DAVAO RESEARCH JOURNAL

P-ISSN 2244-4432
E-ISSN 2984-7125

Effects of shading and soil compaction on the growth, leaf area and biomass allocation of tomatoes (*Lycopersicon esculentum*)

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ABSTRACT. Plants are often exposed to stressors such as shading and soil compaction, influencing their morphology and physiology. This study aimed to determine the effects of shading (e.g. using black, white and transparent cloths) and disturbance on the growth, leaf area, and biomass allocation of plants using tomatoes (*Lycopersicon esculentum*). The establishment of the study area and gathering of field data were conducted for one month at Davao Oriental State College of Science and Technology (DOSCST), Mati City, Davao Oriental. In the shading experiment, the leaf weight ratio (LWR) of the plants was revealed to be directly proportional to their exposure to sunlight. A similar trend was observed on the specific leaf area (SLA) and leaf area ratio (LAR) values, with the SLA and LAR values higher on the plots with the most shading and decreasing with increasing exposure to sunlight. In the disturbance experiment, the LWR and SLA were observed to be inversely proportional to the intensity of disturbance with higher values reported on the undisturbed plot. A general pattern was observed in terms of biomass allocation in the plant parts; the stems have the bulk of the weight, followed by the leaves while the roots have the least weight. In the shading experiment, the highest biomass was observed on the white fabric-covered plot and the least on the black fabric-covered plot. In the disturbance experiment, the undisturbed plot was observed to have higher biomass than the disturbed plot. These have implications in terms of crop cultivation.

Keywords: *Biomass allocation, leaf area ratio, leaf weight ratio, soil compaction, specific leaf area,*

Submitted: 22 June 2020
Revised: 24 July 2020
Accepted: 07 September 2020
Published: 18 December 2020

https://davaoresearchjournal.ph

How to cite: Salang, R. Q. M., and Macusi, E. D. (2020). Effects of shading and soil compaction on the growth, leaf area and biomass allocation of tomatoes (*Lycopersicon esculentum*). Davao Research Journal (DRJ), 12(3), 20-32. https://doi.org/10.59120/drj.v12i3.105

INTRODUCTION

Sunlight is a highly heterogeneous environmental resource in nature considered as one of the crucial factors for the growth and development of plants (Valladares and Niinemets, 2008) since it is the primary source of energy utilized by plants in photosynthesis to convert carbon dioxide and water into sugars which the plant uses to develop its stems, leaves, roots, and fruits (Maughan et al., 2017). In certain environments, the presence of larger plant species causes shading and reduces the amount of sunlight reaching the understory. In response to shading, most of the plants generally produce less dry matter since they allocate more of their resources to shoot production and greater specific leaf area to increase the overall photosynthetic surface area (Grime, 2001). There are designations that can be applied to plant species according to their response to thedegree of exposure to sunlight; the sun-tolerant and shade-tolerant species which are photosynthetically inefficient in the light regime in which the other group evolved or became acclimated (Björkman & Holmgren, 1963). Most plant species, however, exhibit an intermediate condition wherein they can acclimate photosynthetically to a range of light conditions through phenotypic plasticity, although the degree of this acclimation varies widely (Givnish 1988). As a result, above-ground competition can lead to the competitive exclusion of smaller or slower-growing individuals and play a decisive role in community structuring (Vojtech et al., 2007). However, it was recently recognized that other than exhibiting competitive relationships, larger plant species have been found to facilitate the smaller plant species through the amelioration of thermal stress, reduction of evapotranspiration and preventing wind damage because of reduced exposure to sunlight (Callaway, 2007).

The compaction of soil results from disturbances particularly by vehicle traffic, trampling by humans and animal grazers, and even the wind-induced movement of large tree roots (Passiouram, 2002) or naturally through settling and/or slumping, particularly when the soil is wet (Koolen and Kuipers, 1983). The natural phenomenon of settling is commonly associated with the frequent alternation of drying and wetting causing shrinkage and swelling of the soil which leads to closer packing of the aggregates. Despite having beneficial effects of mild compaction on plant growth through improving the capillary movement of water to the seeds, its detrimental effects are much more prevalent (Kozlowski, 1999). Soil compaction results in the absence of interconnected air spaces essential to the movement of water, gases as well as the plant roots. This leads to changes in moisture and aeration regimes resulting in the inhibition of plant growth and yield.

` This study was designed and conducted to determine the effects of the different level of shading and disturbance on the growth, leaf area, and biomass allocation of plants using tomatoes (*Lycopersicon esculentum*) as model plants. These were all conducted within the premise of Davao Oriental State College of Science and Technology (DOSCST) from November 28-December 28, 2017.

MATERIALS AND METHODS

Study area

The study area was established on a patch of grassland near the gymnasium of Davao Oriental State College of Science and Technology (DOSCST), Mati City, Davao Oriental. The area was characterized by the dense presence of grasses and weeds, with the substrate composed primarily of loam and partly sandy. The study area was exposed to sunlight throughout the day due to the absence of shade-producing trees or structures in its proximity.

