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Effect of Seed Size and Sowing Depth on Seedling Biomass Production of Soapnut (*Sapindus mukorossi* Gaertn) at Different Time Intervals under Different Organic Manure 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 seedling biomass parameter of soapnut was observed at monthly intervals of 30, 60, 90 and 120 days after sowing. The seedling biomass parameter like, 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 dry shoot weight (1.26 g) (2.22 g) (3.39g), dry root weight (0.29 g) (0.72 g) L3 (1.12 g) and total dry weight(1.55 g) (2.94 g) (4.52 g). Among sowing depths, D1 showed better dry shoot weight (1.08 g) D_1 (1.94 g) (3.21 g), dry root weight (0.25 g) (0.59 g) (1.01 g) and total dry weight (1.33 g) (2.53 g) (4.22 g) as compared to D_2. Among organic manures doses, M_3 showed better dry shoot weight(1.18g) (2.03g) (3.29 g), dry root weight (0.28 g) M_3 (0.64 g) (1.10 g) and total dry weight(1.46 g) (2.67g) (4.38 g). 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.

INTRODUCTION

Sapindus mukorossi or soapnut tree (Ritha) is an important MPTs of north India, belongs to family

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Sapindaceae. It is distributed across warm-temperate and tropical regions in Southeast Asia and North and South America (Liu *et al*. 2019). In India, particularly found in Indo-Gangetic plains, Shivaliks and sub Himalayan tracts at altitudes from 200 m to 1500 m. 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 soap nut. 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 fruits of 'Ritha' are most valuable part of the plant. Its fleshy portion contain saponin, which is a good substitute for washing soap and as such is used for the preparation of quality shampoos, detergents (Bahar and Singh 2007). Soap nuts have medicinal value as an expectorant, emetic, contraceptive and for treatment of excessive salivation, epilepsy, psoriasis, head lice and migraines. Soap nut inhibit tumor cell growth. Soap nut are among the list of herbs and minerals in Ayurveda. Nuts are used in ayurvedic medicine for the treatment of eczema and psoriasis.

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. 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 and 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. Five randomly selected seedling per replication were carefully uprooted without breaking the roots and observations were taken at an interval of 60, 90, 120 days after sowing for seedling biomass.

Root and shoot weight (g): The seedlings were washed with running tap water and excess of water was wiped out by placing it between the folds of filter paper. Then the seedlings were cut at collar with secateurs and root and shoot weights was taken separately as fresh and dry weights. After drying to constant weight in oven at 60^{o}C and expressed in grams (g).

Total dry biomass of seedlings (g): It was expressed in grams as the sum of dry root weight and dry shoot weight.

RESULTS AND DISCUSSION

Biomass production studies

Dry shoot weight (g)

The content of the Table 1 revealed that at an internal of 60 days after sowing, in seed size categories, maximum dry shoot weight was observed in L_3 (1.26 g) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (0.82 g). Sowing depth D_1 recorded higher dry shoot weight (1.08 g) in comparison to D_2 which recorded (1.02 g). Among different organic manure doses, maximum dry shoot weight was recorded in M_3 (1.18g) which was significantly superior to all other organic manure doses while minimum dry shoot weight was recorded in M_1 (0.92 g). Interactions between organic manure and seed size categories (M×L) maximum dry shoot weight was recorded in M_3L_3 (1.46 g) which was statistically at par with M_5L_3 (1.43g) while minimum was recorded in M_1L_1 (0.69g).

