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*Research Article*

# Rubber Crumb Pollution Affecting the Growth of Some Leguminous Plants

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**ABSTRACT**

**The effect of different concentrations of rubber crumb collected from the vicinity of rubber factories situated in S.I.T.E area Karachi was studied on the seedling growth of *Pithecellobium dulce* (Roxb) Benth., *Adenanthera pavonina* L. and *Pisum sativum* L. under natural environmental conditions. All the treatments exhibited inhibition of most of growth parameters (shoot length, seedling length, number of leaves, shoot dry weight, leaf dry weight, total plant dry weight and specific leaf area) in *P. dulce.* However, *A. pavonina* showed improved growth in root length, number of leaves, root dry weight, shoot dry weight, leaf dry weight, total dry weight, root/shoot ratio and leaf weight ratio. *P. sativum* was the most affected plant as compared to *P. dulce* and *A. pavonina* and showed highly declined growth under all the rubber crumb treatments. *P. sativum* plants treated with 30% rubber crumb did not survive after two weeks of growth. This showed that the soil contaminated with rubber crumb drastically affected the plant growth. The findings of this research could be helpful in monitoring and controlling the pollutant levels in soils of the industrial areas. Such information could also be useful for landscaping and urban planning.**

## INTRODUCTION

Pakistan is an agrarian country with high population growth. Soils are intensively cropped to meet the increasing demand for food production. However, soils of Pakistan are inherently low in fertility to support economic crop production. Due to high cost and scarcity of chemical fertilizers, the land disposal of agricultural, municipal and industrial wastes is widely practiced as a major and economic source of nutrients and organic matter for growing cereal crops by poor farmers in Pakistan. The most reported heavy metals in waste amended agricultural soils are Cu, Pb and Zn (Younas and Shahzad, 1998). Soil and environment are under tremendous pressure due to industrial expansion and discharge of effluents. Very few people are aware of this globally important issue (Leonard, 1993). Karachi has five main industrial estates like, Sindh Industrial Trading Estate (S.I.T.E.), Korangi Industrial Trading Estate (K.I.T.E.), North Karachi Industrial Trading Estate (N.I.T.E.), Landhi Industrial Trading Estate (L.I.T.E.) and Hub Industrial Trading Estate (H.I.T.E.), which emit toxic pollutants into air, water and soil. S.I.T.E. is the first industrial zone of Karachi comprising of 1784 hectares. There are over 2516 industrial units of varying sizes in the estate and includes all kinds of industries. It has many types of rubber products manufacturing factories that contribute largely in enhancing the pollution of the city. These industries create the problem of solid waste, which eventually devastates nearby vegetation. Discarding the large amounts of waste rubber materials is posing major problems of wastage of valuable rubber and disposal of waste rubber leading to environmental pollution (Tekasakul and Tekasakul, 2006). The severity of some of the local impacts of industry and the high cost of remediation industry is becoming an increasingly sensitive issue (Roger, 1996). Production of waste rubber amounts up to 2 million tons annually with 12% growth rate every year (Li, 2008). About 80 million scrap tires were produced in 2002 and sometimes their scrap rubber is used as a fuel. Tires contain more than 90% organic material and have a heat value of 32.6 mJ/kg as compared with that for coal of 18.6-27.9 mJ/kg (Adhikari *et al*., 2000). Miguel *et al*., (2002) reported that the rubber exhibits high concentrations of sulfur (16,200 ppm) and zinc (12,700 ppm). Other inorganic species found at relatively high concentrations include iron (2818 ppm), calcium (1544 ppm), magnesium (444 ppm) and aluminum (956 ppm). Fractured rubber from tires is high in leachable zinc (Ledoux, 2007; Smolders and Degryse, 2002). Leaf tissue analysis of some tree species revealed an increased zinc level than normal (Bush *et al*., 2003). The level of Fe was highest in plants grown in soil from a rubber factory. Similarly, the level of $Cu^{++}$ was significantly higher in plants of rubber factory soil (Rehman and Iqbal, 2007; Rehman *et al*., 2011). The foliage of *Senna holosericea* showed the highest concentration of zinc at a rubber factory as compared to control area (Rehman and Iqbal, 2008). Mattina *et al*. (2007) examined out-gassing and leaching from synthetic turf rubber crumbs under aqueous ambient temperatures and found benzothiazole, butylated hydroxyanisole, n-hexadecane and 4-(t-octyl) phenol to be most common. Heavy metals such as zinc, selenium, lead and cadmium were also found.

