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Pawar NR
Assistant Professor, College of Horticulture, Mulde, Dr. Babasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Dalvi NV
College of Horticulture, Mulde, Dr. Babasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Jagtap DN
College of Horticulture, Mulde, Dr. Babasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Nikam RD
College of Horticulture, Mulde, Dr. Babasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Haladavnekar PC
College of Horticulture, Mulde, Dr. Babasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Corresponding Author:
Pawar NR
Assistant Professor, College of Horticulture, Mulde, Dr. Babasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Effect of shade intensity on root development, biomass accumulation (fresh and dry weight), and survival percentage of ornamental foliage plants

Pawar NR, Dalvi NV, Jagtap DN, Nikam RD and Haladavnekar PC

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Abstract
Shade intensity is one of the most important environmental factors influencing the growth and establishment of ornamental foliage plants. This study evaluated the effect of different shade intensities on root development, biomass accumulation (fresh and dry weight), and survival percentage of selected ornamental foliage plants. The experiment was conducted under varying shade levels (e.g., 25%, 50%, and 75% shade, full sunlight) using a Split Plot Design with appropriate replications. Growth parameters, including root length, root volume, fresh and dry biomass of roots and shoots, and plant survival percentage, were recorded and analyzed statistically. The results indicated that moderate shade (approximately 50%) significantly enhanced root development, biomass accumulation, and plant survival compared to full sunlight and heavy shade treatments. Plants grown under excessive shade exhibited reduced biomass production due to limited photosynthetic activity, whereas plants under full sunlight experienced stress, resulting in lower survival and poorer root growth. Moderate shading provided favorable microclimatic conditions by reducing heat and water stress while maintaining adequate light for photosynthesis. The findings suggest that optimizing shade intensity is essential for improving the growth, quality, and survival of ornamental foliage plants in nursery production. These results provide practical recommendations for nursery managers and commercial growers to enhance plant performance and production efficiency.

Keywords: Growth parameters, Ornamental foliage plants, Shade intensity

Introduction
Shade intensity is one of the most important environmental factors influencing the growth, development, and quality of ornamental foliage plants. Light regulates several physiological and biochemical processes, including photosynthesis, respiration, transpiration, and nutrient uptake, all of which directly affect plant growth. Since many ornamental foliage plants are naturally adapted to the shaded understory of tropical forests, providing an optimum level of shade is essential for maximizing their vegetative growth and aesthetic value.

Root development is a key indicator of plant establishment and overall health. A well-developed root system enhances water and nutrient absorption, improves anchorage, and increases the plant's ability to tolerate environmental stress. Shade intensity can significantly influence root growth by altering the availability of photosynthates that are transported from leaves to roots.

Excessive shade may reduce carbohydrate production, resulting in poor root growth, whereas moderate shade often promotes balanced shoot and root development in shade-loving ornamental species.

Biomass accumulation, expressed as fresh weight and dry weight, is another important measure of plant growth. Fresh weight reflects the water content and succulence of plant tissues, while dry weight represents the actual accumulation of organic matter produced through photosynthesis. The amount of light available to plants directly affects biomass production, as it determines the rate of photosynthesis and the partitioning of assimilates among different plant organs. Appropriate shade levels can therefore improve both fresh and dry biomass, while excessive or insufficient light may adversely affect plant growth.

Survival percentage is an important parameter for evaluating the adaptability and successful establishment of ornamental foliage plants under different shade conditions.

Higher survival rates indicate that the environmental conditions are favorable for plant growth and maintenance. Suitable shade levels reduce heat stress, minimize water loss through transpiration, and create a more favorable microclimate, thereby improving plant survival. Conversely, excessive shading or exposure to intense sunlight may reduce plant vigor and increase mortality.

Therefore, evaluating the effect of different shade intensities on root development, biomass accumulation (fresh and dry weight), and survival percentage provides valuable information for identifying the optimum shade level required for the commercial production and maintenance of ornamental foliage plants. Such information is useful for nursery management, greenhouse cultivation, and landscape applications, ultimately contributing to improved plant quality and higher production efficiency.

