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Morphological and Physiological Responses of *Alysicarpus vaginalis* L. (*Aswenna*), A Native Ground Cover; Under Induced Water Deficit Conditions

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Abstract

Background: Frequent occurrence of droughts has become a major challenge in agriculture and horticulture sectors, limiting the crop production. Therefore, screening for drought tolerance plants has become a key requirement in the landscape industry. The current study was conducted to investigate the drought tolerance ability of *Alysicarous vaginalis* L. (Fabaceae), to be used as a drought tolerant ground cover plant.

Methods: Tip cuttings of *A. vaginalis* were planted in pots and water stress conditions were imposed on plants through irrigating the plants up to the field capacity daily (T_1: control), every fifth (T_2), tenth (T_3), fifteenth (T_4) and twentieth (T_5) day. Each treatment consisted of 20 replicates arranged in Completely Randomized Design inside a plant house. Morphological characteristics were recorded up to 60 days along with the survival rate of plants. General Linear Model (GLM) was used for the statistical comparisons.

Results: All the plants survived in all treatments. All the growth parameters differed significantly among the treatments ($P<0.05$ at 5% level of significance), where the highest leaf area, number of leaves, leaf fresh weight, leaf moisture content, shoot moisture content and shoot fresh weight were observed in T_2, while, plants in T_5 showed the lowest morphometric parameters, except for leaf hair density and root Length. Therefore, the significant water stress resistant characteristics were observed at T_5.

Conclusions: *A. vaginalis* can be recommended as a water stress tolerant plant with a potential to be used in outdoor landscaping as a ground cover plant, with low maintenance requirements.

Keywords: *Alysicarpus vaginalis,* Drought Tolerance Plants, Ground Cover, Landscaping, Water Stress

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INTRODUCTION

Global climate change, which is referred to the long-term changes in the average weather patterns, is currently viewed as one of the most devastating threats to the environment and socio-economic sectors [1]. This has caused numerous adverse impacts on the environment, humans and prevailing climatic patterns, leading to continuous rising of temperature, changes in precipitation patterns and elevated frequency of natural disasters.

Water is a vital commodity for the survival and sustainable existence of all living beings. Undesirable impacts of droughts on societal, and environmental activities take place primarily as a water stress and then as a scarcity. This significantly influence the survival and productivity of plants [2-3]. The water consumption in the agricultural context, is a major component of overall water demand in the world. Thus, droughts or water deficit conditions are one of the most important environmental constrains faced by the agriculture sector [4-5].

Plant water stress has been defined as a state of insufficient level of water prevalence, which affects the normal functioning of a plant [6]. Plants experience water stress conditions as a result of limited absorption and high evapotranspiration demand or as a combined effect of both [7]. Water stress is multidimensional in nature and affects plants at various levels of their organization by changing plant anatomy and ultrastructure, resulting decrease in leaf size, reduction of stomata count, thickening of cell walls and early senescence. In fact, under long periods of drought, many plants will dehydrate and die. This hinders the possibility of the plants in reaching potential growth and yield [2, 5, 8].

Since landscaping is a segment that majorly deals with plants, water scarcity has become a major issue especially in outdoor landscaping, as it needs more water than indoor landscaping. Therefore, outdoor landscaping is more liable to adverse climatic conditions. Especially ground covers, and turfs are adversely affected by water crisis, which possess higher water requirements for maintenance. With the increasing shortages in rainfall, water restrictions for landscaped areas have become a common issue in many tropical countries around the world [9-10].

Water stress tend to influence landscape plants by decreasing the aesthetic and functional quality of the plants. Various symptoms including, stunted growth, wilting, curling, or browning of leaves, leaf firing, no flowering and increased insect or disease attacks would appear as consequences of water stress, reducing the overall ornamental plant quality, during a water deficit period of a plant [11]. Consequently, landscape managers are struggling to address the foresaid challenges, while sustaining the landscape quality with less water consumption. As a response, landscaping practices are being evolved based on the emerging variations in climate.

Drought tolerant landscaping remains as an innovative concept, which has recently gain popularity among plant scientists and landscape professionals. Growing native plants, using effective irrigation systems, use of wastewater for watering and practicing xeriscaping are some of the approaches used in this concept to enhance the sustainability of landscaping plants in the face of climate change [12-13]. Therefore, screening of plants for water stress resistance is a widely used strategy in drought tolerant landscaping.

Drought tolerant/ water stress resistance plants use less water, but still provide beauty and functionality in the landscape designs. They are capable of surviving long periods of water deficient conditions through development of various morphological, anatomical and metabolic adaptations. Ability of storing water internally, development of extensive root systems, decreasing the leaf area, optimizing the stomatal closure, reduced plant growth, osmotic adjustments, development of a thick waxy cuticle layer and leaf hairs on the leaf surface could be recognized as some of such adaptations [14]. Most drought tolerant plants use several of these features to survive on low amounts of irrigation [1]. Understanding the minimal irrigation requirements and extent of water stress that a particular plant species can tolerate while exhibiting acceptable quality, is of immense importance in landscape designing [9]. This would enable the landscape designers to establish a pleasing landscape with a certain degree of water stress tolerance, using selected plants.

