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PLASTIC CONTAMINATION, AN EMERGING THREAT FOR AGRICULTURAL SOIL HEALTH: A CASE STUDY IN MEMARI II C. D. BLOCK, PURBA BARDHAMAN, WEST BENGAL, INDIA

PIYUSH MAJI* AND BISWARANJAN MISTRI**

Department of Geography, The University of Burdwan, Bardhaman 713 104, West Bengal, India

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ABSTRACT

Soil health is an important part of the sustainable agricultural system; Intensive farming without damaging the soil is the core principle of sustainable agriculture. Agricultural practices are considered as systematic, scientific and expertise activity. In agricultural fields, the application of plastic-coated fertilizers or plastic-contained sludge water is often detrimental to soil health, field production and human health as well. The present study focused on the potential pathways of plastic in agricultural lands, the amount and categorical division of detected plastics, as well as its effect on the different physical properties of the soil. The majority of detected plastic materials were analysed as LDPE (44.50%) followed by PP (30.38%), PET (18.60%), PS (5%) and HDPE (0.65%). Compared to the two clusters, the result shows that in control clusters, bulk density (1.04 g/cm^3), soil porosity (60.61%), water-filled pore spaces (56.10%) and soil aggregate stability (48%) have been identified as ideal or stable soil conditions. However, compared with contaminated clusters, the findings suggest that higher bulk density (1.58 g/cm^3), low soil porosity (40.26%), low water content or pore spaces filled with water (38.77%) and lower aggregation (36%) that all have proved that plastic enriched soil is harmful and it declines the soil health day by day.

KEY WORDS : Agricultural soil health, Plastics, Control clusters, Contaminated clusters, Soil physical properties

INTRODUCTION

Nowadays plastic has become the most common usable and ubiquitous material in the planet earth. But bakelite was the one and only plastic material a few decades ago (early 20s), even if it was restricted only within the military sector. After the 1950s the plastic production jumped from 2 mt to 380mt in 2015 (Geyer *et al.,* 2017). World widely 18 kg of plastics are being used by a human being and estimated 120MT of plastic wastes has been generated per day. (Dhayagode *et al.,* 2011). Production of such an immense amount of plastic was not a concern unless a significant amount of waste was generated. In 2018, University of California and Santa Barbara have conducted a survey, and they have measured that at about 79% of produced plastic has been left as garbage. In case of India almost 11kg plastic consumed by an Indian (Venkatesl and Kukreti, 2018) and estimating to 22 kg within 2022 (Agarwal, 2018). With its largest imported plastic of 7,800 tonnes from America in 1994, India ranked 4th in importing of plastics (Dhayagode *et al*., 2011). Over the last few decades, most of the studies have focused primarily on plastic pollution in marine (Wessel *et al*., 2016), lake (Sruthy *et al*., 2016) or freshwater environment (Horton *et al*., 2017), but in terrestrial environment like agricultural soil has remained been under shadow. Similarly, a few studies have concentrated on plastic problem and management in rural areas.

Singh *et al*. (2019) define healthy soil depends on

(* Research Scholar, ** Associate Professor) good combination of major key properties of soil, mentioned as physical, chemical and biological. Soil properties are also regarded as indicators of soil quality (Cardosa *et al.,* 2013). Physical properties of soil like bulk density, soil porosity, soil pore spaces, aggregate stability, due to its direct contact with nature, are more vulnerable to external disturbances. Soil health is also relatively similar to human health (Magdoff, 2001). So, excessive application of hazardous materials is also harmful to the health and function of agricultural soil (Kibblewhite *et al.*, 2007; Aggarwal, 2017). In recent era, various way of use of plastics materials in agricultural land made differences in soil health, especially in changing of physical properties of soil. Some studies have taken this problem seriously and have attempted to examine the potential sources of plastic in agricultural land. The most common sources have been evolved as organic fertilizer (Weithmann *et al.,* 2018), sewage sludge water (Corradini *et al.,* 2019), surface water, plastic mulching (Qi *et al.,* 2018) and some others unreported and immeasurable sources.

