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Effects of Plastic Debris on Soil Permeability of Airable Lands in Bangladesh

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Abstract

This paper reviews almost all the aspects related to the agriculture like soil health, permeability, plastic debris of different sizes and impact of microplastics and Nano plastics on huma health and plant growth. This paper explored that three is research gap in respect of quantitative analysis by determining the soil permeability to assess the effects of plastic debris on the soil morphology. In this paper, negative impacts of plastic debris on the soil permeability or hydraulic conductivity are alleged for the flooding of airable lands and lowering of irrigative water bed that demands thorough scientific research in the days to come. Hence, the core objective of this review paper is to propose a suitable method to evaluate soil permeability or hydraulic conductivity to get insight of the solution to the forthcoming issues, caused by the effects of plastic debris on the soil health of airable lands in Bangladesh.

Keywords: Plastic Debris; Soil Health; Permeability

Introduction

Plastic debris, originated from plastic products, ends up in the soil, river water, and finally to the ocean. They are reported as one of the major contributors to marine, soil, and environmental pollution [1]. Numerous reviews on soil pollution due to plastic debris have been published over the decades from different angles like the accumulation of microplastics (MP) and nanoplastics (NP) and their impacts on plant growth and human health [2]. It is reported that MPs and NPs have markedly changed both the physical and chemical properties of the soil accounting for adverse effects on their reactivity [3]. Additionally, highlighted the release of toxic oligomeric and monomeric constituents, entering into the food chain [4]. The various sources of plastic debris in the form of MPs and NPs and their adversaries on the soil ecosystem have already been assessed and reported [5]. A recent laboratory study on MPs pollution in terms of effects on the soil has been examined and suggested that there is substantial context-dependency in microplastic effects in soil [6]. Another research showed that microplastics could affect nutrient and/or substrate availability, likely due to its absorption or its competition for physicochemical niches with microorganisms [7]. Several key findings are also reported on the effects of MPs. They are as:

Adherence and Accumulation: MPs in soil can adhere to crop seeds and root surfaces, or accumulate within their vascular systems. This can lead to the obstruction of water and nutrient uptake by plants.

Oxidative Damage: MPs, including nanoplastics, can induce oxidative damage to plants. This disrupts their metabolic processes and can impair overall plant health and growth.

Chemical Additives: Chemical additives released from MPs can trigger cytotoxic (toxic to cells) and genotoxic (damaging to genetic material) effects in plants. This highlights the potential direct harm caused by the chemicals associated with plastic debris.

Alteration of Soil Conditions: MPs alter both biotic (living organisms) and abiotic (non-living factors) conditions of the soil. This alteration can affect the availability of water and nutrients to crops, crucial factors for plant growth and development.

Combined Toxicity: "The cumulative or combined toxicity of different types of microplastics in soil can exacerbate their adverse effects on plants. This suggests that the presence of multiple types of MPs can have synergistic negative impacts" [8]. Thus, the reviewes emphasize the significant repercussions of MPs and NPs on plants in soil ecosystems.

Besides, Soil Research and Development Institute (SRDI) of Bangladesh conducted a study in 2020 to assess the soil fertility trend of airable lands in Bangladesh from 20210 to 2020 and showed an increasing trend of fertility keeping its chemical component in focus but not the permeability or in other terms hydraulic conductivity evaluated, which is one of the components of the soil health and profile as well [9]. It calls for experimental evidences of impacts of the deposited plastic debris on permeability or hydraulic conductivity that would require to examine the soil health of the airable lands particularly in Bangladesh to face the upcoming challenges in the context of climate change.

