Pak. J. Agri. Sci., Vol. 5X(X), xxx-xxx; 20XX
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/20.9528
http://www.pakjas.com.pk

EFFECT OF INDUCED SOIL COMPACTION ON THE ECO-MORPHOLOGICAL TRAITS OF EARLY STAGE *Bombax ceiba* STUMPS

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Soil compaction has been recognized as global problem affecting the soils throughout the world. More demands of food and wood with increased population, has resulted in intensive cultivation and increased mechanization of our farmlands and irrigated forest plantations. This mechnization causes soil compaction and affects soils quality physically as well as chemically on every passage. Many studies have been conducted to assess soil compaction tolerance of agronomic crops but study reporting soil compaction tolerance of trees is scarce. This research was conducted to analyze the impacts of compacted soil on sprouting and eco-morphological traits of *Bombax ceiba* at initial growth stages during 2016. It is a fast growing multipurpose farm freindly tree species. Uniformed sized stumps of *B. ceiba* were planted in five types of earthern beds that were under five different induced soil compaction levels. Morphological (i.e. Sprouting %age, survival %age, diameter of the plant, shoot length, shoot fresh weight, shoot dry weight , root length, root fresh weight, root dry weight and root/shoot ratio etc.) and physiological parameters (i.e. photosynthetic rate, transpiration rate, stomatal conductance and photosynthetic water use efficiency) were measured at the termination of experiment. It was found that the morphophysiological parameters were strongly effected by the induced soil compaction. Compacted soil reduced sprouting and survival %age upto 55%, stem diameter growth upto 60%, root and shoot length upto 55%, fresh weight of shoot and root upto 44% whereas their dry biomass were reduced upto 50% as compared to un-compacted soil. Leaf area and number of leaves were also reduced to half when compared with control treatments. This study shows that careless mechanization of farmlands and irrigated forest plantations may result in the poor plant growth and biomass production.
Keywords: Bulk density, plant growth, mechanization, photosynthetic rate, forestry etc.

INTRODUCTION

Soil is one of the most important factor as far as agriculture and forestry is concerned. Soil quality performs a critical role in the progress and survival of societies in a specific region as it provides the basic necessities of life and other valuable products to the human beings (Hillel, 2009). For instance, soils have high degree of depletion rate because these are nonrenewable resources and their rate of development and reformation is very slow (Van-Camp *et al.,* 2004). To handle the universal issues like food shortage, climatic instability, energy and water crisis sustainable use of soil is essential (Lal, 2009). Today's agriculture and forestry, carried out on variety of soils are something very different from conventional ones. Rising demands for food and shelter have resulted in the mechanization of each and every operation right from start till the end almost in all developed countries. This mechanization of different operations in agriculture and forestry has resulted in soil compaction (Ishaq *et al.,* 2001; Silva *et al.,* 2008; Nawaz *et al.,* 2013; Jourgholami *et al.,* 2014). Deterioration of the land is a worldwide burning issue because of its extent and intensity. It has adverse effects on the climate and human food production resources (Duran and Pleguezuelo, 2008; Kormanek *et al.,* 2015).

Compaction of soil is referred to the process by which soil bulk density is increased and soil particles becomes compacted resulting in closer interaction with each other (SSSA, 1996). Soil compaction is the rearrangement of soil particles, which enhances the bulk density; reduces porosity and volume (Lindemann *et al.,* 1982). Soil compaction occurs when soil particles come close together due to the pressure applied by external agents like intensive activities by human or by the use of heavy machinery etc. This can be measured on surface level or sub soil surface level, resulting in limited plant growth through different means (Jones *et al.,* 2003). Moreover, soil is considered to be compacted when air filled pores are reduced resulting in limited root penetration and poor soil infiltration and drainage (Hillel, 1982).

Soil compaction can be caused by vehicular traffic (Cassel, 1983; Smith, 2001), by natural calamity (Koolen and Kuipers, 1983), by pedestrian traffic (Patterson, 1977; Jim, 1993), by the hooves of livestock and wildlife (Rolf, 1994; Arbuckle and Lasley, 2013; Ferrara *et al.,* 2015). Soil compaction caused by any mean results in increased bulk density. In

Washington DC pedestrian traffic increased soil bulk density from 1.20 to 1.60 g/cm^3 at first site and1.70 to 2.20g/cm^3 at second site (Horn *et al.*, 1995; Gomes *et al.*, 2002).