Typically, plastic materials such as propylene, polymer, ethylene and hydrocarbon are manufactured with hazardous chemical bonding (Geyer *et al*., 2017). A study has shown that 96% of single-use plastic ends up as waste in landfills (Williamson, 2003). Plastic bags are often non-biodegradable and difficult to decompose; it can take up to 1000 years for certain materials to decompose in soil (Jalil *et al.,* 2013). Due to microorganism or sometimes mechanically macroplastics are disintegrated and spread all over the soil (Stevens, 2001). These piles of synthetic materials are nothing but a danger to the soil environment and the growth of agriculture (Jalil *et al.,* 2013). The present study is mainly focused on the counting plastic additives, categorical division of counted plastic, observing or identifying the potential pathways of plastic in agricultural lands and most significantly impact of plastic and its ingredient parts on soil's physical properties.

MATERIALS AND METHODS

Selection of the study area and soil sampling techniques

The district of Bardhaman was well known as 'rice bowl of Bengal,' but recently (in 2017) the district was bifurcated into two, Purba Bardhaman and Paschim Bardhaman. Still a greater amount of food grains is contributed by Purba Bardhaman as the district includes blocks are involved in cultivation. Pilot survey and questionnaire survey methods have confirmed that the Memari II C.D.Block (23° 12' 30" N to 23° 22' 4" N and 88° 2' 17" E to 88° 14' 37" E) would be the right place for this work, as 65% of the land partly depends on bio-fertilizers for cultivation (*Mankar krishi sahayak office*, 2019). In order to identify the sampling sites, adaptive cluster sampling (after Thompson, 1992) was chosen. Total 58 grids of target objects have been identified as initial sample (Fig. 1). For this work, two separate treatments, plastic control clusters and contaminated plastic clusters, were chosen to compare the harmful effect of plastic on soil health.

Plastic measurement and soil analytical procedures

Many single-use plastics, nanoplastics (< 1 mm) to macroplastics (> 25 mm), are contained everywhere. At present, various density separation methods have been used with various saline solutions to isolate microplastics (> 5 mm) from sediments and water (Crawford *et al.,* 2017). It was recorded that more than 65 percent of the studies used saturated NaCl 1.2 g / cm^3 separation to detect microplastic in sediments (Quinin *et al.,* 2016). All microplastics additives that are lighter than this density are easily floated over the solution, except for denser polyvinyl chloride (PVC). Multi-tier sieving technique for the extraction of macroplastics from soil has been used to calculate macroplastics (> 25 mm). Core cutter and USDA-NRCS procedures have been followed to measure dry bulk density and other soil properties such as soil porosity, water-filled pore spaces and soil aggregate stability. The width and height of the cutter ring was 4.50 cm and 7.80 cm respectively.

RESULTS AND DISCUSSION

All the major three properties of soil are very much responsive to various internal disturbances. Often the cause behind the disturbances seems to be some external deleterious application in the soil. The use of plastic-coated fertilizers or plastic-enriched sludge water is one of the reasons for changes in soil properties. Some studies have shown that plastic mulching is detrimental to agricultural soil properties (Bandopadhyay *et al.,* 2018; Sintim *et al.,* 2018). As plastic films disintegrate their components and remain on the soil's pore spaces and alter various soil properties. Now, this work includes understanding the categorical separation, source and, most notably, behaviour of plastics over soil physical properties below the surface of the soil and also understand the reasons behind these changes in details.

Quantification of detected plastic additives in the agricultural soil

It is always been challenging task to quantify plastic particles in any sediments or even marine or lake water. Though, some techniques are very popular. In the case of quantifying or identifying plastic additives such as FTIR-Spectroscopy, Raman Spectroscopy, Density separation method (using Zn brine or NaCl brine solution, etc.), visual detection (only for macroplastics), multitier sieving method etc. Most of the identified plastics in the study area belong to low density plastic materials, so after applying the multitier sieving process, the most common Nacl 1.2g/cm^3 solution was made for separate plastic. The techniques also help to compare between two separate clusters, contaminated clusters and control clusters. Among 28 grids of plastic contaminated sites, averagely 4500 mg/Kg^{-1} and 430 mg/Kg^{-1} soil have been measured as macroplastics and microplastics respectively. Although, the differences in the quantity of plastics are scarcely varied, still Bohar-I GP and Bohar-II GP have been identified as highest macroplastic (6400 mg/Kg^{-1}) and microplastic (840 mg/ Kg^{-1}) site. The measured plastics were different in categorically and heterogeneously distributed in the agricultural lands. However, several agricultural lands with plastics free have been found in plastic control clusters. GPs such as Barapalashan II, Satgachia I, Satgachia II and some parts of Kuchut have been measured as plastic control sites.

