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Effect of Seed Size and Sowing Depth on the Growth Parameters of Soapnut (*Sapindus mukorossi* Gaertn) at Different Time Intervals under Treatment with Different Organic Manures Doses

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ABSTRACT

The seeds of *Sapindus mukorossi* were collected from trees with the ideal phenotypical characters of good height, large crown and medium aged with abundant seed production. The seeds based on their diameter were graded into three classes i.e., small (L_1) (<1.2 cm), medium (L_2) (1.2-1.4 cm) and large (L_3) (>1.4 cm). Graded seeds were sown at two depths viz., 1.0 cm (D_1) and 1.5 cm (D_2) and were applied with control (M_1), vermicompost @ 5 t/ha (M_2) and vermicompost @ 10 t/ha (M_3), FYM @ 5 t/ha (M_4) and FYM @ 10 t/ha (M_5). The growth parameter of soapnut was observed at monthly intervals of 30, 60, 90 and 120 days after sowing. The growth and seedling biomass parameter like shoot length, root length seedling height, collar diameter; number of lateral roots, shoot dry weight, root dry weight and total biomass were significantly related to seed size, sowing depth and application of different organic manure doses. Among seed size categories, large seed (L_3) produced higher shoot length (2.34cm) (15.35 cm) (21.49 cm) (26.68 cm), root length (1.87 cm) (10.00 cm) (15.09 cm), (18.28 cm), collar diameter (1.28 mm) (3.10 mm) (3.67 mm) (4.64 mm), seedling height (4.21 cm) (25.35 cm) (44.97 cm) (36.58 cm) and number of lateral roots (5.37) (30.17) (43.03) (63.03). Among sowing depths, D_1 showed better shoot length (1.27cm) (13.40 cm) (19.50 cm) (24.53 cm), root length (1.00 cm) (8.76 cm) (13.14 cm) (16.35 cm), collar diameter (0.82 mm) (2.89 mm) (3.46 mm) (4.29 mm), seedling height (2.27cm) (22.16cm) D_1 (32.64 cm) (40.88 cm) and number of lateral roots (3.09) (24.80) (41.00) (54.71) as compared to D_2. Among organic manures doses, M3 showed better shoot length (26.44 cm) (15.50 cm) (21.41 cm) (1.31cm), root length (0.99 cm) (9.70 cm) (14.31 cm) (17.36 cm), collar diameter (0.83 mm) (3.10 mm) (3.65 mm) (4.50 mm), seedling height (2.29cm) (25.20 cm) (35.72 cm) (43.91 cm) and number of lateral roots (3.56) (27.44) (42.17) (57.67). The effectiveness of organic manures was in the order of vermicompost @10 t/ha > FYM @ 10t/ha > vermicompost @ 5 t/ha > FYM @ 5t/ha > control (no manure) and other hand, interactions viz. M×D, L×D and M×L×D were found to be non-significant.

Keywords Graded seeds, Seedling biomass, Sowing depth, Organic manures, Vermicompost.

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INTRODUCTION

Sapindus mukorossi or soapnut tree (Ritha) is an important MPTs of north India, belongs to family Sapindaceae. The tree is native to China and Japan and much more cultivated in North India, in the moister tracts along the foot of Himalayas from *ravi* eastwards upto 1500 m elevation. The tree is also found wild in the valleys of north-western Himalayas, Assam and West Bengal (Upadhyay and Singh 2012). The tree is cultivated in many parts of India as ornamental and for its saponaceous fruits. *Sapindus mukorossi* is a moderate sized deciduous tree. It has a spreading crown and short clean bole attaining a height of about 20 m. The fruits are collected from the trees during winter months for seeds and or sale in the market as soapnut. The seeds retain their viability for one to two years. Occasionally, the tree come up from the self sown seeds and can also be raised artificially by direct sowings or by transplanting the nursery raised seedlings. The dried fruit of *S. mukorossi* has a soapy texture because of the presence of saponins and has traditionally been used to prepare Ayurvedic shampoos, detergents and hand wash for its bio surfactant activity (Bahar and Singh 2007). In addition, *S. mukorossi* is reported to have various pharmacological properties such as anticancer, anti-inflammatory, antiparasitic, antiviral, antifungal and antibacterial activities (Shah *et al.* 2017). Traditionally, powdered seed of *S. mukorossi* was utilized in the treatment of dental carries, common cold and nausea (Shah *et al.* 2017).

Among various factors responsible for successful plantation program, use of quality seeds in terms of genetic and physical attributes is of paramount importance. The seed size have been found to have a marked bearing on the quality of the nursery stock in numerous species and *Sapindus mukorossi* need not necessarily provide an exception to this. It is therefore, worthwhile to determine the optimum seed size for improving the physical quality of the seedlings/ growing stock. Sowing of seeds at proper depth is essential for the successful seedling emergence and subsequent growth because of difference in the micro-environments at various soil depths. Seeds must be well covered with soil in nursery to avoid damage by heat or desiccation and to avoid washing away by showers or watering (Azad *et al.* 2011). Chima *et al.* (2018) stated that seeds must be sown at a depth of twice to the diameter of seeds for longer seeds (1.5 -2 cm) and four times to diameter of small seeds (<1.5 cm). The seedling biomass of any crop is the result of available nutrients during the seedling growth period and these nutrients can be supplied either by chemical fertilizers, organic manures or some other means. It has been seen that intensive and continuous use of chemical fertilizer posed a serious threat to the environment and led to residual effect in the food product. Organic farming is best way to attain sustainable growth and productivity by taking care of quality of produce, which is considered imperative for human and animal health.

Organic fertilizers are 'naturally' occurring compounds manufactured through natural process (such as composting) or naturally occurring mineral deposits. Manure promotes plant growth, provides nutritious food to soil organisms, adds genetic and functional diversity to soils and improves the chemical and physical soil properties. Koninger *et al.* (2021). These include farm yard manure, vermicompost, enriched manure, biofertilizer, green manures.

Sapindus mukorossi importance lies in the sale of fruits, which are mainly sold in the local market. A number of farmers are earning livelihood by marketing and selling the fruits from their planted trees. As the domestication and cultivation started the demand for quality seedling during planting time is very high. But low, delayed and uneven germination has created problem in raising seedling in nursery. The application of organic manures as soil supplement may improve the performance of this species but knowledge and information about the response of this species to organic manures are scarce. Therefore, in consideration of this, it is important to understand the effect of interaction between and among the variables of seed sizes, sowing depths and organic manures so as to develop strategy for better approach to cultivation and sustained benefits.