Figure 1. Establishment location of the study area in the City of Mati, Davao Oriental.

Establishment of the study area

Shading and disturbance experiment

In preparation, the selected area was cleared of grasses and weeds. On this clearing, four (4) plots measuring 2 x 1 m with mounds approximately 5 inches high were made (see Figure 2A-B). Twenty (20) holes with depths of 1 inch each were made on each plot, arranged in two (2) rows with ten (10) holes per row. One hundred and sixty (160) tomato (*Lycopersicon esculentum*) seeds were germinated beforehand on a germination box containing soil from the study area to ensure uniformity in the growth and development; these seeds were allowed to germinate for one (1) week. With the plots prepared, eighty (80) germinated tomatoes were transplanted (more seedlings were germinated than what were to be used to account for possible mortality) to the plots, with one (1) tomato plant per hole or twenty (20) per plot. The plots were regularly watered daily.

After transplanting, the plots were subjected to different treatments to mimic the effects of varying degrees of shading on the tomato plants in terms of their growth and leaf area (Figure 2C-F). Four (4) stakes were erected on each side of the three (3) plots, with the remaining plot unaltered to serve as the control setup. On these stakes, various coverings were suspended for each plot: white fabric, black fabric, and a transparent cellophane cover. Black fabric was used to represent inense shading, white fabric for light shading, a transparent cover for very light shading, and an uncovered plot to serve as control. The plots were regularly watered daily.

Disturbance experiment

Adjacent to the setup for the shading activity, two (2) plots were made measuring 2 x 1 m with mounds approximately 5 inches high. With the plants transplanted, the plots were then subjected to different treatments to mimic the effect of disturbance on the growth and leaf area of the plants. On a plot, the soil immediately surrounding each plant was gathered and compacted to form a mound approximately three (3) inches high around each plant to represent disturbance while the other plot remained unaltered to represent the absence of disturbance and act as the control.

DOI: https://doi.org/10.59120/drj.v12i3.105

Figure 2. Prepared plots for the shading and plant disturbance experimental setup. Plots were tilled and furrows formed (A and B), and different shading setups (white fabric C, dark or black fabric D, transparent cover E, and control or no cover F).

Collection of data

Every week for a period of four (4) weeks, the height, number of branches, number of leaves per branch, and the area of the largest leaf per branch were counted and measured with a ruler (Figure 4B). The collected data were duly noted to monitor the growth and changes in the leaf area of the plants on the different setups. After the final counting and measurement on the fourth (4th) week, the plants from each setup were uprooted, cleaned, and labeled and were taken to the laboratory for weighing. Prior to weighing the plants, the leaves, stems, and roots of each plant were separated by hand, cleaned with running water, then dabbed with a paper towel to remove any water left from the rinsing then weighed separately using an analytical balance for precise results. The weight of each part was noted and totaled for each plant.

Data analysis

With the collected data, the Leaf Area Ratio (LAR) (total leaf area per total plant weight) of each setup was calculated every week using the appropriate formula:

$$\textit{Leaf Area Ratio} = \textit{Leaf Weight Ratio} \times \textit{Specific Leaf Area}$$

Wherein:

$$\textit{Leaf Weight Ratio} = \textit{total weight of leaves} / \textit{total plant weight}$$

$$\textit{Specific Leaf Area} = \textit{total area of leaves} / \textit{total weight of leaves}$$

The calculated LAR is then expressed in centimeter squared per gram (cm^2/g).

In the shading experiment, the leaf weight ratio (LWR) and specific leaf area (SLA) were averaged from all set ups, with the LWR presented as the overall average per treatment and the SLA as the weekly average per treatment. The LAR was also calculated weekly per treatment. The biomass allocation was averaged per treatment. A similar calculation strategy was utilized for the disturbance experiment and the results were presented separately.

RESULTS

Effects of shading on leaf weight ratio (LWR) and specific leaf area (SLA)

The effects of shading on the leaf weight ratio (LWR) of the plants revealed that the degree of plants' exposure to sunlight was directly proportional to the leaf weight ratio (LWR). The highest LWR value was observed on the control plot (Figure 3) with the most sunlight exposure, attaining an average value of 0.419. This was followed by transparent and white fabric-covered plots, attaining values of 0.386 and 0.375 respectively. Despite the relative closeness of the LWR values, the higher LWR of those on the transparent cover could be attributed to the greater sunlight exposure it provides to the plants than that of the white fabric. The least LWR value was observed on the black fabric-covered plot which greatly reduces the sunlight exposure of the plants, attaining only 0.297.