Groenevelt and Grunthal (1998) found that a rubber crumb-based soil amendment could enhance the physical properties of soils susceptible to the negative effects of compaction. Rubber crumb adds resiliency to sports turf. They further noticed that admixtures containing 20% or less rubber crumb maintained recommended total porosity values. Tompkins *et al*. (1998) noticed that the rubber crumb treatment promoted turf color in the spring due to earlier green up. However, the combination of high rubber crumb and high compost may have reduced winter survival. Matta *et al*. (1999) tested rubber crumb on sports turf as mulches to improve soil aeration with great success. Various kinds of industrial pollutants of rubber factory effluent adversely affected on elemental bioaccumulation and metabolite concentration in component parts of *Triticum aestivum* var. UP-262 plants (Habib and Iqbal, 1996). Rehman *et al*. (2011) found that the plants grown in the soil from rubber factory drastically affected the growth of *Albizia lebbeck* plants.

The objective of this study was to investigate the effects of rubber crumb on the growth of two tree species and a crop species. Plants of *Pithecellobium dulce, Adenanthera pavonina* and *Pisum sativum* were selected for this purpose. *P. dulce* (Mimosaceae) out of 100-200 species in this genus is the only species that has become widespread outside its origin. *P. dulce* thrives in dry warm climates. This species is found on most soil types including clay, limestone, and sands. *Pithecellobium* species are noted for their tolerance of heat, salinity and impoverished soils. They are also tolerant to drought conditions.

*Adenanthera pavonina* (Mimosaceae) is a secondary forest tree favoring precipitation. *Adenanthera* species are found scattered in primary and secondary, evergreen to dry deciduous rainforests, but also in the open savannah. It is found on a variety of soils from deep, well drained to shallow and rocky soil. This tree prefers neutral to slightly acidic soils.

*Pisum sativum* (Papilionaceae) is an annual, green vegetable, widely grown as a cool season vegetable crop. They do not thrive in the summer heat of warmer temperate and lowland tropical climates but do grow well in cooler high altitude tropical areas. Peas grow best in slightly acidic, well-drained soils.

## MATERIALS AND METHODS

Healthy and uniform size seeds of *Pithecelobium dulce* and *Adenanthera pavonina* were collected from

University Campus while *Pisum sativum* seeds were purchased from a local seed store. Due to hard seed coats, seeds were soaked in distilled water for 24 hours then dried in air and were sown in garden soil at one cm depth in large pots. The pots were irrigated daily with tap water. After about 3 weeks uniform size seedlings were transplanted into pots (7.3 cm in diameter and 9.6 cm in depth) containing garden soil and rubber crumb mixed in different ratios (10% rubber crumb + 90% garden soil; 20% rubber crumb + 80% garden soil; 30% rubber crumb + 70% garden soil). Garden soil without rubber crumb served as control. The fraction of soil was one part manure and two parts fine sand. The experiment was conducted in a completely randomized design with each treatment replicated five times. Each pot had only one seedling and the pots were irrigated daily with tap water. Every week, pots were reshuffled to avoid light/shade or any other climatic effects and after every week seedlings height, plant cover, leaf length and leaf breadth was recorded. The experiment was conducted for 8 weeks on *A. pavonina* and *P. dulce* while for 4 weeks on *P. sativum.*