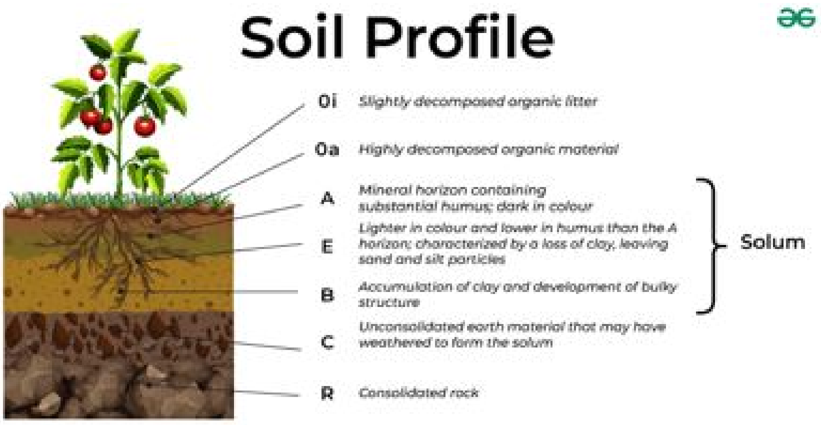

Figure 1: The various layers in the soil profile [10]

This soil permeability or hydraulic conductivity is the important characteristic measurable indicator or parameter of the physical component of soil health as well as soil profile. The soil is the topmost layer of the earth's crust mainly composed of organic minerals and rock particles that support life. A soil profile is a vertical cross-section of the soil, made of layers running parallel to the surface. These layers are known as soil horizons as shown in Figure 1 [10]. However, there are two approaches for the measurement of permeability or hydraulic conductivity, such as: (i) laboratory based and (ii) field based [11]. Permeability or hydraulic conductivity is defined as the capacity of fluid and/ or water flow through the soil pores that is crucial to supply nutrient and water to plants' roots. Laboratory based approach has two methods, namely constant head method and falling head method. The objectives of this review article are (ii) to explain how permeability affects soil health and is impacted by plastic debris, and (iii) to describe calculating the permeability rate/coefficient of airable lands in laboratory-based approach using the falling head method (suitable for moderate or low soil permeability) to assess the soil conditions or/and soil health of the northern areas in Bangladesh where irrigation for harvesting crop is her main agroeconomic activity.

Soil Health and Permeability

Soil Health

"Soil is a component of primary importance in crop production, even if it is often neglected, or only regarded as a physical support for the growth of plants" [12]. However, with the increasing societal concerns for the sustainability of agriculture, soil must be considered as a living system. This system provides food, fibre, fuel, clean water, and resources, which are central to our ability to feed the growing world population with sufficient calories and nutrition to support human wellbeing [13]. The sustainability of the aforesaid services, given by soil entails the maintenance of soil health that necessitates to know and understand the meaning of soil health. Although soil health, soil fertility and soil quality are used interchangeably since longer period of time but presently the concept of soil health embodies soil quality and soil fertility. This soil quality and fertility are closely associated with agriculture. "A healthy agricultural soil is one that is capable of supporting the production of food and fibre, to a level and with a quality sufficient to meet human requirements, together with continued delivery of other ecosystem services that are essential for maintenance of the quality of life for humans and the conservation of biodiversity" [14]. Hence, the soil quality perceived to be correlated with an integration of three major components — sustained biological productivity, environmental quality, and plant and animal health [15]. On the other hand, soil fertility can be conceptualized as the combined properties of physicochemical and biological components, notably the microbial communities, primordial for soil function to give nutrients to the plant and crop growth [16]. Where the soil permeability is one of the measurable characteristic indicators or parameters of physical component in physicochemical properties that may use to assess the soil health of airable lands, which is yet to probe under the influence of plastic debris.

