Asian Journal of Agricultural and Horticultural Research

Volume 11, Issue 4, Page 70-81, 2024; Article no.AJAHR.123437
ISSN: 2581-4478

Response of Water Management on Above and Below Ground Growth Pattern Distribution of Cashew Seedling (*Anacardium occidentale* L.) in the Nursery

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ajahr/2024/v11i4341

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/123437

Original Research Article

Received: 17/07/2024
Accepted: 19/09/2024
Published: 04/10/2024

ABSTRACT

Water management is a very significant practice, as it influences the successful growth of many crops. In Nigeria, Cashew farmers use different cashew nuts and varying watering rate for their nursery operations. These necessitates this study, to enhanced cashew morphological growth and to checkmate water management. The experiment laid in 4 x 10 x 3 factorial design on a randomized complete block of three replications, examines medium, large cashew nut biotypes,

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Cite as: *Nduka Beatrice Abanum, Aremu-Dele Olufemi, Ibe Osita, Ugioro Osasogie, Adegbala Amos Adebayo, and Umar Salisu. 2024. "Response of Water Management on Above and Below Ground Growth Pattern Distribution of Cashew Seedling (Anacardium Occidentale L.) in the Nursery". Asian Journal of Agricultural and Horticultural Research 11 (4):70-81. https://doi.org/10.9734/ajahr/2024/v11i4341.*

and 200ml, 300ml watering rates applied fortnightly. Monthly harvest done from each treatment to monitor seedlings development. Data on vegetative characterices collected were used to calculate leafiness parameters, Leaf Area Ratio, Leaf Area, Specific Leaf Weight and Leaf weight ratio. At emergence the large biotype produced highest values (93.33%) of germination, while the least was from the medium nuts that received 200ml of water (66.7%). However, the medium cashews nut seedling greatly exploits the 200ml of water application for morphological growth. This does not exclude the fact that the results obtained from the cashew leafiness that 300ml of water was readily available for the seedling use at one month of harvest, but at later stages 2nd and 3th months of harvest, the medium biotype exhibited longer tap root system. The dynamic of the Fresh Shoot (14.72g), and Root (5.94g) weight results were positively influenced by the 200ml watering rate in large cashew seedlings, suggesting a potential adaptation for efficient water use. The large biotypes seedling having 300ml of water (3.0) application had much root hairs when compared to the medium (2.67). The study reveals that water management plays a crucial role in the growth pattern distribution of cashew seedlings. However, further investigations on the adverse effects of differing watering rate, and different cashew nut biotype in Nigeria is subject to validation and the findings shared to cashew nursery operators.

Keywords: Cashew; growth; leafiness; root; shoot; seedlings; water.

1. INTRODUCTION

Among the global problem affecting the development of agricultural crops and food production is water shortage [1]. The report of Morrison et al. [2] indicates that climate change may have a detrimental impact on water availability and potentially leading to water scarcity. In urban areas for example, lack of availability of water may increase the need for nursing seedlings with a developed root system at transplanting to avoid crop failure [3].

Cashew plants has become among one of the most important trees species on account of its growth rate. Its rooting and shoot system development relationship to water requirement is among one area of research focus all over the world. Water is a limiting factor to cashew productivity despite being a drought tolerant plant [4]. In 2014 [5] a review paper stated that an estimated 1% of cashew planted area in the world is irrigated. Although the importance of root and shoot in plants cannot be emphasis, their abilities according to Diaz et al. [6] and [7], in adapting to different ecosystem processes and responses is among its importance to crop productivity. Apart from plants morphological growing pattern, the root and shoots behavior and competition pattern of different crops are also very important and well documented. Both root and shoot traits are genetically determined and influenced by metabolic processes that facilitate and promote healthy growth. However, their development can be modified in response to environmental conditions, allowing them to adapt to external stresses [8]. Furthermore, the problems associated with root and shoot is indisputable, yet often overlook and a bit neglected. This complex relationship between both (root and shoot) plant mechanism is characterized by the root's role in water acquisition [9], which, when compromised, triggers a signal to the shoot, prompting the activation of adaptive measures to ensure plant survival [10]. This adjustment is well explained by Hodge [11] in the variations of resource availabilities variable by partitioning of root and shoot. However, in contrast as stated by Khalil et al. [12], the intensity and regulation of shoot–root interactions are complex because a root system buried in the soil remain difficult and challenging to be study. More so, responses on above and below-ground competition behavior are such that shoot system may not influence that of the root system interactively [13], because water absorption is a mechanical and biochemical process done by the root [14], while the shoot controls rate of transpiration [15]. It is understood that the complex relationship that exists between root development and soil pore structure can have a significant effect on physiochemical and biological status of the soil activity [16,17]. Physiologically, [18] plants roots and shoots respond to drought and water stress and a reduce mortality and resource acquisition need in protégé shrub, when the soil becomes dry as reported [18]. However, despite the complexity of the root and shoot system, it reflects how the plant explores and acquires nutrient [19].