Seedlings of *P. dulce* and *A. pavonina* were carefully removed from the pots after 8 weeks and *P. sativum* after 4 weeks. They were washed thoroughly to remove adhering soil and root, shoot and seedling length was measured. Root, shoot and leaves were separated and dried in an oven at 80°C for 24 hours. Oven-dried weights of roots, shoots, leaves and total plant were recorded with an electrical balance. Root/shoot ratio, leaf weight ratio, specific leaf area and leaf area ratio were determined as given by Rehman and Iqbal (2009). Reduction in the percentage of growth or germination was determined in treatments of rubber and pencil crumb to control soil using the following formula:

$$\text{Reduction in growth (\%)} = \frac{\text{Growth in control soil - Growth in treated soil}}{\text{Growth in control soil}} \times 100$$

For soil analysis, the collected soil samples were air-dried, lightly crushed and passed through 2mm sieve, labeled and kept in the laboratory. Maximum water holding capacity ( M.W.H.C. ) was measured by the method of Keen (1931). Soil organic matter was determined according to Jackson (1958) and organic matter was converted into total organic carbon by conversion factor 1.724 (organic matter / 1.724 = g organic carbon) given by Nelson and Sommers (1996). Calcium carbonate concentration was determined by acid neutralization, as described by Qadir *et al*. (1966). Electrical conductivity and total dissolved salts were determined by E.C meter (AGB 1000). Soil pH was recorded by a direct pH-reading meter (AD 1000 pH meter), (Adwa Romania). Available sulfur in soil was determined by turbidity method as described by Iqbal (1988) using a spectrophotometer (Jenway 6305, England). Bulk density and total porosity were determined by using the core method described by Birkeland (1984). Chlorides were evaluated through titration by Mohr's method (Allen *et al*., 1974). Cation exchange capacity was estimated by method of Rhodes and Polemio (1977). The data were statistically analyzed by ANOVA and DMRT ($p<0.05$) using personal computer software packages SPSS version 13.0 (Duncan, 1955).

## RESULTS

Table 1 shows that bulk density increased in 20% and 30% treatments while it decreased in 10% treatment. Significant increase in porosity, maximum water holding capacity, organic matter, total organic carbon, electrical conductivity, available sulfate and chlorides is evident from Table.1, whereas decrease in calcium carbonate, pH, cation exchange capacity and total dissolved salts, was observed from 10% to 30% rubber crumb treated soil as compared to control (Table 1).

**Table 1:** Characteristics of soil used in experiment

| Treatments | 0% | 10% | 20% | 30% |
|---|---|---|---|---|
| Bulk Density ($g\ cm^{-3}$) | 1.55 b ± 0.025 | 1.35 a ± 0.01 | 1.56 b ± 0.025 | 1.56 b ± 0.025 |
| Porosity (%) | 41.69 a ± 0.95 | 49.50 b ± 0.0 | 42.0 a ± 1 | 41.80 a ± 0.2 |
| M.W.H.C (%) | 42.37 a ± 0.19 | 65.85 a ± 2.19 | 65.01 a ± 2.17 | 63.84 a ± 2.13 |
| Organic Matter (%) | 3.45 a ± 0.05 | 14.20 b ± 0.1 | 16.31 c ± 0.21 | 18.48 d ± 0.22 |
| Total Organic Carbon (g) | 1.71 a ± 0.32 | 8.24 b ± 0.06 | 9.46 c ± 0.12 | 10.72 d ± 0.13 |
| $CaCO_3$ (%) | 21.11 c ± 0.65 | 13.35 b ± 0.45 | 10.86 a± 0.36 | 10.89 a ± 0.1 |
| E.C ($mS\ cm^{-1}$) | 0.65 a ± 0.05 | 0.9 a ± 0.4 | 0.8 a ± 0.1 | 0.85 a ± 0.15 |
| pH | 7.94 a ± 0.01 | 7.71 a ± 0.09 | 7.82 a ± 0.04 | 7.67 a ± 0.01 |
| Available Sulfur ($\mu g\ g^{-1}$) | 8.5 a ± 0.5 | 50.0 b ± 1.53 | 42.0 b ± 5.77 | 40.67 b ± 8.09 |
| C.E.C ($meq\ L^{-1}$) | 105.55 b ± 0.56 | 27.75 a ± 5.75 | 30.0 a ± 10 | 33.75 a ± 8.75 |
| $Cl^-$ ($meq\ L^{-1}$) | 5.28 a ± 0.47 | 35.65 b ± 0.05 | 44.25 c ± 0.05 | 56.0 d ± 0.19 |
| T.D.S (%) | 0.85 c ± 0.05 | 0.8 b ± 0 | 0.55 a ± 0.05 | 0.55 a ± 0.05 |

Statistical significance determined by analysis of variance. Numbers followed by the same letters in each row are not significantly different ($p<0.05$), according to Duncan's Multiple Range Test.