MATERIALS AND METHODS

The selection of trees was based on the ideal phenotypical characters of good height, large crown, and medium aged trees with abundant seed production. The seeds of *Sapindus mukorossi* were collected from the three districts of Himachal Pradesh viz., Sirmour, Solan and Kullu. The experiments related to seeds and nursery technology of *Sapindus mukorossi* were conducted in nursery area of the university, respectively. Experimental field was prepared by ploughing the field twice and made smooth by harrowing followed by planking during January-February. The plots were prepared to accommodate all the treatments. The sunken nursery beds (1m x 1m) were prepared in the nursery area. Sowing was done during the month of March. Before sowing, the seeds based on their diameter were graded into three classes i.e. small (L_1) (<1.2 cm), medium (L_2) (1.2-1.4 cm) and large (L_3) (>1.4 cm). Seeds of *S. mukorossi* were sown at two different depths S_1 (1.00 cm) and S_2 (1.5 cm) for raising seedlings. Nursery beds were kept moist by sprinkling water and kept free from weeds. Organic manures viz., FYM and vermicompost were applied to all the plots except control. Five different doses of organic manures viz., without manure (M_1) (control), Vermicompost (5 t/ha) (M_2), Vermicompost (10 t/ha) (M_3), FYM (5t/ha) (M_4) and FYM (10t/ha) (M_5) were applied to respective plots. The following growth and seedling biomass were recorded in nursery condition. Five randomly selected seedlings per replication were carefully uprooted without breaking the roots and observations were taken at an interval of 30, 60, 90, 120 days after sowing.

Shoot length (cm): It was measured with the help of meter scale from leading shoot tip to the collar region of the seedling at ground surface.

Root length (cm): The length of tap root was recorded in centimeters using measuring scale by placing it horizontally on the ground.

Collar diameter (mm): Collar diameter of the seedling was measured in millimeters (mm) by using digital vernier calliper.

Seedling height (cm): Seedling height was recorded in centimeters using a scale from root tip to the top/ tip of stem.

Seedling height = Shoot length + Root length

Number of roots / seedling: After washing the seedling thoroughly each fibrous root was counted.

RESULTS AND DISCUSSION

Shoot length (cm)

Shoot length was recorded at monthly intervals of 30, 60, 90 and 120 days after sowing and the respective data presented in Table 1. The contents of the table revealed that at an interval of 30 days in seed size categories, maximum shoot length was recorded in L_3 (2.34cm) and there was no measurable shoot length in small seed category (L_1). Irrespective of seed size and doses of organic manure, sowing depth D_1 recorded significantly better shoot length of 1.27cm than D_2 (1.09cm). Among organic manure doses maximum shoot length was recorded in M_3 (1.31cm) which was statistically at par with M_5 (1.24 cm) while minimum shoot length was recorded in M_1 (1.03cm). Among cumulative effect of seed size and sowing depth (L×D), maximum shoot length was recorded in D_1L_3 (2.48cm) while there was no measurable shoot length

Table 1. Effect of seed size, sowing depth and organic manures (doses) on shoot length (cm) of *Sapindus mukorossi* at different time intervals under nursery condition.

Category	30 DAS											
	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	0.00	0.97	2.27	1.08	0.00	0.9	2.03	0.98	0.00	0.93	2.15	1.03
M_2	0.00	1.33	2.40	1.24	0.00	1.07	2.20	1.09	0.00	1.20	2.30	1.17
M_3	0.00	1.60	2.63	1.41	0.00	1.23	2.37	1.20	0.00	1.42	2.50	1.31
M_4	0.00	1.23	2.57	1.27	0.00	1.03	2.13	1.06	0.00	1.13	2.35	1.16
M_5	0.00	1.53	2.53	1.36	0.00	1.13	2.27	1.13	0.00	1.33	2.40	1.24
Mean	0.00	1.33	2.48	1.27	0.00	1.07	2.20	1.09	0.00	1.20	2.34	-

CD (0.05)	Seed size (L)	Depth (D)	LxD	Doses (M)	MxD	MxL	MxLxD
	0.06	0.05	0.8	0.08	NS	0.13	NS

Table 1. Continued.

Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
	60 DAS											
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	7.70	11.37	12.97	10.68	6.97	10.50	12.28	9.91	7.33	10.93	12.62	10.30
M_2	10.92	13.97	15.66	13.52	10.10	13.12	14.92	12.71	10.51	13.55	15.29	13.12
M_3	13.41	16.20	18.91	16.17	12.24	15.00	17.26	14.84	12.83	15.60	18.09	15.50
M_4	9.61	12.77	14.37	12.25	8.96	11.90	13.70	11.52	9.29	12.33	14.03	11.88
M_5	11.64	14.33	17.18	14.39	10.85	13.48	16.24	13.52	11.25	13.91	16.71	13.95
Mean	10.66	13.73	15.82	13.40	9.82	12.80	14.88	12.50	10.24	13.26	15.35	-

CD (0.05)	Seed size (L)	Depth (D)	LxD	Doses (M)	MxD	MxL	MxLxD
	0.22	0.18	NS	0.28	NS	0.48	NS

Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
	90 DAS											
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	14.08	17.48	18.93	16.83	13.48	16.65	18.22	16.12	13.78	17.07	18.58	16.47
M_2	17.02	20.13	21.88	19.68	16.33	19.36	21.09	18.93	16.68	19.75	21.48	19.30
M_3	18.97	21.98	24.99	21.98	18.18	20.85	23.49	20.84	18.57	21.41	24.24	21.41
M_4	15.79	18.94	20.78	18.50	15.18	18.12	19.82	17.71	15.49	18.53	20.30	18.11
M_5	17.80	20.44	23.29	20.51	16.93	19.63	22.38	19.65	17.37	20.04	22.83	20.08
Mean	16.73	19.79	21.97	19.50	16.02	18.92	21.00	18.65	16.38	19.36	21.49	

CD (0.05)	Seed size (L)	Depth (D)	LxD	Doses (M)	MxD	MxL	MxLxD
	0.12	0.1	NS	0.15	NS	0.26	NS

Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
	120 DAS											
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	18.81	22.68	24.32	21.94	18.31	21.87	23.67	21.28	18.56	22.27	23.99	21.61
M_2	21.89	25.33	26.97	24.73	21.16	24.54	26.29	24.00	21.52	24.94	26.63	24.36
M_3	23.90	26.85	29.91	26.88	23.12	26.08	28.81	26.00	23.51	26.46	29.36	26.44
M_4	20.61	24.12	25.74	23.49	20.06	23.32	25.01	22.80	20.34	23.72	25.38	23.15
M_5	22.65	25.64	28.52	25.6	21.87	24.82	27.59	24.76	22.26	25.23	28.05	25.18
Mean	21.57	24.92	27.09	24.53	20.90	24.13	26.27	23.77	21.24	24.53	26.68	

CD (0.05)	Seed size (L)	Depth (D)	LxD	Doses (M)	MxD	MxL	MxLxD
	0.18	0.14	NS	0.23	NS	0.39	NS

in D_1L_1 and D_2L_1. Whereas interactions between organic manure and seed size (M×L), maximum shoot length was recorded in M_3L_3 (2.50 cm) which was statistically at par with M_5L_3 (2.40 cm) while there was no measurable shoot length observed in M_1L_1, M_2L_1, M_3L_1, M_4L_1 and M_5L_1. While other interactions M×D and M×L×D were found to be non-significant.

At 60 days after sowing in seed size categories, maximum shoot length was observed in L_3 (15.35 cm) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (10.24 cm). Among two sowing depths, depth D_1 (13.40 cm) performed significantly better than D_2 (12.50 cm). In case of organic manure doses, maximum shoot length was recorded in M_3 (15.50 cm) which was significantly superior to all other organic manure doses while minimum shoot length was recorded in M_1 (10.30 cm). In combinations, treatment combination (M_3L_3) recorded highest shoot length (18.09 cm) which was significantly superior to all other combinations, while minimum was recorded in M_1L_1 (7.33 cm). Other interactions viz. M×D, L×D and M×L×D were found to be non-significant.

At an interval of 90 days after seed sowing in seed size categories, maximum shoot length was observed in L_3 (21.49 cm) while minimum shoot length was recorded in L_1 (16.38 cm). Among sowing depths, D_1 (19.50 cm) performed significantly better than D_2 (18.65 cm) in terms of shoot length. Among various organic manure doses, maximum shoot length was recorded in M_3 (21.41 cm) which was significantly superior to all other organic manure doses while minimum shoot length (16.47cm) was recorded in M_1 (control). In cumulative effect of organic manure and seed size categories (M×L), maximum shoot length was recorded in M_3L_3 (24.24 cm) which was significantly superior to all other combinations while minimum shoot length was recorded in M_1L_1 (13.78 cm) combination. On other hand, other interactions viz. M×D, L×D and M×L×D were found to be non-significant.

In seed size categories maximum shoot length was observed in L_3 (26.68 cm) which was significantly superior to all other seed categories, after 120 days of sowing. Minimum shoot length was recorded in L_1 (21.24 cm). Among two sowing depths, D_1 (24.53 cm) performed significantly better than D_2 (23.77 cm). Among different organic manure doses, higher shoot length was recorded in M_3 (26.44 cm) which was significantly superior over other organic manure doses while minimum shoot length (21.61 cm) was recorded in M_1 (control). Interactions between organic manure and seed size categories (M×L) higher shoot length was recorded in treatment combination M_3L_3 with a value of 29.36 cm while minimum was recorded in M_1L_1 (18.56 cm). Other interactions viz. M×D, L×D and M×L×D were found to be non-significant.

Root length (cm)

Data on root length was recorded at intervals of 30, 60, 90 and 120 days after sowing and presented in Table 2. The contents of the table revealed that after 30 days of sowing, maximum root length was re-

Table 2. Effect of seed size, sowing depth and organic manures (doses) on root length (cm) of *Sapindus mukorossi* at different time intervals under nursery condition**.**

30 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	0.00	0.57	1.73	0.77	0.00	0.53	1.57	0.70	0.00	0.55	1.65	0.73
M_2	0.00	0.97	1.97	0.98	0.00	0.70	1.77	0.82	0.00	0.83	1.87	0.90
M_3	0.00	1.23	2.20	1.14	0.00	0.87	1.63	0.83	0.00	1.05	1.92	0.99
M_4	0.00	0.87	2.13	1.00	0.00	0.67	1.73	0.80	0.00	0.77	1.93	0.90
M_5	0.00	1.17	2.13	1.10	0.00	0.77	1.83	0.87	0.00	0.97	1.98	0.98
Mean	0.00	0.96	2.03	1.00	0.00	0.71	1.71	0.80	0.00	0.83	1.87	-

CD (0.05)	Seed size (L)	Depth (D)	LxD	Doses (M)	M×D	M×L	M×L×D
	0.07	0.06	0.1	0.09	NS	0.16	NS

60 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	6.13	7.52	8.53	7.40	5.30	6.48	7.52	6.43	5.72	7.00	8.03	6.92
M_2	6.89	8.89	10.23	8.67	5.73	7.91	9.22	7.62	6.31	8.40	9.73	8.15
M_3	7.99	9.98	12.72	10.23	7.25	8.75	11.50	9.16	7.62	9.36	12.11	9.70
M_4	6.92	7.95	9.51	8.13	5.46	6.97	8.56	6.99	6.19	7.46	9.03	7.56
M_5	7.33	9.27	11.56	9.39	7.29	8.32	10.62	8.74	7.31	8.80	11.09	9.07
Mean	7.05	8.72	10.51	8.76	6.20	7.69	9.49	7.79	6.63	8.20	10.00	-

Table 2. Continued.