Therefore, determining the optimal water requirements for various growth stages of tree crop seedlings [20] is crucial and paramount, as it can help reduced cost for commercial nurseries [21] and enhance the resilience of producers to climate change [22]. Consequently, there is a pressing need to investigate and examine the traits associated with adaptation in cashew seedlings, particularly their rooting and shoot growth patterns, in the face of climate change. The study examined how cashew seedlings shoot morphology and below ground root characteristics react to variations in water supplied at different stages of growth.

Therefore, the objective of this study is to:

- Investigate large and medium cashew seedling emergence to different watering rates.
- Investigate how cashew seedlings' shoot morphology (above-ground characteristics) and root characteristics (below-ground traits) respond to different water supply levels at various stages of growth.

2. MATERIALS AND METHODS

The experiment was conducted in Cocoa Research Institute of Nigeria (CRIN) Headquarters Ibadan Nursery house situated in southern Nigeria, having a mean relative humidity of 90.14%, maximum temperature (28.76o^{C}) and minimum temperature of 23.18o^{C} during the study period. Soil was collected from two adjacent farm plot at 10cm below the soil surface that have a good amount of recomposited plant materials and mixed together. The soil was air-dried, sieved with 2 mm mesh sieve to a uniform texture. An equal amount from *159634.8 volume* of the sandy loam soil was put into a black polytene bags of 14.2cm diameter (radius) and 16.8cm length (height). Two yellow color large and medium cashews nut sizes were sown and later thinned to one. The experiment was laid factorially at 4 x 10 x 3 on a Randomized Complete Block (RCD) of three replications. Two levels of 200ml and 300ml watering quantities was measured with a graduated cylinder and applied to the soil in an interval of 4 days in the morning hours only. Cashew seedling emergence data was collected at 2, 3 and 4 weeks after sowing (WAS).

Data collected on vegetative growth include Plant height (cm) (measured with a meter rule), Leaf area (cm^2), Stem diameter (mm) (Vernier calliper) and Leaf number (manually counted) on four sample plants which was done at two-week intervals from 4 to 12 weeks after sowing. On monthly bases a destructive sampling of seedlings from each treatment was harvested by cutting the polythene bags carefully longitudinally, uprooting the seedlings and washed to remove the soil particles gently from the roots by a moderate stream of tap running water, while keeping the root hair intact. The uprooted seedlings were further partitioned by cutting with sterilized scissors into shoot and root to ascertain a proper growth rate measurements from each part. Data collected on the destructive samples are root fresh weight, shoot fresh weight, taproot length, dry root weight and dry shoot weight. The root growing section was defined from the point where the root tip (dark cap) shows no visual characters above the soil, while the shoot growing point were defined as between the visual characters to the point of no leave formation. Fresh weight measurement was done on root and shoot weight, root and shoot length, Additionally, the root hair (Rh) was visually measured by scoring method technique as Light (1), Moderate (2) and Dense (3). The total root and shoot volume were also obtained by calculation and the separated seedling parts were dried at 70°C to constant mass and weighed. The results obtained were subjected to DW:FW ratio for each component, to obtain the estimate of the whole plant biomass [22]. At the end of each monthly harvest, the effects of water management on some aspects of growth and the dry matter production monitored was calculated, including cashew leafiness parameters: Leaf Area Ratio (LAR) and the amount of Leaf Area formed per unit of biomass expressed in g of plant dry weight. The Specific Leaf Weight (SLW) which is a measure of leaf weight per unit leaf area (g) and Leaf weight ratio (LWR) expressed as the dry weight of leaves to whole plant dry weight in gram. Other calculation includes:

Volume of the polybag used calculated as:

$$\mathrm{VPB} = \mathrm{\omega r2h} \qquad [23]\ \mathrm{i}$$

Where,

constant number = 3.1416
r is the radius of the poly bag i.e., half (1/2) the diameter = 7.1cm
h is the height of the poly bag = 16.8cm

Therefore, the volume of the polythene bag (VPB) = 2660.58cm^3

The volume of soil used in this experiment is calculated as

$$\text{VPB X NPB} = \text{TVS} \qquad [23] \text{ ii}$$

Where:

VPB = Volume of the polythene bag
NPB = Numbers of polybag
TVS = The total volume of soil used (159634.8 cm^3)

The leafiness of the plant was calculated using the formula from iv, v and vi respectively.

Leaf Area Ratio (LAR) $\text{LAR} = \frac{\text{Leaf area per plant}}{\text{Plant dry weight}}$ [24] iii

Leaf weight Ratio (LWR) $\text{LWR} = \frac{\text{Leaf dry weight}}{\text{Plant dry weight}}$ [25] iv

Specific Leaf Weight (SLW) $\text{SLW} = \frac{\text{Leaf weight}}{\text{Leaf area}}$ [26] v

All data was subjected to Analysis of Variance (ANOVA) using Minitab Version 17 statistical software and treatment means were separated using the Tukey Standardized test at a 0.05% probability level.

3. RESULTS AND DISCUSSION

At three (3) and four (4) weeks after sowing as shown in Fig. 1, germination was enhanced without any comparable significant difference between either with the cashew nut sizes or the watering rate used. The experiment corroborated [27] work that under different environmental conditions seedlings may have different watering requirement but as the study progresses the use of 300ml water treatment on the large cashew nuts significantly produced the highest values (93.33%) of germination, followed by the same biotype with 200ml (80.00%) respectively. A delay in germination was obtained from the medium nuts that received 200ml of water (66.7%.) This duration of germination between the different sizes of cashew nuts may support the fact that the larger the cashew nuts the more a higher volume of water is needed, or it can serve as an insight for an agronomic requirement to attain optimum seedling production. At 4 WAS, the large cashew nut watered with 300ml (L300) produced a notably different cashew seedling emergence than the medium biotypes at both watering rates. This result also implies that the large biotype responds positively to the higher watering rate of 300ml while no response was observed among the medium nut types to both watering rates.

Fig. 2 shows that no comparable difference in plant height was observed among the treatments over the period of observation. However, large nuts seedlings subjected to a 300 ml watering rate (L300) had the tallest height (39.82cm) from 4 to 12 WAS. In addition, 300ml watering rate produced a taller seedling height than 200ml in both cashew biotypes, which implies that the higher watering rate showed potential of improving cashew seedling height. This agrees to the findings of Biernbaum and Versluys [28] who stated that little quantity of water is needed for the overall healthy growth performance of forest seedlings. A tall seedling plant was also recorded when 200ml was used in a medium size nut although not significantly enhanced.