At an interval of 90 DAS in seed size categories, maximum dry shoot weight was observed in L_3 (2.22 g) which was significantly superior to all other seed categories, while it was recorded minimum in L_1 (1.58 g). Among two sowing depths, depth D_1 (1.94 g) performed significantly better than D_2 (1.83g) in terms of dry shoot weight. Among different organic manure doses, maximum dry shoot weight was recorded in M_3 (2.03g) which was statistically at par with M_5 (2.01g) while minimum dry shoot weight was recorded in M_1

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

	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	0.69	0.99	1.09	0.92	0.69	0.97	1.07	0.91	0.69	0.98	1.08	0.92
M_2	0.83	1.11	1.19	1.04	0.80	1.05	1.15	1.00	0.81	1.08	1.17	1.02
M_3	1.02	1.18	1.50	1.23	0.86	1.12	1.41	1.13	0.94	1.15	1.46	1.18
M_4	0.78	1.07	1.19	1.01	0.77	1.03	1.11	0.97	0.78	1.05	1.15	0.99
M_5	0.95	1.12	1.46	1.18	0.83	1.07	1.39	1.10	0.89	1.10	1.43	1.14
Mean	0.86	1.09	1.29	1.08	0.79	1.05	1.23	1.02	0.82	1.07	1.26	

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

Table 1. 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	1.40	1.78	1.89	1.69	1.38	1.71	1.83	1.64	1.39	1.75	1.86	1.67
M_2	1.67	1.91	2.34	1.97	1.55	1.84	2.05	1.81	1.61	1.88	2.20	1.89
M_3	1.72	1.97	2.50	2.06	1.66	1.91	2.40	1.99	1.69	1.94	2.45	2.03
M_4	1.63	1.87	2.31	1.93	1.44	1.81	2.03	1.76	1.53	1.84	2.17	1.85
M_5	1.72	1.93	2.47	2.04	1.67	1.85	2.39	1.97	1.70	1.89	2.43	2.01
Mean	1.63	1.89	2.30	1.94	1.54	1.83	2.14	1.83	1.58	1.86	2.22	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.04	0.04	NS	0.06	NS	0.10	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	2.63	3.20	3.25	3.03	2.60	3.12	3.19	2.97	2.61	3.16	3.22	3.00
M_2	2.98	3.27	3.40	3.22	2.80	3.21	3.33	3.11	2.89	3.24	3.37	3.17
M_3	3.07	3.34	3.57	3.33	2.99	3.28	3.47	3.25	3.03	3.31	3.52	3.29
M_4	2.96	3.22	3.39	3.19	2.80	3.14	3.31	3.09	2.88	3.18	3.35	3.14
M_5	3.04	3.31	3.54	3.30	2.98	3.22	3.47	3.22	3.01	3.27	3.50	3.26
Mean	2.94	3.27	3.43	3.21	2.83	3.19	3.35	3.13	2.89	3.23	3.39	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.05	0.04	NS	0.06	NS	0.11	NS

(1.67g). Interaction between organic manure and seed size categories (M×L), maximum dry shoot weight was recorded in M_3L_3 (2.45 g) which was statistically at par with M_5L_3 (2.43g) while minimum dry shoot weight was recorded in M_1L_1 (1.39g).

After 120 days of seed sowing in seed size categories, maximum dry shoot weight was observed in L_3 (3.39g) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (2.89 g). Among two sowing depths, depth D_1 (3.21 g) performed significantly better than depth D_2 (3.13 g). Among various organic manure doses, maximum dry shoot weight was recorded in M_3 (3.29 g) which was statistically at par with M_5 (3.26g) while minimum dry shoot weight was recorded in M_1 (3.00g). Among interaction between organic manure and seed size categories (M×L), maximum dry shoot weight was recorded in M_3L_3 (3.52g) which was statistically at par with M_5L_3 (3.50g) while minimum was recorded in M_1L_1 (2.61g). On other hand, other interactions viz., M×D, L×D and M×L×D were found to be non-significant.

Dry root weight (g)

At an interval of 60 DAS in seed size categories, maximum dry root weight was observed in L_3 (0.29 g) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (0.19 g). Among two sowing depths, depth D_1 (0.25 g) performed significantly better than D_2 (0.23 g). (Table 2). Effect of different organic manure doses showed that maximum dry root weight was recorded in M_3 (0.28 g) which was significantly superior to all other organic manure doses while minimum dry root weight was recorded in M_1 (0.19 g). Among interactions between organic manure and seed size categories (M×L), maximum dry root weight was recorded in M_3L_3 (0.35 g) which was significantly superior to all other combinations while minimum was recorded in M_1L_1 (0.13 g).

