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Crop production and economic loss due to wind erosion in hot arid ecosystem of India

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A R T I C L E I N F O

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A B S T R A C T

Wind erosion is a severe land degradation process in hot arid western India and affects the agricultural production system. It affects crop yield directly by damaging the crops through abrasion, burial, dust deposition etc. and indirectly by reducing soil fertility. In this study, an attempt was made to quantify the indirect impact of wind erosion process on crop production loss and associated economic loss in hot arid ecosystem of India. It has been observed that soil loss due to wind erosion varies from minimum 1.3 t ha^{-1} to maximum 83.3 t ha^{-1} as per the severity. Yield loss due to wind erosion was found maximum for groundnut (*Arachis hypogea*) (5–331 kg ha^{-1} yr^{-1}), whereas minimum for moth bean (*Vigna aconitifolia*) (1–93 kg ha^{-1} yr^{-1}). For pearl millet (*Pennisetum glaucum*), which covers a major portion of arable lands in western Rajasthan, the yield loss was found 3–195 kg ha^{-1} yr^{-1}. Economic loss was found higher for groundnut and clusterbean (*Cyamopsis tetragonoloba*) than rest crops, which are about ₹ 191–12465 ha^{-1} depending on the severity of wind erosion. For mustard (*Brassica* spp.) and wheat (*Triticum* spp.) the economic loss was about ₹ 47–3181 ha^{-1}, whereas for pearl millet the economic loss was lowest (₹ 36–2294 ha^{-1}). In this calculation only indirect impact of wind erosion in terms of reduction in soil fertility was considered. There is need of future research work for assessing the direct damage on crops by wind erosion process, addition of which may lead to higher magnitude of losses.

1. Introduction

Soil erosion through water and wind is a major land degradation process and affects the soil productivity worldwide (Li et al., 2009; García-Ruiz et al., 2015). It has been estimated that about 75 billion metric tons of soil are removed by wind and water erosion each year (Pimentel et al., 1995) and most of these removal take place from agricultural land (Montgomery, 2007). However, the critics note that 75% of the eroded soils eventually deposit on another site and thus the soils are not truly lost from the landscape (Larson et al., 1983). But the source area of erosion e.g. the croplands are ultimately affected. About 80% of agricultural land in the world is affected by moderate to severe erosion whereas 10% suffers from slight to moderate erosion (Speth, 1994). Average soil erosion rate is as high as 40 tons ha^{-1} yr^{-1} in Asia, Africa and South America whereas in United States and Europe, it is about 17 tons ha^{-1} yr^{-1} (Barrow, 1991). Whereas, the rate of soil formation is about 2.5 cm topsoil in every 100–1000 years, which is equivalent to 0.4–4 tons ha^{-1} yr^{-1} (Pimentel et al., 1976; Brady and Weil, 1999; Verheijen et al., 2009). Therefore, it is quite clear that the soil losses through erosion far exceed the natural rate of soil formation. Impact of such losses on crop yield needs proper assessment, which will help in implementing suitable soil conservation and land management practices for mitigating the land degradation process. Several attempts have been made previously to establish the relationships between soil loss and crop yield and these are comprehensively described in few literatures (Lal, 1987; van Baren and Oldeman, 1998; Den Biggelaar et al., 2001; Pimentel and Burgess, 2013). Most of these previous studies quantified the impact of water erosion on crop productivity (Follet and Stewart, 1985; Lal, 1988; Larney et al., 1995; Larson et al., 1990; Alfsen et al., 1996; Sharda et al., 2010; Sharda and Dogra, 2013), whereas the studies related to wind erosion on crop productivity are limited (Lyles, 1975; Lyles, 1977; Larney et al., 1998; Zobeck and Bilbro, 2001, Nordstrom and Hotta, 2004).

Soil erosion affects the crop productivity through any of the following pathways: (i) removal of nutrient rich topsoil affecting soil productivity, (ii) reduction in topsoil thickness and thus restricts rooting depth, (iii) removal of organic matter and thus affects productivity, (iv) affecting soil water retention capacity since finer

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particles having higher water retention potential are removed, and (v) removal of soil biota and thus deteriorating soil health. The effect of wind erosion on crops is mainly manifested through blowing away of nutrient rich top soil leaving behind a coarser substrata which is poor in nutrients. Other effect includes crop damage by sand blasting or abrasion actions on tender stems and leaves, and crop burial by deposition of aeolian sediments. Effect of erosion on crop productivity is hardly visible since soil degradation is a slow process, implying relatively small annual changes whereas crop yields in any case vary considerably due to management, precipitation and other factors (Alfsen et al., 1996). Moreover, the technological interventions in crop production systems often mask the effect of erosion on crop productivity.