During the last decades, due to increased air temperature and intensity of solar radiation caused by climate changes, an increasing area of crops is being grown under shading materials of various types. Nets are commonly used in agricultural crops for specific modification of sunlight, improving microenvironment, and providing physical protection. They not only decrease light quantity but also alters light quality to a varying extent and also change other environmental conditions (Smith *et al*., 11). Cut greens grown under different shade-net gave better performance in terms of plant height, number of leaves, number of branches, leaf area, number of roots, etc. compared to control. Nettings, regardless of colour, reduce radiation reaching crops underneath which is directly proportional to the shade factor and modify microenvironment. Keeping these facts in view the present study was undertaken to observe the production and quality of dracaena under different colour shade-nets.

Cut greens are an important component of the floricultural industry and are largely used for decoration as a-filler in floral compositions. They provide freshness, colour and variety to various decorations, arrangements and bouquets. Foliage plants are one of the important cut greens and are used widely for its beautiful foliage. Nets are commonly used in agricultural crops for specific modification of sunlight, improving microenvironment, and providing physical protection. They not only decrease light quantity but also alters light quality to a varying extent and also change another environment. Nets have three major uses in horticulture (i) shading, for protection from too much solar radiation; (ii) protection from environmental hazards such as strong winds, hail and sand storms; (iii) protection from flying pests like birds, fruit bats, etc. Study the effect of different shade levels on the growth and biomass production potential of Cactus (*Opuntia ficus* (L.) Mill.) under the arid Kachchh, Gujarat. Cactus in pots were grown for twelve months under 25, 50 and 75% shade; along with under full sun control.

Shade level significantly affected plant response; the shading improved plant characters like height, number of leaves, leaf area, and overall plant weight. However, plant survival decreases at under high shade level (75%), mainly due to rotting. The plants grown in 25% and 50% shade levels produced the highest leaf area, no. of leaves and biomass than plants subjected

to 75% shade and control. Plants grown under 75% shade level were taller, due to more longitudinal and less wide leaves (cladodes) along with more root length. Overall, up to 50% shading was found best for horti-based or agroforestry-based cactus pear cultivation or intercropping. (Dev *et al*., 2018) [7]

- To find out the effect of shade conditions on sprouting.
- To find out the effect of shade conditions on growth performance of ornamental foliage plants.
- To find out optimum shade conditions for foliage plants.

Methodology

The field experiment was conducted at College of Horticulture, Mulde for successive three years (2020-2023) and laid out in Split plot design along with 4 green colour shade net conditions (main treatments) and 06 woody foliage plants (sub treatments) and replicated twice. The object of field experiment was to optimize the shade net intensities for better growth performance of ornamental plants. The observations on sprouting and growth parameters were recorded. The experiment was carried out during Year 2020-21, 2021-22, 2022-23. The experiment carried out in Split Plot Design with two replications. Main plot treatments consist of four different Shade conditions viz., 25% Shade net, 50% Shade net, 75% Shade net and Control, while Sub plot Treatments consists of six different Foliage plants viz., Red Acalypha, Green Acalypha, Malphigia, Arelia, Croton and Coleus. There were 24 treatment combinations.

Result and Discussion

Fresh weight (g)

It is revealed from Table 1 that fresh weight of different woody foliage plants was varied significantly among different shade conditions. In case of shade conditions significantly highest fresh weight was observed in M_3 - 75% (0.67 g) shade condition. Lowest fresh height observed in M_4- (0.53 g) open condition. Among different woody plants, significantly the highest fresh weight (1.32 g) was noticed in P_5 (croton), while the lowest fresh weight observed in P_3 (malphigia). In case of interaction effect significantly highest fresh weight (1.47 g) was recorded with croton under 50% shade condition. Whereas, significantly lowest fresh weight (0.04) was recorded with malphigia under 25% shade condition open condition it was at par with M_2P_3, M_3P_3 and M_4P_3.