At an interval of 90 DAS in seed size categories,

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

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	0.13	0.21	0.24	0.19	0.12	0.19	0.26	0.19	0.13	0.2	0.25	0.19
M_2	0.2	0.26	0.29	0.25	0.18	0.24	0.26	0.22	0.19	0.25	0.27	0.24
M_3	0.24	0.27	0.37	0.3	0.22	0.26	0.32	0.27	0.23	0.27	0.35	0.28
M_4	0.19	0.24	0.29	0.24	0.17	0.23	0.26	0.22	0.18	0.24	0.27	0.23
M_5	0.22	0.25	0.33	0.27	0.19	0.24	0.29	0.24	0.21	0.24	0.31	0.25
Mean	0.2	0.25	0.3	0.25	0.18	0.23	0.28	0.23	0.19	0.24	0.29	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.01	0.01	NS	0.01	NS	0.02	NS

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	0.36	0.47	0.65	0.49	0.34	0.45	0.6	0.46	0.35	0.46	0.63	0.48
M_2	0.41	0.65	0.71	0.59	0.4	0.64	0.7	0.58	0.4	0.65	0.7	0.58
M_3	0.47	0.68	0.83	0.66	0.46	0.67	0.76	0.63	0.47	0.67	0.8	0.64
M_4	0.4	0.65	0.74	0.59	0.39	0.63	0.71	0.58	0.39	0.64	0.72	0.59
M_5	0.46	0.67	0.78	0.63	0.42	0.65	0.76	0.61	0.44	0.66	0.77	0.62
Mean	0.42	0.62	0.74	0.59	0.4	0.61	0.7	0.57	0.41	0.62	0.72	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.01	0.01	NS	0.01	NS	0.02	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	0.78	0.85	1.07	0.90	0.66	0.82	1.03	0.84	0.72	0.84	1.05	0.87
M_2	0.83	1.07	1.14	1.01	0.8	1.04	1.10	0.98	0.82	1.05	1.12	1.00
M_3	1.04	1.09	1.20	1.11	1.01	1.06	1.17	1.08	1.02	1.08	1.19	1.10
M_4	0.82	1.06	1.11	1.00	0.79	1.02	1.10	0.97	0.81	1.04	1.11	0.98
M_5	0.86	1.07	1.19	1.04	0.83	1.04	1.13	1.00	0.85	1.06	1.16	1.02
Mean	0.87	1.03	1.14	1.01	0.82	1.00	1.11	0.97	0.84	1.01	1.12	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.01	0.01	NS	0.01	NS	0.02	NS

maximum dry root weight was observed in L_3 (0.72 g) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (0.41). Among two sowing depths, depth D_1 (0.59 g) performed significantly better than D_2 (0.57 g). Among different organic manure doses, maximum dry root weight was recorded in M_3 (0.64 g) which was significantly superior to all other organic manure doses while minimum dry root weight was recorded in M_1 (0.48 g). An interaction between organic manures and seed size categories (M×L), maximum dry root weight was recorded in M_3L_3 (0.80 g) which was significantly superior to all other combinations while minimum dry root weight was recorded in M_1L_1 (0.35g).

At an interval of 120 days after sowing in seed size categories, maximum dry root weight was observed in L_3 (1.12 g) which was significantly superior to all other seed categories, while minimum dry root weight was recorded in L_1 (0.84 g). Among two sowing depths, depth D_1 registered significantly higher dry root weight (1.01 g) than D_2 (0.97 g). Effect of organic manure doses showed that maximum dry root weight was recorded in M_3 (1.10 g) which was significantly superior to all other organic manure doses while minimum dry root weight was recorded in M_1 (0.87 g).

