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Pulverized Tires as Soil Amendment for Plant Growth.

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Abstract — Automobile waste tires are cumbersome waste materials, but might be processed to be a beneficial materials. The aim of this study was to determine the effects of pulverized tires as a soil amendment to benefit plant growing. Our study focused on the effects of pulverized tire rubber on soil aeration, water retention, and plant nutrition. Three different amounts of 0% (control), 5% and 10% by weight of pulverized tires were used to determine their effects on soil water holding capacity and aeration in pots. Hydroponic experiment with cucumber plants was used for testing the effect of the pulverized material on plant nutrition. Our findings revealed that soil amended with pulverized tires had lower bulk density and higher water retention at low water suction (0-100 cm water head suction) as compared to non amended soil. Also, soil treated with pulverized tires showed a significant decrease in aeration in term of oxygen content as compared to the non-amended soil. The direct effect of pulverized tires on plant nutrition was due to zinc toxicity leading to significant decrease in plant growth compared to untreated plants. In future research, we recommend to assess particle size optimization of the pulverized tires to improve water retention and aeration in compacted and poorly aerated soils. We also recommend using it at rate that will not exceed proper zinc nutrition. However, in zinc deficient soils, the high zinc content from pulverized tires might be of importance as nutrient for the growing plants.

Index term — aeration, environment, soil, waste tires.

1 INTRODUCTION

As world population grows, soil becomes a more precious commodity for agriculture almost everywhere (Erickson, 1960). Soil amendments can improve the soil quality conditions, but the commonly used organic matter are quite short-lasting in soils, not easily available and expensive thus other materials might be preferred to support plant growth (Letey *et al*., 1962). Amendment of a compacted soil can improve the physical properties such as soil structure, texture and tilth (Black *et al*., 1957) which eventually may increase soil water retention, infiltration rate and aeration (Williams *et al*., 2001). Also, amending the soil is likely to affect the soil bulk density because bulk density relates to the combined volume of the solids and pore spaces, and any factor that influences soil pore space may affect bulk density. Previous studies demonstrated that waste tires from motor vehicles, motor cycles and bicycles being pulverized into small pieces are important alternative materials for amending the soil and thus increases soil quality conditions for supporting plant growth (Letey *et al*, 1962). Furthermore, a beneficial use of this waste stream is of outmost environmental importance because more than 1000 million worn tires are released per year in the world which leads a significant disposal and storage problems in landfill and stockpiles (Dhir et al., 2001). Using pulverized automobile tires to amend soils might be an important means to reduce tire wastes from accumulating in the environment, thus solving this serious problem in many countries (Bowman *et al*., 1994; Giere, et al., 2004).

However, to date, the effect of pulverized automobile tires on soil aeration, water retention and nutrient availability for plants is unclear. In other side,most of the compacted soils are facing the problem of being poor aerated due to either artificial or natural occurrences in their properties, which reduces quality and quantity of crop yield. Other studies show that about 20% of tire rubbers in the soil can reduce the soil compaction and increase aeration to great extent when added to the sports fields (Rogers et al., 1994; Xiao *et al*., 2009; Yilmaz and Degirmenci, 2009).

On the other hand, the pulverized tires might be found to release toxic agents such as zinc, lead, cadmium, chromium and molybdenum (San Miguel *et al*., 2002). These elements may be more problematic in soil if their concentrations are higher than the optimal range, for example; some researches show that approximately 2% of pulverized tires mixed with sand may cause a decline in plant growth and poor yield that is directly attributed to zinc toxicity (Schulz, 1987).

We hypothesized that after pulverizing waste tires, the resulted pulverized materials could be used to amend any compacted and poor-aerated soils to benefit plant growth. The general objective of this research was to examine the feasibility of using pulverized tires for increasing plant performance in soils suffering from compaction, poor aeration, and poor hydraulic properties.

2 MATERIALS AND METHODOLOGY

This research was conducted for five months in 2015 at The Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem in Israel.

The effects of the pulverized tires on soil physical properties and aeration were measured in pot experiment. Under this study, we used pulverized tires at different amount in weight percentage of 0%, 5% and 10%. The effects on plant nutrition were studied hydroponically by growing cucumber plants in a controlled step-in growing chamber.