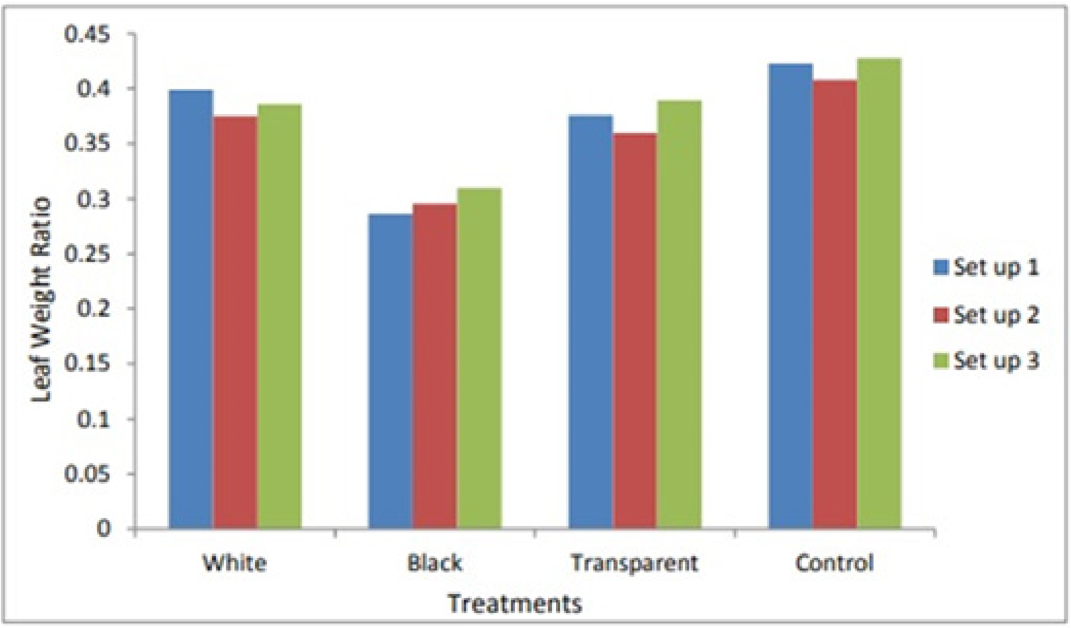

Figure 3. Averaged leaf weight ratio (LWR) per treatment of the different set ups.

The values of specific leaf area (SLA) of the different setups were observed to be inversely proportional to the degree of plants' exposure to sunlight and have demonstrated a consistent result across all setups (Figure 4). The highest specific leaf area (SLA) value was observed to be on the black fabric-covered plot which consistently demonstrated the highest SLA through the four (4) weeks (13.97 cm^2). This was followed by the white fabric-covered plot (11.89 cm^2), with SLA values consistently remaining second. The SLA of the transparent covered and control plot had negligible differences due to their relatively close values, observed to have only been significantly separated on the 3rd week, only to come close once again on the final (4th) week (9.10 cm^2 and 8.77 cm^2 respectively).

Effects of shading on leaf area ratio (LAR)

The effects of shading on the leaf area ratio (LAR) value of the different setups revealed a consistent trend wherein the LAR value was demonstrated to be inversely proportional to the degree of plants' exposure to sunlight.

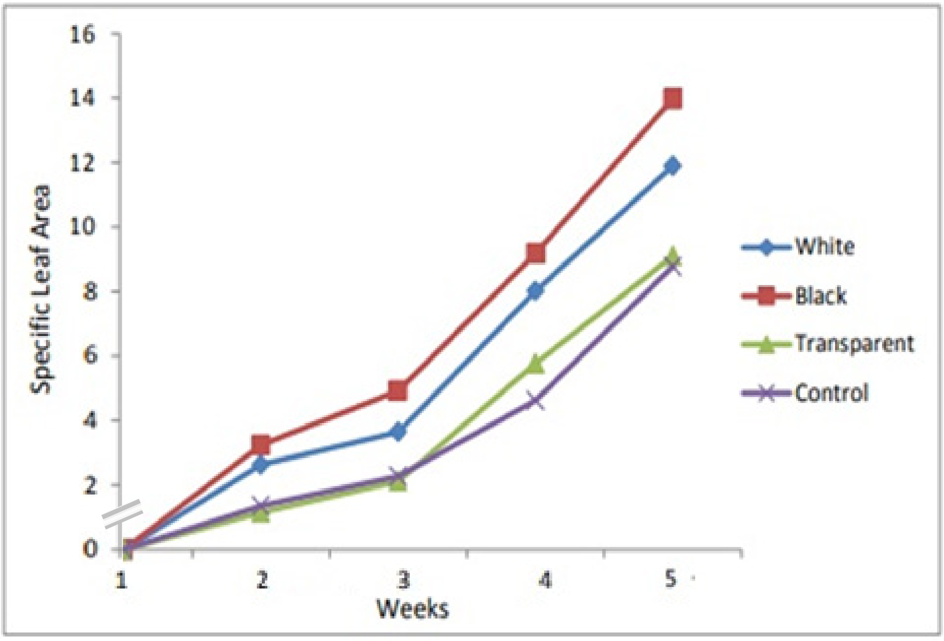

Figure 4. Averaged specific leaf area (SLA) per treatment on the different set ups.