Categorical identification of plastic additives in the soil

In 1988, the Society of Plastic Industry (PSI) standardised different plastic items and labelled certain codes to determine whether they were recyclable or not. Each and every plastic product has a specific density and, in the case of that density separation method was useful to distinguish and classify different plastic additives. After visual detection and identification, multi-tier sieving and density separation method, the findings were confirmed that the highest plastic products were identified as low density polyethylene (LDPE) with 44.50% of the counted items. Much of the fragments were recognised as single-used and household plastic items, e.g. small parts of carrying bags or low-density bottles etc. Low-density polyethylene (LDPE) was followed by polypropylene (PP) at

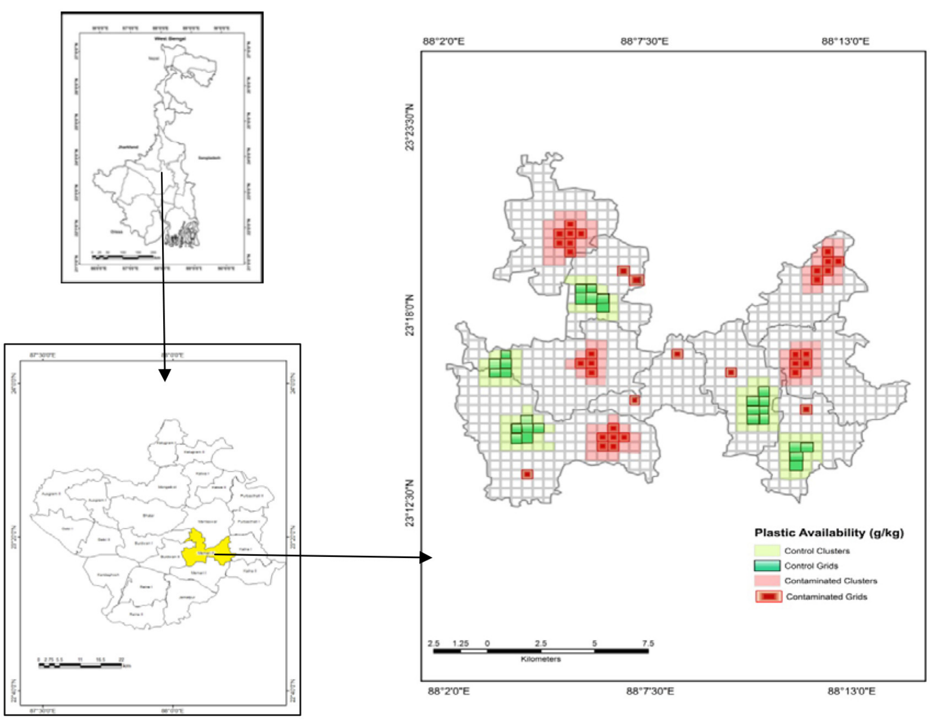


Fig. 1. Selected sampling sites as control clusters (green) and contaminated clusters (red) followed by adaptive cluster sampling

30.38%. Basically food wrapper, chocolate wrapper, chips packets are major sources of Polypropylene (PP). Polyethylene Terephthalate (PET) plastics are very unusual and hardly found in rural environment, still 18.60% items have been categorised under PET plastics products. Polystyrene (PS) stands fourth position among four major plastics with 145 (5%) items, some basic but rarely used plastics like tea cups or plastics boxes have been found in some fields. High Density Polyethylene (HDPE) products have hardly been detected (0.65%); most of the high density plastics were below the plow layer (up to 7 inch beneath the soil surface) and mostly disintegrated.