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2.1 Cucumber Seed Germination in Vermiculate

Cucumber seeds were germinated in vermiculite as soilless medium. First, 64 seeds were soaked in saturated $CaSO_4 \cdot 2H_2O$ solution for 6 hours to softened the seed coat while being aerated with oxygen pump. Then, the seeds were transferred into 12 small pots with vermiculite, five seeds in each pot. The pots were irrigated with saturated $CaSO_4 \cdot 2H_2O$ solution and kept for five days, till germination inside a large container covered with aluminium foil to prevent light penetration. After germination the aluminium foil cover was removed and light was turned on for a day/night cycles of 16/8 hours with a photosynthetic active radiation (PAR) of 280 μmoles/m^2/s at leaf height and day/night temperature of 25/20 ±1 °C.

2.2 Cucumber Seedling Growth in Hydroponic Solution

After germination, uniform and healthy seedlings were selected and transferred into 1-Liter containers, one seedling in each container, with hydroponic solution from stock solution made by : 0.5M $Ca(NO_3)_2 \cdot 4H_2O$, 0.5M K_2SO_4, 0.1M KCl, 0.5M $MgSO_4 \cdot 7H_2O$, 0.1M KH_2PO_4, 0.1M H_3BO_3, 0.005M $MnSO_4 \cdot H_2O$, 0.005M $ZnSO_4 \cdot 7H_2O$, 0.002M $CuSO_4$, 0.0001M $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$, and 0.05M Fe-EDTA.

2.3 Leaf Tissue Digestion and Elemental Analysis

At this stage, the top plant leave number 5 and 6 were cut from each group as explained by Cleveland *et al*. (2008), cleaned with 0.1% detergent (Ashby, 1969; Wallace et al., 1980), rinsed rapidly 3 times in distilled water (Sonneveld and Van Dijk, 1982) to avoid leaching of elements from the leaves (Bahn et al., 1959), then dried in the oven at 65^{o}C for 72 hours and ground into powder by mortar-pestle (Jones, 1991). Each powdered leave sample in approximate of 0.25g was put into glass tube and 2.5ml of concentrated HNO_3 (65%) was added and the mixture was heated in a digestion block at 80^{o}C in the for 1 hour. Solutions were allowed to cool before the adding of 2.5 ml of a strong oxidant $HClO_4$ (65%) and then boiled at 180^{o}C for 16 hours. The sample solutions were cooled and poured into measurement bottles where distilled water was added to make 25ml sample solution. Elements concentration in the digest was analyzed by using Inductive Coupled Plasma Spectrometer-ICP machine.

2.4 Soil Oxygen Content Determination

In order to determine the oxygen content in the soil, the data logger with oxygen sensor connected to the oxygen electrode was used for recording the data from the soil in the green house. In this experiment, a compacted silty loam soil with poor aeration was prepared and put into 15 pots perforated at the bottom. Each pot was twice holed at 4.5 cm sideway from the base to allow insertion of perforated tubes, one for continues measurement with in-soil probe and the other for periodic air sampling by suction.

Approximately 4.0 kg of compacted silt loam soil was amended with pulverized tires at a ratio of 10%, 5% and 0% in 5 replicates per each treatment.

The soil pots were put inside of a filled large water container where they absorbed the water through the perforated holes from bottom. After absorbing water to saturation point, the pots were taken out of the water bath container, allowed to drain out the water for 15 minutes then each pot was weighed again. All pots remained in the green house for five days and their weights were taken twice a day. At day six, the oxygen electrodes were connected through inserted tube at sideway middle to six pots with two pots per each treatment while other nine pots were left for making easy in measuring the weight and syringe sucking oxygen. The pots were irrigated with 200ml of water after two days and re-measured.

To ensure microbes are active for oxygen consumption in the soil, we irrigated the pots with 200ml of 1mM sodium succinate solution at day 7. By using oxygen sensors, the oxygen data were sent to the data logger to be recorded. We downloaded the data by using laptop with Mat Lab software after each 48 hours consecutively for 10 days.

2.5 Soil Water Retention Determination

To determine the soil water retention curves, the suction funnel was used. About 200g of amended soil at three different treatments 0%, 5% and 10% of pulverized tires was put separately into the suction funnel, allowed to slowly absorb water from the bottom through pipe to reach the saturation point. The water was allowed then to drain from suction funnel into the measuring cylinder at predefined suctions ranging from 0 cm to 100 cm water head. The volume of water was measured by measuring cylinder at each 10 cm intervals.