Dry weight (g)

However, it is revealed from Table 2 that dry weight of different woody foliage plants was varied significantly among different shade conditions. In case of shade conditions highest dry weight was observed in M_3 - (0.19 g) 75% shade conditions. Lowest dry weight observed in M_4- (0.11 g) control. Among different woody foliage plants, significantly the highest dry weight (0.35 g) was noticed in P_5 (croton), while the lowest dry weight observed in P_3 (malphigia). In case of interaction effect significantly highest dry weight (0.46 g) was recorded with croton under 75% shade condition. Whereas, significantly lowest dry weight (0.01) was recorded with malphigia under 25% shade condition open condition it was at par with M_2P_3, M_3P_3 and M_4P_3.

Number of roots

It is noticed from Table 3 that numbers of roots of different woody foliage plants were varied significantly among

different shade conditions. In case of shade conditions significantly the highest number of roots (40.34) observed in 50% shade condition. Lowest numbers of roots observed in M_4- (25.93) open condition. Among in different woody foliage plants, significantly the highest number of roots (46.67) was noticed in P_6 (coleus), while the lowest numbers of roots observed in P_2 green acalypha (17.30). In case of interaction effect significantly maximum number of roots (62.48) was recorded with coleus under 50% shade condition. Whereas significantly minimum number of roots per plant was recorded with green acalypha under open condition.

Length of root (cm)

It is noticed from Table 4 that length of roots of different woody foliage plants were varied significantly among different shade conditions. In case of shade conditions on significantly the highest length of roots (42.52 cm) was observed in M_2 - 50% shade condition and was superior over all. Lowest root length observed in M_4- (25.39 cm) open condition. Among different woody foliage plants, significantly the highest length of roots (41.34 cm) was noticed in P_2 (green acalypha), while the lowest root length observed in P_5 (croton). In case of interaction effect significantly maximum length of roots (58.37 cm) was recorded with green acalypha under 50% shade condition. Whereas, significantly minimum length of roots per plant (16.13 cm) was recorded with coleus under 75 % shade condition which was at par with coleus under open condition.

Survival (%)

It is noticed from Table 5 that survival (%) of different woody foliage plants were varied significantly among different shade conditions. In case of shade conditions significantly the highest survival was observed in M_2 - 50% (97.92 %) shade intensities and was superior over all. Lowest survival observed in M_4- (81.17%) open condition. Among in different woody foliage plants significantly the highest survival (91.63 %) was noticed in P_1 (red acalypha) it was at par with P_6. while the lowest survival observed in P_2 (green acalypha) it was at par with P_4, P_3 and P_5. In case of interaction effect non significantly maximum survival % (99 %) was recorded with arelia, croton and coleus under 50% shade condition. Whereas, significantly minimum survival % (82%) was recorded with green acalypha under open condition it was at par with red acalypha under open condition.

Table 1: Effect of different shade conditions on fresh weight (g) in woody foliage plants (at the end of one year)

Treat	Fresh weight (g)																			
Orn. Plnts	Year 2020-21					Year 2021-22					Year 2022-23					Pooled				
	Shade condition					Shade condition					Shade condition					Shade condition				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
P_1	0.53	0.44	0.54	0.69	0.55	0.40	0.51	0.80	0.36	0.52	0.47	0.60	0.82	0.36	0.56	0.47	0.51	0.72	0.47	0.54
P_2	0.42	0.76	0.65	0.44	0.56	0.63	0.58	0.67	0.33	0.55	0.76	0.69	0.68	0.38	0.63	0.60	0.68	0.66	0.38	0.58
P_3	0.05	0.06	0.09	0.03	0.05	0.04	0.05	0.04	0.10	0.05	0.04	0.04	0.04	0.11	0.06	0.04	0.05	0.06	0.08	0.06
P_4	0.67	0.80	0.65	0.24	0.59	0.86	0.65	0.53	0.47	0.62	0.88	0.58	0.53	0.74	0.68	0.80	0.67	0.57	0.48	0.63
P_5	1.37	1.30	1.54	0.93	1.28	1.28	1.51	1.10	1.37	1.31	1.29	1.60	1.09	1.45	1.36	1.31	1.47	1.24	1.25	1.32
P_6	0.44	0.44	0.43	0.64	0.49	0.48	0.47	0.96	0.42	0.58	0.37	0.48	0.97	0.46	0.57	0.43	0.46	0.78	0.50	0.54
Mean	0.58	0.63	0.65	0.49		0.61	0.62	0.68	0.51		0.63	0.66	0.69	0.58		0.61	0.64	0.67	0.53	
	M	P	MXP	M	P	MXP	M	P	MXP	M	P	M×P								
F test	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG								
SEm (±)	0.007	0.017	0.034	0.001	0.016	0.032	0.004	0.013	0.025	0.005	0.012	0.023								
CD @ 5%	0.021	0.051	0.102	0.003	0.048	0.096	0.012	0.039	0.075	0.015	0.036	0.069								