M.W.H.C.=Maximum water holding capacity, E.C.=Electrical conductivity, C.E.C.=Cation exchange capacity, $Cl^-$ =Chlorides, T.D.S.= total dissolved salts.

0%=Garden soil; 10% =10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil.

Root length increased in 10% and 20% rubber treatment as compared to control whereas shoot length, seedling length, number of leaves, shoot dry weight, leaf dry weight, total plant dry weight and specific leaf area reduced in 10% and 20% treatments of rubber crumb as compared to control (Table 2a and 2b). 10% rubber crumb treatment caused an elevation in leaf area (1.2 $cm^2$), root dry weight (0.044 g), root/shoot ratio (0.85), leaf weight ratio (0.43 $cm^2g^{-1}$) and leaf area ratio (7.48 $cm^2g^{-1}$) of *P. dulce* as compared to leaf area (1.13 $cm^2$), root dry weight (0.042 g), root/shoot ratio (0.50), leaf weight ratio (0.33 $cm^2g^{-1}$) and leaf area ratio (7.22 $cm^2g^{-1}$) as provided in Table 2a and 2b.

Plant cover and seedling fresh weight increased in 20% rubber crumb treatment whereas these parameters decreased in 10% rubber treatment (Table 2a). The rubber crumb treatment 20% showed decline in leaf area (8.85%), root dry weight (9.52%), root per shoot ratio (16%) and leaf area ratio (3.6%) than control (Table 3b). When 30% rubber crumb treatment was applied to *P. dulce* all the growth parameters except leaf weight ratio suppressed as compared to control (Table. 3a and 3b).

*A. pavonina* showed better growth of root length, number of leaves, shoot dry weight, leaf dry weight, total plant dry weight, root/shoot ratio and leaf weight ratio increased in all rubber crumb treated plants of *A. pavonina* (Table 4a and 4b). Shoot length, seedling length, seedling fresh weight and root dry weight increased in 10% and 20% treatments as compared to control (Table 4a and 4b). *A. pavonina* plants in 30% rubber crumb showed reduction in shoot length (12.48%), seedling length (3.58%), leaf area (17.39%), plant cover (5.83%), and seedling fresh weight (18.30%) as compared to control (Table 5a and 5b). Specific leaf area and leaf area ratio decreased in all rubber crumb treatments as compared to control (Table 5a and 5b).

*P. sativum* was adversely affected by rubber crumb amendment. All the growth parameters were highly reduced in all rubber crumb treated plants of *P. sativum* as compared to control (Table. 6a, 6b, 7a and

7b). Plants grown in 30% rubber crumb did not survive after two weeks.

## DISSCUSION

The results showed that porosity and maximum water holding capacity increased in all rubber crumb amended soil. Significant decrease in soil bulk density was also observed in 10% rubber crumb treated soil. Arvidsson (1998) proved that high amount of organic matter resulted in decreased bulk density and increased porosity of soil. Zhao *et al*. (2009) also found out that crumb rubber amendment decreased bulk density. Electrical conductivity and pH slightly increased by the incorporation of rubber crumb. In all treatments of rubber crumb, level of available sulfates and chlorides elevated highly. These findings suggested that rubber crumb amendment increased soil salinity but decreased in levels of total dissolved salts in the samples is might be due to low percentage of other soluble mineral salts. Cation exchange capacity was also found to be decreased in all the samples. This could be caused by the low level of total dissolved salts.

