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Impacts of Sand and Dust Storms on Agriculture and Potential Agricultural Applications of a SDSWS

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Abstract. This paper will give an overview of the various impacts of sand and dust storms on agriculture and then address the potential applications of a Sand and Dust Storm Warning System (SDSWS) for agricultural users. Sand and dust storms have many negative impacts on the agricultural sector including: reducing crop yields by burial of seedlings under sand deposits, the loss of plant tissue and reduced photosynthetic activity as a result of sandblasting, delaying plant development, increasing end-of-season drought risk, causing injury and reduced productivity of livestock, increasing soil erosion and accelerating the process of land degradation and desertification, filling up irrigation canals with sediments, covering transportation routes, affecting water quality of rivers and streams, and affecting air quality. One positive impact is the fertilization of soil minerals to terrestrial ecosystems. There are several potential agricultural applications of a SDSWS. The first is to alert agricultural communities farmers to take preventive action in the near-term such as harvesting maturing crops (vegetables, grain), sheltering livestock, and strengthening infrastructure (houses, roads, grain storage) for the storm. Also, the products of a SDSWS could be used in for monitoring potential locust movement and post-storm crop damage assessments. An archive of SDSWS products (movement, amount of sand and dust) could be used in researching plant and animal pathogen movement and the relationship of sand and dust storms to disease outbreaks and in developing improved soil erosion and land degradation models.

1. Introduction

Sand and dust storms are a natural hazard which can affect large areas of continents and can even produce impacts across continents. As several other papers from this workshop have shown, there are impacts on human health and the economies of countries. This paper will provide an overview of the various impacts of sand and dust storms on agriculture and then discuss the potential applications of a SDSWS for agricultural users. In regards to agriculture, sand and dust storms are related to soil erosion and land degradation. There are several climatic factors that are involved in land degradation such as rainfall, floods, droughts, solar radiation, temperature, evaporation, and wind [1]. In the arid and semi-arid zones of the world, it is estimated that 24% of the cultivated land and 41% of the pasture land are affected by moderate to severe land degradation from wind erosion [2]. Wind erosion is a function of weather events interacting with soil properties and past and present land management through its effects on soil structure and vegetation cover. Drylands are particularly vulnerable to wind erosion since they undergo long periods of dry weather with strong winds that regularly occur, the vegetative land cover does not sufficiently protect the soil, and the soil surface is disturbed due to inappropriate management practices. Soil roughness, erodibility, and wetness along with the quantity and orientation of crop residues are parameters that impact the transport of eroded soils. Over-grazing, over-cultivation and destruction of soil by mining, construction, and off-road traffic stimulates and accelerates soil wind erosion in dryland regions. Sand and dust storms are a large scale manifestation of soil and wind erosion.

2. Impacts of Sand and Dust Storms on Agriculture

There are several different kinds of agricultural impacts due to sand and dust storms [3,4]. One of the most direct impacts is the loss of crop and livestock. There is a direct loss of plant tissue as a result of sandblasting by the sand and soil particles. With this loss of plant leaves, there is reduced photosynthetic activity and therefore reduced energy (sugars) for the plant to utilize for growth, reproduction, and the development of grain, fibre, or fruit. If the timing of the sand and dust storms is early enough in the agricultural season, the plant might be able to regrow the lost leaves and the loss in the final crop yield could be relatively minor. However, even in this instance, any regrowth of leaves will still probably result in yield losses. Additionally, the loss of energy for plant growth would also delay plant development and in regions with short growing seasons, this could increase the end-of-season drought risk by move the moisture-sensitive period (reproduction to grain-filling) past the period of favourable rain and result in lower yields and production. If the sand and dust storms occur later in the season, the plant damage will reduce yield during grain development and if it occurs at maturity but before harvest, there will be a direct harvest loss. If there is a large enough deposit of sand or soil material early in the season, the young plant would be buried and possibly killed to lack of sunlight for photosynthesis. Livestock not sheltered from the storm could be directly harmed and any stress from the physical environment to livestock can reduce their productivity and growth [5].

The loss of soil productivity is another agricultural impact to be considered. The loss of topsoil increases soil erosion and accelerates the process of land degradation and desertification. Topsoil contains the most fertile fraction of the soil and contains many of the vital nutrients such as potassium and phosphorous for plant growth and can be transported long distance. This process is of particularly concern since it potentially affects soil resources and therefore crop productivity on a long-term basis, by removing the layer of soil that is inherently rich in nutrients and organic matter. The cost to productivity is difficult to measure but is likely to be quite substantial. [6] developed an index of wind erosion capacity (C) defined as (equation 1):

$$C = \frac{V^3}{2.9(P - E_p)} \tag{1}$$

where V = wind speed at standard observing levels (~ 10 m), m s^{-1}; P = precipitation (mm); and E_p is potential evapotranspiration (mm). As the above equation demonstrates, when soil movement is sustained, the quantity of soil that can be transported by the wind varies as the cube of the velocity. Models indicate that wind erosion will sharply increase above a threshold wind speed.