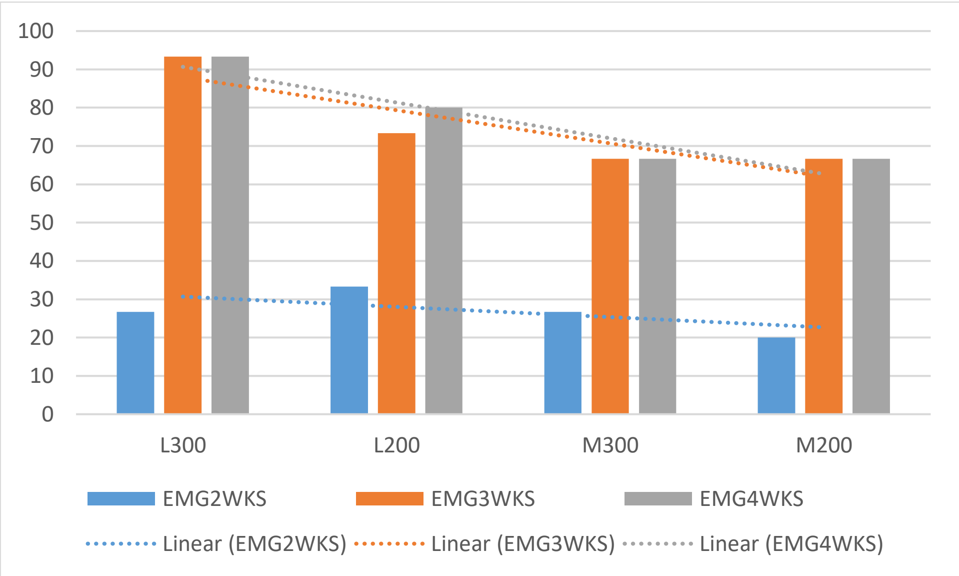

Fig. 1. Watering effects on seedling emergence dates at 2, 3 and 4 weeks (WKS) after sowing

Fig. 2. Watering effects on seedling height (cm) at 4 to 12 weeks (WKS) after sowing

Among the treatments as shown in Fig. 3, no comparable difference in cashew seedling number of leaves was observed all through the period of observation. However, the large biotype seedlings subjected to a 300ml watering rate (L300) had the highest number of leaves from 4 to 12 WAS. This may not be far-fetched as [29] reported that they may exist a coordinated between plant root and its leaves production, although this variable is subjected to response from the environment on which it's grown. Moreover, the root's ability to absorb available water in soil affects the overall growth of plants.

The cashew seedling biotypes respond variably to the watering rates applied as shown in Fig. 4. Stem girth served as index for plant vigor and as such, the medium cashew seedling who received 200ml water produced 7.12mm and 6.32mm thicker stem, than the medium cashew nut biotypes and large nut cashew seedling size with 300ml (6.6mm) and (7.03mm) water application (respectively). Furthermore, the higher watering rate produced thicker stems in both biotypes at 12 WAS.

There was a comparable difference and active growth rate among the treatments in the cashew seedling leaf area (Fig. 5) in the early periods of the experiment (4,6,8 and 10 WAS) but a non-comparable result was observed at 12 WAS. However, large cashew biotype seedlings subjected to a 300ml watering rate produced the largest leaf area from 4 to 12 WAS. 300ml watering rate produced seedlings with larger leaves when compared to 200ml among the two biotypes. This implies that the higher watering rate showed potential for improved cashew seedling leaf area irrespective of the biotypes. According to Wilson [30], it was reported that leaf area parameter in plants reduces when subjected to water stress. From this result, it could be inferred that both watering rates did not subject the seedlings to water stress. However, the 300ml watering rate showed improved results.

The physical and chemical properties of the soil used for the experiment are presented in Table 1. The soil is slightly acidic (pH 6.3), this falls within the acceptable range of 5.5 -7.5 for tree crops [31]. However, the total N, available P, K and Ca values were below the required value for optimum cashew production since they are lower than the critical level (N-0.10%, K- 0.12, Ca-0.8%) determined for Cashew production in Nigeria [31]. The organic carbon content of the soil was low as well. There was water percolation within the soil which was filtered, stored for plant utilization, and redistributed across flow paths to groundwater and surface water bodies in the polybags.