Potential pathways of plastic in the agricultural lands

In their study, Hurley and Nizzetto categorised three major sources of plastics in agricultural soils: I. fragmentation of plastic wastes already present in soil environment II. deposition of plastic from surrounding environment through run off and III. inputs from various agricultural practices. Many studies have shown that the bio-fertilizer (Fagerheim *et al.*, 2020; Piehl *et al.*, 2018) and sewage sludge water (Anikwe *et al.*, 2002) were the two major sources of plastics in agricultural lands. In the study area, total 160 farmers have been selected randomly for conversation about their preferences of applying fertilizers. After questionnaire survey and direct observation, the acquired data confirmed that plastic rich bio-fertilizers are being used for cultivation in 61.25% (98 fields) of total farmlands, while 38.75% (62 fields) of farmlands are mainly based on plastic enriched sludge-based fields. If averagely 5 g plastics have been generated daily then it becomes monthly 150 g, which is massive garbage in size. After conversation with the villagers especially with farmers, it came to know that this huge amount of plastics usually remain in the dumping ground which mainly use as compost site. Farmers like to apply this compost as bio-fertilizer to their lands for improving of the soil health as it carries organic contents but plastics mixed fertilizers are equally harmful for soil. It is a way to drag the plastic into the agricultural lands. Apart from compost, organic enriched sewage sludge water is also considered useful for crop production but sewage sludge water is equally responsible for dragging the plastics into the farmlands (Bläsing *et al.*, 2017). Due to lack of

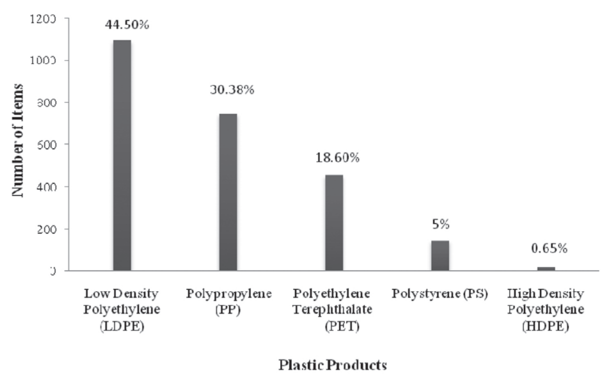
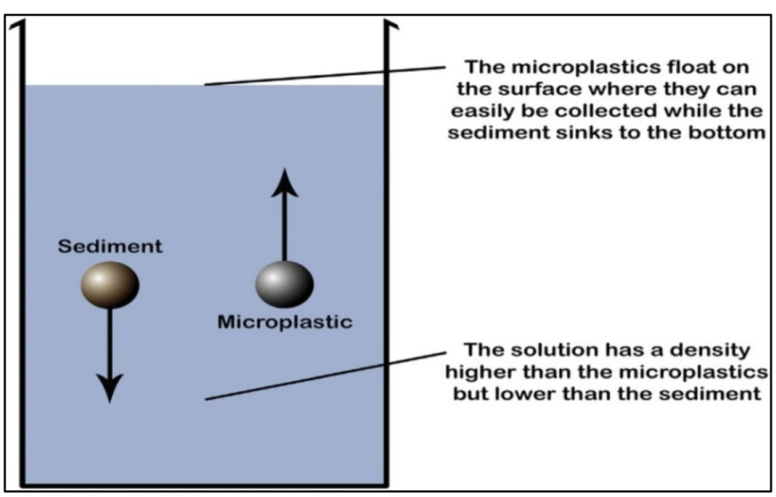


Fig. 3. Multi-tier sieving method used to separate macroplastics through sieve size >25mm (source: Crawford *et al.*, 2017)



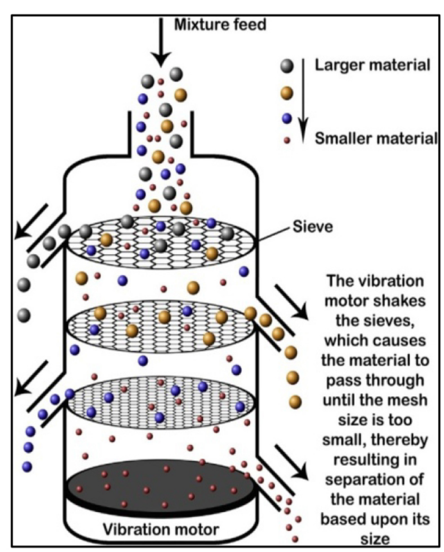


Fig. 2. Density separation method used to extract microplastics from any sediment, usually denser brine solution assists to float microplastics over the solution (Source: Crawford *et al.*, 2017)

proper techniques, other sources are left immeasurable for example sometimes micro to macro plastics are conveyed by wind in farmlands. Some plastics are reached due to overflow of cannel water into the agricultural lands, but there are some limitations in case of measuring the sources of plastics in agricultural fields.