Alysicarpus vaginalis, commonly known as "Aswenna" (Sinhala; *local language*) or "Alyce Clover" (English) is a widely distributed plant in South Asia. It belongs to the family Fabaceae and is recognized to possess a potential drought tolerance. Based on general observations, *A. vaginalis* shows a notable survival ability under water deficit conditions, making it an appealing choice for outdoor landscaping. In case of morphology, *A. vaginalis* is a semi woody herbaceous annual plant with a creep growing nature. Thin cylindrical stem often grows up to 60 to 120 cm in length, while ascending is branched wiry, glabrous, and often rooting at base. Leaves can grow up to 1.2 to 5 cm in length with alternate arrangements, where shape may vary from liner lanceolate to broadly oval, cordate at base and glabrous surface.

Flowers of *A. vaginalis* are bisexual, pinkish violet in colour with five sepals and five petals [15]. This plant has been traditionally used in herbalism for diuretics, leprosy, pulmonary troubles, back pain, treat stones in the bladder and renal calculi [15-16]. Furthermore, *A. vaginalis* is a native plant in Sri Lanka, which is naturally distributed within all three climatic zones of the country, making it a better choice for landscaping [17].

Despite its wide distribution and native nature, *A. vaginalis* is being limitedly used in landscaping within Sri Lanka. Furthermore, the water stress resistance of *A. vaginalis* has not been assessed to evaluate its potential to be used in drought tolerant landscaping. Therefore, the current study was conducted to evaluate the resistance of *A. vaginalis* for water deficit stress conditions, with the view of introducing it in sustainable landscaping context as a drought tolerant ground cover with low maintenance.

METHODOLOGY

Location

This experiment was conducted at the Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, situated in the Low Country Intermediate zone (IL_{1a}), under plant house condition to prevent any interference from rainfall on experimental pots.

Collection of Planting Materials and Propagation

The planting material (stem cuttings) of *A. vaginalis* were collected from Makadura area. The most successful plant part to propagate *A. vaginalis* is tip cuttings of the stem. Five-centimeter length tip cuttings of *A. vaginalis* were obtained and planted in black polythene pots (6 cm x 15 cm in size; gauge 150) using a mixture of topsoil and compost (1:1 ratio) as the media. Plants were allowed to establish in a propagator, which was prepared using transparent polythene with a gauge of 500 to facilitate better propagation. Plants were kept inside the propagator for six weeks for rooting, followed by another week for hardening outside the propagator. Plants were irrigated according to the requirements.

Screening for Drought Tolerance

Healthy vigorously grown 100 similar sized plant pots were randomly selected, maintaining a density of 2 plants per pot. According to Fu *et al*. [18], water stress conditions can be replicated by extending the frequency of irrigation. Hence, *A. vaginalis* plants in the current study were subjected to five water stress conditions by varying the addition of a constant amount of water with five different applying frequencies as, daily

(T_1- control), every fifth (T_2), tenth (T_3), fifteenth (T_4) and twentieth (T_5) day as indicated in Table 1. The field capacity of the soil medium in pots was considered as the constant irrigation amount for all the treatments. Pots were arranged in a Completely Randomized Design (CRD) and maintained under an average sunlight of 2.36 Klux inside a plant house. The environmental parameters including temperature (T), relative humidity (RH) and light intensity inside the plant house were recorded three times per day. The water stress conditions were maintained for 60 days, and the entire experiment was replicated for 20 times.

Table 1: Treatments used in the Experiment

Treatment	Water Application/ Irrigation Intervals
T1 (control)	Everyday
T2	Once in 5 days
T3	Once in 10 days
T4	Once in 15 days
T5	Once in 20 days

Growth Parameters

During the study period several growth parameters, namely plant height (from the base of the plant to the tip in cm), number of leaves, number of shoots per plant and the number of surviving plants were recorded at one-week intervals. At the end of 60 days survival rate of the plants were recorded. Then the plants were uprooted and the total leaf area (cm^2, Bench top leaf area meter model Li-3100C), fresh weight of leaves, shoots and roots (g), length of the longest root (cm), dry weight of leaf, shoots and roots (g, oven dried at 80 ^{0}C for 72 hours) were measured. Leaf, root and shoot moisture content were calculated. Further, the leaf hair density was measured using dissecting microscope (model Euromex Holland).

Statistical Analysis

All the recorded data were entered into Excel sheets adhering to quality control procedures. General Linear Model followed by Tukey's pair-wise comparison was used to identify the significance in temporal variations of studied growth and morphological parameters of *A. vaginalis* under different water stress conditions. IBM SPSS (version 23) was used for the statistical analysis.