Setup 1

On the first setup (setup 1), all treatments were observed to have close LAR values during the 1st week (Figure 5). The black fabric-covered plot experienced a sudden increase in the LAR value during the 2nd week, reaching 0.538 cm^2/g, the other treatments were observed to remain having close values. This trend continued in the 3rd week, however, the treatment with the transparent-covered plot had a sudden increase in LAR value while the treatment with the white fabric-covered plot and the control plot had relatively close values. On the final (4th)

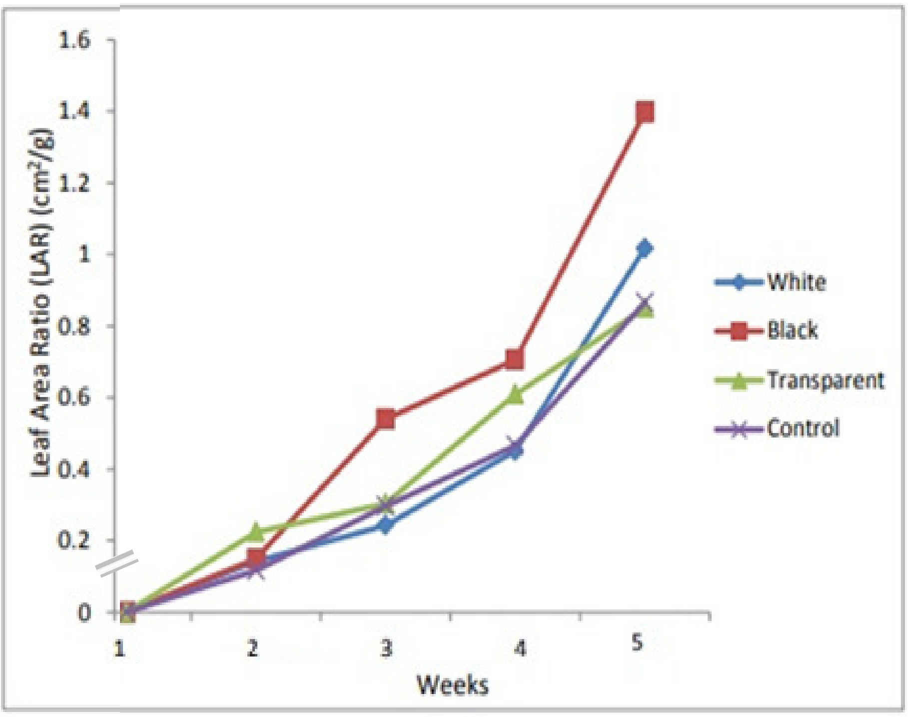

Figure 5. Leaf Area Ratio (LAR) of setup 1 for the duration of the study.

week, it was observed that the black fabric-covered plot attained the highest value of LAR with 1.39 cm²/g, followed by the white fabric-covered plot with 1.014 cm²/g, and the transparent-covered plot and the control plot had close values of LAR with 0.848 and 0.863 cm²/g respectively (Figure 5).

Setup 2

On the second set up (setup 2), the treatments with the white and transparent cover and the control plot were observed to have close values during the 1st week, while the treatment with the black fabric had a higher LAR value