Rubber crumb caused extreme reduction in growth of *P. dulce* and *P. sativum* plants. Reduction in growth of plants might be due to harmful components present in rubber crumb. The toxicity of some metals may be so high that plant growth is retarded before large quantities of an element can be translocated (Haghiri, 1973). Zhao *et al*. (2009) reported that adverse effects of rubber crumb on turf grass growth might be attributed to some toxic substances releasing from crumb rubber. Miguel *et al*. (2002) reported that rubber exhibits high levels of sulfur, zinc and other heavy metals. Improvement in growth of *A. pavonina* to certain extend under rubber treatments is may be due to the resistance of this species against toxic substances present in rubber crumb. As better growth was observed in 10% and 20% rubber crumb treated *A. pavonina* plants, 30% rubber crumb treated plants showed highly declined growth than control. Enhancement in growth is might be because of high levels of organic matter and total organic carbon. Because organic matter is known to improve, soil fertility and plant growth. It is often added to garden soil in large amount (Faber *et al*., 2002). Low amount of total dissolved salts and calcium carbonate might also be responsible for enhancement of growth in plants. Because when soil contains high amount of soluble salts, then it develops unfavorable characters due to salinity which reduces the ability of plants to take up water, and this quickly causes reductions in growth rate, along with a suite of metabolic changes (Munns, 2002). Suppression of growth of *P. dulce* and *P. sativum* in rubber crumb amended soil may have been resulted from accumulation and translocation of high amount of chlorides and that caused salinity in soil, which ultimately leads to the osmotic stress in plants. Zhu (2002) also reported similar results. Cerda *et al*. (1984) observed that excess sulfate caused a reduced yield of tomato. This showed that the soil contaminated with rubber crumb drastically affected the plant growth. The findings of this research could be helpful in monitoring and controlling the pollutant levels in soils of the industrial areas. Such information could also be useful for landscaping and urban planning.

**Table 2 a:** Growth of *Pithecellobium dulce* in different concentrations of rubber crumb

| Treatments | Root Length (cm) | Shoot Length (cm) | Seedling length (cm) | No. of Leaves | Leaf Area (sq cm) | Plant Cover (cm) | Seedling Fresh Weight (g) |
|---|---|---|---|---|---|---|---|
| 0% | 10.86 a ±1.69 | 18.80 b ±1.19 | 29.66 b ±2.21 | 21.60 a ±1.96 | 1.13b ±0.21 | 21.10 a ±1.69 | 0.74 a ±0.13 |
| 10% | 10.90 a ±1.55 | 13.26 a ±1.12 | 24.16 ab ± 1.40 | 20.60 a ±1.17 | 1.20 a ±0.22 | 19.50 a ±1.60 | 0.64 a ±0.06 |
| 20% | 12.92 a ±0.72 | 14.42 a ±0.98 | 27.34 ab ±1.10 | 20.20 a ±2.8 | 1.03 a ±0.10 | 23.20 a ±0.86 | 0.78 a ±0.07 |
| 30% | 9.20 a ±0.96 | 13.30 a ±1.78 | 22.50 a ±2.67 | 19.80 a ±2.99 | 0.94 a ±0.24 | 18.90 a ±1.31 | 0.62 a ±0.07 |

Statistical significance determined by analysis of variance. Numbers followed by the same letters in the same column are not significantly different ($p<0.05$), according to Duncan's Multiple Range Test.

± Statistical error.

0% = garden soil; 10%=10% rubber crumb + 90% garden soil; 20% = 20% rubber crumb + 80% garden soil; 30% = 30% rubber crumb + 70% garden soil