Assessing the correlation between plastics additives and bulk density

Among the various physical properties of the soil, bulk density (pb) is one of the significant ones that indicates the compaction of soil particles, which implies how soil ingredients are attached or detached to each other. According to USDA-NRCS, any kind of fluctuation in bulk density has influenced other soil properties. The bulk density was standardised by USDA-NRCS with some specific soil texture. This implies that a standard bulk density value has to be for each and every textual class. Laboratory results have confirmed that all soil samples (58 grids) belong to the textual class of clay loam (Sand 20-45%, Silt 15-53%, Clay 27-40%). Clay loam is considered as productive textual class. However, the ideal bulk density value must be < 1.10 g/cm^3 for the clay loam texture (Table 2). The values of 1.49 g/cm^3 and 1.58 g/cm^3 indicate affected root growth, poor health and polluted soil.

Plastic differentiates bulk density value

Although a positive correlation has been seen between detected plastics and soil dry bulk density (Fig. 6). But the impact of plastic on bulk density is not supposed to be positive. Because, from the previous table (Table 2), it has been seen that for clay loamy texture, the ideal pb value is <1.10 g/cm^3. Two different clusters show a different result in a same textual class. Through the diagram, it has been observed that all the bulk density (pb) values of control clusters have been analysed under the ideal density while in case of contaminated sites, the result shows totally opposite. The pb values have exceeded the ideal value and somewhere extremely high. The maximum (6200 mg/kg^{-1} soil) plastic additives have been found in Bohar-I GP and it consequences the highest pb value (1.82 g/cm^3) have also been measured here. On the other side Barapalashan II, Satgachia I, Satgachia II and some parts of Kuchhut GP have been considered as plastic free fields. According to the farmers of above

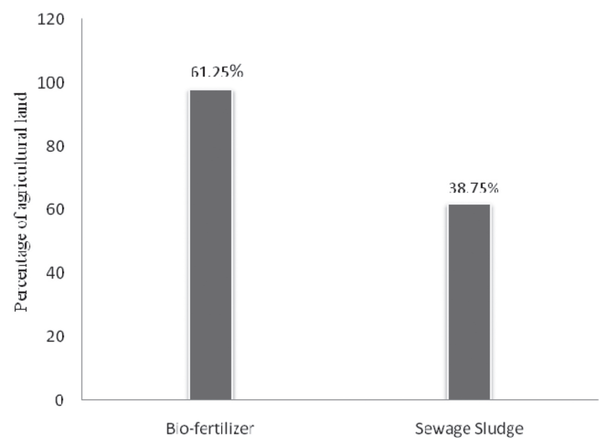


Fig. 4. The highest plastics items have been identified as Low Density Polyethylene (LDPE) followed by Polypropylene (PP) Polyethylene Terephthalate (PET) Polystyrene (PS) High Density Polyethylene (HDPE)

Table 1. A details chart on sources, amount and household uses of detected plastics items. Highest plastics products have been identified as Low Density Polyethylene (LDPE) with 1095 items, while lowest plastic items have been found as High Density Polyethylene (HDPE) with total 16 items throughout the sampling sites

Major Plastics Products	Sources	Number of Items	Household Uses
Low Density Polyethylene (LDPE)	Carry bags, squeezable bottles etc	1,095	Primarily low density plastics, mostly use to carry items, all are single use plastics.
Polypropylene (PP)	Chips packets, biscuits wrappers, straw, fabric	748	Denser than LDPE plastics, mostly use to carry items all are single use plastics.
Polyethylene Terephthalate (PET)	Clothing fibres, rope, fibres, jar etc.	458	Use as a container of beverage or other goods.
Polystyrene (PS)	Coffee cups, food boxes etc	145	All are medium dense plastics, use as food keeper.
High Density polyethylene (HDPE)	Compost containers, bin, pipes etc	16	All are hard in density, various kind of use, but less in numer.

mentioned GPs, " *we apply compost fertilizer, keeping in separate pit but we do not apply the compost fertilizers of dumping site because these sites constist of a lot of hazadous materials sometimes glasses as well, so we like to avoid that site.*" The average bulk density value of control and contaminated clusters were 1.04 g/cm^3 and 1.58 g/cm^3 respectively. So the control clusters or plastic free fields were shown under ideal value of pb. On the other hand contaminated sites were observed higher pb value, and also indicating affected root growth and poor soil health.