Shade conditions:
M_1 - 25% shade net, **M_2** - 50% shade net,
M_3 - 75% shade net, **M_4** - Control

Ornamental plants:
P_1- Red Acalypha **P_2**- Green Acalypha
P_3- Malphigia **P_4**- Arelia
P_5- Croton **P_6**- Coleus

Table 2: Effect of different shade conditions on dry weight (g) in ornamental foliage plants (at the end of one year)

Treat	Dry weight (g)																			
Orn. Plnts	Year 2020-21					Year 2021-22					Year 2022-23					Pooled				
	Shade condition					Shade condition					Shade condition					Shade condition				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
P_1	0.13	0.12	0.17	0.06	0.12	0.20	0.14	0.18	0.08	0.15	0.17	0.20	0.19	0.09	0.16	0.16	0.15	0.18	0.07	0.14
P_2	0.11	0.20	0.21	0.07	0.15	0.11	0.21	0.22	0.03	0.14	0.16	0.21	0.22	0.08	0.17	0.13	0.21	0.21	0.06	0.15
P_3	0.02	0.02	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.01	0.03	0.01	0.01	0.04	0.01	0.02
P_4	0.02	0.17	0.13	0.14	0.11	0.02	0.16	0.15	0.13	0.12	0.03	0.18	0.20	0.16	0.14	0.02	0.17	0.16	0.14	0.12
P_5	0.30	0.29	0.43	0.29	0.33	0.30	0.30	0.47	0.38	0.36	0.31	0.28	0.48	0.33	0.35	0.30	0.29	0.46	0.33	0.35
P_6	0.08	0.06	0.06	0.03	0.06	0.07	0.05	0.06	0.03	0.05	0.08	0.07	0.09	0.04	0.07	0.08	0.06	0.07	0.03	0.06
Mean	0.11	0.14	0.17	0.10		0.12	0.15	0.18	0.11		0.13	0.16	0.21	0.12		0.12	0.15	0.19	0.11	
	M	P	MXP	M	P	MXP	M	P	MXP	M	P	M×P								
F test	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG								
SEm (±)	0.008	0.005	0.009	0.001	0.004	0.009	0.005	0.007	0.014	0.004	0.004	0.008								
CD @ 5%	0.024	0.015	0.027	0.003	0.012	0.027	0.015	0.021	0.042	0.012	0.012	0.024								

Shade conditions:
M_1 - 25% shade net, M_2 - 50% shade net,
M_3 - 75% shade net, M_4 - Control

Ornamental plants:
P_1- Red Acalypha P_2- Green Acalypha
P_3- Malphigia P_4- Arelia
P_5- Croton P_6- Coleus

Table 3: Effect of different shade conditions on number of roots per cutting in woody foliage plants (at the end of one year)