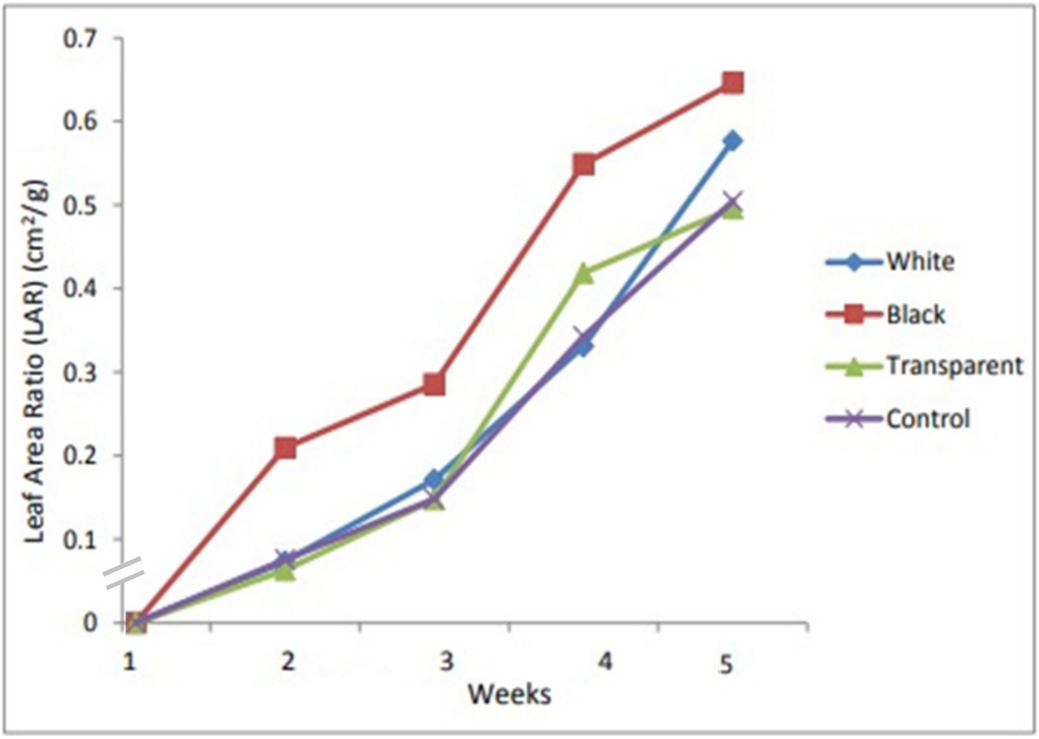

Figure 6. Leaf Area Ratio (LAR) of set up 2 for the duration of the study.

with 0.209 cm²/g. This trend continued in the 2nd week. The value of the LAR on the transparent covered plot slightly increased to 0.418 cm²/g while those covered with white fabric and the control plot remained to have close LAR values of 0.331 and 0.342 cm²/g respectively. In the final (4th) week, results showed that the black fabric-covered plot attained the highest values of LAR with 0.646 cm²/g, followed by the white fabric-covered plot with 0.577 cm²/g. Those on the transparent covered plot and the control plot had close values of LAR with 0.496 and 0.504 cm²/g respectively (Figure 6).

Setup 3

On the third set up, the treatments with white fabric and transparent covered plots and the control plot were observed to have close LAR values during the 1st week (Figure 9). During the same period, the black fabric-covered plot was observed to have the highest LAR value with 0.077 cm²/g. In the 2nd week, the black fabric and transparent covered plots didn't have any noticeable increase though they remained the to have the highest and lowest LAR values respectively. Despite attaining a moderate increase, the LAR values of the white fabric-covered plot and the control plot remained to have close values. On the 3rd week, all treatments and the control plot had significantly increased, with the black fabric-covered plot attaining the highest LAR value of 0.414 cm²/g, followed by the white fabric-covered plot with 0.325 cm²/g, and the control plot with 0.266 cm²/g. The lowest LAR value was on the

DOI: https://doi.org/10.59120/drj.v12i3.105

transparent-covered plot on the 3rd week, all treatments and the control plot had significantly increased, with the black fabric-covered plot attaining the highest LAR value of 0.414 cm^2/g, followed by the white fabric-covered plot with 0.325 cm^2/g, and the control plot with 0.266 cm^2/g. The least LAR value was on the transparent covered plot with only 0.238 cm^2/g. On the 3rd week, all treatments and the control plot had significantly increased, and this trend continued to the final (4th) week, with the black fabric-covered plot attaining the highest LAR value of 0.414 cm^2/g, followed by the white fabric-covered plot with 0.325 cm^2/g, and the control plot with 0.266 cm^2/g. The least LAR value was on the transparent covered plot with only 0.238 cm^2/g (Figure 7).

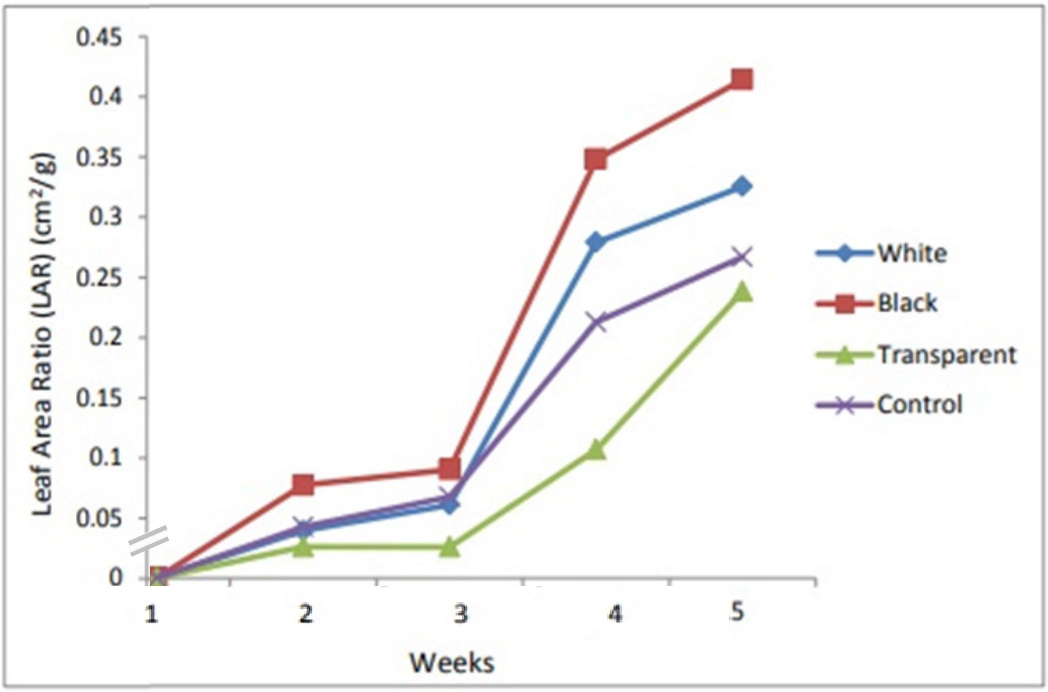

Figure 7. Leaf Area Ratio (LAR) of set up 3 for the duration of the study.