This vehicular intervention causes soil compaction and affects soils physical as well as chemical quality on every arable operation (Naghdi *et al.*, 2017). In developed countries, the systematization of the farms and forest areas has become crucial need of the community. This includes intensive cropping patterns which directly or indirectly affect soil structure and ultimately results in the degradation of soil (Ishaq *et al.*, 2001; Silva *et al.*, 2008). It has been estimated that about 67 million hectare of soil around the globe has been influenced by soil degradation by the vehicular transportation. Area of about 32 million hectare in Europe, 17 million hectare in Africa, 10 million hectare in Asia, 4 million hectare in Australia and few parts of Northern America has been estimated as affected by soil compaction (Hamza and Anderson, 2005; Silveira *et al.*, 2010; Nawaz *et al.*, 2013).

General impact of compacted soil on the growth and development of plant is destructive (Ishaq *et al.,* 2001; Saqib and Akhtar, 2004b), however, this may bring about no impact or enhance the production (Greacen *et al.*, 1980). Compacted soil may restrict root developement, decrease uptake of minerals, and huge loss of soil nutrients characterized by poor plant growth. Drastic effect of compacted soil has been reported when coupled with salinity etc (Saqib and Akhtar, 2004a). In general, soil compaction adversely affects seedling emergences (Jordan *et al*., 2003), limits shoot developement (Ishaq *et al.,* 2001) and it results in stunted root growth (Kristoffersen and Riley, 2005).

Because of mechanized operations, soil compaction can be severe in forests but it can have more spatial variability than in agriculture due to presence of tree stumps and heavy roots in the soil (Cambi *et al.,* 2015). In agro-forestry and silvo-pastoral systems, the grazing animals and use of machinery for planting operations can cause soil compaction which ultimately affects plant growth (Atkinson *et al.,* 1985; Wairiu *et al.,* 1993; Kormanek *et al.,* 2015; Ferrara *et al.,* 2015).

Many studies have been conducted to study soil compaction tolerance on crop plants but studies reporting soil compaction tolerance of trees are scarce (Drewry *et al.,* 2008). Most of the reviews investigated the undesirable impacts of compaction on crops and grazing areas (Unger and Kaspar 1994; Greenwood and Mckenzi, 2001; Lipiec and Hatano 2003; Kormanek *et al.,* 2015). Local flora is also seriously affected by this global issue and this has been reported in previous studies of two bush land species of New Zealand (Bassett *et al.*, 2005), North American Douglas-fir (Heilman *et al.*, 1981), in woodlands of Pine species which were subjected to heavy vehicular traffic during felling and other silvicultural operations (Kozlowski *et al.*, 1999) and in severely damaged *Eucalyptus salmonophloia* forests of Western Australia (Yates, 2000a).

It is established fact that principle needs for industrial wood (72 %) and fuelwood (90%) of Pakistan are met by the wood coming from farmlands through agro-forestry. *Bombax ceiba* is one of the best multipurpose farm friendly tree species which is being widely used in agro-forestry due to its economic and medicinal value (Rahim and Hasnain, 2010). It is found throughout Pakistan and parts of tropical and sub-tropical Asia, Australia, and Africa. Problems hindering growth of this fast growing tree species has not been addressed properly. Soil compaction has become a serious issue of state forests and farm lands of Punjab due to the overuse of machinery and livestock movement. It is worth mentioning that no appreciable research has been conducted in Pakistan to assess the impact of soil compaction on the growth and yield of crops when integrated with trees. Keeping in view the severity of this problem in agro-forestry systems the current research was enacted to assess the impacts of soil compaction on different eco-morphological traits of *Bombax ceiba.*

MATERIALS AND METHODS

Site description**:** Trial was conducted in the research area of Department of Forestry and Range Management, University of Agriculture, Faisalabad, Pakistan. The selected site was situated at 73.077º Longitude and 31.443º Latitude which is located 186 meters above sea level. Climatic conditions

Table 1. Climatic conditions of experimental site.