As revealed in Table 2, no significant difference in Leaf Area Ratio (LAR) was observed among the treatments in Month 1 (M1), Month 2 (M2) and Month 3 (M3) of harvest. This implies that the watering rates did not influence the LAR of cashew seedlings irrespective of the biotype. However, higher leaf area ratio (LAR) was observed in L300 than L200 and M200 than M300 at M3 after sowing. A similar result as LAR was also observed in Leaf Weight Ratio LWR (Table 2). Specific Leaf Weight (SLW) showed variability at one month of harvest (M1) among the treatments with M300 having the highest SLW. M300 had the highest SLW all through the period of observation. Conclusively, the watering treatments did not significantly affect the Leaf Area Ratio (LAR) or Leaf Weight Ratio (LWR) of the cashew seedlings, but specific leaf weight (SLW) was consistently highest in the M300 treatment throughout the observation period. In line with the observation that [32] plant growth and biomass production is directly proportional to the water supply and use of water in plant and [33], plant growth and biomass production are directly proportional to the water supply and use of water in plants, this was not the case in this result which could be because of the similar performance of the two watering rates on cashew seedling LAR, LWR and SLW. Apart from water being defined on dry matter partitioning, [34], there was a reduced pattern in the calculated leaf weight ratio at three months of harvested recorded in the medium cashew nuts seedling (Table 2).

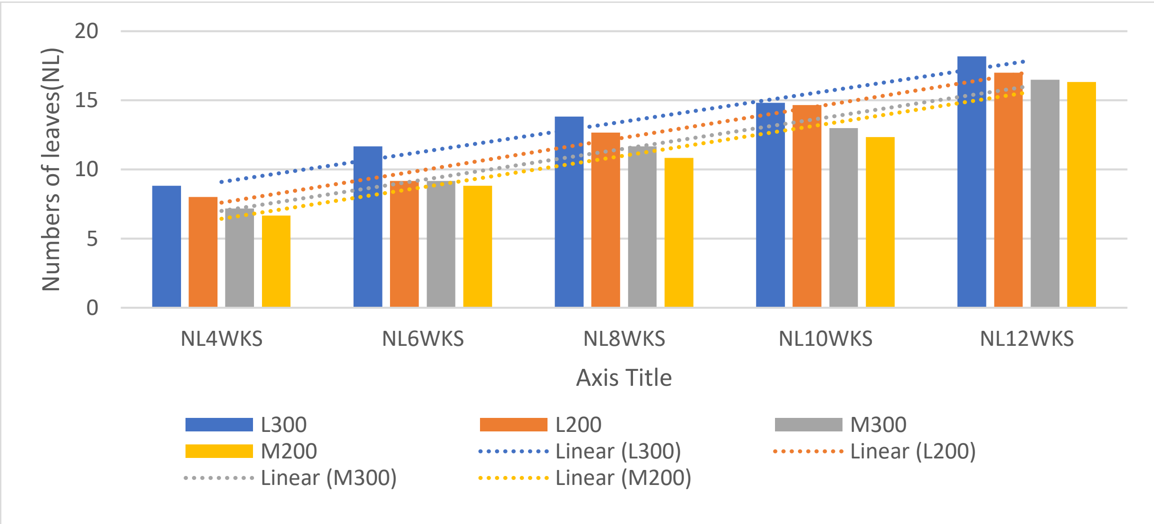

Fig. 3. Watering effects on number of leaves (NL) at 4 to 12 weeks (WKS) after sowing