**Table 2 b:** Growth of *Pithecellobium dulce* in different concentrations of rubber crumb

| Treatments | Shoot Dry Weight (g) | Root Dry Weight (g) | Leaf Dry Weight (g) | Total Plant Dry Weight (g) | Root/Shoot Ratio | Leaf Weight Ratio ($cm^2g^{-1}$) | Specific Leaf Ratio ($cm^2g^{-1}$) | Leaf Area Ratio ($cm^2g^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 0% | 0.042a ±0.01 | 0.11b ±0.026 | 0.084a ±0.02 | 0.232a ±0.06 | 0.50ab ±0.13 | 0.33a ±0.04 | 26.61a ±15.11 | 7.22a ±2.67 |
| 10% | 0.044a ±0.01 | 0.05a ±0.004 | 0.078a ±0.01 | 0.232a ±0.02 | 0.85b ±0.18 | 0.43ab ±0.04 | 18.56a ±5.89 | 7.48a ±2.075 |
| 20% | 0.038a ±0.01 | 0.09ab ±0.011 | 0.076a ±0.011 | 0.198a ±0.02 | 0.42a ±0.08 | 0.35ab ±0.03 | 15.17a ±15.11 | 5.26a ±0.59 |
| 30% | 0.034a ±0.01 | 0.08ab ±0.014 | 0.07a ±0.018 | 0.186a ±0.04 | 0.39a ±0.07 | 0.36ab ±0.04 | 18.05a ±7.24 | 4.49a ±0.71 |

Statistical significance determined by analysis of variance. Numbers followed by the same letters in the same column are not significantly different ($p<0.05$), according to Duncan's Multiple Range Test.
± Statistical error.

0% = garden soil; 10% = 10% rubber crumb + 90% garden soil; 20% = 20% rubber crumb + 80% garden soil; 30% = 30% rubber crumb + 70% garden soil

**Table 3 a:** Percent Reduction in growth of *Pithecellobium dulce* in different concentrations of rubber crumb as compared to control

| Treatments | Root Length (cm) | Shoot Length (cm) | Seedling Length (cm) | No. of Leaves | Leaf Area (sq cm) | Plant Cover (cm) | Seedling Fresh Weight (g) |
|---|---|---|---|---|---|---|---|
| 10% | 0.37+ | 29.47 | 18.54 | 4.63 | 6.19+ | 7.58 | 13.51 |
| 20% | 18.97+ | 23.3 | 7.82 | 6.48 | 8.85 | 9.95+ | 5.41+ |
| 30% | 15.29 | 29.26 | 24.14 | 8.33 | 16.81 | 10.43 | 16.22 |

+ Percentage increase

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 3 b:** Percent Reduction in growth of *Pithecellobium dulce* in different concentrations of rubber crumb as compared to control

| Treatments | Root Dry Weight (g) | Shoot Dry Weight (g) | Leaf Dry Weight (g) | Total Plant Dry Weight (g) | Root / Shoot Ratio | Leaf Weight Ratio | Specific Leaf Area ($cm^2g^{-1}$) | Leaf Area Ratio ($cm^2g^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 10% | 4.76+ | 54.55 | 7.14 | 0 | 70+ | 30.3+ | 30.25 | 3.6+ |
| 20% | 9.52 | 18.18 | 9.52 | 14.66 | 16 | 6.06+ | 42.99 | 27.15 |
| 30% | 19.05 | 27.27 | 16.67 | 19.83 | 22 | 9.09+ | 32.17 | 37.81 |

+ Percentage increase

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 4 a:** Growth of *Adenanthera pavonina* in different concentration of rubber crumb

| Treatments | Root Length (cm) | Shoot Length (cm) | Seedling Length (cm) | No. of Leaves | Leaf Area (sq cm) | Plant Cover (cm) | Seedling Fresh Weight (g) |
|---|---|---|---|---|---|---|---|
| 0% | 5.83 ab ±0.41 | 6.17 b ±0.03 | 12 abc ±0.44 | 13.33 a ±1.45 | 1.38 a ±0.09 | 34.33 a ±1.33 | 0.53 ab ±0.03 |
| 10% | 8.40 b ±1.67 | 6.2 b ±0.06 | 14.6 c ±1.63 | 13.67 a ±0.88 | 1.26 a ±0.15 | 34.33 a ±0.67 | 0.80 d ±0.06 |
| 20% | 6.93 ab ±1.05 | 6.73 c ±0.29 | 13.7 abc ±0.82 | 15.33 a ±1.33 | 1.60 a ±0.29 | 36.00 a ±2.52 | 0.77 d ±0.07 |
| 30% | 6.17 ab ±0.09 | 5.4 a ±0.06 | 11.6 ab ±0.03 | 14.67 a ±0.33 | 1.14 a ±0.2 | 32.33 a ±1.2 | 0.43 a ±0.03 |

