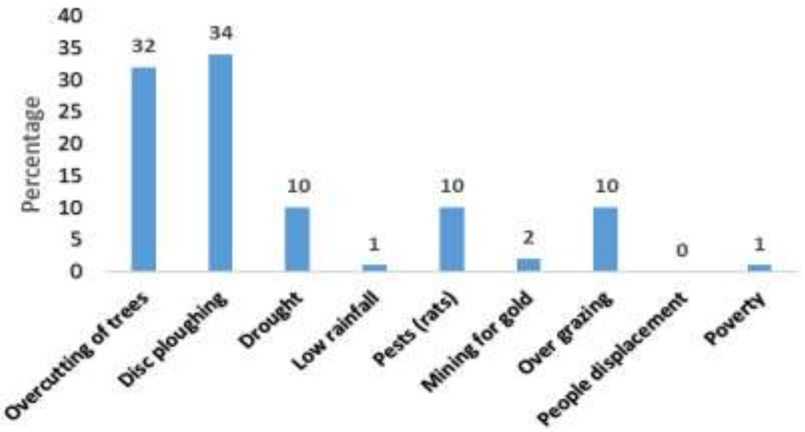
Table (2): Soil accumulation (ton ha^{-1} $year^{-1}$) in horizontal traps at Namla village in North Kordofan State in western Sudan.

Trap distance from belt (m)	**Soil Accumulation (Ton ha^{-1} $year^{-1}$) North of belt**	**Soil Accumulation (Ton ha^{-1} $year^{-1}$) South of belt**	**Reduction%**
01	300.0	209.7	30.1
10	150.9	105.0	32.4
20	96.3	67.7	29.7

Respondents' views on land degradation due to wind erosion and restoration

- ***Drivers of land degradation at Namla village in North Kordofan***

The local community's perceptions regarding the drivers of land degradation are presented in Fig 3. A high percentage (34%) of the respondents regarded the use of disc plough to cultivate the fragile and vulnerable sandy soils, as the main driver of land degradation which is related to the severity of wind erosion followed by overcutting of trees for domestic reasons and for sale, as the second (32%) main driver of land degradation. However, drought, animal pests, namely rats, and over-grazing by livestock have a similar magnitude in terms of the percentage of respondents who stress these three problems as important drivers of land degradation in their areas. On the other hand, gold mining, low rainfall, displacement, and poverty were mentioned by a low percentage (0-2%) of the respondents.



Fig(3):Drivers of land degradation at Namla village in North Kordofan.

Production constraints to agricultural production

The questionnaire results revealed several of environmental and socio-economic constraints that are believed by the local people to have resulted in decreased agricultural production. Drought, poverty, lack of finance, and desertification are the most important constraints mentioned by about two-thirds (30 out of 50) of the male respondents. However, the judgment by female farmers shows great discrepancy from that of men farmers. About half of the female farmers considered the lack of finance to their agricultural activities, as the most important constraint. Moreover, poverty, drought, lack of improved seeds, desertification, and agricultural pests were considered by about one- third of the participating female farmers. For land tenure, only a few (seven farmers) face the problem of land shortage (Fig. 4).

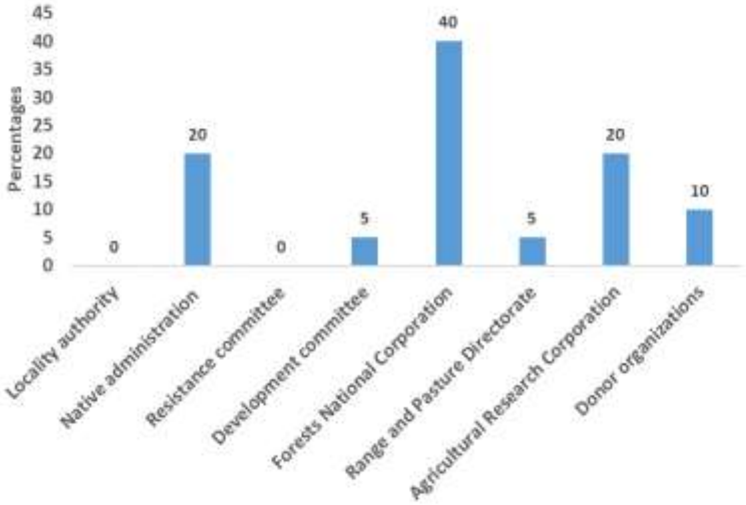


Fig (4): Production constrains to agricultural production at Namla village in North Kordofan. constrains of agricultural production at Namla village in North Kordofan are pests, drought, seed shortage, poverty, lack of finance, land shortage and desertification