2.6 Bulk Density and Total Porosity Determination

To determine bulk density, first, the treated soil samples were dried in the oven overnight at 105^{o}C, then measured their weights, followed by measuring their volumes by using the measuring cylinder. Finally, the bulk density was determined as the ratio of oven dry soil weight to the bulk volume of soil.

At the same time, total porosity was determined as ratio of sum of air porosity and water filled porosity to the bulk volume of the soil.

2.7 Data Analysis

The data we collected were analysed by using analysis of variance (ANOVA) procedures while separated means were compared by least significant difference with Tukey Kramer's HSD test at 5% significant level using JMP software.

3 Results

Table 1a. The effect of pulverized tires for mineral nutrient in cucumber leaf tissues and in spent nutrient solutions (Macronutrients)

Medium	Concentration (% and mg/L)				
	K	P	Ca	Mg	S
0%-PT^{L}	1.94^{b}	0.26^{b}	2.55^{a}	0.27^{b}	0.61^{a}
0%-PT^{N}	1.68^{b}	0.88^{b}	42.3^{c}	0.00^{b}	36.4^{c}
5%-PT^{L}	3.76^{a}	0.64^{a}	1.57^{c}	0.52^{a}	0.67^{a}
5%-PT^{N}	59.4^{a}	2.75^{a}	74.0^{a}	2.56^{a}	68.4^{b}
10%-PT^{L}	4.00^{a}	0.90^{a}	1.97^{b}	0.55^{a}	0.69^{a}
10%-PT^{N}	60.3^{a}	3.36^{a}	57.4^{b}	1.34^{a}	83.5^{a}
*	63	3	80	12	38
**	3-5	0.3-1	1.4-3.5	0.3-1.2	0.4-0.7

^{L}Concentration of mineral nutrients in Leaf tissue solution (%), ^{N}Concentration of mineral nutrients in the spent nutrient solution (mg/L), *Concentrations in newly prepared (spent) nutrient solution,

**Adequate range for mineral nutrient in cucumber plant (Reuter and Robinson, 1997).

Data are presented as average of five replicates (N=15). The values with different letters are significantly different (P-value<0.05).

Table 1b.The effect of pulverized tires for mineral nutrient in cucumber leaf tissues and in spent nutrient solution (Micronutrients)

Medium	Concentration ($mg \cdot Kg^{-1}$ dry weight and mg/L)							
	B	Na	Zn	Mn	Mo	Cd	Cr	Pb
0%-PT^{L}	8.42^{b}	110^{c}	23.0^{c}	13.4^{c}	4.67^{a}	0.00^{a}	0.03^{b}	0.00^{a}
0%-PT^{N}	0.00^{c}	0.00^{b}	0.01^{b}	0.00^{b}	0.00^{b}	0.00^{a}	0.00^{b}	0.00^{a}
5%-PT^{L}	40.7^{a}	2043^{a}	521^{b}	42.0^{a}	1.62^{b}	0.00^{a}	0.18^{a}	0.00^{a}
5%-PT^{N}	0.00^{b}	87.0^{a}	4.34^{a}	0.02^{a}	0.02^{a}	0.00^{a}	0.00^{b}	0.00^{a}
10%-PT^{L}	39.4^{a}	1065^{b}	783^{a}	29.6^{b}	1.97^{b}	0.01^{a}	0.19^{a}	0.00^{a}
10%-PT^{N}	0.06^{a}	173^{ab}	3.78^{a}	0.02^{a}	0.02^{a}	0.00^{a}	0.01^{a}	0.00^{a}
Initial solution*	100	0	33	27	7	0	0	0
Adequate range**		25-60	ND	25-100	50-300	0.8-3.3	ND	ND

^{L}Concentration of mineral nutrients in Leaf tissue solution ($mg\ kg^{-1}$ dry weight), ^{N}Concentration of mineral nutrients in spent nutrient solution (mg/L), *Concentrations in newly prepared (spent) nutrient solution,

**Mineral nutrients in cucumber plant (Reuter and Robinson, 1997). ND: Adequate range for these elements has not been determined.

Data are presented as average of five replicates (N=15). The values with different letters are significantly different (P-value<0.05).