RESULTS AND DISCUSSION

Effect of Water Stress on Leaf Parameters

The studied morphological and physiological parameters unveiled pronounced responses under the imposed stress conditions, which revealed restraining effects of *A. vaginalis* under the water deficit conditions. Significant alternations in the leaf area, leaf count, leaf hair density, leaf fresh weight and leaf moisture content were found in *A. vaginalis* ($P<0.05$) grown under different water stress conditions as indicated in Table 2. The highest leaf area was indicated by T_2 (113.5±13.8 cm^2), while T_5 (66.0±5.0 cm^2) reported the lowest value for the leaf area. The leaf area of *A. vaginalis* denoted a significant decreasing trend along with the water stress, except for T_2 treatment. A similar trend was observed in leaf count also, where, the highest leaf count was observed at T_2 (50.80±5.59), whereas T_5 (30.65±2.59) denoted the lowest value.

A vaginalis comprise of single type leaf hair (trichome) as shown in Figure 1. Leaf hair density showed a significant variation ($P<0.05$ at 95 % level of confidence) among the treatments, where the highest leaf hair density was observed from T_5 (648.14±15.96 cm^2). On the other hand, T_1 and T_2 recorded the lowest values as 241.40±12.71 cm^2 and 278.10±13.27 cm^2, respectively (Table 2). In case of leaf fresh weight, T_2 (1.25±0.16 g) recorded the highest leaf fresh weight, while T_5 (0.61±0.02 g) had the lowest. Even though, the leaf fresh wight denoted a significantly ($P<0.05$) decreasing trend under increasing water deficit conditions (except for T_2), leaf dry weight didn't denote any significance. However, the highest mean value for leaf dry weight was observed from the T_2 treatment (1.25±0.16 g), while plants reared under T_5 (0.61±0.02 g) denoted the lowest mean value (Table 3). A similar significantly decreasing trend in leaf moisture content was noted from *A. vaginalis* grown under gradually increasing water deficit conditions, except for T_2

treatment, which reported the highest moisture content as 1.00±0.13 g.

Effect of Water Stress on Root Characteristics

Root growth is an important parameter of plant performance. In the present study, the lowest root length (12.74±0.74 cm) was denoted by T_2, while the T_5 treatment reported the lowest root fresh weight (0.112±0.013 g) and the moisture content (0.065±0.012 g). Meanwhile, *A. vaginalis* plants maintained under T_5 denoted the highest root length as 19.18±0.63 cm. Further, the highest root fresh weight (0.144±0.025 g) and the moisture content (0.101±0.019 g) values were observed from the *A. vaginalis* reared under T_2 treatment as shown in Table 3.

Table 2: Leaf Parameters of *Alysicarpus vaginalis* subjected to Different Treatments

Treatment	Leaf Area (cm^2)	Leaf Count	Leaf Hair Density (cm^2)	Leaf Fresh Weight (g)	Leaf Dry Weight (g)	Leaf Moisture Content (g)
T_1	$90.08±13.54^{a,b}$	$48.6±5.8^{a,b}$	$241.40±12.71^{d}$	$0.94±0.13^{b}$	$0.04±0.006^{a}$	$0.76±0.11^{b}$
T_2	$113.52±13.84^{a}$	$50.8±5.^{a}$	$278.10±13.27^{d}$	$1.25±0.16^{a}$	$0.04±0.007^{a}$	$1.00±0.13^{a}$
T_3	$85.91±10.11^{b}$	$42.7±4.0^{b}$	$453.00±23.61^{c}$	$0.89±0.12^{b}$	$0.04±0.003^{a}$	$0.71±0.09^{b}$
T_4	$80.08±7.65^{b}$	$41.9±4.9^{b}$	$537.29±22.58^{b}$	$0.87±0.08^{b}$	$0.04±0.005^{a}$	$0.69±0.07^{b}$
T_5	$66.05±5.03^{c}$	$30.7±2.1^{c}$	$648.14±15.96^{a}$	$0.61±0.02^{c}$	$0.03±0.004^{a}$	$0.45±0.05^{c}$

Note: *Mean ± SE of each value is included. Means with different superscript letters within a column show significant differences among the means as indicated by Tukey's pair-wise comparison followed by One-way ANOVA (P<0.05).* *T_1: Control, T_2: Once in 5 days, T_3: Once in 10 days, T_4: Once in 15 days and T_5: Once in 20 days.*

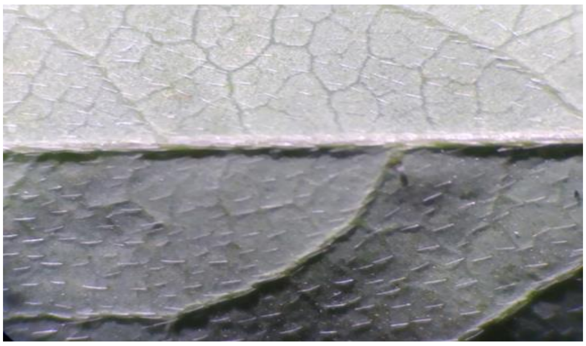

Figure 1: Leaf Trichome of *A. vaginalis*

Even though, the root length of *A. vaginalis* indicated significant variations among the treatments (P<0.05), the post-hoc analysis evidenced that there are no significant differences (P>0.05 at 95 % level of confidence), between T_1, T_3, T_4 and T_5 in case of root fresh weight and moisture content (Table 3). Meanwhile, the variations in root fresh weight and root moisture content remained non-significant (Table 3), suggesting that the studied water stress conditions have no notable effect on the above parameters of *A. vaginalis*.