- **Institutions in support of local community in restoration activities**

The focus group discussion with the village respondents concerning institutions that are more committed to supporting them regarding environmental problems and possible restoration methodologies revealed a number of active civil and government institutions as summarized in Fig 5. The results indicate that the Forests National Corporation (FNC) is the most supportive institution to the community to achieve restoration for the protection of their village and farms. About 40% of the respondents believe that FNC is the most supportive institution for their environmental protection efforts. Secondly, the native administration and the Agricultural Research Corporation were found to have similar (20% in support of the village community) contributions to support to the local community. Thirdly, the donor organizations working in the state were also active in supporting the village`s environmental issues. in addition to that, the respondents expressed that “neither the government authority within the locality and village resistance committee has any support given to the community.

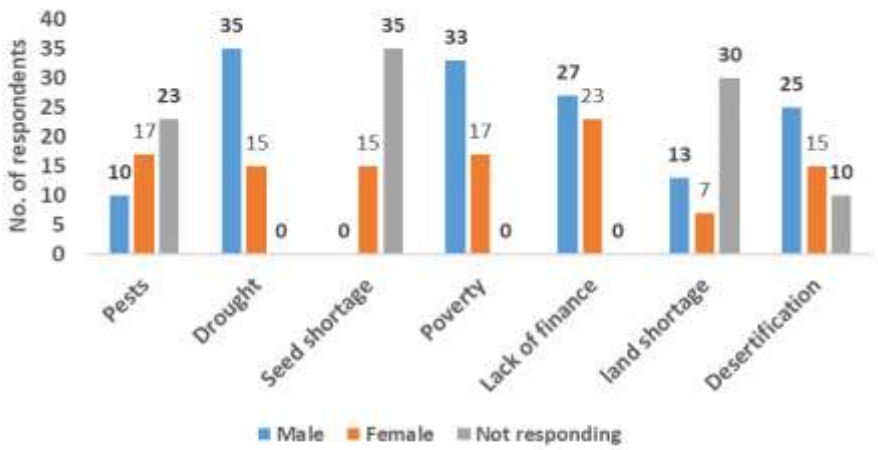


Figure (5): Institutions in support of local community to achieving restoration of degraded lands.

Discussion

Wind erosion as a natural and human induced phenomenon and its widespread negative impacts on the environment and the social wellbeing of people in the drylands, is widely known. Land degradation and environmental pollution and the amount of accumulated soil occur as due to the transport of the finest and most valuable soil particles by wind and water (Grini *et al*., 2003; Stout *et al*., 2009). In this study a high percentage, about one third, of the respondents regarded the use of disc plough in cultivating the fragile sandy soils, as the main driver of land degradation followed by overcutting of trees and that drought, animal pests, namely rats, and over grazing by livestock were also considered as important drivers of land degradation. However, in North Darfur, which also lies in the drylands of Sudan, tree cutting ranked first followed by fire and poverty which both ranked second. Therefore, tree cutting mainly for domestic reasons such as its use as charcoal or wood for cooking and for sale is a common driver in drylands. Nevertheless, it is clear that this result confirms that the drivers of land degradation are location specific as stated by Mirzabaev *et al*. (2015).

The effect of wind erosion on agricultural land, pollution of atmosphere and decreased soil fertility is widely known especially in African drylands. In Sudan, there is quite number of studies that have been conducted on the effects of shelterbelts and wind breaks on micro-climate as well as their socioeconomic impacts on rural populations. Nonetheless, very few attempts have been carried out to measure erosion in terms of assessing vulnerability of soils to erosion or in terms of soil loss or soil transported by wind and accumulated on other sites. In a comparable environment in northern Sudan, the Mutwali *et al.* (2015) measurement of soil erodibility showed an evidence of moderate wind erosion in the form of surface creep, and a high soil accumulation of 76.8 tons ha^{-1} day^{-1} obtained at the 15 cm height's vertical sand traps. Furthermore, the development of methods for measuring soil erosion and sand accumulation in different areas in northern and western Sudan and studies on effective methods for controlling wind erosion with the involvement of local communities, were conducted by Mutwali *et al*. (2018). However, this study, which was conducted in the same site and three years later, showed less soil accumulation of 70.0 ton ha^{-1} day^{-1} in the 15 cm trap height and that soil accumulation decreased with increasing trap height. The decrease in accumulation is attributed to the more protection offered by the shelterbelt after its increased growth at the age of 13 years old as compared to previous measurements carried out at the age of 10 years. Also, the accumulation of sand was found to decrease at its leeward side according to the distance from the shelterbelt (Mutwali,2015).