For amended nutrient solutions showed an increase of B, Na, Zn, Mn and Cr in cucumber leaf tissues while K, P and Ca were observed to increase in spent nutrient solution, with exceptional of Cd and Pb which were not found in both leaf tissue and nutrient solution (Table 1a and 1b).

Also B, Na, Zn, Mn and Cr were significantly higher in 5%-PT and 10%-PT leaf tissues than in 0%-PT leaf tissues. Although, there was no significant difference in S among 0%-PT, 5%-PT and 10%-PT in leaf tissues, but higher significant increase of S was observed in 5%-PT and 10%-PT than 0%-PT in spent solutions. In addition, Mo showed a significant reduction in 5%-PT and 10%-PT leaf tissues, and on other hand, Cd and Pb were not found in either leaf tissues or spent nutrient solution.

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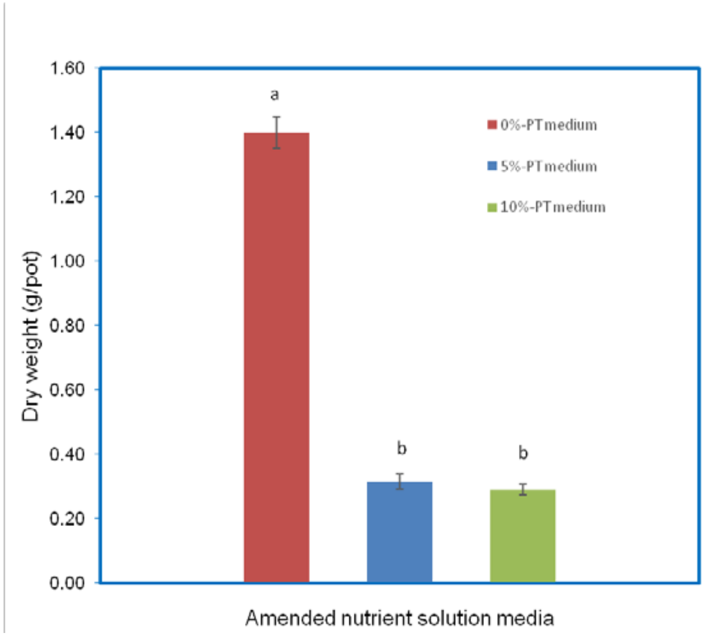

Fig.1.The effect of pulverized tires on dry weight of cucumber plants grown in nutrient solution.

Amending the nutrient solution with pulverized tires decreased the plant dry weights (Figure 1). Our results indicated that, there was significant (P-value<0.05) decrease of dry weights for 5%-PT and 10%-PT plants than that of 0%-PT plants. However, there was no significant difference in dry weight between 5%-PT and 10%-PT plants.

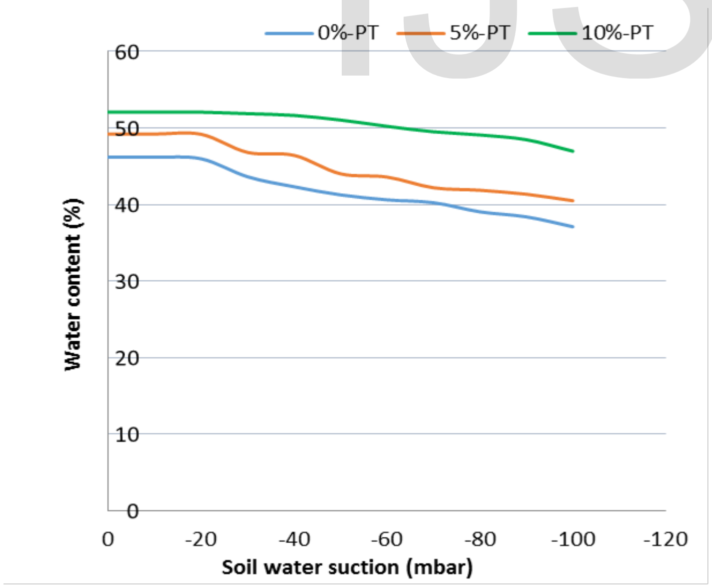

Fig. 2. The effect of pulverized tires to the soil water retention as obtained by using suction funnel within 10 hours in the laboratory.