Other impacts include filling up irrigation canals with sediments, covering transportation routes, reducing temperatures, covering railroads and roads, causing household dust damage, affecting water quality in rivers and streams, affecting air quality, polluting the atmosphere and destroying mining and communication facilities [3]. They accelerate the process of land degradation and cause serious environment pollution and huge destruction to ecology and the living environment. Atmospheric loading of dust caused by wind erosion also affects human health and environmental air quality.

While this loss of productive topsoil has large negative consequences for the land from which it is taken from, this topsoil can benefit areas where precipitates out. [3] cites several examples of mineral dust playing important role in the supply of nutrients and micronutrients to terrestrial ecosystems. Among the examples is the accumulation of sand-dust from the Sahara into Amazon Valley which brings 1-4 kg of phosphate per ha per year. Also, sand and dust from China are the major component of ice crystals which are alkali and neutralize the emergence of acid rain in Japan.

3. Measures to Combat SDS

Wind and soil erosion have been problems for some time across many different regions of the world. After the Dust Bowl in the 1930s in the United States, the Sahel drought in the 1970s and 1980s, and periodic sand and dust storms in China, many strategies and methods were developed that focus on preventing the soil/sand from being eroded and transported. One the best methods is the use of windbreaks or shelterbelts to reducing the impact of wind speed, which would then reduce the amount of soil material from being carried and transported. A windbreak is defined as structures that reduce wind speed and shelterbelts as rows of trees planted for wind protection [7]. For the best wind reduction and greatest downwind influence, the windbreak should be most porous near the ground and the density of the barrier should increase logarithmically with height in accordance with wind speed. Wind reduction is a function of shelter location as well as the height above the plants. The benefits of windbreaks include decreased soil erosion, increased crop yields, reduced potential and actual evapotranspiration; improved internal plant water relations, reduced livestock stress, control of drifting snow, building maintenance and energy savings [3,7,8]. These generalities are subject to variation depending on soil moisture and the benefits may be most dramatic in dry years or under critical moisture shortages. Examples of widespread use of windbreaks include the U.S. Great Plains after the Dust Bowl years in the 1930s [7]; the Rhone Valley in southeastern France, and the Netherlands [9].

Another method of reducing soil erosion is the use of crop residues [4]. Conservation tillage operations or soil mulching increase the cohesion of soil particles and thereby reduce soil erosion. Surface crop residues help stabilize soils by reducing soil water loss and the erosive force of wind. Vertical residues are much more effective that flat surface cover in controlling soil loss by wind. Special farming implements, such as chisel-type ploughs, which permit the cultivation of vegetated surfaces and maintain a rough, well-textured surface could be used for this purpose [3].

4. Potential Agricultural Applications

There are many potential agricultural applications for a SDSWS and the sand and dust storm models. These can be grouped into three categories: tactical, strategic, and research applications (table 1). The tactical applications focus on actions that farmers can take after a crop has been planted and are of a short-term nature (daily, weekly). Specifically, these are the actions that would be related with a near real-time warning or alert system for farmers and agricultural communities. If this system was in place, farmers could take preventive action such as harvesting grain or vegetable crops that are nearing their maturity and that by harvesting them before the storm, some production could still be obtained. If the crop is immature, the only other action that could be undertaken is physically protecting crops in the field. This is impossible for large fields of crops, but could possibly be done for very small plots of high-value crops (i.e. vegetables and fruits). Another preventive action would be to move livestock to a place (i.e. barn, sheltered valleys) where the impacts of sand and dust storm would be minimized. Finally, with enough warning, farmers or agricultural communities could strengthen infrastructure such as houses, roads, and crop storage facilities before the storm. This would also reduce the physical damage of the storm.

These tactical applications would be the primary focus of a SDSWS. For other applications, the model output of a SDSWS would have greater utility. Strategic applications of sand and dust storm models would be focused on long-term planning and investments in crops and infrastructure that would use improved climatologies based on sand and dust storm models for a particular region or locality. There are already climatologies available for many regions based on long-term weather observations. By integrating the existing long-term observation with the models, more detailed information could be determined such as the average direction and size of sand and dust storm for a region. This would then be used to improve existing or develop new windbreaks and shelterbelts. Another potential application of the sand and dust storm models would be post-storm crop damage assessments. The sand and dust storm models would assist national governments and international institutions in determining whether crop damage in a particular locality was caused by a sand and dust storm and this would aid prevention efforts.

Table 1. Summary of Potential Agricultural Applications of a Sand and Dust Storm Warning System (SDSWS).