Months /Years	Temperature (ºC)			R.H. (%age)	Rainfall (mm)	Sunshine duration (hrs)	Pan Evap. (mm)	Evap. Transp. (mm)	Wind Speed (Km/h)
	Max.	Min.	Avg.						
Nov/2015	27.1	12.1	19.6	61.5	8.8	6.60	2.4	2.1	2.6
Dec/2015	21.8	7.2	14.5	62.6	0.0	7.00	1.9	1.6	2.3
Jan/2016	17.3	7.7	12.5	74.4	13.1	3.50	1.2	0.8	2.7
Feb/2016	23.3	9.3	16.3	58.1	7.8	8.50	2.3	1.6	3.8
Mar/2016	26.8	15.6	21.2	59.7	66.7	6.60	2.7	1.9	4.7
Apr/2016	34.3	20.2	27.2	34.2	5.6	8.30	6.1	4.3	5.2
May/2016	39.8	25.6	32.8	28.8	25.0	10.40	9.5	6.4	5.4
Jun/2016	40.2	28.5	34.4	38.9	39.9	9.38	8.7	5.9	4.3
Jul/2016	36.6	27.4	32.0	59.6	193.5	8.20	6.0	4.2	4.6
Aug/2016	35.7	26.5	31.1	62.2	48.1	7.00	5.7	4.0	4.2

during study period were recorded from nearby meteorological station at University of Agriculture, Faisalabad, Pakistan (Table 1). Physico-chemical properties of the nursery soil are given in Table 2.

Table 2. Physico-chemical properties of soil at two different depths.

Parameters	0-15 cm	15-30 cm
pH	8.0±0.01	8.2±0.02
EC (dSm^{-1})	1.68±0.1	1.35±0.1
TSS (ppm)	1176±35	1236±10
Nitrogen (%)	0.077±0.005	0.05±0.005
Phosphorous (ppm)	3.9±0.1	9.8±0.2
Potassium(ppm)	280±5	250±5
Organic matter (%)	1.54±0.05	0.91±0.02
Sand (%)	40±3	69.0±5
Silt (%)	45±3	18.5±2
Clay (%)	15±2	12.5±2

***Experimental design*:** Bed experiment was laid to examine the stumps growth response of *Bombax ceiba* at different soil compaction levels. The compaction was achieved with manual soil compactor. 8kg weight from 60 cm height was dropped to develop compaction levels. Five soil compaction levels were developed in 5 uniformed size beds in this experiment with three replications, having 0, 10, 20, 30, 40 beatings respectively. Experiment was attributed by randomized complete block design (RCBD). Bulk density was calculated by using volumetric ring method (Pedrotti *et al.,* 2005).

Dry Bulk Density (g/cm^3) = Dry Mass/Volume

Following treatments were established to accomplish the trial:

***Plant sowing and harvesting*:** Stumps of *Bombax ceiba* were planted in beds having different compaction levels by using planting rod without affecting the compaction levels. Transplanting was carried out in second week of March. Beds were in sunlight, water was applied on daily basis in measured quantity, and data was recorded after 5-6 days of sprouting. Experiment was terminated in third week of September. Selected plants were harvested and roots were excavated with great care.

***Morpho-physiological response*:** Data regarding morphological response (like survival %age, diameter of plant, shoot length, shoot fresh weight, shoot dry weight, root length, root fresh weight, root dry weight, root/shoot ratio, leaf area, no. of leaves etc.) and physiological response (Photosynthetic rate, respiration rate, stomatal conductance and photosynthetic water use efficiency etc.) was recorded at the termination of the experiment. These physiological parameters were measured by using infrared gas analyzer (IRGA, LCA-4, Analytical Development Company, Hoddesdon, England). Different cultural practices were carried out as per requirement.

***Statistical analysis*:** General linear model (One-way ANOVA) was used to analyze the growth response in different treatments and means were compared by using least significant differences test (LSD). Results were statistically analyzed by using Minitab-2017.

RESULTS

***Morphological Response*:** Morphological response of *Bombax ceiba* seedlings was significantly different in all the treatments (as $P<0.05$). Comparison of means of all selected morphological parameters revealed significant reduction with the increase of soil bulk density/soil compaction. Sprouting and survival %age was reduced upto 55%, stem diameter growth was reduced to 60%, root and shoot length were reduced upto 55%, fresh weight of shoot and root were reduced upto 44% whereas their dry biomass were reduced upto 50%. Leaf area and number of leaves were also reduced to half when compared with control treatments (Figure 1).