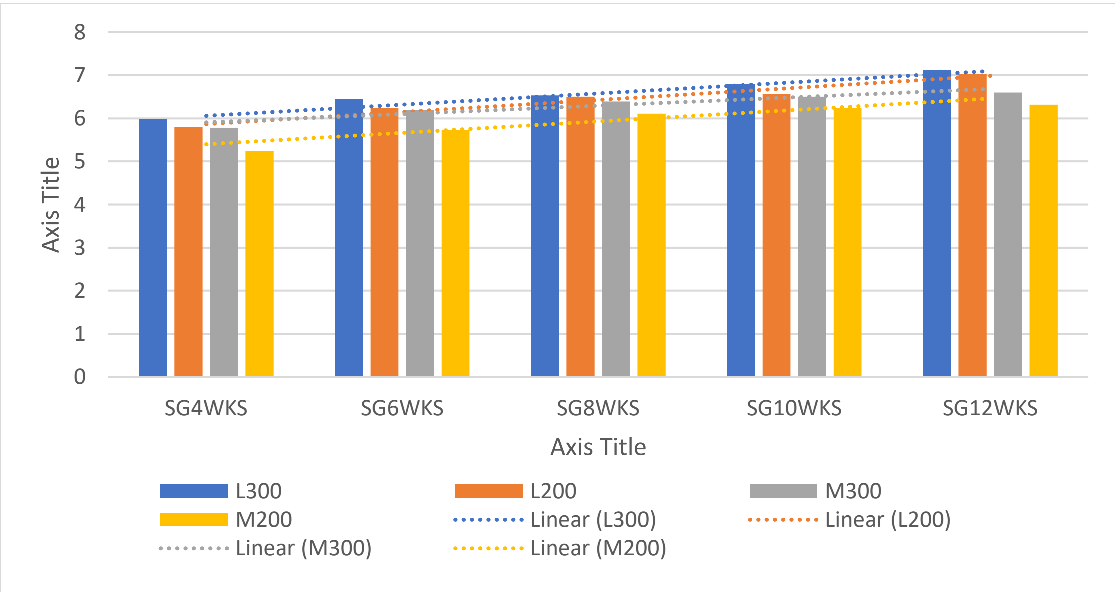

Fig. 4. Watering effects on Stem girth (SG)(mm) at 4 to 12 weeks (WKS) after sowing

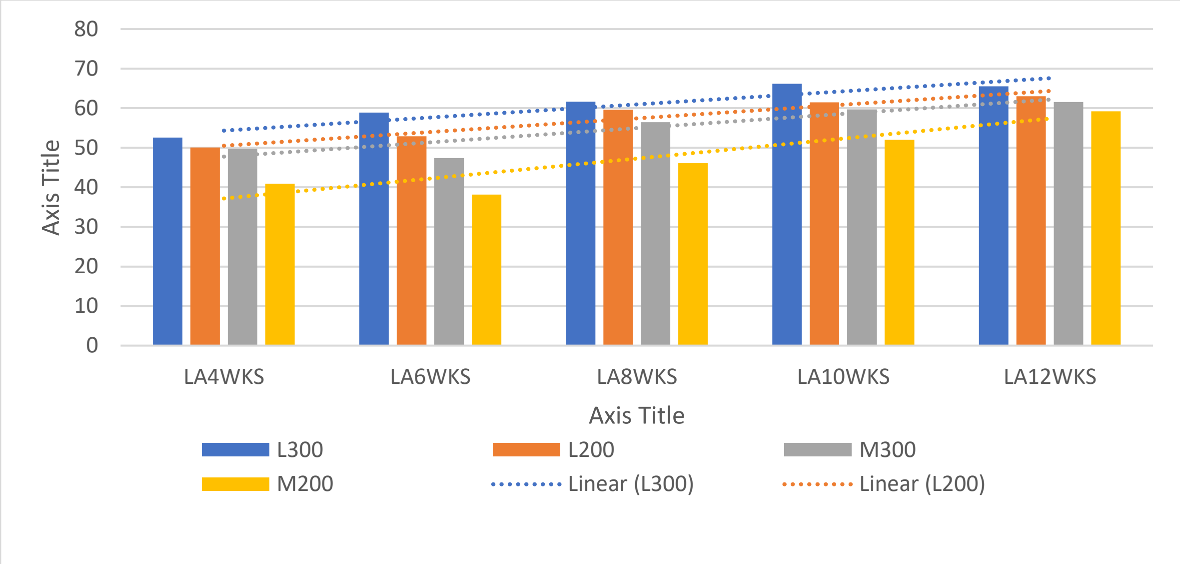

Fig. 5. Watering effects on leaf area (LA)(cm^2) at 4 to 12 weeks (WKS) after sowing