Effects of shading on biomass allocation

The recorded fresh weight of the plants on the different shading treatments revealed that the plants' biomasses were directly proportional to the degree of plants' sunlight exposure. From the data, a general pattern was observed in terms of the biomass allocation in the plant parts; the stems have the bulk of the weight, followed by the leaves while the roots have the least weight (Figure 8). Furthermore, the data also revealed that the highest overall biomass was observed on the white fabric-covered plot with an average total biomass of 20.36 g, followed by the transparent-covered plot with 18.26 g and the control plot with 17.79 g. The least total biomass was on the black fabric-covered plot with only 14.00 g (Figure 8).

Effects of disturbance on leaf weight ratio (LWR) and specific leaf area (SLA)

The intensity of disturbance to plants due to soil compaction as a result of trampling by animal grazers or through anthropogenic activities was revealed to be inversely proportional to the leaf weight ratio value (LWR).

The averaged leaf weight ratio (LWR) value from all setups was observed to be higher on the undisturbed plot (Figure 9A) with 0.425 than on the disturbed plot with only 0.348. A

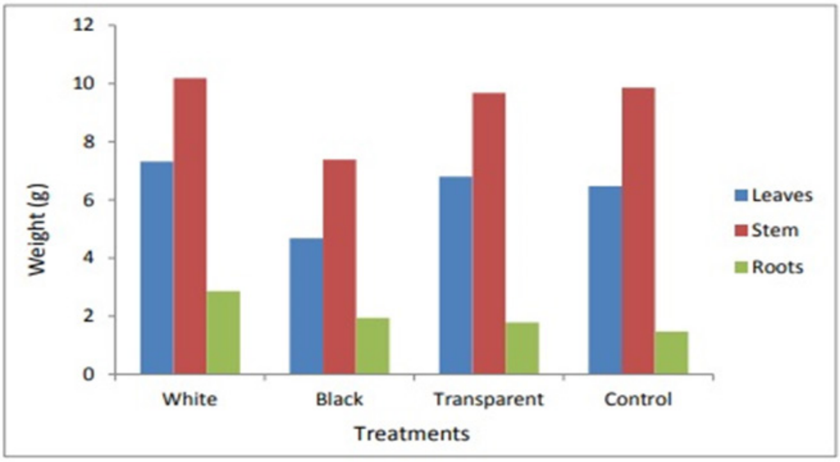

Figure 8. Averaged biomass allocation on the different treatments of the setups.

similar trend was observed on the specific leaf area (SLA) value (Figure 9B). The averaged specific leaf area (SLA) value was observed to be inversely proportional to the intensity of disturbance as revealed by the results. Despite attaining a higher SLA value in the 1st week (1.00 cm^2/g), the disturbed plot was surpassed by the undisturbed plot in the 2nd week with a small difference in SLA values (1.72 cm^2/g and 1.52 cm^2/g respectively). It became more significant on the 3rd week with 3.17 cm^2/g on the undisturbed plot and 2.13