Soil Permeability or Hydraulic Conductivity

Soil permeability or hydraulic conductivity is one of the physical components in physicochemical propertis that enables to transmit water, mixer of nutrients and air in and through the soil [17]. This soil permeability or hydraulic conductivity is seen as one of the soil quality indicators to consider for irrigation of agriculture and fish culture [18]. The more permeable the soil, the greater the seepage. Some soil is so permeable and seepage so great that it is not possible to build a pond or water storage for irrigation without special construction techniques. Soils are generally made up of layers and soil quality often varies greatly from one layer to another. Before pond or water reservoir/storage construction, it is important to determine the relative position of the permeable and impermeable layers. The design of a pond or water reservoir should be planned to avoid having a permeable layer at the bottom to prevent excessive water loss into the subsoil by seepage. This seepage is another quality parameter of soil required to consider for construction works of any sort. The dikes of the pond or water storage should be built with soil which will ensure a good water retention [19]. Again, soil quality will have to be checked with this in mind. Many factors affect soil permeability. Sometimes they are extremely localized, such as cracks and holes, and it is difficult to calculate representative values of permeability from actual measurements. A good study of soil profiles provides an essential check on such measurements. Observations on soil texture, structure, consistency, colour/mottling, layering, visible pores and depth to impermeable layers such as bedrock and claypan form the basis for deciding if permeability measurements are likely to be representative or not. The size of the soil pores is of great importance with regard to the rate of infiltration (movement of water into the soil) and to the rate of percolation (movement of water through the soil) [20]. Pore size and the number of pores are closely related to soil texture and structure, and also influence soil permeability or hydraulic conductivity. This permeability or hydraulic conductivity is commonly measured in terms of the rate of water flow through the soil in a given period of time. It is usually expressed either as a permeability rate in centimetres per hour (cm/h), millimetres per hour (mm/h), or centimetres per day (cm/d), or as a coefficient of permeability k in metres per second (m/s) or in centimetres per second (cm/s) [21]. Soil permeability/hydraulic conductivity classes, used for agriculture and conservation, are shown in Table1 based on permeability rates and permeability coefficient.

Table 1: Soil permeability rates and coefficients for various soil permeability/hydraulic classes

Soil permeability/hydraulic conductivity class	Permeability rate		Permeability coefficient	
	cm/hour	cm/day	cm/s	m/s
Very slow	Less than 0.13	Less than 3		
Slow	0.13 - 0.3	12-Mar		
Moderately slow	0.5 - 2.0	Dec-48		
Moderate	2.0 - 6.3	48 - 151		
Moderately rapid	6.3 - 12.7	151 - 305		
Rapid	12.7 - 25	305 - 600		
Very rapid	More than 25	More than 600		

Effects of Plastic Debris

Plastic Debris

Single-use items such as bottles, bags, and straws are major contributors to plastic debris, which adversely affects all ecosystems. According to the United Nations Environment Programme, over 460 million metric tons of plastic are produced every year. Macro-plastics (pieces larger than 0.5 mm) made up 88% of global plastic leakage to the environment in 2019, around 20 million metric tons, polluting all ecosystems. As such much of the world's plastic pollution is originated by plastic debris [22]. The most visible impacts of plastic debris are the ingestion, suffocation, and entanglement of species. Wildlife such as birds, whales, fish, and turtles take indigestible plastic waste for food and die of starvation as their stomachs become filled with it. It also causes internal and external injuries that reduce the ability to swim and fly. of the leading causes of biodiversity loss and species extinction. Plastic pollution can also seep carcinogenic chemicals (such as those contained in certain plastic products or fireproofing coatings) into the soil. These can run into groundwater or rivers, affecting exposed people and ecosystems. Besides, climate impacts begin with oil and gas extraction, the refining of these products into plastics, and then plastic pollution itself. Incinerated plastic debris/waste releases greenhouse gases and other pollutants into the atmosphere, including carbon dioxide, dioxins, and methane. After breaking the plastic debris/waste into its possible forms (fragments, fibres/filaments, beads/spheres, film sheets, and pellets) by the nature like sun heat, aging, etc.,, they are currently classified as (i) Macroplastics (>200 mm), (ii) Mesoplastics (5–200 mm), (iii) Microplastics: plastic snippets varying in dimensions from 0.1 μm (micron, i.e., one-thousandth of a millimeter, 10-6 m) to 5 mm, including: (a) Medium-sized microplastics (1.01–4.75 mm) (b) Lesser microplastics (0.33–1.00 mm) and (iv) Nanoplastics: plastic particles ranging in size from 1 nm (0.001 μm) to 100 nm (0.1 μm or millimicron, i.e., one-thousandth of a micron; 10-9 m [23]. The various sources of plastic debris in the form of plastic particles (MPs and NPs) are summarized in Figure 2 [24] for better understanding Thus far, effects of plastic debris in the form of MPs and NPs are discussed mostly from chemical and biological viewpoints in numerous review and research articles. The adverse effect of plastic debris on soil health may be assessed by the measurement of soil permeability (hydraulic conductivity of soil). Where their impacts on soil permeability or hydraulic conductivity were not discovered sufficiently to evaluate the soil health for agriculture, which is perceived as a research gap as derived from different review and research articles. An endeavor is made in this review to explore the impact of plastic debris on the soil health by calculating permeability rate/coefficient through a suggestive measurement procedure.