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.16	0.13	NS	0.2	NS	0.35	NS

Category	90 DAS											
	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	9.13	11.49	12.84	11.15	8.57	10.68	12.58	10.61	8.85	11.08	12.71	10.88
M_2	10.52	13.66	15.40	13.19	9.85	12.88	14.60	12.44	10.19	13.27	15.00	12.82
M_3	12.00	14.67	17.67	14.78	11.16	13.88	16.51	13.85	11.58	14.27	17.09	14.31
M_4	9.81	12.99	14.80	12.53	9.21	12.13	13.83	11.73	9.51	12.56	14.32	12.13
M_5	11.32	13.96	16.81	14.03	10.45	13.16	15.89	13.17	10.89	13.56	16.35	13.60
Mean	10.56	13.35	15.50	13.14	9.85	12.54	14.68	12.36	10.20	12.95	15.09	-

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.1	0.08	NS	0.13	NS	0.23	NS

Category	120 DAS											
	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	12.82	14.68	16.32	14.61	12.00	13.87	15.67	13.84	12.41	14.27	15.99	14.23
M_2	13.90	16.83	18.47	16.40	13.63	16.04	17.80	15.83	13.77	16.44	18.13	16.11
M_3	14.90	17.85	20.91	17.88	14.24	17.08	19.81	17.04	14.57	17.46	20.36	17.46
M_4	13.37	16.12	17.74	15.74	13.06	15.33	17.01	15.14	13.22	15.73	17.38	15.44
M_5	14.15	17.14	20.02	17.10	13.38	16.32	19.09	16.26	13.76	16.73	19.55	16.68
Mean	13.83	16.52	18.69	16.35	13.26	15.73	17.87	15.62	13.55	16.13	18.28	-

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.2	0.16	NS	0.25	NS	0.44	NS

corded in large sized seeds (L_3) (1.87 cm) and there was no measurable root length in L_1. Irrespective of seed size and organic manure doses, sowing depth D_1 recorded significantly better root length of 1.00 cm than D_2 (0.80 cm). In organic manure doses, maximum root length was recorded in M_3 (0.99 cm) which was statistically at par with M_5, M_2 and M_4 while it was recorded minimum in M_1 (0.73 cm). Among interactions between seed size and sowing depth (L×D), maximum root length was recorded in D_1L_3 (2.03 cm) whereas no measurable root length was found in D_1L_1 and D_2L_1. Other interactions, between organic manure and seed size (M×L) root length was recorded maximum in M_5L_3 (1.98 cm) which was statistically at par with M_3L_3, M_4L_3, M_2L_3 whereas it was recorded negligible in M_1L_1, M_2L_1, M_3L_1, M_4L_1 and M_5L_1. Other interactions M×D and M×L×D were found to be non-significant.

At an interval of 60 DAS in seed size categories, maximum root length was observed in L_3 (10.00 cm) which was significantly superior to all other seed categories, while minimum root length was recorded in L_1 (6.63 cm). Among two sowing depths, D_1 (8.76 cm) performed significantly better than D_2 (7.79 cm). Among different doses of organic manures, maximum root length was recorded in M_3 (9.70 cm) whereas minimum was recorded in M_1 (6.92 cm). Among interactions between organic manure and seed size categories (M×L), maximum root length was recorded in M_3L_3 (12.11 cm) and minimum root length was recorded in M_1L_1 (5.72 cm). On other hand, other interactions viz. M×D, L×D and M×L×D were found to be non-significant.

After 90 days of seed sowing in seed size categories, maximum root length was recorded in L_3 (15.09

cm), whereas minimum root length was recorded in L_1 (10.20 cm). Among two sowing depths D_1 (13.14 cm) performed significantly better than D_2 (12.36 cm). Among different organic manure doses, maximum root length was recorded in M_3 (14.31 cm) which was significantly superior to all other organic manure doses while minimum root length was recorded in M_1 (10.88 cm). Among interactions between organic manure and seed size categories (M×L), maximum root length was recorded in M_3L_3 (17.09 cm) which significantly differ from other combinations while minimum root length was recorded in M_1L_1 (8.85 cm). On the other hand, other interactions viz. M×D, L×D and M×L×D were found to be non-significant.

At 120 DAS in seed size categories, maximum root length was observed in L_3 (18.28 cm) which was significantly superior to all other seed categories, while minimum root length was recorded in L_1 (13.55 cm). Among two sowing depths, sowing depth D_1 (16.35 cm) performed significantly better than D_2 (15.62 cm) in terms of root length. Among different doses of organic manure, maximum root length was recorded in M_3 (17.36 cm) which was significantly superior over other doses while minimum (14.23 cm) root length was recorded in M_1. Interactions between organic manure and seed size categories (M×L) maximum root length was recorded in M_3L_3 (20.36 cm) which was significantly superior to all other combinations while minimum root length was recorded in M_1L_1 (12.41 cm). On other hand, other interactions viz., M×D, L×D and M×L×D were found to be non-significant.

Collar diameter (mm)

Collar diameter of soapnut seedling was recorded at a monthly interval of 30, 60, 90 and 120 days after sowing and the respective data presented in Table 3. At 30 DAS, in seed size categories, maximum collar diameter was recorded in L_3 (1.28 mm) whereas no measurable collar diameter was observed in L_1. Other

Table 3. Effect of seed size, sowing depth and organic manures (doses) on collar diameter (mm) of *Sapindus mukorossi* at different time intervals under nursery condition.

30 DAS

Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	0.00	1.14	1.28	0.81	0.00	1.14	1.27	0.80	0.00	1.14	1.27	0.81
M_2	0.00	1.17	1.25	0.81	0.00	1.14	1.30	0.81	0.00	1.16	1.28	0.81
M_3	0.00	1.21	1.32	0.85	0.00	1.20	1.27	0.82	0.00	1.21	1.30	0.83
M_4	0.00	1.17	1.27	0.81	0.00	1.17	1.24	0.80	0.00	1.17	1.26	0.81
M_5	0.00	1.22	1.33	0.85	0.00	1.14	1.31	0.82	0.00	1.18	1.32	0.83
Mean	0.00	1.18	1.29	0.82	0.00	1.16	1.28	0.81	0.00	1.17	1.28	

CD (0.05)	Seed size (L)	Depth (D)	LxD	Doses (M)	M×D	M×L	M×L×D
	0.03	NS	NS	NS	NS	NS	NS

60 DAS

Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	2.15	2.67	2.93	2.58	2.03	2.53	2.80	2.45	2.09	2.60	2.87	2.52
M_2	2.62	2.97	3.13	2.91	2.42	2.84	3.05	2.77	2.52	2.91	3.09	2.84
M_3	2.89	3.24	3.34	3.16	2.69	3.18	3.28	3.05	2.79	3.21	3.31	3.10
M_4	2.37	2.87	3.10	2.78	2.32	2.83	3.03	2.73	2.35	2.85	3.06	2.75
M_5	2.78	3.09	3.23	3.03	2.56	2.96	3.12	2.88	2.67	3.02	3.18	2.96
Mean	2.56	2.97	3.15	2.89	2.40	2.87	3.06	2.78	2.48	2.92	3.10	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.03	0.02	NS	0.04	NS	0.06	NS

Table 3. Continued.