Among the studied shoot parameters, number of branches, shoot fresh weight and shoot moisture showed significant variations (P<0.05) among different water stress conditions (Table 4). The highest number of branches (3.2±0.5), shoot fresh weight (1.29±0.7 g) and shoot moisture content (1.01±0.13 g) were reported from the T_2 treatment, while *A. vaginalis* reared under the T_5 treatment had the lowest values as 1.7±0.4, 0.62±0.05 g and 0.44±0.03 g, respectively. A similar trend was apparent in shoot length also, where plants maintained under T_2 had the highest shoot length as 39.8±1.3 cm, while the lowest was observed in T_5 (36.1±1.1 cm). However, this trend was not statistically significant (P>0.05) as shown in Table 4. In general, all the shoot parameters of *A. vaginalis* denoted a decreasing trend with the

Table 3: Root and Shoot Parameters of *Alysicarpus vaginalis* subjected to Different Treatments

Treatment	Root Length (cm)	Root Fresh Weight (g)	Root Moisture Content (g)
T_1	18.91±0.95^a	0.117±0.021^a	0.075±0.017^a
T_2	12.74±0.74^b	0.144±0.025^a	0.101±0.019^a
T_3	17.98±1.27^a	0.113±0.018^a	0.076±0.014^a
T_4	18.03±1.18^a	0.120±0.018^a	0.078±0.014^a
T_5	19.18±0.63^a	0.112±0.013^a	0.065±0.012^a

Note: *Mean ± SE of each value is included. Means with different superscript letters within a column show significant differences among the means as indicated by Tukey's pair-wise comparison followed by One-way ANOVA (P<0.05). T_1: Control; T_2: Once in 5 days; T_3: Once in 10 days; T_4: Once in 15 days and T_5: Once in 20 days*

Table 4: Shoot Parameters of *Alysicarpus vaginalis* subjected to Different Water Stress Levels

Treatment	Shoot Length (cm)	Number of Branches	Shoot Fresh Weight (g)	Shoot Moisture (g)
T_1	38.1±1.8^a	3.1±0.6^a	0.99±0.14^{a,b}	0.75±0.12^{a,b}
T_2	39.8±1.3^a	3.2±0.5^a	1.29±0.17^a	1.01±0.13^a
T_3	36.6±1.1^a	3.0±0.5^a	0.99±0.11^{a,b}	0.80±0.09^{a,b}
T_4	36.5±1.5^a	2.5±0.4^a	0.91±0.09^{a,b}	0.71±0.07^{a,b}
T_5	36.1±1.1^a	1.7±0.4^b	0.62±0.05^b	0.44±0.03^b

Note: *Mean ± SE of each value is included. Means with different superscript letters within a column show significant differences among the means as indicated by Tukey's pair-wise comparison followed by One-way ANOVA (P<0.05). T_1: Control; T_2: Once in 5 days; T_3: Once in 10 days; T_4: Once in 15 days and T_5: Once in 20 days.*

increasing water deficit conditions (except in T2). Most interestingly, a 100 % survival rate was observed (within 60 days) from plants reared under the five water stress treatments, reflecting a higher water stress tolerance ability.

Water stress can be defined as a situation in which plant water relationship alter the interface for normal functioning, by influencing the plant performances at various levels leading to anatomical, physiological, biochemical and molecular responses [19]. Environmental stresses could trigger a wide variety of plant responses, ranging from altered gene expression and cellular metabolism to changes in growth rate and plant productivity. Landscaping is a special segment in horticulture, which is highly affected due to water deficit conditions. In landscaping, ground covers are widely used to cover the spaces in gardens, public open spaces and playing areas providing aesthetic beauty and enhancing the conservation of soil [20].

Generally, the water requirement of ground covers is high in maintaining the visual quality, signifying the importance of utilizing plants with drought tolerance and low irrigation requirements [21]. Hence, screening of drought tolerance ground covers is of great importance in sustaining landscaping [22]. The present study was designed with the context on investigating the effects of induced water deficit conditions on a selected plant species, *A. vaginalis*.