As a land use system, shelterbelts are regarded as agroforestry techniques that transform degraded land into a properly managed system that combines woody perennials with field crops. Shelterbelts have a variety of benefits such as: reducing soil erosion, protecting water resources, storm damage, reducing land degradation and desertification and acting as windbreaks and thus protecting agricultural land and consequently resulting in increased crop production (Abdel Magid, and Diab, 2014). By this, shelterbelts play an important role in achieving food security and livelihoods of the rural communities to adapt to climate change and its negative impacts. Therefore, shelterbelts and windbreaks are major components of successful agricultural systems in wind-erosion-prone areas throughout the world. Previous research on the effect of shelterbelts against moving sands showed that 44.4% of farmers interviewed at Namla village in North Kordofan emphasized their role in curbing wind erosion (Mutwali et, al. 2018).

The questionnaires results revealed a number of environmental and socio-economic constraints that are believed to have resulted in decreased agricultural production. Although the ranking of the agricultural constraints differs among men and women, yet both groups considered poverty and lack of finance or financing institutions as the main constraints facing agricultural production. In line with this, The National Household Baseline Survey (NHBS) indicates that the prevalence of the global poverty in Sudan was 36.1%, while the poverty incidence in North Kordofan is estimated at 39.1% (African Development Bank, 2018). However, with respect to lack of finance, more than half of the men respondents lack finance to their field crops as compared to about 46% of women farmers. In this respect, (ILO, 2022) in its socio-economic assessments of Sudan revealed that the financial services sector covers only 3% of country's total demand (ILO, 2022). Therefore, provision of credit to needy farmers before the start of the rainy season seems of paramount importance to ensure food security and resilience of local communities against climate shocks.

The group discussion with the local village community has also pursued the issue of institutions that are supportive to the community in restoration of degraded ecosystems. The results indicate that the Forests National Corporation (FNC) is the main government institution that is supportive to the community to achieve restoration for the protection of their village and farms. However, the native administration is the second in importance regarding institutional support to the village community followed by research institutions. The active role of the native administration is well acknowledged by farmers in most rural areas of the Sudan. This was evidenced in similar surveys carried out in a number of states (FNS-REPRO, 2019).

Conclusions

This study demonstrates the importance of measuring wind erosion, sand movement and the role of establishing shelterbelts in reducing sand movement and desertification in the extremely dry areas of western Sudan. A high percentage of the respondents regarded the use of disc plough in cultivation of the fragile and vulnerable sandy soils, as the main driver of land degradation followed by over cutting of trees for domestic purposes and for sale. On the other hand, drought, lack of improved seed and poverty are the main constraints to agricultural production. However, by restoring degraded lands, the local communities believe that the Forests National Corporation (FNC), the native administration and the Agricultural Research Corporation as the most supportive institutions to their efforts.

Further research and studies should be conducted on measuring wind erosion and the environmental and socio-economic role of restoration in increasing resilience of local communities to climate change

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التقييم الفيزيائي و الاجتماعي لتعرية الرياح و امكانية إعادة التأهيل في الاراضي الجافة بغرب السودان

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الملخص

أجريت هذه الدراسة يوليو 2022 في ولاية شمال كردفان (خطي دائرتي عرض 11.15 درجة – 16.45 درجة شمالاً، خطي طول 27.05 درجة – 32 درجة شرقاً) في غرب السودان على تربة رملية فقيرة بطبيعتها معرضة بشدة للتعرية بفعل الرياح. الهدف هو تقييم تعرية الرياح وآثاره الاجتماعية والبيئية واستخدام الأحزمة الواقية للحماية من التعرية. تم استخدام مصائد رملية مختلفة لقياس معدل تراكم التربة. تم إجراء المسوحات الاجتماعية لتقييم أسباب تدهور الأراضي وتحييد آثار تدهورها. تم الحصول على أعلى تراكم للتربة (70.0 طن هكتار $^{-1}$ سنة $^{-1}$) عند ارتفاع 15 سم للمصيدة. كما كان تراكم الرمال عند 30 سم وارتفاع 45 سم عاليا (< 40 طن هكتار $^{-1}$ سنة $^{-1}$). أثبتت الدراسة أن الرياح تهب على مستويات مختلفة تحمل حبيبات الرمل. كما بينت الدراسة أن استخدام المحراث القرصي في التربة الرملية هو المسبب الرئيسي لتدهور الأراضي يليه قطع الأشجار. ومع ذلك، فإن الجفاف ونقص البذور المحسنة والفقر من المعوقات الرئيسية للإنتاج الزراعي.

الكلمات المفتاحية:تعرية الرياح، آثاره الاجتماعية والبيئية،تدهور الأراضي، المسوحات الاجتماعية،- مصائد رملية، تراكم الرمال.