The inclusion of pulverized tires in the soil media resulted in slight increase in water retention (Figure 2). The soil treated with 10%-PT had significantly (P-value<0.05) higher increase of water retention than 5%-PT and 0%-PT, however the soil treated with 5%-PT did not show significant difference with 0%-PT soil.

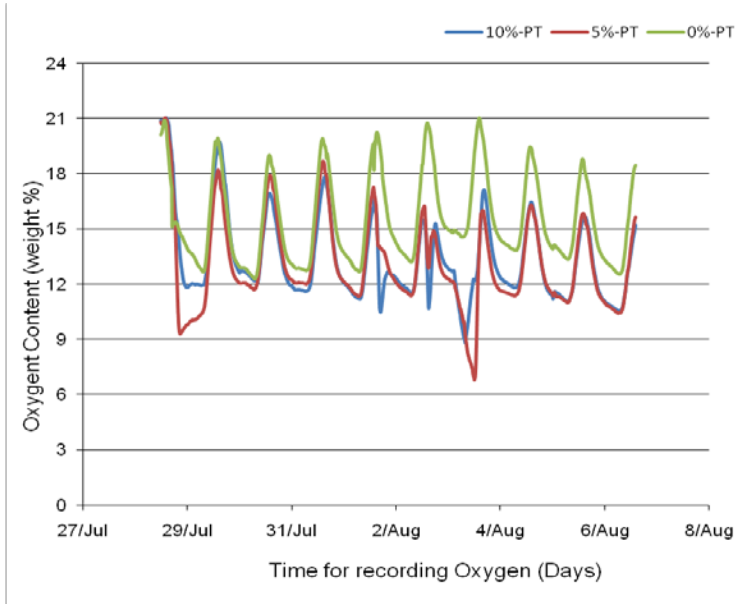

Fig. 3. The effect of pulverized tires to the oxygen content (aeration) of the soil within 10 days in pot experiment.

Applying pulverized tire to the soil media decreased the soil aeration (Figure 3). We found out that, 0%-PT soil indicated an increase in oxygen content significantly (P-value<0.05) as compared to 5%-PT and 10%-PT from day 1 to 6. Moreover, there was no significant difference in oxygen content between the soil amended with 5%-PT and 10%-PT soil. There was a sharp decrease of oxygen content at day seven in amended soil/Table 2. The effect of inclusion of pulverized tires on soil bulk density and porosity.

Table 2. The effect of inclusion of pulverized tires on soil bulk density and porosity.

Medium	Bulk Density (g/cm^3)	Total Porosity (vol %)
0%-PT soil	1.43 ± 0.08^a	46.17 ± 2.96^a
5%-PT soil	1.35 ± 0.15^b	49.21 ± 5.68^b
10%-PT soil	1.27 ± 0.07^c	52.09 ± 2.72^c

Data are presented as average and standard of five replicates (N=15). The values with the different letters are significantly different (P-value<0.05)

In adding the pulverized tires to the soil increased and decreased porosity and bulk density respectively (Table 2). Our results indicated that, there was significant (P-value<0.05) increase in total porosity, water filled porosity and air filled porosity for 5%-PT and 10%-PT soil as compared to 0%-PT soil. In addition, there was significant decrease in bulk density for 5%-PT and 10%-PT as compared to 0%-PT soil.

4 Discussion

4.1 The Effect of Pulverized Tires in Plant Nutrition

Analysis of cucumber leaf tissues revealed significant increase B, Na, Zn, Mn and Cr mineral ions in both plants amended with pulverized tires, however K, P and Ca mineral ions decreased in plant leaf tissues amended with pulverized tires as compared control plant (Table 1a and 1b). Only Mo showed a decrease in plant leaf tissues for amended solutions, while heavy metals such as Cd and Pb were not found in the plant leaf tissues. With the exception of Na and Zn which were in excess, other nutrient values were in optimal range of enabling the growth of cucumber plants in the solution media as per adequate range (Reuter and Robinson, 1997). We found that Zn nutrient level in cucumber leaf tissues increased 23 times in 5%-PT and 34 times in 10%-PT plant tissues. The values for zinc mineral ions was seen to rise at high number compared with adequate range of 30-500 mg Kg^{-1} (Reuter and Robinson, 1997). We suggest that pulverized tires might be a source of high level of zinc. Our findings correspond with those of Yamaguchi *et al*. (1991) who reported on Zn increase in leaves of cucumber grown in soil amended with the Zn-containing compound zinc dimethyl and zinc diethyl-dithiocarbamate which is used during tires manufacturing. Furthermore, our results are similar to the results of Evans and Harkess (1997), Handreck (1996), and Owings and Bush (2001) who reported that plants grown in soilless potting media containing pulverized tire rubber showed high Zn level in their tissues that could lead a decrease in plant yield with an increase of rubber content in those media.