Category	90 DAS											
	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	2.96	3.18	3.41	3.18	2.92	3.14	3.38	3.15	2.94	3.16	3.39	3.17
M_2	3.21	3.48	3.78	3.49	3.18	3.44	3.64	3.42	3.20	3.46	3.71	3.46
M_3	3.46	3.71	3.96	3.71	3.34	3.57	3.87	3.59	3.40	3.64	3.92	3.65
M_4	3.08	3.33	3.61	3.34	3.08	3.30	3.55	3.31	3.08	3.32	3.58	3.33
M_5	3.31	3.54	3.81	3.56	3.27	3.47	3.68	3.47	3.29	3.51	3.74	3.51
Mean	3.21	3.45	3.72	3.46	3.16	3.38	3.62	3.39	3.18	3.42	3.67	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.03	0.02	NS	0.04	NS	0.07	NS

Category	120 DAS											
	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	3.67	3.94	4.14	3.92	3.47	3.74	3.93	3.71	3.57	3.84	4.03	3.81
M_2	4.00	4.17	4.91	4.36	3.79	3.99	4.72	4.17	3.90	4.08	4.82	4.26
M_3	4.21	4.38	5.22	4.60	4.01	4.16	5.02	4.40	4.11	4.27	5.12	4.50
M_4	3.86	4.16	4.38	4.13	3.65	3.96	4.18	3.93	3.76	4.06	4.28	4.03
M_5	4.06	4.19	5.06	4.43	3.86	3.99	4.86	4.23	3.96	4.09	4.96	4.33
Mean	3.96	4.17	4.74	4.29	3.76	3.97	4.54	4.09	3.86	4.07	4.64	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.04	0.03	NS	0.05	NS	0.09	NS

factors viz., sowing depth (D) and organic manures doses (M) were found to be non-significant. At an interval of 60 DAS in seed size categories, maximum collar diameter was recorded in L_3 (3.10 mm) which was significantly superior to all other seed categories, while minimum collar diameter was recorded in L_1 (2.48 mm). Among two sowing depths, depth D_1 (2.89 mm) performed significantly better than D_2 (2.78 mm). Among different organic manure doses, maximum collar diameter was recorded in M_3 (3.10 mm) which was significantly superior to all other organic manure doses while minimum collar diameter was recorded in M_1 (2.52 mm).

In a cumulative effect of organic manure and seed size categories (M×L), maximum collar diameter was recorded in M_3L_3 (3.31 mm), while minimum collar diameter was recorded in M_1L_1 (2.09 mm). On other hand, other interactions viz., M×D, L×D and M×L×D were found to be non-significant. After 90 days of seed sowing in seed size categories, maximum collar diameter was recorded in L_3 (3.67 mm) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (3.18 mm). Among sowing depths, D_1 (3.46 mm) performed significantly better than D_2 (3.39 mm). Among different doses of organic manure, maximum collar diameter was recorded in M_3 (3.65 mm) which was significantly superior to all other organic manure doses while minimum collar diameter was recorded in M_1 (3.17 mm). Among interactions between organic manures and seed size categories (M×L), maximum collar diameter was recorded in M_3L_3 (3.92 mm), while minimum was recorded in M_1L_1 (2.94 mm). On other hand, other interactions viz., M×D, L×D and M×L×D were found to be non-significant.

At 120 DAS in seed size categories, maximum collar diameter was observed in L_3 (4.64 mm) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (3.86 mm). Among sowing depths, D_1 (4.29 mm) performed significantly better than D_2 (4.09 mm). Among different organic manure doses, maximum collar diameter was recorded in M_3 (4.50 mm) which was significantly superior to all other organic manure doses while minimum collar diameter was recorded in M_1 (3.81 mm). An interaction between organic manure and seed size categories (M×L), maximum collar diameter was recorded in M_3L_3 (5.12 mm), while minimum collar diameter was recorded in M_1L_1 (3.57 mm). On other hand, other interactions viz., M×D, L×D and M×L×D were found to be non-significant.

Seedling height (cm)

The contents of Table 4 revealed that at an interval of 30 DAS in seed size categories, maximum seedling height was recorded in L_3 (4.21 cm) and there was no measurable seedling height in L_1. Irrespective of seed size and organic manure doses, sowing depth D_1 recorded significantly better seedling height of 2.27cm than D_2 (1.90 cm). In organic manure doses maximum seedling height was recorded in M_3 (2.29cm) which was statistically at par with M_5 (2.23cm) while minimum was recorded in M_1 (1.76cm). Among interactions between seed size and sowing depth (L×D) maximum seedling height was recorded in D_1L_3 (4.51cm) whereas no measurable seedling height was found in D_1L_1 and D_2L_1. Interactions between organic manure and seed size (M×L), maximum seedling height was recorded in M_3L_3 (4.42 cm) which was statistically at par with M_4L_3, M_5L_3, M_2L_3 while no measurable seedling height was recorded in M_1L_1, M_2L_1, M_3L_1, M_4L_1 and M_5L_1. At an interval of 60 days after sowing in seed size categories, maximum seedling height was observed in L_3 (25.35 cm) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (16.87cm). Among two sowing depths, D_1 (22.16cm) performed significantly better than D_2 (20.29cm). Among different organic manure doses, maximum seedling height was recorded in M_3 (25.20 cm) which was significantly superior to all other organic manure doses while minimum seedling height was recorded in M_1 (17.21 cm). Among interactions, organic manure and seed size categories

Table 4. Effect of seed size, sowing depth and organic manures (doses) on seedling height (cm) of *Sapindus mukorossi* at different time intervals under nursery condition**.**

30 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	0.00	1.53	4.00	1.84	0.00	1.43	3.60	1.68	0.00	1.48	3.80	1.76
M_2	0.00	2.30	4.37	2.22	0.00	1.77	3.97	1.91	0.00	2.03	4.17	2.07
M_3	0.00	2.83	4.83	2.56	0.00	2.10	4.00	2.03	0.00	2.47	4.42	2.29
M_4	0.00	2.10	4.70	2.27	0.00	1.70	3.87	1.86	0.00	1.90	4.28	2.06
M_5	0.00	2.70	4.67	2.46	0.00	1.90	4.10	2.00	0.00	2.30	4.38	2.23
Mean	0.00	2.29	4.51	2.27	0.00	1.78	3.91	1.90	0.00	2.04	4.21	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.11	0.09	0.16	0.15	NS	0.26	NS