Plastics and Soil Porosity

Soil porosity, a physical property of the soil, depends on the soil bulk density. Porosity is also crucial indicator for soil health. Basically, soil porosity tests the pore spaces in soil by percentage. Due to external application on soil, soil porosity could be modified. For two different clusters, soil porosity was quantified in the graph (Fig.8), showing different kinds of results. The trend line

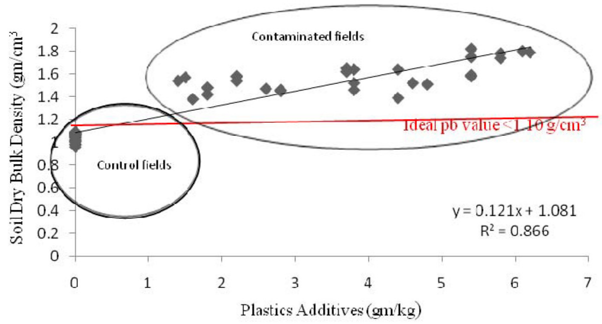


Fig. 5. Bio-fertilizer and sewage sludge water were observed as potential pathways of plastics in agricultural soils. In agricultural fields the major sources of bio-fertilizer were compost and sludge water

(Fig.7) indicates that soil porosity in the contaminated site is negatively correlated with the quantity of plastics. The average porosity of control cluster was 40.26 %. Although it was 60.61% in contaminated clusters, the difference between two clusters was more than 20 per cent. Ideally, 55 percent 65 percent for clay loamy was considered as the normal soil porosity.

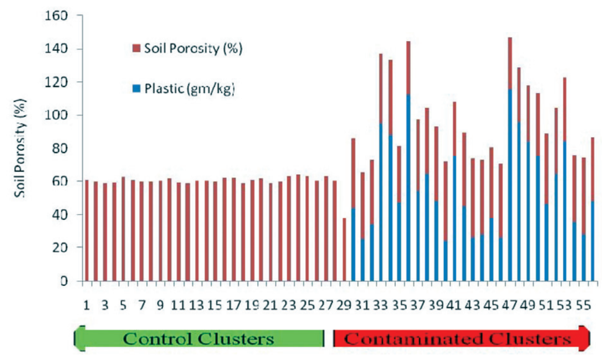


Fig. 6. Correlation between detected plastic additives and analysed the bulk density value, showing that high bulk density value consequences of higher the amount of plastic additives *Dry Bulk Density (g/cm^3): Weight of dry soil core/volume of soil core (USDA-NRCS, 2019)

From the graph (Fig. 8), it is confirmed that the porosity is much higher in control clusters and therefore is normal. In contaminated clusters, the porosity rate has decreased significantly to 40%, suggesting a low porosity and thus suggesting a lower water and soil respiration rate. The method of USDA-NRCS was followed to measure the soil porosity. Almost all clusters in control fields are more or less around 60 %, which means that plastic free compost or fertilizer tends to increase soil

Table 2. A general relationship of soil bulk density to root growth and Soil Health based on soil texture. The saffron part showing that the ideal bulk density value for the textual class of clay loam (<1.10 g/cm^3) (Souce: USDA-NRCS, 2019)

Soil texture	Ideal bulk density for plant growth/ Good Soil Health (g/cm^3)	Bulk density that affects root growth/ affects Soil Health (g/cm^3)	Bulk density that restricts root growth/ Indicated Pollution and Highly Affects Soil Health (g/cm^3)
Sand, loamy sand	<1.60	1.69	>1.80
Sandy loam, loam	<1.40	1.63	>1.80
Sandy clay loam, clay loam	<1.40	1.60	>1.75
Silt, silt loam	<1.40	1.60	>1.75
Silt loam, silty clay loam	<1.40	1.55	>1.65
Sandy clay, silty clay, clay loam	<1.10	1.49	>1.58
Clay(>45 percent clay)	<1.10	1.39	>1.47

porosity (Fig. 8), but the opposite result has been seen in contaminated clusters, showing low porosity, also indicating that plastic particles are rapidly decreasing soil porosity. The trend line (Fig. 7) also supports a similar kind of findings with the composite bar graph (Fig. 8), indicating a negative association between porosity and plastics, that means higher volume of plastic decreases soil porosity.