Tactical (short term)	Strategic (long-term)	Research
Near-term warnings for agricultural communities to take preventive action:	Improved SDS climatologies for long-term planning for agricultural communities:	Forecasting locust movement
		Improving Soil / Wind Erosion and Land Degradation Models
- harvesting maturing crops	- Planning windbreaks and shelterbelts (direction, size, etc)	
- sheltering livestock,	- Planning for infrastructure and crops	Plant and animal pathogen movement and the relationship of SDS to disease outbreaks
- strengthening infrastructure (houses, roads, crop storage)	- Post-storm crop damage assessments.	Archive of SDSWS products for forensic use

Since sand and dust storm models take into account the movement suspended soil material, they would also be also useful in forecasting locust movement. With the recent locust outbreak in Africa in 2002-2003, WMO and FAO have been coordinating their efforts to assist national locust control personnel in using meteorological data and forecast models. [10] provides monthly updates of the locust situation and the SDS models are potentially well-adapted to be used for this application. With the advent of the sand and dust storm portal, these models can be evaluated for this purpose.

Another important area of research and potential application for sand and dust storm models and SDSWS products is the movement of plant and animal pathogens and the relationship of sand and dust storms to disease outbreaks. Since pathogens can be carried by dust particles and can be considered as dust themselves, sand and dust storm models and SDSWS products could aid in determining the transport of the plant and crop diseases. An archive of SDSWS products (movement, amount of sand and dust) could be used in researching plant and animal pathogen movement. [11] provides an excellent overview and history of plant diseases that have been transported across continents. The limited diversity of plant genetics of globally distributed crops causes a problem of uniform susceptibility to disease and the intercontinental dispersal of pathogens may cause crop diseases on a global scale. For example, the original plantation of Arabic coffee in the Americas can be traced to a single bush taken from Java in 1706. [11] and others give several examples of plant diseases that are suspected of being aerially transported vast distances to impact crops on other continents. These include: sugarcane rust which is suspected of traveling from Cameroon to the Dominican Republic in June 1978 (also [12]); coffee leaf rust from Angola to Bahia, Brazil in 1970; and wheat stem rust from southern Africa to Australia in 1969. Other diseases include the potential recent transport of soybean rust from South America to North America in 2000 and a new form of wheat stem rust that has the potential to move form eastern Africa to South Asia [13]. This transport of pathogens is not limited to plant diseases. There is speculation that Foot and Mouth Disease which affects livestock can be transported by via dust [14,15,16]. Policy makers need to know the source of disease outbreaks whether by airborne or by human transport in order to take preventive measures. An example of this is the uncertainty of the sources of Avian Bird Flu.

Another area of research for the potential agricultural applications of sand and dust storm models and products is in improving soil/wind erosion and land degradation models. For over 100 years, soil erosion data has been collected and analyzed by soil scientists, agronomists, geologists, hydrologists, and engineers and simple soil erosion relationships has been developed from this data that incorporates the major soil erosion factors. The Universal Soil Loss Equation (USLE) was developed in the mid-1960s for understanding soil erosion in agricultural applications and was updated in the 1980s and renamed the Revised Universal Soil Loss Equation (RUSLE) to incorporate the large amount of information that had accumulated since the original. The RUSLE is defined in equation 2 as:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{2}$$

where A is the soil loss per year (t/ha/year); R represents the rainfall-runoff erosivity factor; K is the soil erodibilty factor; L represents the slope length; S is the slope steepness; C represents the cover management, and P denotes the supporting practices factor [17]. The Wind Erosion Prediction System (WEPS) is a process-based, daily time-step, computer model that predicts soil erosion via simulation of the fundamental processes controlling wind erosion [18]. WEPS can calculate soil movement, estimate plant damage, and predict PM10 emissions when wind speeds exceed the erosion threshold. WEPS is intended for conservation planning, assessing wind erosion and for aiding the development of regional and national policy. Both of these existing models and formulations could be improved by analyzing sand and dust storm model output over many years.

5. Final Thoughts

There are three general components of effective warning systems that a SDSWS should adhere to and these are monitoring, forecasting, and advisories. Potential products for agricultural applications of a SDSWS should include areal extent, severity, duration, and potential impacts. For forensic uses, an archive of SDSWS products (movement, amount of sand and dust) should be developed to be used in researching the relationship of sand and dust storm to plant and animal disease outbreaks and in developing improved soil erosion and land degradation models. Other useful products and information that could be used from sand and dust storm models include insight into weather patterns associated with sand and dust storm, meso-scale features that ignite storms, and the vertical data from the models. Another important aspect is that the various models should be grouped by the capability for users. It is important to note that for operational public warning systems, output from sand and dust storm models are only for guidance and should not be considered as final end-products. This is same issue with Numerical Weather Prediction models used for forecasting day-to-day weather by the National Meteorological Services (NMS) of the world. The end user should not be expected to understand detailed graphs and maps in order to know tomorrow’s weather. They rely on weather information that has translated from model output into easy to understand language. Therefore, there is the need for another level between the sand and dust storm models and final users. The NMS of the world could provide this function since they know the local climate and weather patterns and would be best positioned to make interpretations of sand and dust storm models for agricultural decision makers (farmers, agricultural extension agents, government policy makers).

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