30 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	13.83	18.89	21.50	18.07	12.27	16.98	19.80	16.35	13.05	17.94	20.65	17.21
M_2	17.81	22.86	25.89	22.19	15.83	21.03	24.15	20.34	16.82	21.95	25.02	21.26
M_3	21.40	26.18	31.63	26.40	19.49	23.75	28.76	24.00	20.44	24.96	30.20	25.20
M_4	16.53	20.72	23.88	20.38	14.42	18.87	22.26	18.51	15.48	19.79	23.07	19.45
M_5	18.98	23.60	28.74	23.77	18.13	21.80	26.87	22.27	18.56	22.70	27.80	23.02
Mean	17.71	22.45	26.33	22.16	16.03	20.49	24.37	20.29	16.87	21.47	25.35	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.29	0.24	NS	0.38	NS	0.66	NS

Table 4. Continued.

90 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	23.21	28.96	31.78	27.98	22.04	27.33	30.80	26.73	22.63	28.15	31.29	27.35
M_2	27.55	33.79	37.28	32.87	26.19	32.23	35.69	31.37	26.87	33.01	36.48	32.12
M_3	30.97	36.64	42.66	36.76	29.34	34.72	40.00	34.69	30.15	35.68	41.33	35.72
M_4	25.60	31.93	35.58	31.04	24.39	30.26	33.66	29.43	25.00	31.10	34.62	30.24
M_5	29.12	34.41	40.10	34.54	27.39	32.79	38.27	32.81	28.25	33.60	39.18	33.68
Mean	27.29	33.15	37.48	32.64	25.87	31.47	35.68	31.01	26.58	32.31	36.58	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.2	0.16	NS	0.26	NS	0.44	NS

120 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	31.63	37.35	40.64	36.54	30.31	35.73	39.33	35.13	30.97	36.54	39.99	35.83
M_2	35.79	42.17	45.43	41.13	34.79	40.59	44.09	39.82	35.29	41.38	44.76	40.48
M_3	38.79	44.69	50.82	44.77	37.37	43.16	48.62	43.05	38.08	43.93	49.72	43.91
M_4	33.98	40.25	43.49	39.24	33.13	38.66	42.02	37.93	33.55	39.45	42.75	38.59
M_5	36.79	42.79	48.54	42.71	35.24	41.14	46.67	41.02	36.02	41.96	47.61	41.86
Mean	35.4	41.45	45.78	40.88	34.17	39.86	44.15	39.39	34.78	40.65	44.97	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.37	0.3	NS	0.47	NS	0.82	NS

(M×L), maximum seedling height was recorded in M_3L_3 (30.20 cm) which was significantly superior to all other combinations while minimum was recorded in M_1L_1 (13.05 cm).

At an interval of 90 DAS in seed size categories, maximum seedling height was observed in L_3 (36.58 cm) which was significantly superior to all other seed categories, while minimum seedling height was recorded in L_1 (26.58 cm). On the other hand among two sowing depths, depth D_1 (32.64 cm) performed significantly better than D_2 (31.01 cm). Among different organic manure doses, maximum seedling height was recorded in M_3 (35.72 cm) which was significantly superior to all other organic manure doses while minimum seedling height was recorded in M_1 (27.35 cm). Interactions between organic manures and seed size categories (M×L), maximum seedling height was recorded in M_3L_3 (41.33 cm) which was significantly superior to all other combinations while minimum was recorded in M_1L_1 (22.63 cm).

At an interval of 120 days after sowing in seed size categories, maximum seedling height was observed in L_3 (44.97 cm) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (34.78 cm). Sowing depths, D_1 (40.88 cm) performed significantly better than D_2 (39.39 cm). Among different organic manure doses, maximum seedling height was recorded in M_3 (43.91 cm) which was significantly superior to all other organic manure doses while minimum seedling height was recorded in M_1 (35.83 cm). Interaction between organic manures and seed size categories (M×L) , maximum seedling height was recorded in M_3L_3 (49.72 cm) which was significantly superior to all other combinations while minimum was recorded in M_1L_1 (30.97 cm).

Number of lateral roots

Number of lateral roots of soapnut was observed at monthly intervals at 60, 90 and 120 DAS and the data presented in Table 5. After 30 days of seed sowing, in seed size categories, maximum number of lateral roots was observed in L_3 (5.37) which was significantly superior to all other seed categories, while minimum number of lateral roots was recorded in L_1. Maximum number of lateral roots was observed in D_1 sowing depth (3.09) while minimum was recorded in D_2 (2.73), however non significant variation has been observed among the various sowing depths. Among different doses of organic manure, maximum number of lateral roots was recorded in M_3 (3.56) which were statistically at par with M_5 while minimum number of lateral roots was recorded in M_1 (2.33). At 60 DAS in seed size categories, maximum number of lateral roots was recorded in L_3 (30.17) which were significantly superior to all other seed categories, while minimum number of lateral roots was recorded in L_1 (17.92). Among two sowing depths, depth D_1 (24.80) performed significantly better than D_2 (22.98). Among different doses of organic manure, maximum number of lateral roots was recorded in M_3 (27.44) which were significantly superior to all other organic manure doses while minimum number of lateral roots was recorded in M_1 (19.17). Other interactions viz. M×L, M×D, L×D and M×L×D were found to be non-significant.

At an interval of 90 days after sowing in seed size categories, maximum number of lateral roots was observed in L_3 (43.03) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (34.73). Among two sowing depths, depth D_1 (41.00) performed significantly better than D_2 (37.56). Among various doses of organic manure, maximum number of lateral roots was recorded in M_3 (42.17) which were significantly superior to all other organic manure doses while minimum number of lateral roots was recorded in M_1 (35.83).

At an interval of 120 DAS in seed size categories, maximum number of lateral roots was observed in L_3 (63.03) which were significantly superior to all other seed categories, while minimum number of lateral roots was recorded in L_1 (45.97). Among two sowing depths, sowing depth D_1 registered maximum

Table 5. Effect of seed size, sowing depth and organic manures (doses) on number of lateral roots of *Sapindus mukorossi* at different time intervals under nursery condition.