Soil water content and soil pore spaces filled with water

Soil water content means the difference in weight between wet soil and oven dry soil. The procedure is provided by USDA-NRCS has been used to measure soil content. In addition, the data of soil water content were used to quantify soil pore spaces filled with water condition, which assist to reveal the status of the soil health. The technique has been applied to both the control and contaminated clusters. And it has been reported that the average water content value was recorded as 0.34 g/cm^3 in the case of control clusters and calculated the percentage of pore spaces filled with water after adding the value, averagely it shows 56.10%, which enables a strong state of water holding and water infiltration. In the case of contaminated clusters, the average water content value is 0.16 g/cm^3 and the percentage of water filled pore spaces is 38.77%, which suggests hard condition for water transpiration. The difference between two is almost 20%, so it is again proven from this value that plastic additives minimise the percentage of pore space filled with water.

The distribution of soil ingredients in two different clusters have been represented through

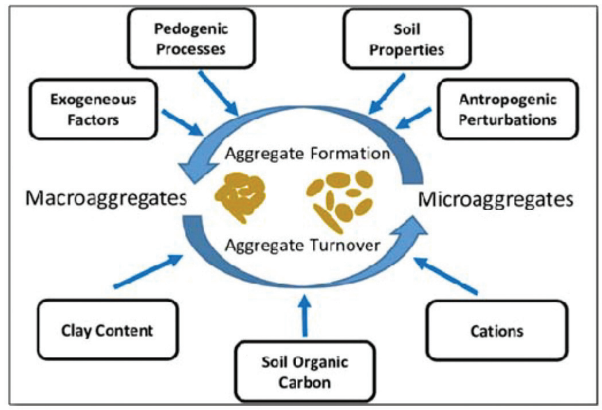


Fig. 8. The composite bar graph shows comparative value for both the clusters viz. control and contaminated, plastic contaminated clusters are having lower porosity than plastic control clusters Soil Porosity= 1-(soil bulk density/2.65*)
*The default value of 2.65 is used as a rule of thumb based on the average bulk density of rock (USDA- NRCS, 2019).

Fig. 7. Correlation of soil porosity and plastic in soils

Table 3. Soil water content (g/cm^3) and pore spaces filled with water condition (%) lower in plastic contaminated clusters than control clusters

Sample site	Water content* (g/cm^3)	Soil porosity**	Calculation: (water content/soilporosity) x 100	Percent of pore space filled with water
Control	0.342	0.61	(0.342g/cm^3/ 0.610) x 100	56.10
Contaminated	0.157	0.40	(0.157g/cm^3/0.405) x 100	38.77

Water Content (g/cm^3) = soil water content (g/g) x bulk density (g/cm^3)
*Average value of Water content and Soil porosity
**1 - (soil bulk density/2.65)* as default value

this pie graphs (Fig.9a and 9b). The findings are scientifically estimated. The distribution of soil ingredients for both clusters has been identified differently. In contaminated clusters, the total pore space is 40.5%, of which 38.77 % is filled with water and the remaining 61.23% is estimated as air-filled pore spaces. The remaining 59.50% of the materials are solid (4% organic matter, 96% sand, silt and clay). On the other hand, a huge difference has been measured in control clusters. In control clusters, the total pore spaces estimated at 61% is distributed as 56.10% water-filled pores and 43.9% air-filled pores. The remaining 39% is quantified as solid materials.

Soil Aggregate stability

The aggregation power of soil against moving water is determined by aggregate soil stability (USDA-NRCS). It governs how the soil particles aggregate and bind to each other. The micro-particles of organic matter have biological ingredient that helps to properly stick the soil so the higher proportion of organic matter in soil assists to increase soil aggregate stability (SAS). Basically, the organic matter is disposable and mixes easily with the soil. Artificial products are not easily disposed in the soil, such as plastic additives. For soil health, such artificial or synthetic materials are extremely hazardous. During water flows over the soil surface, the plastics particles easily disintegrate the aggregation of soil, resulting in the breaking of soil integration. After Bronick and Lal (2005), there are several factors responsible for the disaggregation of soil ingredients, such as anthropogenic perturbations.