Findings of the study denoted a range of water stress adaptations in *A. vaginalis* plants exposed to varying levels of water stress. Leaf characteristics such as, leaf area and leaf count of *A. vaginalis* plants denoted significant variations among the imposed stress conditions. Water stress conditions has been recognized to often modify the leaf growth and in turn the leaf count, individual leaf size/leaf area and biomass of plants [23]. As per the results of the current study, *A. vaginalis* plants grown under T_2 treatment (113.52±13.84 cm^2) recorded the highest leaf area, while the lowest value was observed from T_5 (66.05±5.03 cm^2). The leaf area has been reduced significantly with the induced stress conditions. Conversely the highest leaf count was denoted by T_2 (48.6±5.8 leaves), while the lowest value was by T_5 (30.7±2.1 leaves). Expansion of the leaf area of a plant is influenced by temperature conditions, leaf turgor and plant growth requirements. Under stress conditions, cell elongation is influenced leading to reduction in cell size and thereby reduction in leaf size [24]. The reduction in the leaf area is a modification to avoid evapotranspiration losses by lowering the stomatal activity and to increase water use efficiency in plants, which aids the survival under water deficit conditions [25-26].

A study conducted by Chaves *et al.* [27] emphasized that leaves become spindle shaped and leaf area tends to get reduced in grass cultivars under water deficit conditions. A similar variation in wheat genotypes has been reported by Foulkes *et al.* [28]. Further, a study on *Arachis hypogeae*, a plant in the same family of *A. vaginalis*, has also reported a similar trend of leaf area reduction under water deficit conditions [29]. Therefore, significant reduction in total number of leaves, total leaf area, and total leaf biomass could be recognized as a critical response of plants to survive under water deficit conditions [30]. Thus, with the significant reduction in leaf area and leaf count under water deficit conditions, *A. vaginalis* evidence its potential as a drought tolerant ground cover.

Leaf trichome is another parameter, which confers the ability of plants to withstand the stress conditions. The leaves of *A. vaginalis* typically bares single trichome leaf hairs. The findings of the current experiment denoted a significantly increasing trend in leaf hair density along with the elevating water deficit condition. Low leaf hair densities were observed from the *A. vaginalis* plants maintained under high irrigation frequencies in T_1 and T_2 (241.4±12.7 cm^2 and 278.1±13.2 cm^2, respectively). Leaf hairs are a protective mechanism in plants, where higher leaf trichome density is induced by drought or defoliation to protect plants from drought by reducing absorption of solar radiation. This in turn reduces the heat load gained by the leaves and minimizes the need for transpirational cooling [31]. A recent field experiment on *Solanum lycopersicum* by Armero *et al.* [32] has reported an increasing trend in thricome density with the water deficit conditions, while a similar observation has been experienced in olive cultivar by Ennajeh [33].

Root growth is another important parameter for plants, where a prolific root system contributes for the tolerance of water stress conditions. Despite being significant, the highest mean values for root fresh weight (0.144±0.025 g) and root moisture content (0.101±0.019 g) were recorded in T_2 , while T_5 with the lowest irrigation frequency reported the lowest mean values for these parameters as 0.112±0.013 g and 0.065±0.012 g, respectively. On the contrary, the highest mean value for the root length was recorded from T_5, while the lowest was observed at T_2, denoting an increasing trend in the root length with the decreasing frequency in irrigation. This implies that *A. vaginalis* plants tend to allocate more energy towards the elongation of roots, under water stress conditions.

Further, increased root growth reflects the ability of plants to withstand water stress, making it to be widely applied to screen plant cultivars for drought tolerance [25, 34-35]. Roots play an important role in catering for the water requirements of plants, while being the main engine of meeting the transpiration demand [36]. A study by Kemp and Culvenor [37], conveyed that deeper rooting improves drought tolerance of perennial temperate C_4 grasses. In addition, a study conducted by Riaz *et al* [26], has evidenced that the root length of grass cultivars tends to significantly reduce under water stress conditions, while studies on *Albizzia* seedlings [38] and *Erythrina* seedlings [39] also have expressed a similar trend.

Shoot length, which determines the rate of ground coverage in ground covers, also remain as a critical determinant of drought tolerance. Even though, no significant difference was denoted ($P>0.05$) in the shoot length with the imposed stress conditions, the highest mean height was observed in T_2, while the lowest mean shoot length was reported from *A. vaginalis* plants maintained under T_5. Water stress is an important limiting factor at the initial phase of plant growth and establishment, where the shoot height is correlated with the declining of cell enlargement [2]. A similar decreasing trend in shoot height under increasing water deficit conditions have been reported for a variety of plants such as *Albizzia* [40], *Erythrina* [41] and *Populus cathayana* [42]. This further verifies the drought tolerance potential of *A. vaginalis*.

Growth parameters like fresh and dry weight have a profound effect in water-limited conditions. Water stress influence the dry matter accumulation, which results in reduced plant biomass. In the present study, no significant differences were observed in the leaf dry weight, root and shoot fresh weights. Yet the results indicated that the degree of water deficit conditions leads to a gradual decrement in the shoot and root dry weights, where the highest mean root (0.144±0.025 g) and shoot (1.29±0.17 g) fresh weights were recorded in T_2. A parallel configuration was also observed with the leaf fresh and leaf dry weight, agreeing with the fact that water stress leads to growth reduction, which is reflected in dry weight [25]. This fact is further supported by several recent studies conducted as field or pot experiments. According to Shao *et al.* [19], low levels of fresh and dry weight of shoot is a result of a reduction in plant growth, photosynthesis and plant structure during the water stress conditions [43]. A similar reduction in biomass has been reported in Avacado cultivars [44] and pearl millets [45].