Treat	Number of root per cutting																			
Orn. Plnts	Year 2020-21					Year 2021-22					Year 2022-23					Pooled				
	Shade condition					Shade condition					Shade condition					Shade condition				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
P_1	22.51	25.61	16.32	14.02	19.61	14.66	31.39	22.14	12.05	20.06	12.70	27.40	23.58	12.40	19.02	16.62	28.13	20.68	12.82	19.56
P_2	19.32	19.85	15.42	15.85	17.61	13.15	20.41	17.60	13.92	16.27	12.60	27.01	18.25	14.30	18.04	15.02	22.42	17.09	14.69	17.30
P_3	15.73	31.04	30.51	30.70	26.99	28.69	29.91	33.10	25.32	29.25	28.60	30.10	17.60	25.70	25.50	24.34	30.35	27.07	27.24	27.25
P_4	31.55	56.44	44.91	41.81	43.68	43.30	55.88	32.96	29.93	40.52	43.00	55.60	32.90	38.30	42.45	39.28	55.97	36.92	36.68	42.21
P_5	27.59	40.97	40.41	15.65	31.15	37.51	41.09	28.95	27.38	33.73	40.00	46.09	29.50	28.50	36.02	35.03	42.72	32.95	23.84	33.64
P_6	36.25	61.43	52.33	47.03	49.26	50.37	63.42	35.42	40.01	47.30	41.00	62.60	36.30	33.93	43.46	42.54	62.48	41.35	40.32	46.67
Mean	25.49	39.22	33.32	27.51		31.28	40.35	28.36	24.77		29.65	41.47	26.35	25.52		28.81	40.34	29.34	25.93	
	M	P	MXP	M	P	MXP	M	P	MXP	M	P	M×P								
F test	NS	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG								
SEm (±)	2.20	1.58	3.16	0.69	1.21	2.41	0.38	0.50	0.99	0.73	0.86	1.71								
CD @ 5%	6.60	4.74	9.48	2.07	3.63	7.23	1.34	1.50	2.97	2.19	2.58	5.13								

Shade conditions:
M_1 - 25% shade net, M_2 - 50% shade net,
M_3 - 75% shade net, M_4 - Control

Ornamental plants:
P_1- Red Acalypha P_2- Green Acalypha
P_3- Malphigia P_4- Arelia
P_5- Croton P_6- Coleus

Table 4: Effect of different shade conditions on length of longest roots (cm) in woody foliage plants (at the end of one year)

Treat	Length of longest roots (cm)																			
Orn. Plnts	Year 2020-21					Year 2021-22					Year 2022-23					Pooled				
	Shade condition					Shade condition					Shade condition					Shade condition				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
P_1	39.17	40.87	26.68	28.92	33.91	29.51	41.01	26.70	32.59	32.45	32.76	41.76	21.13	28.98	31.16	33.81	41.21	24.83	30.16	32.51
P_2	35.52	58.74	36.25	33.33	40.96	43.80	58.05	38.17	33.44	43.36	33.65	58.31	34.42	32.41	39.70	37.66	58.37	36.28	33.06	41.34
P_3	29.01	34.39	27.26	25.44	29.02	25.32	33.18	27.27	25.34	27.78	29.43	44.13	28.21	24.69	31.61	27.92	37.23	27.58	25.15	29.47
P_4	32.52	44.45	38.89	28.15	36.00	27.92	44.46	36.93	28.51	34.45	42.72	44.75	37.21	28.05	38.18	34.39	44.55	37.68	28.23	36.21
P_5	20.61	28.14	28.06	20.06	24.22	17.66	30.07	25.86	17.23	22.70	20.11	28.92	25.68	20.56	23.82	19.46	29.04	26.53	19.28	23.58
P_6	28.73	42.86	17.54	18.15	26.82	27.68	48.92	13.19	9.59	24.84	27.92	42.44	17.65	21.59	27.40	28.11	44.74	16.13	16.44	26.35
Mean	30.93	41.57	29.11	25.67		28.65	42.61	28.02	24.45		31.10	43.38	27.38	26.05		30.22	42.52	28.17	25.39	
	M	P	MXP	M	P	MXP	M	P	MXP	M	P	M×P								
F test	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG	SIG								
SEm (±)	0.70	0.78	1.56	0.75	0.83	1.65	0.24	0.59	1.18	0.25	0.50	1.00								
CD @ 5%	2.10	2.34	4.68	2.25	2.48	4.96	0.72	1.77	3.54	0.75	1.50	3.00								