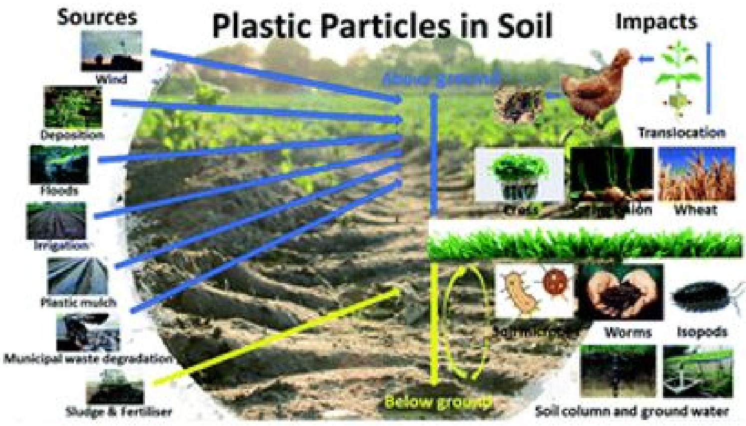

Figure 2: The various sources of plastic debris in the form of plastic particles (MPs and NPs) in the soil [24]

Perceived Impact of Plastic Debris on Soil Permeability or Hydraulic Conductivity

Despite the various use of plastic products in global economic activities including a huge share in the modern agriculture [25], the plastic debris, generated from the use of plastic products, have evolved significant environmental and social issues. Subsequently, the plastic debris have become concern to the global scientific community and presently to Bangladesh as well. The plastic waste management and recycling rate are found to be only 22% and 9% globally and becomes much lower than that of deposition rate in various path ways as depicted in Figure 3 [26].

Figure 3: The various pathways of plastic debris come to the soil in the form of plastic particles (MPs and NPs) [26]

Bangladesh is not the exception rather found to be collected amounting to 646 metric tons of plastic debris daily and only 10% are being recycled [27]. Moreover, soils likely receive significantly more plastic debris than oceans as reported in a recent survey [28]. It is perceived that a large amount of accumulated plastic debris in macro, micro and nano forms fill the soil pores and reduces the soil permeability or hydraulic conductivity that ultimate to change the surface morphology of airable land. Consequently, flood and waterlocked damages the crop growth in the rainy season and water bed gets lower and hinders the irrigation by deep tube wells for harvesting crop in the dry season. Besides the lower permeability impedes air flow through the soil up to plant roots and causes improper photosynthesis and inadequate nutrient absorption by plant roots [29]. The aforesaid diversity in impacts is perceived as a result of the plastic debris in the form of MPs and NPs on soil permeability or hydraulic conductivity. A formal study is yet to conduct in this aspect, which is alleged as a research gap to assess the soil health. Therefore, it is suggestive to conduct scientific research by measuring soil permeability or hydraulic conductivity using soil samples from the northern area of our Bangladesh. Accordingly, the principle and methods for determining the soil permeability or hydraulic conductivity are highlighted in the subsequent section of this review paper.