Table 1. The properties of the soil used in this study

Properties	Units
Organic Carbon (gkg-1)	20.67
Total Nitrogen (gkg-1)	0.68
Available phosphorus (mgkg-1)	2.98
Exchangeable bases (cmol kg-1)	
Potassium (K)	0.12
Calcium (Ca)	0.27
Magnesium (Mg)	0.66
Sodium (Na)	0.42
Manganese (Mn)	0.03
Exchangeable acidity (cmolkg-1)	
Aluminum (Al)	0.22
Hydrogen (H)	0.12
ECEC-Base saturation%	2.1
Physical Properties (gkg-1)	
Sand	810
Silt	121
Clay	69
Textural Class	Sandy loam

Table 2. Watering effect on cashew seedling on, LAR, LWR and SLW on 1, 2 and 3 months of harvest

TRT	M1 LAR(g)	M2 LAR(g)	M3 LAR(g)	M1 LWR(g)	M2 LWR(g)	M3 LWR(g)	M1 SLW(g)	M2 SLW(g)	M3 SLW(g)
L300	49.13a	20.70a	12.42a	0.45a	0.42a	0.41a	0.05b	0.05a	0.06a
L200	34.44a	24.03a	10.95a	0.54a	0.49a	0.40a	0.06ab	0.06a	0.06a
M300	29.77a	22.2a	11.40a	0.45a	0.48a	0.38a	0.07a	0.08a	0.08a
M200	37.6a	31.74a	13.17a	0.36a	0.44a	0.45a	0.05b	0.05a	0.07a

Key, L-Large nut size, M-Medium nut size, MI, M2, M3- I,2,3Months Respectively, LAR-leaf area ratio, LWR-leaf weight ratio, and SLW- Specific Leaf Weight, g-gram

Table 3. Watering effect on, cashew seedling LW, TRL, FSW and FRW at 1, 2 and 3 months of harvest

TRT	M1 LW (g)	M2 LW (g)	M3 LW (g)	M1 TRL (cm)	M2 TRL (cm)	M3 TRL (cm)	M1 FSW (g)	M2 FSW (g)	M3 FSW (g)	M1 FRW (g)	M2 FRW (g)	M3 FRW (g)
L300	0.61a	1.22a	2.13a	18.5a	26.07a	27.73a	2.89a	9.23a	12.33a	0.55a	2.24a	3.43c
L200	0.80a	1.37a	2.4a	20.23a	22.1ab	30.8a	4.55a	8.54a	14.72a	0.61a	2.03a	5.94a
M300	0.64a	1.347a	2.29a	20.6a	22.83ab	33.17a	4.56a	9.77a	11.85a	0.90a	2.07a	3.86bc
M200	0.53a	0.90a	1.95a	24.07a	16.43b	30.5a	3.31a	6.73a	11.99a	0.61a	2.46a	4.49b

Key, L-Large nut size, M-Medium nut size, MI, M2, M3-I,2,3Months Respectively, LW-leaf weight, TRL-Taproot length, FSW-Fresh shoot weight, FRW-Fresh root weight, g-gram, cm-centimeter

Table 4. Watering effect on, cashew seedling DSW, DRW, and Root Hair (Rh) at 1, 2 and 3 months of harvest

TRT	M1 DSW(g)	M2 DSW(g)	M3 DSW(g)	M1 DRW(g)	M2 DRW(g)	M3 DRW(g)	M1 Rh	M2 Rh	M1 Rh
L300	0.92a	2.1a	4.00a	0.29a	0.78a	1.07b	1.0a	2.33a	3.0a
L200	1.22a	2.05a	4.13a	0.29a	0.55a	1.91a	1.33a	1.67b	3.0a
M300	1.11a	2.13a	3.89a	0.34a	0.56a	1.32ab	1.33a	2ab	2.67a
M200	1.09a	1.48a	3.74a	0.35a	0.46a	1.18b	1.0a	1.33b	2.33a

Key, L-Large nut size, M-Medium nut size, MI, M2, M3-I,2,3Months Respectively, DSW- Dry shoot weight, Dry root weight, Rh-Root hair, g-gram.