Since crop production is a function of several factors e.g. soil, weather, quality and quantity of inputs, management practices, pest and disease occurrence etc, it is also very difficult to isolate the sole effect of erosion on crop productivity (Frye, 1987; Stocking and Sanders, 1993; Littleboy et al., 1996). Therefore, it requires that all other factors determining the crop yield to be kept constant or controlled as much as possible while determining the effect of erosion on crop productivity. In case of water erosion, such controlled experiments on runoff plots are possible where degree of erosion is different across plots but is difficult for wind erosion study. However, such controlled experiments on wind erosion with unique designs have been conducted in few places which allowed the comparison of crop yields between eroded, non-eroded and deposited areas (Fryrear, 1981; Zobeck and Bilbro, 2001). Other than the controlled experiment, relating crop yield with topsoil thickness or percent reduction in crop yield with topsoil removal is often considered as the most viable approach of assessing the effect of erosion on crop productivity. The approach has been used in both water erosion (Alfsen et al., 1996; Larney et al., 1995) and wind erosion study (Lyles, 1975, 1977). Since the crop production does not only depend on the quantity but also on the quality and distribution of soil layers in the overall rooting zone, topsoil thickness is sometimes not considered as adequate measure of productivity (Hoag, 1998). Moreover, such relationship between soil depth and crop yield needs to be available for each soil category presents in the interested region of application, which are very limited. Hence, in this manuscript, a novel approach of relating soil test crop response (STCR) equations developed through long term experiments with nutrient removal through wind eroded soil loss is proposed to assess the crop production loss due to wind erosion. The approach is further tested in western Rajasthan, India. The crop production loss is further converted to economic loss using minimum support price of each crop of the region.

2. Materials and methods

2.1. Study area

In India, about 12.4 m ha area is affected by wind erosion (ICAR, 2010). The western part of India in Rajasthan which accounts for ~62% of hot arid regions of the country is mostly vulnerable to wind erosion, because of its vast sandy terrain and climatic characteristics. The study area in western Rajasthan consists of 12 States of Rajasthan and located between 69.47–76.12 °E and 24.6–30.2 °N (Fig. 1). About 48% area is occupied by sand dunes of various types and morphology and 76% area in this region is affected by wind erosion and deposition activities (Moharana et al., 2013; Kar et al. 2009). Over last five decades, human population in arid western Rajasthan has been increased by three and half fold whereas livestock population has been almost doubled. The region has experienced 32 moderate to severe droughts since independence. The land use statistics for the year 2005–06, showed that about 61.15% area in arid western Rajasthan is utilized for cultivation which includes 12.97% net irrigated area. An analysis of land use/land cover changes between 1982–83 and 2005–06 indicated an increase in net-irrigated area by 128%, and in double cropped area by 70% whereas a decline in culturable waste area by 7.70%. It indicates the quantum of population pressure on dryland environment of western Rajasthan. Such biotic pressures forced farmers to cultivate even semi-stabilized dunes for more crops and in the process, destabilize the soil surface and enhances the sand drifting and spread. Impacts of activated sand dunes or newly formed dunes cause serious problem to adjoining agricultural land, railway tracks, roads, irrigation networks and settlements, which are evident in many parts of the region.

2.2. Crop production loss due to wind erosion

One of the commonly followed approaches to quantify the crop production loss due to wind erosion was suggested by Lyles (1975), in which removal of topsoil was related with crop yield reduction. Considering the core principle of this approach, a new procedure using soil test crop response (STCR) equations has been proposed in this study to assess crop production losses due to wind erosion process. This new approach involves the following steps: i) characterization of wind erosion severity category in the region, ii) collection of crop productivity data as per wind erosion severity categories, iii) collection of average soil loss rate in each wind erosion severity category iv) computation of nutrient loss through wind eroded soil v) application of region specific STCR equations for calculating the crop yield loss due to nutrient loss. Finally, economic loss due to wind erosion can be assessed by multiplying the computed crop production loss with minimum support price of respective crop. The STCR approach was applied in western Rajasthan to assess crop production loss due to wind erosion. In the following section, details of each step of STCR approach in western Rajasthan are described.

2.2.1. Mapping wind erosion severity categories in western Rajasthan

Wind erosion severity map of western Rajasthan was prepared by supervised classification of remote sensing images (Singh et al., 1992). First, different terrains with field indicators of erosion/deposition features were identified for different degree of wind erosion severity. At the second step ground truth observations on field indicators of erosion/deposition features were related with false colour composites (FCC) of remote sensing products e.g. images acquired by LISS-III and LISS-IV camera of IRS-P6 satellite as well as the google earth images.

Terrain properties and annual rainfall along with land surface conditions were grouped together to categorize a land unit into a single class out of four pre-identified severity classes e.g. slight, moderate, severe and very severe. Field indicators of erosion/deposition features for different terrains representing different wind erosion severity classes are given in Table 1.

The field indicators were further verified through visual interpretation of false color composites (FCC) of remote sensing images acquired during summer months (May-June). Characteristics erosion/deposition features and corresponding remote sensing signatures are mentioned in Table 2.

Using the above mentioned field indicators and remote sensing signatures; the wind erosion map of wind erosion severity was prepared at 1: 1 million scale. Detailed description of the map and the procedure followed to prepare it are available in Narain et al. (2000).

2.2.2. Average productivity of selected crops in western Rajasthan

Productivity of major crops in western Rajasthan was collected from agricultural statistics database of Government of Rajasthan during the period from 2001 to 2010 (http://www.krishi.rajasthan.gov.in/). Fifteen tehsils representing either irrigated or rainfed croplands were selected by overlaying land use/land cover (LU/LC) grid, wind erosion index layer, and wind erosion severity grid. The list of selected tehsils is given in Table 3 and its locations in western Rajasthan are depicted in Fig. 2. Crop productivity data of these selected tehsils were extracted from the database to assess the crop productivity under each wind erosion severity category.