***Physiological Response*:** Physiological response of *Bombax ceiba* was significantly different in all the treatments (as $P<0.05$). Comparison of means of selected physiological parameters revealed significant reduction with the increase of soil bulk density respectively. Photosynthetic rate was reduced to 51%, transpiration rate was reduced to 60%, stomatal conductance was restricted to 50% and photosynthetic water use efficiency was also reduced to 52% with range from control to high intensity compaction levels respectively (Figure 2).

DISCUSSION

Increasing level of soil compaction strongly affected the morphological response of *Bombax ceiba* stumps which supported the concept that increasing soil compaction can have drastic effects on plant growth and forest ecosystem as well (Hartmann *et al.,* 2014). The morphology and biomass production by above ground (i.e. Sprouting %age, survival %age, diameter of plant, shoot length, shoot fresh weight, shoot dry weight, leaf area, no. of leaves etc.) and below ground parameters (i.e. Root length, root fresh weight, root dry weight and root/shoot ratio etc.) were negatively impacted by increasing level of soil compaction. Thus, poor growth response was observed at high intensity level of compaction.

Table 3. Soil bulk densities determined in nursery for experimentation.

Beds	Bed-1 Controlled (T0)	Bed-2 (10 beatings) (T1)	Bed-3 (20 beatings) (T2)	Bed-4 (30 beatings) (T3)	Bed-5 (40 beatings) (T4)
B. Densities (mg/m^3)	1.3 ± 0.03	1.40 ± 0.05	1.55 ± 0.04	1.65 ± 0.08	1.8 ± 0.1