30 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	0.00	3.00	4.33	2.44	0.00	2.67	4.00	2.22	0.00	2.83	4.17	2.33
M_2	0.00	3.33	5.33	2.89	0.00	3.00	4.67	2.56	0.00	3.17	5.00	2.72
M_3	0.00	4.33	7.00	3.78	0.00	4.00	6.00	3.33	0.00	4.17	6.50	3.56
M_4	0.00	3.33	5.67	3.00	0.00	3.00	5.00	2.67	0.00	3.17	5.33	2.83
M_5	0.00	3.67	6.33	3.33	0.00	3.33	5.33	2.89	0.00	3.50	5.83	3.11
Mean	0.00	3.53	5.73	3.09	0.00	3.2	5.00	2.73	0.00	3.37	5.37	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.38	NS	NS	0.49	NS	NS	NS

60 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	15.33	17.35	26.33	19.67	14.33	16.33	25.33	18.67	14.83	16.84	25.83	19.17
M_2	19.11	25.33	30.33	24.93	18.00	22.33	28.67	23.00	18.56	23.83	29.50	23.96
M_3	23.00	29.00	34.67	28.89	20.67	26.00	31.33	26.00	21.83	27.50	33.00	27.44
M_4	16.33	24.67	32.33	24.44	15.33	23.67	30.00	23.00	15.83	24.17	31.17	23.72
M_5	19.78	25.72	32.67	26.05	17.33	25.33	30.00	24.22	18.56	25.53	31.33	25.14
Mean	18.71	24.41	31.27	24.8	17.13	22.73	29.07	22.98	17.92	23.57	30.17	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	1.27	1.03	NS	1.64	NS	NS	NS

Table 5. Continued.

90 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	33.33	39.33	38.33	37.00	31.00	36.67	36.33	34.67	32.17	38.00	37.33	35.83
M_2	35.67	42.67	45.67	41.33	32.67	39.33	43.33	38.44	34.17	41.00	44.50	39.89
M_3	38.67	46.67	48.33	44.56	36.33	40.67	42.33	39.78	37.50	43.67	45.33	42.17
M_4	35.33	40.33	45.33	40.33	33.33	36.33	41.67	37.11	34.33	38.33	43.50	38.72
M_5	36.67	41.33	47.33	41.78	34.33	37.33	41.67	37.78	35.50	39.33	44.50	39.78
Mean	35.93	42.07	45.00	41.00	33.53	38.07	41.07	37.56	34.73	40.07	43.03	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	1.74	1.42	NS	2.24	NS	NS	NS

120 DAS												
Category	Sowing depth (D_1)				Sowing depth (D_2)				Seed size			
Doses	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
M_1	47.67	49.67	52.33	49.89	44.00	47.33	52.33	47.89	45.83	48.50	52.33	48.89
M_2	45.00	51.00	63.33	53.11	42.33	50.33	61.00	51.22	43.67	50.67	62.17	52.17
M_3	48.00	56.33	71.00	58.44	46.00	53.67	71.00	56.89	47.00	55.00	71.00	57.67
M_4	47.67	53.00	64.33	55.00	45.33	51.67	64.33	53.78	46.50	52.33	64.33	54.39
M_5	48.00	55.00	68.33	57.11	45.67	52.67	62.33	53.56	46.83	53.83	65.33	55.33
Mean	47.27	53.00	63.87	54.71	44.67	51.13	62.2	52.67	45.97	52.07	63.03	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	2.28	NS	NS	2.94	NS	5.09	NS

number (54.71) of lateral roots, while minimum was recorded in D_2 (52.67), however non significant variation has been observed among the various sowing depths. In organic manure doses maximum number of lateral roots was recorded in M_3 (57.67) which were statistically at par with M_5 while minimum number of lateral roots was recorded in M_1 (48.89). Among interactions between organic manure and seed size categories (M×L), maximum number of lateral roots was recorded in M_3L_3 (71.00) which was significantly superior to all other combinations while minimum number of lateral roots was recorded in M_2L_1 (43.67). On the other hand, other interactions viz. M×D, L×D and M×L×D were found to be non-significant.

Growth and seedling biomass characteristics of *Sapindus mukorossi* viz. shoot length, root length, collar diameter, seedling height and number of lateral roots significantly influenced by seed size categories, sowing depth and different organic manure doses and their interactions (Tables 1-5).

Growth parameters have good positive relationship with seed size and weight. Similar trend of higher growth characteristics with larger sized seeds has been reported in *Jatropha curcas* (Singh and Saxena 2009), *Azadirachta indica* (Uniyal *et al*. 2007), *Castanea sativa* (Cicek and Tilki 2007), *Sapindus emerginatus* (Venkatesh and Nagarajaiah 2010, Suresha *et al*. 2007) and *Buchanania lanzan* (Nandeshwar *et al*. 2005), *Salvadora persica* and *Jatropha curcas* (Dagar *et al*. 2004). Similar variations were also reported with respect to seedling growth and biomass in *Acacia nilotica, Albizia lebbek* and *Dalbergia sissoo* (Khera *et al*. 2004), *Leucaena leucocephala* (Dhanda *et al*. 2003). Large size seeds had the highest mean germination value of 80.25%, while medium size seeds and small size seeds recorded 56.50% and 35.50% mean values of germination in *Gmelina arborea*. (Owoh *et al*. 2011). Ahirwar (2012) examined the effect of seed size and weight on seed germination of *Alangium lamarckii*. Edward *et al*. (2013) was found that combination of nicking and large seeds produced the highest (100%) germination. Mtambalika *et al*. (2014) large seeds had a higher (94.9%) cumulative germination percentage than the other treatments. Mulani *et al*. (2014) studied the effect of seed size and seed weight on germination of *Semecarpus anacardium* and observed highest germination percent (68 ± 3.74) for large size seeds, which was followed by (63 ± 2.55) for medium size seeds and the lowest germination percentage was observed (54 ± 2.92) for the small size seeds. Chima *et al*. (2017) found that germination rate and growth performance, were also affected by seed size with the large seed size class performing best, followed by the medium seed size class in *A. muricata*. Mtambalika *et al*. (2014) also reported about 95% germination of large seeds of *Afzelia quanzensis*. However, Umeoka and Ogbonnaya (2016), observed the opposite in *Telfairia occidentalis* where small seeds germinated faster and were more established than the medium and large seeds. The success of larger seeds in plant vigor was explained by Ali and Idris (2015), who interpreted this phenomenon better using the seeds anatomical and physiological characters. Larger seeds have more endosperm to supply adequate potential for increased growth and enhanced development. Domic *et al.* (2020) found larger and medium seeds exhibited comparatively similar growth, survival percentages and final size, maternal plant size was positively associated with improved seed quality and seedling performance in Polylepis tree. Tumpa *et al*. (2021) examined the influence of seed size on four parameters: germination rate, seedling height and root collar diameter and sturdiness quotient. Seed size has been shown to have a positive influence on both seedling height and root collar diameter, whereas no such correlation was noted for germination rate and sturdiness quotient in sweet chestnut (*Castanea sativa* Mill.).