Principle and Method of Determining Soil Permeability of Hydraulic Conductivity

Principle

The method of determining the soil permeability is based on Darcy's law which states the principle that governs the movement of fluid in the given substance. Darcy's equation describes the capability of the liquid to flow via any porous media like a rock. The law is based on the fact that, the flow between two points is directly proportional to the pressure differences between the points, the distance, and the connectivity of flow within rocks between the points [30]. Measuring the interconnectivity is known as soil permeability. To understand the mathematical aspect behind liquid flow in the substance, Darcy's law can be described as the relationship between the instantaneous rate of discharge through a porous medium and pressure drop at a distance. The relevant diagram of this law is shown in Figure-4 [31]. Darcy's law is mathematically expressed as:

$$Q = -kA\frac{dh}{dl}$$

Where in:

Q is the rate of water flow

k is the hydraulic conductivity

A is the column cross-section area

dh/dl indicates a hydraulic gradient.

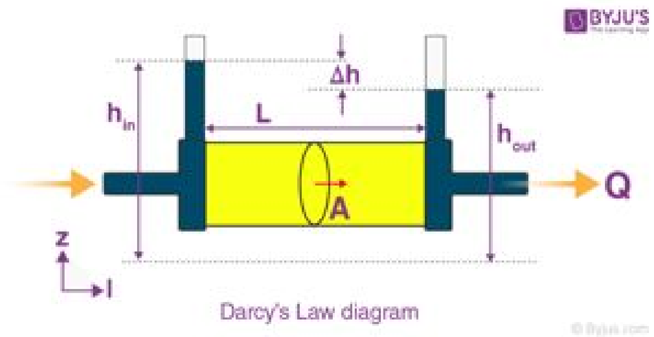

Figure 4: Darcy's law diagram [31]

Proposed Method

There are two approaches to determine the soil permeability or hydraulic conductivity such as field approach and laboratory-based approach. Soil permeability (or hydraulic conductivity) refers to the degree with which water can flow through a soil and it has the same unit as velocity [32]. Generally, this property is necessary for the calculation of seepage through earth dams or under sheet pile walls, the seepage rate from waste storage facilities and the rate of settlement of clayey soil deposits. There are two types of laboratory test procedures for determination of the coefficient of permeability of soil, *k* (i) Constant head method for high permeability soils and (ii) Falling Head Method for medium and low permeability soils. The falling head method is suggestive to determine the permeability or hydraulic conductivity of the soil with different types and number of plastic debris or wastes accumulated in the soil, which are perceived as one of the responsible factors for changing the soil morphology. The falling head permeability test (variable head test) is a common laboratory test or method performed to determine the permeability of fine grained soils with medium and low permeability such as silts and clays [33]. In this test a relatively short sample is connected to a standpipe which provides both the head of water and measurement of water quantity flowing through the sample. The measurement setup is shown in Figure 5.

Sample Preparation

This testing method can be applied to an undisturbed sample, compacted sample or prepared sample in the laboratory by placing it inside the permeameter cell. The soil samples will have to be prepared by mixing different concentration and different sizes of plastic particles (plastic debris) with desired soil samples in the laboratory. Before placing the soil sample in the permeameter, measure the inside diameter (D) and height (L) of the permeameter cell. Place porous stone or filter paper in the bottom of the cell, then put the soil sample. Add a filter paper on the top of the soil sample and assembly the top part of the permeameter device. Saturate the soil sample by flowing water through it. It is important to note that the sample be fully saturated; otherwise, the falling head test will give erroneous results. Then apply a vacuum or remove any entrapped air within the sample.

Test procedure: (i). Determine the standpipe area (Note that the diameter of the standpipe depends on the permeability of the tested soil). (ii). Locate h_1 and h_2 on the standpipe. Then fill it with distilled water. (iii) Allow water to flow down through the sample and observe the water level in the standpipe. As soon as it reaches the level h_1,start the timer clock. (iv) When the level of water in the standpipe reaches h_2, stop the clock and record the time required for the water in the standpipe to drop from h_1 to h_2. (v) Refill the standpipe and repeat the test two to three times. Use the same h_1 and h_2 values and obtain the corresponding elapsed times. Record the temperature of water (T) for each run.