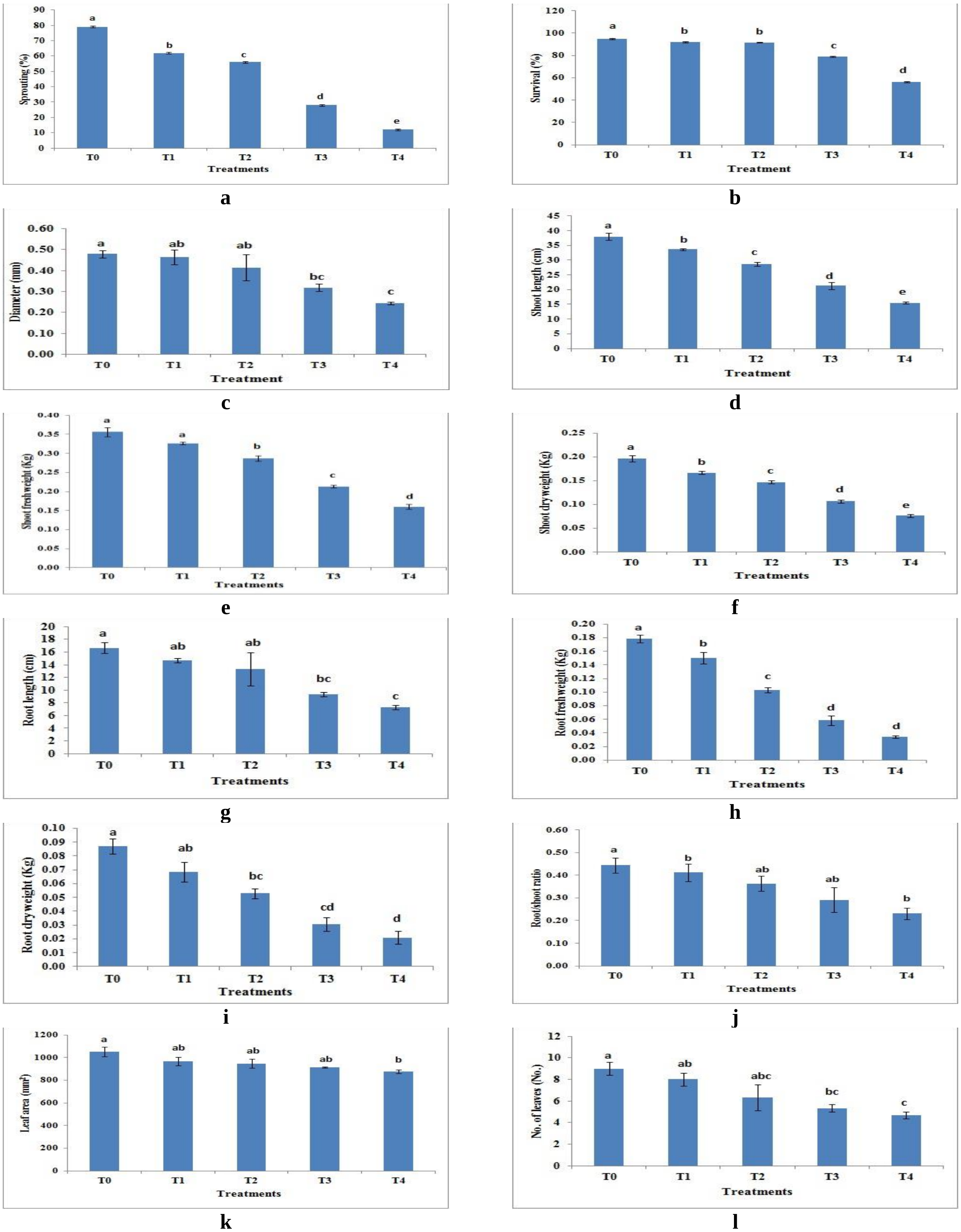

Figure 1. **Effect of soil compaction on a) Sprouting %age; b) Survival %age; c) Diameter; d) Shoot length; e) Shoot fresh weight; f) Shoot dry weight; g) Root length; h) Root fresh weight; i)) Root dry weight j) Root/shoot ratio k) Leaf area l) Number of leaves. Values are means ± SE headed by different letters represent significant differences (P < 0.05).**