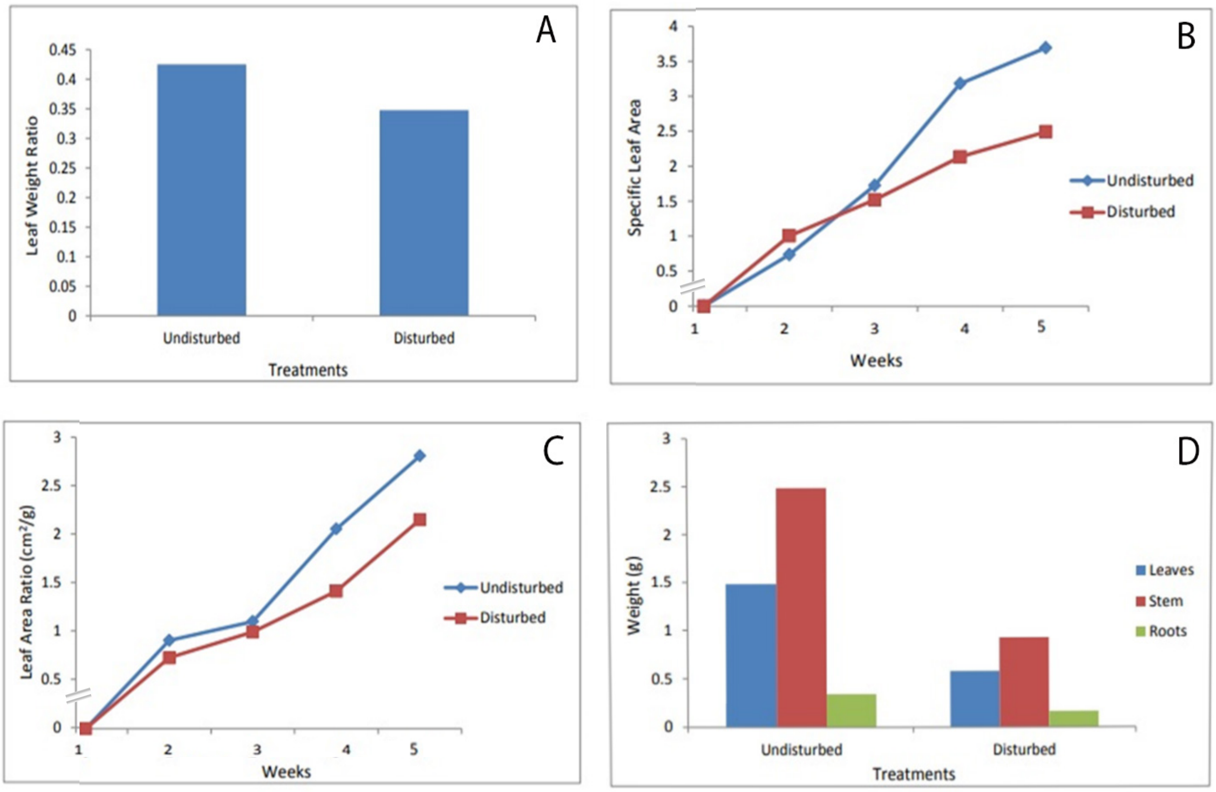

Figure 9. Averaged leaf weight ratio (LWR) per treatments of the setups (A), specific leaf area (SLA) per treatments of the set ups (B), leaf area ratio (LAR; C) and differences in biomass of leaves, stems and roots of the undisturbed and disturbed setups (D).

DOI: https://doi.org/10.59120/drj.v12i3.105

cm^2/g on the disturbed plot. This trend continued to the final (4th) week, with the undisturbed plot attaining the higher SLA value of 3.68 cm^2/g while the disturbed plot attained only 2.48 cm^2/g (Figure 9B).

Effects of disturbance on leaf area ratio (LAR)

The effects of disturbance on the leaf area ratio (LAR) of plants revealed a consistent trend wherein the LAR value was demonstrated to be inversely proportional to the intensity of disturbance on the plants. In the 1st week, the LAR value of the undisturbed plot was observed to be higher than that of the disturbed plot 0.914 and 0.735 cm^2/g respectively). This difference in LAR values was observed to decrease in the second week. The LAR value of the undisturbed plot increased significantly in the third week to 2.067 cm^2/g while no observable change in the rate of increase on the disturbed plot with 1.42 cm^2/g. In the final week, the trend continued wherein the undisturbed plot had the higher LAR value of 2.82 cm^2/g while the disturbed plot attained only 2.16 cm^2/g (Figure 9C).

Effects of disturbance on biomass allocation

The recorded fresh weight of the plants on the different shading treatments revealed that the plants' biomasses were inversely proportional to the intensity of disturbance that the plants were subjected to. From the data, a general pattern was observed in terms of biomass allocation in the plant parts. The stems have the bulk of the weight, followed by the leaves while the roots have the least weight (Figure 9D). Furthermore, it was observed that the average total plant weight of the undisturbed plot was higher (4.29 g) than that of the disturbed plot (1.65 g). The average root weight of the plants from the undisturbed plot was observed be significantly higher (0.339 g) than on the disturbed plot.

DISCUSSION

In the natural environment, smaller plants often experience shading from nearby larger plant species, resulting in the reduction and limiting of the penetration of the radiant energy into the understory. Because of their relatively small nature, these plants are also prone to disturbances particularly trampling by their natural grazers or because of anthropogenic activities. These events have effects on the growth, leaf area, and biomass allocation of these small plants. The effect of shading was evaluated with various shading implements to represent the varying degrees of shading in nature. Between the black and white fabric-covered plots, the plants covered with white fabric were observed to have higher biomass allocation. This was attributed to the leaves with larger areas that are thinner and longer stems that are smaller in diameter on the plants grown under the black fabric which significantly reduces the amount of sunlight reaching the plant compared to those grown under the white fabric which permits larger amounts of sunlight. The vegetative growth of plants maintained under low light intensity is optimized to increase light interception and facilitate photosynthetic processes (Kasperbbauer, 1987) and these shade-induced changes in morphology are strategies for increasing the area of tissues that can absorb light (Givnish, 1988; Almeida et al., 2005) enabling the plants to grow in low light environment. This morphological adaptation of the leaves in response to shading influences the value of leaf weight ratio (LWR) towards a decreasing trend considering that the weight of the leaves becomes lighter for the total plant weight and the opposite was observed for the plantsgrown with sufficient exposure to sunlight wherein the leaves were thicker hence heavier, similar to the study of Cornelissen et al. (2003)