Androgenic disturbances are mostly due to external factors like application of fertilizers, irrigation or tillage system. Sometimes cultivators become unaware about the recommended dose of application. As all else, soil has its weakness on external aspects, the improper use of fertilizers, tillage or irrigation could be caused of changes in the soil properties. Likewise, applications of the hazardous materials like plastics contained fertilizers equally affect for changing of various soil properties. SAS is one of the key physical properties, which actually depends on the ingredients materials of soil.

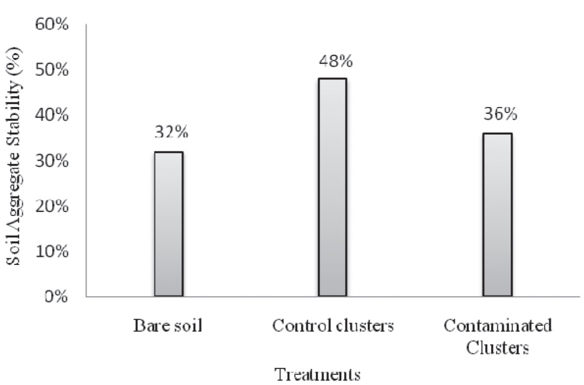


Fig. 11. Comparison of aggregate stability between three different treatments viz. bare soil, control clusters and contaminated clusters

$$\text{Soil Aggregate Stability (\%)} = \frac{\text{weight of dry aggregates - sand)}}{\text{(Weight of dry soil - sand)}} \times 100$$

Three separate treatment fields, i. Bare Soil ii. Control Clusters and iii. Contaminated clusters have been chosen in order to know the status of aggregate stability. The first one is non-agricultural fallow lands, where farming practices remain inactive for a long time; here the percentage of organic matter is very poor. The control clusters are bio-compost based agricultural fields, and most importantly, these all are plastic free compost fertilizers so, it enriched with purely natural and organic materials. The last one has been categorised as plastic enriched bio-fertilizers fields, where farmers apply compost fertilisers enriched with plastic additives. After observation, detection and questionnaire survey, total 150 fields have been selected as bare fields (50 fields), control fields (50 fields) and contaminated fields (50 fields). To quantify the aggregate stability of soil, USDA-NRCS procedure has been followed. The average data was placed on the diagram after the procedure was applied to three separate treatment fields (Fig. 11).

It is clearly understood from the diagram (Fig. 12) that the average SAS varies from each treatment, being 32% in bare soil, 36% in contaminated clusters and 48% in control clusters. Based on the results, it has been found that organic fertilizers have better SAS, while the average SAS has been recorded below the control clusters for farms cultivated with plastic-enriched fertilisers. Thus, it is inferred that plastics have an effect on SAS and soil aggregates are reduced. Soil is therefore quickly cracked up and internally decreases soil health.

CONCLUSION

In the developing countries like India, agricultural outcomes share 60% of GDP among all the economic activities. Agricultural productivity helps to move the country towards growth and also generating opportunities for jobs. Indeed, agricultural development has been driven by soil quality and systematic agricultural practices. In the soil environment, some kind of external disruption for a long time creates barriers to agricultural productivity or its development; healthy soil is often favourable to high productivity. Different aspects have been revealed from the present study with a new perspective. Collected data indicates that unregulated bio-fertilizers and sludge water have been identified as possible sources of plastic particles in the agricultural soils. While comparing clusters, the analysed data suggest that plastics have caused of differences in soil health. Higher bulk density (1.58 g/cm^3), low porosity (40.26%), lower pore spaces filled water (38.77%) and low aggregation (36%) all are inciting a poor healthy soil in plastic contaminated sites. In the block, 64 % of farmers were reported as unaware of the effect of plastics on soil health. Consequently, lack of knowledge of plastic waste and management has also emerged as a major problem in the rural environment. Micro-organisms and other biological properties of soil, such as soil respiration and microbial activities and even groundwater are also influenced by plastics. There is, therefore, an urgent need for more studies to illustrate other aspects of this harmful impact in the terrestrial environment, economy and human health.

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