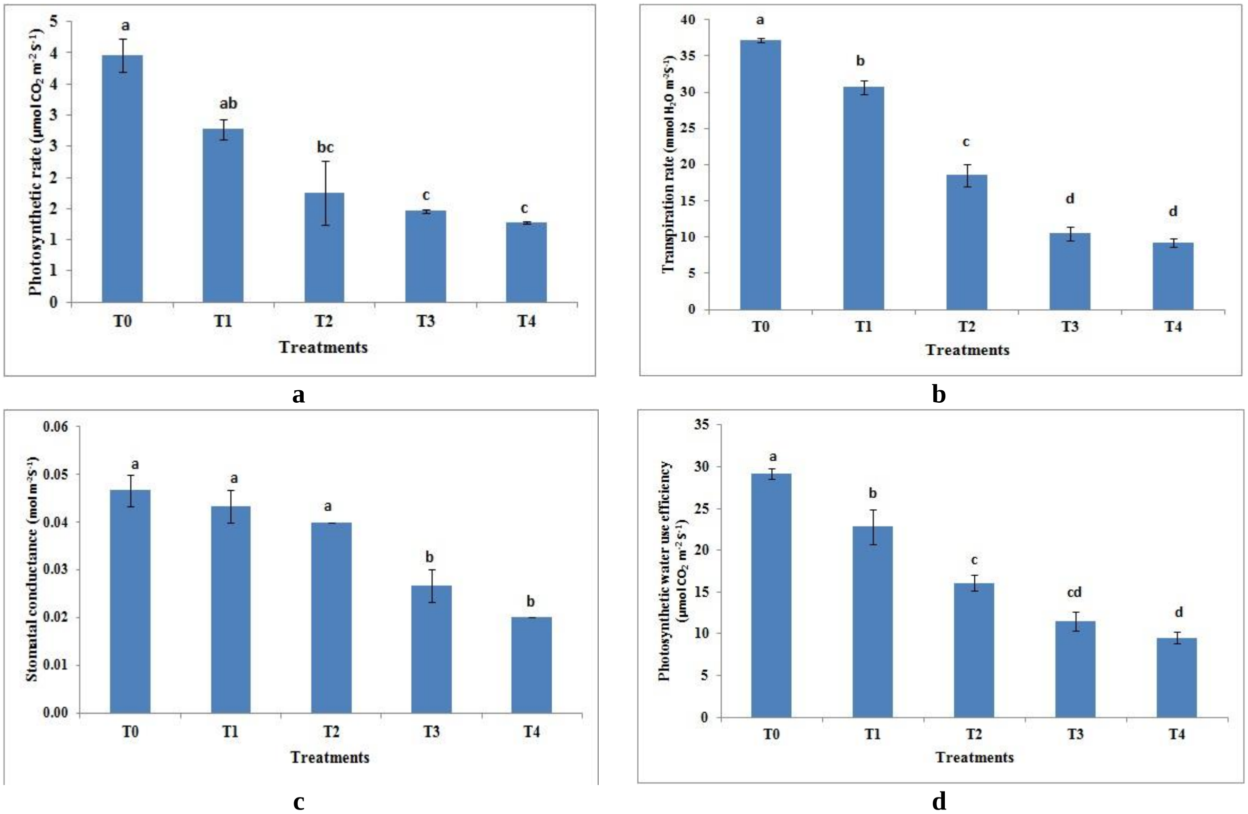

Figure 2. Effect of soil compaction on a) Photosynthetic rate (µmol CO_2 m^{-2} S^{-1}); b) Transpiration rate (mmol H_2O $m^{-2}S^{-1}$); c) Stomatal conductance (mol m^{-2} S^{-1}); d) Photosynthetic water use efficiency (µmol m^{-2} S^{-1}). Values are means ± SE headed by different letters represent significant differences ($P < 0.05$).

Poor sprouting, survival and shoot growth were observed in current study with the increase of compaction intensity which confers the previous findings of Alameda and Villar 2009. Roots perform key role in the overall growth of plants by up taking nutrients. Soil compaction can limit root growth by restricting access to water and nutrients thus affecting the biomass production and overall plant growth (Blouin *et al.,* 2008; Magagnotti *et al.,* 2012; Kormanek *et al.,* 2015; Nawaz *et al.,* 2016). Limited primary growth of roots and less number of leaves with reduced leaf area were observed in this study which is exactly in line with the findings of Ramalingam *et al.,* 2017 who reported decrease in fresh and dry root biomass of different plants, with the increasing intensity of soil compaction. Similarly, decrease in root/shoot ratio was observed with the increasing intensity of soil compaction in this study which is in line with the findings of Miller and Donahue 1990 & Blouin *et al.,* 2008.

Plant physiology was also significantly influenced by different soil compaction intensities. Response regarding photosynthetic rate, transpiration rate, stomatal conductance and photosynthetic water use efficiency etc was worsened with the increasing level of soil compaction. Limited root growth leads to restricted supply of nutrients and water (Blouin *et al.,* 2008), this ultimately results in poor leaf growth, decrease in photosynthetic rate, decrease in transpiration rate, poor stomatal conductance and poor water use efficiency. Decline in these physiological phenomena confers poor survival during early growth stages and the findings of current study (Misra & Gibbons 1996, Gomez *et al.,* 2002, Jordan *et al.,* 2003, Alameda & Villar, 2009).

Though the current study exhibited steady and expected responses to different levels of soil compaction but across the globe some positive impacts have also been observed. Some articles reported positive impact of soil compaction on biomass production of different plants up to a defined level (Alameda & Villar, 2009; Bejarano *et al.,* 2010). Negligible impact of compacted soil was reported on average stand volume of *Pinus taeda* and its impact on soil properties which supports the findings of current study (Sanchez *et al.,* 2006). Different results of the current study were may be due to difference in soil texture and its ability to retain water. Along with compaction, soil water content is another principle factor that determines the survival and morphological characters of the plants. Soil water contents facilitate the root penetration that reduces the impact of compaction on plant growth and its biomass production. Moreover, moderate compaction of coarse textured soil generally improves the root contact with soil which helps in better nutrients absorption (Day *et al*., 2010; Arvidsson 1999, Gomez *et al.* 2002).

Whereas in current study loamy to clay soil was used that can get compacted easily (Eckelmann *et al.,* 2006), may have resulted in oxygen deficit soil with low moisture contents and porosity. This may have seriously influenced the reduction in size and biomass production of all the seedlings.

***Conclusion*:** This study investigated the morpho-physilogical response of *Bombax ceiba* stumps as affected by different levels of soil compaction. Soil bulk density, a parameter used in this study is very sensitive to soil texture and structure which makes it tough to assess different soil challenges. Anyhow from our results it can be concluded that soil compaction 1) causes changes in morphology of above and below ground plant parts; 2) decreases growth and biomass production by all plant parts; 3) has drastic effects on different plant physiological mechanisms. Therefore, in agro-forestry *Bombax ceiba* can be grown in normal soil bulk density (i.e. 1.3 ± 0.03 Mg/m^3) for best results.

***Acknowledgements*:** The research was funded by International Foundation of Science (IFS Grant No. D/5279). We are also thankful to the staff of Forestry Research Area, University of Agriculture, Faisalabad, Pakistan for their support and cooperation.

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