The present findings indicate that in terms of the leave weight (LW), either 200 or 300ml of water application rate greatly increased LW but 200ml of water application is superfluous from the medium size seedlings (Table 3). On the order hand, the Cashew large nut seedlings were able to utilize 300ml water application significantly at two and three months of harvest to enhance his taproot length growth (TRL). Although not significantly, the greatest TRL was produced in the medium cashew nut seedlings, having a larger mean value when compared to the large nut sizes used in this study. Nippert and Holdo [35] work is justified to that obtained from this study as he reported that the root depth distribution and accessibility of water may be a function of its depth was in line to this study (Table 3). Understanding the water use dynamic of the fresh shoot, and fresh root weight of cashew seedlings may provide information about the water requirement at different growing months. The results of the fresh shoot weight from the cashew nut sizes were not significantly enhanced after the different periodically harvest, but the application of 300ml of water applied to the medium cashew nut sizes was maximum in producing higher value when compared to the large cashew nut seedlings. Table 3 also shows that the medium cashew nut seedlings appropriately use 200ml water better than the large cashew nuts to sustain and develop healthy root system that grows in length. This corroborated the fact that root serves as carrier organs use to obtain resources. Moreso [36] according to their works stated that differences in water use cannot simply be equated with differences in plant growth but as a plant growth meditator [37] and [38] reported the plant roots through the process of water uptake is a mediator of the soil and water conservation in it.

Table 4 shows that the watering rates did not influence the dry shoot weight (DSW) of both large and medium cashew seedlings all through the period of observation. Notable differences in dry root weight (DRW) were only observed at third month of harvest (M3) with the large cashew seedlings that received 200 ml watering rate having a higher weight of 1.91g than its 200ml counterpart with 300ml watering rate. while no significant difference was observed among the medium biotypes though 300 ml application rate produced higher DRW than 200 ml application. A similarity between the shoot and root dry weight existed in this study (Table 4) the two different cashew nut sizes and different amount of water (200 and 300ml) application was not significant. This may be attributed to the soil used or that the soil had a good water structured capacity that allowed effective functioning of both the shoot and the root on the seedling's development. The proportion of root hair mass growth acted statistically in a similar growth pattern in respective to the rate of water application and the cashew nut sizes at M3 after sowing. However, the root hair grows vigorously in the middle cashew nuts (Table 4) that received 300ml of water when compared to the large cashew nuts seedlings of other watering rate.

4. CONCLUSION

This study tested two cashew nuts biotype to two levels of water applications. The morphology growth pattern was good irrespective of the cashew nuts sizes and the amount of water used. The large biotype cashew seedling emergence was improved with the application of a 300ml watering rate while the rate produced the same result as 200ml for the medium biotype cashew seedlings. The study reveals that water management plays a crucial role in the growth pattern distribution of cashew seedlings. Growth traits such as plant height, leaf number, leaf area and stem diameter showed improvement with increased water supply of 300ml than 200ml. For the root traits, only the fresh and dry root weights of large biotype cashew seedlings were positively improved under the 200ml watering rate, suggesting a potential adaptation mechanism to optimize water use efficiently. The medium cashew biotype seedlings at both 300ml and 200ml watering rates did not influence any improvement of the root traits. It could also be said that the different biotypes respond variably to water availability. Root growth is consistently longer with the medium nuts having 300ml of water at the first month of harvest, this may be attributed that a smaller nut size may have limited capacity to acquire water but or water will be expected more to for cashew seedling growth as the months in the nursery progresses. The water management for cashew large nut should be bestowed with higher watering rate and the actual water requirement for the different cashew nut sizes developed. It is also important to consider the root depth distribution of the seedlings down the soil profile in the polybags. Moreso, the choice of the rate of water requirement may differ with different size of bags. Thus, it becomes necessary to study tap root distribution and its relationship to vary water applications on the soil properties and the volumetric content in a nursery management. From this study, it could be said that tailored water management strategies in optimizing both root and shoot development in cashew seedlings are critical for enhancing their resilience to water scarcity, particularly in regions facing climate change-induced water challenges.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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