The relative moisture content is considered as one of the easiest parameters that can be used to screen plants for drought tolerance. Drought tolerant plant species tend to keep high relative moisture contents with compared to drought-sensitive species [46]. A significant variation was observed in the moisture content of leaves and shoots, where the plants in treatment T_2 showed the highest mean value, while plants in T_5 recorded the lowest. Tambussi *et al.* [47] has also reported a similar trend in wheat cultivars under water stress conditions, further emphasizing the drought tolerance capacity of *A. vaginalis*.

In the current study, *A. vaginalis* plants responded differently to varying conditions of water availability, where plants in T_2 treatment that were irrigated once in 5 days recorded the best growth performances, except for root length and leaf hair density. However, the growth performance of *A. vaginalis* plants in T_1 treatment, which were irrigated daily, remained significantly lower than in T_2, suggesting that more water availability would also impose negative impacts on the growth of *A. vaginalis*. Water logging conditions may induce the production of numerous metabolic chemicals in plants that could alter the plant architecture, anatomy, metabolism, growth patterns and survival strategies of plants [48].

A study by Mass *et al*. [49] on the growth responses of nine tropical grasses under flooding conditions, has revealed a significant reduction in forage dry matter and shoot growth, while a moderate negative impact has been reported in tomato plants under flooding conditions [50]. This suggests that *A. vaginalis* may impose a negative growth pattern under water logging conditions as well. Nevertheless, plants in treatment T_5 showed the best drought tolerance characteristics, suggesting that *A. vaginalis* is capable of altering the morphological features and plant growth parameters to thrive well under water stress conditions. Therefore, *A. vaginalis* could be recommended as an ideal candidate for sustainable landscaping as a drought tolerant ground cover with low maintenance.

CONCLUSIONS

Landscaping of outdoor places using low water use ground cover plants is a promising alternative to conventional lawn grass-based landscapes due to the potential in reducing the overall water usage in maintenance. As depicted by the findings, the leaf area, leaf hair density, number of leaves, leaf fresh weight, leaf moisture content, shoot moisture content, shoot fresh weight, and root length of *A. vaginalis* maintained under different water stress conditions varied significantly among treatments.

The T_5 (irrigated once in 20 days) recorded the highest leaf hair density (648.14±15.96 hairs/cm^2) and root length (19.18±0.63 cm), while denoting the lowest values for leaf area (66.05±5.03) and leaf count (30.65±2.59), demonstrating the best drought tolerance characters. Furthermore, a 100% survival rate was observed from *A. vaginalis* under all treatment conditions.

In the view of findings of the present study, it can be concluded that *A. vaginalis* positively responded to water deficit conditions, where it can be recommended as a water stress tolerant plant. Therefore, *A. vaginalis* can be used as a low maintenance ground cover plant in climate smart landscaping. However, detailed studies are needed to elucidate the underlying anatomical parameters and biochemical processes, which are responsible for differential responses to water deficit conditions. Further, supplementary studies with prolonged water stress conditions are recommended to identify the maximum recovering ability of *A. vaginalis.*

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

AUTHORS' CONTRIBUTIONS

NS: Designed the study, supervised the experiments and wrote the initial draft of the manuscript; NC: Carried out the investigations and collected data; KY: Supervised the study and reviewed the manuscript; LU: Supported the designing of the research, conducted the statistical analysis and wrote the manuscript. All authors read and approved the manuscript.

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REFERENCES

1 Bandara RMAL, Yakandawala K. and Abeynayake NR. Drought tolerance of a native plant *Helicteres isora* L. In Proceedings of 16th Agricultural Research Symposium. Wayamba University of Sri Lanka. 2017; 339-343.

2 Saidi A, Ookawa T, Hirasawa T. Responses of root growth to moderate soil water deficit in wheat seedlings. Plant production science. 2010; 13(3):261-268.

3 Jaleel CA, Manivannan PA, Wahid A, Farooq M, Al-Juburi HJ, Somasundaram RA, Panneerselvam R. Drought stress in plants: a review on morphological characteristics and pigments composition. Int. J. Agric. Biol. 2009; 11(1):100-105.

4 Sen, 2015 - Dasgupta P, Das BS, Sen SK. Soil water potential and recoverable water stress in drought tolerant and susceptible rice varieties. Agricultural Water Management. 2015; 152:110.

5 Sarkar B, Savita SK, Varalaxmi Y, Vanaja M, Kumar NR, Sathish P, Lakshmi NJ, Prabhakar M, Shanker AK, Yadav SK, Maheswari M. Stress Reactions of Maize Genotypes to Drought Stress at Different Phenophases and Recovery. Russian Journal of Plant Physiology. 2022;69(3):54.