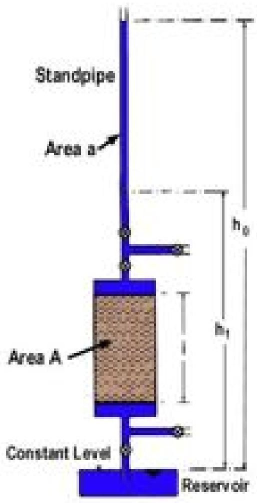

Figure 5: Experimental setup for permeability measurement using falling head method [33]

Calculation: Calculate coefficient of permeability, *k*. as follows [34]:

$$k_T = 2.303\frac{aL}{At}log_{10}\frac{h_1}{h_2}$$
$$k_{20} = k_T\frac{\eta_T}{\eta_{20}}$$

Where k = coefficient of permeability (hydraulic conductivity) (m/s). a = the inside area of the standpipe (a= $\pi/4d^2$), d= inside diameter of standpipe). L = Length of the sample. A =the inside area of specimen (a= $\pi/4D^2$), D= inside diameter of permeameter). t = elapsed time of test (s). h_1 = the elevation of water in the standpipe at time t=0.h_2 = the elevation of water in the standpipe at time equal to t. Usually the average coefficient of permeability of the test sample is expressed in two significant figures, with the form $k_T = 2.3 \times 10^{-4}$ m / s.

Proposed Data Sheet and Tables for Analysis

Specimen diameter, D = 10 cm. Specimen height, L = 11 cm. Specimen area, A =81 $(cm)^2$. Water Temp., T = 27 °C (RT). Standpipe area, a = Vol./h = $Q/(h_1-h_2)$.

Table 2: Proposed data table for different concertation of plastic particles at constant size of plastic particles

Sample weight	h_1 (cm)	h_2 (cm)	Test Time (s)	Q_{out} $(cm)^3$	k_T (cm/s)	k_{20} (cm/s)
Sample 1						
Sample 2						
Sample 3						
Sample 4						
Sample 5						
Sample 6						
Sample 7						

Table 3: Proposed data table for different size of plastic particles of constant concentration or weight

Sample Size	h_1 (cm)	h_2 (cm)	Test Time (s)	Qout $(cm)^3$	k_T (cm/s)	k_{20} (cm/s)
Sample 1						
Sample 2						
Sample 3						
Sample 4						
Sample 5						
Sample 6						
Sample 7						

Mitigation and Limitation

Probable Solutions

The probable solutions to mitigate issues if plastic debris may be as follows [35]:

- Developing biodegradable alternatives of singe-used plastic items.
- Encouraging individual to use biodegradable single-plastic items by societal awareness.
- Reducing use of synthetic plastic in agroeconomic activities.
- Recycling plastic waste.

- Improving sewerage systems to screen out or filter out industrial plastic waste to impair mixing them in the river water.
- Classifying the soil quality of airable lands by measuring permeability or hydraulic conductivity to formulate laws and regulations.

Limitation

The trend analysis of the effects of plastic debris on the soil health was not possible to discuss in this mini review paper because the absence of real data on the measurement of permeability or hydraulic conductivity. Accordingly, it is suggested to measure permeability or hydraulic conductivity by galling head method.

Globally to meet the forthcoming food challenges, the effects of morphological changes of the airable lands due to indiscriminate use of the single-used plastic materials needs attention. Already series of investigations showed the nature and classifications of plastic debris and their negative impacts from different angles. More scientific researches on the soil health requires more responsiveness for the purpose depending on the research gap as evolved from various reviews. In this review, the negative impacts of plastic debris on soil permeability or hydraulic conductivity are highlighted as perceived threat to the agriculture because of lowering the irrigative water bed during the dry season and flooding of the airable lands during the rainy season in Bangladesh. Accordingly, an effort has been made to propose a suitable method for the measurement of soil permeability or hydraulic conductivity to assess the soil health and mitigate the issues of plastic debris in airable lands of Bangladesh. Evaluation of electrical conductivity (EC) using 4-probe and pH value of the airable lands is also be suggestive as additional information to assess the soil health of airable lands in Bangladesh under the sway of plastic debris.

Declaration of Interest

We, the authors and our immediate family members, have no financial interests to declare.

The authors declare no competing interests.

Data Availability

No.

Data will be made available on request.

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