Statistical significance determined by analysis of variance. Number followed by the same letters in the same column is not significantly different, according to Duncan's Multiple Range Test at $p < 0.05$

± standard error

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 4 b:** Growth of *Adenanthera pavonina* in different concentration of rubber crumb

| Treatments | Root Dry Weight (g) | Shoot Dry Weight (g) | Leaf Dry Weight (g) | Total Plant Dry Weight (g) | Root/Shoot Ratio | Leaf Weight Ratio | Specific Leaf Area ($cm^2g^{-1}$) | Leaf Area Ratio ($cm^2g^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 0% | 0.027 a ±0.009 | 0.06 a ±0.006 | 0.06 a ±0.003 | 0.15 a ±0.01 | 0.94 ab ±0.062 | 0.43 a ±0.043 | 21.79 b ±1.362 | 9.33 b ±1.104 |
| 10% | 0.047 a ±0.009 | 0.07 a ±0.003 | 0.12 bc ±0.015 | 0.24 bc ±0.01 | 1.36 ab ±0.279 | 0.49 a ±0.038 | 10.79 a ±5.246 | 5.31 a ±0.497 |
| 20% | 0.050 a ±0.021 | 0.08 a ±0.006 | 0.13 c ±0.018 | 0.26 c ±0.04 | 1.03 ab ±0.147 | 0.51 a ±0.024 | 11.99 ab ±1.488 | 6.11 a ±0.621 |
| 30% | 0.027 a ±0.003 | 0.07 a ±0.012 | 0.08 ab ±0.006 | 0.17 ab ±0.01 | 1.14 ab ±0.029 | 0.47 a ±0.049 | 14.54 ab ±3.114 | 6.49 ab ±0.754 |

Statistical significance determined by analysis of variance. Number followed by the same letters in the same column is not significantly different, according to Duncan's Multiple Range Test at $p< 0.05$.

± standard error
0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 5 a:** Percentage reduction of *Adenanthera pavonina* in different concentrations of rubber crumb as compared to control

| Treatments | Root Length (cm) | Shoot Length (cm) | Seedling Length (cm) | No. of Leaves | Leaf Area sq cm) | Plant Cover (cm) | Seedling Fresh Weight (g) |
|---|---|---|---|---|---|---|---|
| 10% | 44.08+ | 0.49+ | 21.67+ | 2.55+ | 8.70 | 0 | 50.94+ |
| 20% | 18.92+ | 9.08+ | 13.92+ | 15+ | 15.94+ | 4.86+ | 45.28+ |
| 30% | 5.83+ | 12.48 | 3.58 | 10.05+ | 17.39 | 5.83 | 18.30 |

+ percentage increase
0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 5 b:** Percentage reduction of *Adenanthera pavonina* in different concentrations of rubber crumb as compared to control

| Treatments | Root Dry Weight (g) | Shoot Dry Weight (g) | Leaf Dry Weight (g) | Total Plant Dry Weight (g) | Root/Shoot Ratio | Leaf Weight Ratio | Specific Leaf Area ($cm^2g^{-1}$) | Leaf Area Ratio ($cm^2g^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 10% | 74.07+ | 16.67+ | 100+ | 60+ | 44.68+ | 13.95+ | 50.48 | 43.09 |
| 20% | 85.19+ | 33.33+ | 116.67+ | 73.33+ | 9.57+ | 18.6+ | 44.97 | 34.51 |
| 30% | 0.000 | 16.67+ | 33.33+ | 13.33+ | 21.28+ | 9.3+ | 33.27 | 30.44 |