6 Boutraa T, Akhkha A, Al-Shoaibi AA, Alhejeli AM. Effect of water stress on

growth and water use efficiency (WUE) of some wheat cultivars (*Triticum durum*) grown in Saudi Arabia. Journal of Taibah University for science. 2010; 3(1):39-48.

7 Staniak M, Kocoń A. Forage grasses under drought stress in conditions of Poland. Acta Physiologiae Plantarum. 2015; 37:1-16.

8 Atkinson NJ, Urwin PE. The interaction of plant biotic and abiotic stresses: from genes to the field. Journal of experimental botany. 2012; 13;63(10):3523-3543.

9 Wherley B, Labedzki L. Turfgrass growth, quality, and reflective heat load in response to deficit irrigation practices. Evapotranspiration. Labedzki, L.(Ed.). 2011; 419-430.

10 Fernando MS, Yakandawala K. Performance of selected native ground cover species under induced drought conditions. Journal of Environmental Professionals Sri Lanka. 2015; 4(2).

11 Caser M, Lovisolo C, Scariot V. The influence of water stress on growth, ecophysiology and ornamental quality of potted Primula vulgaris 'Heidy'plants. New insights to increase water use efficiency in plant production. Plant Growth Regulation. 2017 Dec;83: 361-373.

12 Hilaire RS, Arnold MA, Wilkerson DC, Devitt DA, Hurd BH, Lesikar BJ, Lohr VI, Martin CA, McDonald GV, Morris RL, Pittenger DR. Efficient water use in residential urban landscapes. HortScience. 2008; 43(7):2081-2092.

13 Özyavuz A, Özyavuz M. Xeriscape in landscape design. Landscape planning. 2012; 353-360.

14 Basu S, Ramegowda V, Kumar A, Pereira A. Plant adaptation to drought stress. F1000Research. 2016; 5: 1-10.

15 Jayaweera MA. Medicinal Plants (Indigenous and Exotic) Used in Ceylon. The National Science Council of Sri Lanka. 1981: 3:148-149.

16 Rathi MA, Meenakshi P, Gopalakrishnan VK. Hepatoprotective activity of ethanolic extract of *Alysicarpus vaginalis* against nitrobenzene-induced hepatic damage in rats. South Indian Journal of Biological Sciences. 2015; 1(2):60-65.

17 Dassanayake MD. (1996). Fabaceae. In: MD Dassanayake, and WD Clayton (Eds.), A Revised Handbook to the Flora of Ceylon X. Oxford & IBH Publishing Co. Pvt., Ltd. New Delhi. 1996; 152-153.

18 Fu D, Huang B, Xiao Y, Muthukrishnan S, Liang GH. Overexpression of barley hva1 gene in creeping bentgrass for improving drought tolerance. Plant cell reports. 2007; 467-477.

19 Shao HB, Chu LY, Jaleel CA, Zhao CX. Water-deficit stress-induced anatomical changes in higher plants. Comptes rendus biologies. 2008; 331(3):215-225.

20 Meerow AW. Native Ground Covers for South Florida. University of Florida-IFAS Publication EES-60, Gainesville. 1999; 1-10

21 Fan Y, McCann L, Qin H. Households' adoption of drought tolerant plants: an adaptation to climate change?. Journal of Agricultural and Resource Economics. 2017; 236-254.

22 Heflebower R, Cerny-Koenig T, Waters M, Ward R. (350) A Water-wise Plant Recognition Program for Utah. HortScience. 2005; 40(4):1061B.

23 Gómez-del-Campo M, Ruiz C, Lissarrague JR. Effect of water stress on leaf area development, photosynthesis, and productivity in Chardonnay and Airén grapevines. American Journal of Enology and Viticulture. 2002; 53(2):138-143.

24 Reddy AR, Chaitanya KV and Vivekanandan M. Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. Journal of plant physiology, 2004; 161(11); 1189-1202.

25 Boutraa T, Akhkha A, Al-Shoaibi AA, Alhejeli AM. Effect of water stress on growth and water use efficiency (WUE) of some wheat cultivars (*Triticum durum*) grown in Saudi Arabia. Journal of Taibah University for science. 2010; 1;3(1):39-48.