Sowing depth also influenced various growth parameters viz., shoot length, root length, collar diameter, seedling height, number of lateral roots, shoot and root dry weight and total dry weight. The results indicated that sowing depth of 1.0 cm proved to be the best. Sowing of seeds at proper depth is essential for the successful seedling emergence and subsequent growth because of difference in the micro-environments at various soil depths. Similar results have been reported by Venkatesh and Nagarajaiah (2010) and Suresha *et al*. (2007) who studied the effect of sowing depths in *Sapindus emerginatus* (Linn) and reported that seed should be sown at a depth of 0.5 cm -1.0 cm for getting quality nursery stock. Nagarajan and Mertia (2006) also reported that in *Colophospermum mopane* shallow sowing depth and large seeds should be used for best nursery results as improved seedling height, root length and dry matter production. Kumar and Srivastava (2010) had also reported that seed depth affected germination percentage in *Ricinus communis*. Nabi *et al*. (2011) who in their studies on cotton (*Gossypium* spp) and faba beans (*Vicia faba* L.) respectively, reported that germination rate reduced significantly with increased sowing depth. Chima *et al*. (2017) evaluated seedling growth attributes, in most cases, did not vary significantly ($p > 0.05$) between the 2 cm and 4 cm sowing depths on one hand and the 4cm and 6cm sowing depths on the other hand; while they varied significantly ($p < 0.05$) between the 2 cm and the 6 cm depths. Seed sown at 2 cm depth, are recommended for optimum germination and early seedling growth performance in *A. muricata*. Gehlot *et al*. (2014) investigated germination experiments on *Ailanthus excels*, seed sown in different growth substrates at varying depths and found that germination percentage, germination energy and germination values were all greatest when seeds were sown at a depth of 0.5 cm depth and lowest when sown at 1.5 cm depth. This contradicts the findings of Umeoka and Ogbonnaya (2016) who revealed that increasing sowing depths significantly reduced cumulative height growth over time and that small seeds attained the highest plant height irrespective of the sowing depth. However, in another study by Gholami *et al*. (2007) on *Pistacia atlantica*, collar diameter was not significant with changes in sowing depth. Similar results were observed by Ali and Idris (2015), where the number of leaves reduced with increasing sowing depth.

Application of differential doses of organic manures (vermicompost and Farm yard manure) was found to substantially support the growth of *Sapindus mukorossi* seedlings. The data indicates that among the five different doses of the manures, vermicompost @10t/ha was found more effective in enhancing the root and shoot length, collar diameter, seedling height, number of lateral roots, root and shoot dry weight and total dry weight production.

Vermicompost has substantially enhanced the growth as it has been reported by several researchers. Srivastava *et al*. (2006) inferred that vermicompost @ 10 t/ha substantially increased the dry matter yield in *Ceriodaphnia cornuta*. In other crops as cotton (Navlakhe *et al*. 2009), *Pterocarpus marsupium* (Venkatesh *et al*. 2009) and Ashwagandha (Ghosh *et al*. 2009), the plant height, collar diameter, root length, number of leaves and number of primary and secondary branches showed positive relationship with application of vermicompost. The increment in growth performance is attributed to the organic carbon and nitrogen provided by the organic manure. This improve the soil physico-chemical properties further contributes to the better growth of the plant. These results are in conformity with Navamaniraj *et al*. (2008) reported that the potting mixture of vermicompost enhanced seedling growth including stem girth and reduced the mortality of seedlings in *Bixa orelleana*. Shree *et al*. (2007) also divulged that vermicompost used varieties, of mulberry showed higher shoot length, root length, fresh weight and root weight. Singh and Sivaji (2004) observed that cuttings of *Dalbergia sissoo* showed maximum shoot length, primary root length and basal diameter in 50:50 combinations of sand and vermicompost. Vermicompost has outperformed the FYM treatment and supports the findings of Reddy *et al*. (2003) in mulberry (*Morus* sp.) where increased leaf yield, plant height and leaf area in vermicompost treated plots as compared to FYM treated plots. Prasad *et al*. (2017) also reported that application of vermicompost increased percentage pore space and water holding capacity, while decreased the bulk density and percentage of air space. Singh *et al*. (2008) recorded increased plant spread, leaf area, dry matter and total fruit yield in strawberry with the application of vermicompost @ 2.5 to 10 t ha^{-1} in combination with inorganic fertilizers. Baviskar *et al*. (2011) reported the maximum fruit weight, fruit length and fruit breadth in Sapota with application of vermicompost @ 15 kg $plant^{-1}$. Maximum seed germination (%) was recorded in FYM in *Sapindus mukorossi* (Bali and Chauhan 2021). Application of organic manure at various doses yielded better growth and seedlings quality of *Tamarindus indica* as compared to NPK (15:15:15) and Urea fertilizer. (Dachung and Kalu 2019).The application of little doses of fertilizer stimulates cell differentiation and multiplication leading to height increments (Afa *et al*. 2011). The possible cause of differential growth performance could be due to differences in the organic components in different manures; this aspect however, needs further study.

CONCLUSION

The growth and seedling biomass parameter like shoot length, root length, seedling height, collar diameter; number of lateral roots, shoot dry weight, root dry weight and total biomass were significantly related to seed size, sowing depth and application of different organic manure doses. Large size seed (L_3) produced higher growth as compared to small and medium size seeds. Sowing depths of 1.0 cm showed better results of growth and seedling biomass as compared D_2. Vermicompost @ 10t/ha showed better shoot length, root length, collar diameter, seedling height and number of lateral roots. The effectiveness of organic manures was in the order of vermicompost @10 t/ha > FYM @ 10t/ha > vermicompost @ 5 t/ha > FYM @ 5t/ha > control (no manure) and interactions viz. M×D, L×D and M×L×D were found to be non-significant.

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