Shade conditions:
M_1 - 25% shade net, **M_2** - 50% shade net,
M_3 - 75% shade net, **M_4** - Control

Ornamental plants:
P_1- Red Acalypha **P_2**- Green Acalypha
P_3- Malphigia **P_4**- Arelia
P_5- Croton **P_6**- Coleus

Table 5: Effect of different shade conditions on survival (%) in woody foliage plants (at the end of one year)

Treat	Survival (%)																			
Orn. Plnts	Year 2020-21					Year 2021-22					Year 2022-23					Pooled				
	Shade condition					Shade condition					Shade condition					Shade condition				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
P_1	93.00	99.50	85.50	82.50	90.13	98.50	97.50	86.00	82.50	91.13	99.50	100.00	92.50	82.50	93.63	97.00	99.00	88.00	82.50	91.63
P_2	89.00	99.00	83.50	82.00	88.38	88.00	98.00	82.50	69.00	84.38	90.00	97.50	85.50	83.50	89.13	89.00	98.17	83.83	78.17	87.29
P_3	87.00	98.50	83.50	76.00	86.25	87.50	98.00	84.00	87.50	89.25	86.00	96.00	84.00	87.00	88.25	86.83	97.50	83.83	83.50	87.92
P_4	91.00	99.00	85.00	76.00	87.75	91.00	97.50	82.50	83.50	88.63	92.00	95.00	83.00	76.00	86.50	91.33	97.17	83.50	78.50	87.63
P_5	90.00	97.50	86.50	81.50	88.88	88.00	99.00	84.50	77.50	87.25	91.00	98.50	86.00	86.00	90.38	89.67	98.33	85.67	81.67	88.83
P_6	91.00	100.00	86.50	83.00	90.13	93.50	97.50	85.50	87.50	91.00	94.00	94.50	88.00	77.50	88.50	92.83	97.33	86.67	82.67	89.88
Mean	90.17	98.92	85.08	80.17		91.08	97.92	84.17	81.25		92.08	96.92	86.50	82.08		91.11	97.92	85.25	81.17	
	M	P	MXP	M	P	MXP	M	P	MXP	M	P	M×P								
F test	SIG	SIG	NS	SIG	N S	NS	SIG	SIG	SIG	SIG	SIG	NS								
SEm (±)	0.76	0.73	1.47	0.64	1.81	3.62	0.39	0.84	1.67	0.40	0.67	1.33								
CD @ 5%	2.28	2.19	4.41	1.92	5.43	10.86	1.17	2.52	5.01	1.20	2.01	3.99								

Shade conditions:
M_1 - 25% shade net, **M_2** - 50% shade net,
M_3 - 75% shade net, **M_4** - Control

Ornamental plants:
P_1- Red Acalypha **P_2**- Green Acalypha
P_3- Malphigia **P_4**- Arelia
P_5- Croton **P_6**- Coleus

Table 6: Average light intensity from during the Experimental period

Treatment	Morning light intensity (Lux)	Afternoon light intensity (Lux)	Evening light intensity (Lux)	Mean (Day)
Control	5531	122207	14784	47507
25% shade	4975	83464	8159	32199
50% shade	3806	58750	7447	23334
75% shade	3105	19637	4870	9204

Conclusion

It can be concluded that different woody ornamental foliage plants exhibited superior overall growth performance under M_2 (50% shade) compared with the other shade treatments. Plants grown under 50% shade showed better root development, higher fresh and dry biomass accumulation, and improved survival percentage, indicating that this shade level provided the most favorable microclimatic conditions for growth. The M_1 (25% shade) treatment ranked second in terms of overall performance, while the remaining shade levels were comparatively less effective. Therefore, 50% shade can be recommended as the optimum shade intensity for the cultivation and production of woody ornamental foliage plants, as it promotes vigorous growth, greater biomass production, and higher survival, ultimately improving plant quality and nursery production efficiency.

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