+ percentage increase

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 6 a:** Growth of *Pisum sativum* in different concentrations of rubber crumb

| Treatments | Root Length (cm) | Shoot Length (cm) | Seedling length (cm) | No. of Leaves | Leaf Area (sq cm) | Plant Cover (cm) | Seedling Fresh Weight (g) |
|---|---|---|---|---|---|---|---|
| 0% | 14.1 b ±1.97 | 35.00 b ±2.89 | 49.1 c ±4.49 | 26.67 b ±3.48 | 8.33 b ±0.65 | 47.47 b ±5.2 | 5.73 b ±1.14 |
| 10% | 13.03 b ±1.65 | 16.07 a ±3.27 | 29.1 ab ±3.06 | 20.33 ab ±3.38 | 2.58 a ±0.37 | 33.67 a ±1.86 | 3.57 ab ±0.84 |
| 20% | 7.00 ab ±0.61 | 14.03 a ±0.03 | 21.0 a ±0.6 | 14.00 a ±2.08 | 2.20 a ±0.14 | 26.73 a ±0.37 | 3.27 a ±0.5 |

Statistical significance determined by analysis of variance. Number followed by the same letters in the same column is not significantly different, according to Duncan's Multiple Range Test at $p < 0.05$.

± Standard error

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 6 b:** Growth of *Pisum sativum* in different concentrations of rubber crumb

| Treatments | Root Dry Weight (g) | Shoot Dry Weight (g) | Leaf Dry Weight (g) | Fruit Dry Weight (g) | Total Plant Dry Weight (g) | Root/Shoot Ratio | Leaf Weight Ratio | Specific Leaf Area ($cm^2g^{-1}$) | Leaf Area Ratio ($cm^2g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 0% | 0.25 b ±0.04 | 0.11 a ±0.02 | 0.27 b ±0.02 | 0.24 a ±0.03 | 0.87 b ±0.05 | 2.26 c ±0.24 | 0.31 a ±0.01 | 31.23 b ±0.17 | 9.59 b ±0.24 |
| 10% | 0.07 a ±0.03 | 0.14 ab ±0.02 | 0.12 a ±0.02 | 0.12 a ±0.06 | 0.45 a ±0.13 | 0.47 a ±0.18 | 0.30 a ±0.06 | 22.06 a ±4.35 | 6.78 ab ±1.99 |
| 20% | 0.10 a ±0.003 | 0.09 a ±0.02 | 0.10 a ±0.009 | 0.12 a ±0.05 | 0.42 a ±0.08 | 1.17 ab ±0.22 | 0.25 a ±0.02 | 21.68 a ±2.63 | 5.56 a ±1.06 |

Statistical significance determined by analysis of variance. Number followed by the same letters in the same column is not significantly different, according to Duncan's Multiple Range Test at $p< 0.05$

± Standard error

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil.

**Table 7 a:** Percentage reduction of *Pisum sativum* in different concentrations of rubber crumb as compared to control

| Treatments | Root Length (cm) | Shoot Length (cm) | Seedling length (cm) | No. of Leaves | Leaf Area (sq cm) | Plant Cover (cm) | Seedling Fresh Weight (g) |
|---|---|---|---|---|---|---|---|
| 10% | 8.18 | 54.10 | 40.73 | 2.38 | 71.89 | 29.07 | 37.79 |
| 20% | 101.43 | 59.90 | 57.16 | 4.75 | 76.66 | 43.68 | 43.02 |

+ percentage increase

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil

**Table 7 b:** Percentage reduction of *Pisum sativum* in different concentrations of rubber crumb as compared to control

| Treatments | Root Dry Weight (g) | Shoot Dry Weight (g) | Leaf Dry Weight (g) | Fruit Dry Weight (g) | Total Plant Dry Weight (g) | Root/Shoot Ratio | Leaf Weight Ratio | Specific Leaf Area ($cm^2g^{-1}$) | Leaf Area ratio ($cm^2g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 10% | 71.62 | 24.24 + | 53.75 | 49.32 | 47.69 | 79.38 | 48.57 | 29.37 | 29.31 |
| 20% | 58.11 | 15.15 | 61.25 | 49.32 | 9.62 | 48.31 | 57.14 | 30.58 | 41.97 |

+ percentage increase

0%= garden soil; 10%=10% rubber crumb + 90% garden soil; 20%= 20% rubber crumb + 80% garden soil; 30%= 30% rubber crumb + 70% garden soil.

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