However, there was no difference observed concerning the biomass allocation of the plants in the transparent-covered plot and the control plot since their values were relatively close. This could be attributed to the observed similarity in their field conditions and that the transparent cover did not have a noticeable effect on the plant's biomass. It could be inferred that the high biomass of the plant under the white fabric cover is due to the better temperature and humidity due to the moderate shading of the white fabric. The shading experiment demonstrated that with the amount of sunlight reduced, physiological functions such as photosynthesis and growth are inevitably reduced as well. In response to these changes, plants actuate morphological and physiological adaptive traits such as specific leaf area (SLA) value, internode and petiole lengths, leaf size, leaf thickness, leaf mass, and chlorophyll content (Rozendaal, Hurtado and Poorter, 2006). It could be inferred that the smaller plants growing in the understory of larger plant species hence are shaded to certain degrees from the sunlight are exhibiting these adaptations and therefore differ from the same species grown with full exposure to sunlight.

Disturbance to the plants particularly through trampling by animal grazers or by humans results in the compaction of the soil wherein the general stable structure of the soil is pressed together resulting in reduced pore spaces. With compaction, the soil becomes denser and thereby harder for the roots to penetrate the soil, making it generally shallow and malformed (DeJong-Hughes, 2009). This restriction in root growth results in fewer uptakes of soil nutrients and water, resulting in stunted development of the roots as observed in the result of lower biomass of roots of the plants on the disturbed plot compared to the undisturbed plot. The low specific leaf area (SLA) value on the disturbed plot was also observed in the study of Passioura (2002) where the leaf area of the plants was found to be inversely proportional to the hardness of the compacted soil. The study of Beemster and Masle (1996) has earlier observed this relationship between the leaves and the soil hardness on the cellular level by stating that plants grown in hard soil tended to have smaller leaf cells hence smaller leaf area.

The soil compaction on the disturbed plot was also observed to result in a significant reduction of vertical plant growth and development, evidenced by the lower plant height and biomass on the disturbed compared to the undisturbed plant. Soil compaction has frequently been shown to decrease plant growth (Agnew and Carrow, 1985). This is commonly seen and attributed to decreased root growth, decreased soil water content, and decreased levels of oxygen in soils (Scholefield and Hall, 1985). The effects of disturbances particularly soil compaction due to trampling have generally been considered detrimental to the growth and development of plants. These effects are commonly observed in areas frequented by people such as beaches and mountain trails. It is therefore imperative for the local resource management agencies to take the initiative and formulate long-term solutions to mitigate the tourism-induced detrimental effects of soil compaction to the environment. Certain strategies to manage soil compaction were emphasized by Unger and Kaspar (1994) and included soil management (freezing and thawing of soil, controlling the traffic system to specific lanes, growing crops when the soil is sufficiently moist due to timely precipitation or applying irrigation water, usage of no-tillage, crop rotations, or additions of manure or other organic materials, encouraging the formation of large pores on the soil by planting certain plants like alfalfa (*Medicago sativa*), sweet clover (*Melilotus alba*) and guar (*Cyamopsis tetragonoloba*) to manage the crop production system, promote earthworm activity and tillage (usage of various farm tools and implements such as moldboard and disk plow to disrupt compacted soil layers).

CONCLUSION

In the shading experiment, there was a general pattern observed on the ranking of LWR values wherein the highest LWR value was on the plot most exposed to sunlight and decreased in value with the reduction of sunlight. The low value of LWR on the shaded plots was due to the thinning of leaves to dedicate more nutritional resources to the enlargement of the leaf surface and elongation of the stem to compensate for the low sunlight exposure. On the other hand, the general pattern on the ranking of SLA values was observed to be the opposite of that of LWR; the values were higher on the plots with the most shading and decreased with increasing exposure to sunlight. The high value of SLA on the shaded plots was due to the increase in leaf area to compensate for the low sunlight exposure and increase photosynthetic leaf area. A similar trend was observed in the leaf area ratio (LAR) values consistently on the three (3) setups, with the LAR value higher on the plots with the most shading and decreasing with increasing exposure to sunlight. This was attributed to the morphological adjustments to survive in shaded environments. On the disturbance experiment, the average leaf weight ratio (LWR) value was observed to be higher on the undisturbed plot (0.424) than on the disturbed plot (0.348). A similar trend was observed on the specific leaf area (SLA) value which was observed to be inversely proportional to the intensity of disturbance with the undisturbed plot attaining the higher SLA value of 3.678 $cm^{2/}g$ while the disturbed plot attained only 2.483 cm^2/g. The low values of LWR and SLA on the disturbed plots were due to the stunted plant growth and development due to restricted nutrient uptake resulting in smaller leaf areas and lower overall plant biomass. A general pattern was observed in terms of biomass allocation in the plant parts; the stems have the bulk of the weight, followed by the leaves while the roots have the least weight. With the negative effects of soil compaction on the growth and development of plants, proper preventive and management measures must be undertaken to keep vegetation or crops in good condition and increase the yields and therefore income of farmers.

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