26 Riaz A, Younis A, Hameed M and Kiran S. Morphological and biochemical responses of turf grasses to water deficit conditions. Pakistan Journal of Botany, 2010; 42: 3441–

3448.
27 Chaves MM, Maroco JP, Pereira JS. Understanding plant responses to drought—from genes to the whole plant. Functional plant biology. 2003; 30(3):239-264.
28 Foulkes MJ, Sylvester-Bradley R, Weightman R, Snape JW. Identifying physiological traits associated with improved drought resistance in winter wheat. Field crops research. 2007; 103(1):11-24.
29 Suthar DM and Patel MS. Yield and nutrient absorption by groundnut and iron availability in soil as influenced by lime and soil water. Journal of the Indian Society of Soil Science. 1992; 40(3):594-596.
30 Singh TN, Paleg IG and Aspinall D. Stress metabolism I. Nitrogen metabolism and growth in the barley plant during water stress. Australian journal of biological sciences. 1973; 26(1); 45-56.
31 Huttunen, P., Kärkkäinen, K., Løe, G., Rautio, P. & Ågren, J. 2010, Leaf trichome production and responses to defoliation and drought in *Arabidopsis lyrata* (Brassicaceae), Ann. Bot. Fennici, (47), 199–207.
32 Galdon-Armero J, Fullana-Pericas M, Mulet PA, Conesa MA, Martin C, Galmes J. The ratio of trichomes to stomata is associated with water use efficiency in *Solanum lycopersicum* (tomato). The Plant Journal. 2018; 96(3):607-619.
33 Ennajeh M, Vadel AM, Cochard H, Khemira H. Comparative impacts of water stress on the leaf anatomy of a drought-resistant and a drought-sensitive olive cultivar. The Journal of Horticultural Science and Biotechnology. 2010; 85(4):289-294
34 Boutraa T, Akhkha A, Al-Shoaibi AA, Alhejeli AM. Effect of water stress on growth and water use efficiency (WUE) of some wheat cultivars (*Triticum durum*) grown in Saudi Arabia. Journal of Taibah University for science. 2010; 3(1):39-48.
35 Hurd EA. Phenotype and drought tolerance in wheat. Agricultural Meteorology. 1974; 14(1-2):39-55.
36 Huang B, Gao H. Physiological responses of diverse tall fescue cultivars to drought stress. HortScience. 1999; 34(5):897-901
37 Kemp DR, Culvenor RA. Improving the grazing and drought tolerance of temperate perennial grasses. New Zealand journal of agricultural research. 1994; 37(3):365-378.
38 Nanjo T, Kobayashi M, Yoshiba Y, Sanada Y, Wada K, Tsukaya H, Kakubari Y, Yamaguchi-Shinozaki K, Shinozaki K. Biological functions of proline in morphogenesis and osmotolerance revealed in antisense transgenic Arabidopsis thaliana. The Plant Journal. 1999; 18(2):185-193.
39 Nativ R, Ephrath JE, Berliner PR, Saranga Y. Drought resistance and water use efficiency in *Acacia saligna*. Australian Journal of Botany. 1999;47(4):577-586.
40 Patel MS and Golakia BA. Effect of water stress on yield attributes and yield of groundnut (*Arachis hypogaea* L.), Indian Journal of Agriculture Sciences. 1988; 58: 701–703.
41 Pita P and Pardes JA. Growth, leaf morphology, water use and tissue water relation of *Eucalyptus globules* clones in response to water deficit, Tree Physiol. 2001; 21: 599–607.
42 Nautiyal PC, Ravindra V, Joshi YC. Dry matter partitioning and water use efficiency under water deficit during various crowth stages in groundnut. Indian Journal of Plant Physiology (India). 2002; 7, 135–139.
43 Bahreininejad B, Razmjou J, Mirza M. Influence of water stress on morpho-physiological and phytochemical traits in *Thymus daenensis*.2013; 151-166
44 Chartzoulakis K, Patakas A, Kofidis G, Bosabalidis A, Nastou A. Water stress affects leaf anatomy, gas exchange, water relations and growth of two avocado cultivars. Scientia horticulturae. 2002; 95(1-2):39-50.
45 Manivannan P, Jaleel, CA, Kishorekumar A, Sankar B, Somasundaram R. Sridharan R. and Panneerselvam R. Drought stress induced changes in the biochemical

parameters and photosynthetic pigments of cotton (*Gossypium hirsutum* L.). Indian J. Appl. Pure Biol, 2007: 52:369-372.

46 Chaves MM, Pereira JS, Maroco J, Rodrigues ML, Ricardo CP, Osório ML, Carvalho I, Faria T, Pinheiro C. How plants cope with water stress in the field? Photosynthesis and growth. Annals of botany. 2002; 89(7):907-916.

47 Tambussi EA, Bort J, Araus JL. Water use efficiency in C3 cereals under Mediterranean conditions: a review of physiological aspects. Annals of Applied Biology. 2007 Jun;150(3):307-321.

48 Bailey-Serres J, Voesenek LA. Flooding stress: acclimations and genetic diversity. Annu. Rev. Plant Biol. 2008; 59:313-339.

49 Junior RM, Domiciano LF, Ribeiro LF, Pedreira BC. Growth responses of nine tropical grasses under flooding conditions. Tropical Grasslands-Forrajes Tropicales. 2016; 22;4(1).

50 Jannah R, Natalia JD, Kurniadinata OF. Development of Tomato (*Lycopersicum esculentum* Mill.) Roots in Every Growth Stage in Flooding Conditions. Journal of Tropical Horticulture. 2019; 2(1):11-15.