4.2 The Effect of Pulverized Tires in Soil Water Retention

The inclusion of pulverized tires in the soil media resulted in slight increase of water retention (Figure 2). Our results revealed that the soil amended with pulverized tires had higher significant water retention as compared to non-amended soil. We suggest that the fine particles of tires added to the soil might cause the soil particles to aggregate together and become shrinkage hence prevent and block the water from moving out through the pore spaces, hence more water was retained inside the amended soil as compared to non-amended soil. These results are in agreement with the findings of Ok *et al*. (2003) and Bigelow *et al.* (2004) who reported that the physical properties of the soil may be improved by adding tire rubbers through increasing water retention of the amended soil. Additionally, our results are similar to Bowman (1994) who found out that on using fine tire < 1mm diameter slight increased the water container capacity by 54% in amended soil as compared to control soil which its water container capacity was 49%. Thus, particle size of pulverized tires may play a key role in the physical properties of the soil such as total porosity (Bunt, 1976), thus the size of pulverized tires are important is determining the water retention in the soil (Milks et al., 1989). From our study, amended soil having high water retention has a very important indication and application because presence of water in soil makes nutrients to be available to the plants (Argo and Biernbaum, 1995).

More than that, by adding the pulverized tires to the soil increased and decreased porosity and bulk density respectively (Table 2). According to our results, there was significant decrease bulk density and increase of porosity in amended soil as compared to non-amended soil. Our results suggest that, a decrease of bulk density and an increase of porosity may be caused by pulverized tires added in the soil. The pore spaces in soil are important because affects infiltration, root penetration, available water capacity, plant nutrient availability, and soil microorganism activity, which are very important in soil processes and productivity. Our results are in agreement with the findings of Zhao *et al*. (2011) who found out that crumb rubbers improved the properties of amended sand-based medium by decreasing bulk density and increasing water retention.

4.3 The Effect of Pulverized Tires on Soil Aeration

Applying pulverized tire to the soil media revealed a decrease of oxygen content (Figure 3). Although we were expecting the oxygen content in amended soil to be higher than that of non-amended soil, but surprisingly, the results were opposite. Our results indicated that there was significant higher oxygen content in non-amended soil compared to amended soil. The oxygen ranged 6% to 17% in the amended soil and 12% to 21% in the non-amended soil. We suggest that an increase of oxygen content in non-amended soil might be due to the expansion and cracking of soil as it became drier, that condition allowed more air to enter inside and it was recorded by oxygen sensors. On the other hand, the issue of particles size of pulverized tires used under this experiment was a matter of concern, since we used the fine pulverized tires which were less than one millimetre in diameter, we think that the pulverized tire size was too small to increase the pore spaces in soil which could provide more aeration differently as we could use the course pulverized tires in the soil. Also, previous research shows that the particle size of the media may influence the activity of pulverized tires in the soil (Barrett, 1982; Quarrels and Newman, 1994). In contrast, our results are different from Bowman (1994) who reported an increase of air filled porosity in fine pulverized tires of 66% of pulverized tire soil.

5 Conclusions

Our findings from this study showed that plants amended with pulverized tires could not grow and decreased significantly in dry weights by almost 78%. Also, soil amended with pulverized tires had higher water retention than non-amended soil. Surprisingly, the soil amended with pulverized tires had low oxygen content as compared to non-amended soil. Results suggested that, the decrease of plant dry weights was due to zinc toxicity in plants while increase of water retention in soil might be due small size tire particles used in soil which could retain more water, and an increase of soil aeration was due to type of soil (silty loam soil) used from expansion and cracking as it became drier. For this reason, pulverized tires to be used in soil need further investigation. Therefore, for the future research, we recommend to consider the use of pulverized tires at low amount ratio i.e less than 5% by weight and with an increased size of particles greater than one millimeter. These two considerations will help to increase more aeration in compacted soil, while reducing zinc concentration to accumulate in growing plants.

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