Among interactions between organic manures and seed size categories (M×L), maximum dry root weight was recorded in M_3L_3 (1.19 g) which was significantly superior to all other combinations while minimum dry root weight was recorded in M_1L_1 (0.72 g). Interactions between three factors, organic manure, seed size and sowing depth (M×L×D) showed that maximum dry root weight was recorded in $M_3L_3D_1$ (1.20 g) which was statistically at par with $M_3L_3D_2$ (1.17 g) while minimum was recorded in $M_1L_1D_2$ (0.66 g). On other hand, other interactions viz., M×D and L×D were found to be non-significant.

Total dry weight (g)

When data recorded at an interval of 60 DAS in seed size categories, maximum total dry weight was observed in L_3 (1.55 g) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (1.01 g). Between sowing depths, D_1 (1.33 g) performed significantly better than D_2 (1.25 g) (Table 3). Effect of organic manure doses showed that maximum total dry weight was recorded in M_3 (1.46 g) which was significantly superior to all other organic manure doses while minimum total dry weight was recorded in M_1 (1.11 g). Interactions between organic manures and seed size categories (M×L), maximum total dry weight was recorded in M_3L_3 (1.81 g) which was significantly superior to all other combinations while minimum was recorded in M_1L_1 (0.82 g). Among interactions between organic manures and sowing depth (M×D), maximum total

Table 3. Effect of seed size, sowing depth and organic manures (doses) on total dry matter production (g) of *Sapindus mukorossi* at different time intervals under nursery condition.

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	0.83	1.20	1.32	1.12	0.81	1.16	1.33	1.10	0.82	1.18	1.33	1.11
M_2	1.03	1.37	1.48	1.29	0.98	1.29	1.41	1.22	1.01	1.33	1.44	1.26
M_3	1.26	1.46	1.88	1.53	1.08	1.38	1.74	1.40	1.17	1.42	1.81	1.46
M_4	0.98	1.31	1.48	1.25	0.94	1.26	1.37	1.19	0.96	1.29	1.42	1.22
M_5	1.18	1.37	1.79	1.44	1.02	1.31	1.68	1.34	1.10	1.34	1.73	1.39
Mean	1.05	1.34	1.59	1.33	0.97	1.28	1.50	1.25	1.01	1.31	1.55	
CD (0.05)	Seed size (L) 0.03		Depth (D) 0.02		L×D NS		Doses (M) 0.03		M×D NS		M×L 0.06	M×L×D NS
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	1.76	2.25	2.54	2.18	1.72	2.17	2.43	2.10	1.74	2.21	2.49	2.14
M_2	2.07	2.56	3.05	2.56	1.94	2.49	2.75	2.39	2.01	2.52	2.90	2.48
M_3	2.19	2.65	3.33	2.72	2.12	2.58	3.16	2.62	2.16	2.61	3.25	2.67
M_4	2.03	2.51	3.05	2.53	1.82	2.45	2.74	2.34	1.93	2.48	2.90	2.43
M_5	2.18	2.60	3.25	2.67	2.08	2.50	3.15	2.58	2.13	2.55	3.20	2.63
Mean	2.05	2.51	3.04	2.53	1.94	2.44	2.85	2.41	1.99	2.47	2.94	
CD (0.05)	Seed size (L) 0.04		Depth (D) 0.04		L×D NS		Doses (M) 0.06		M×D NS		M×L 0.10	M×L×D NS

Table 3. Continued.

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	3.41	4.05	4.32	3.93	3.25	3.95	4.22	3.81	3.33	4.00	4.27	3.87
M_2	3.81	4.34	4.54	4.23	3.61	4.24	4.44	4.10	3.71	4.29	4.49	4.16
M_3	4.11	4.44	4.77	4.44	4.00	4.34	4.64	4.33	4.05	4.39	4.71	4.38
M_4	3.77	4.28	4.50	4.18	3.60	4.16	4.41	4.06	3.69	4.22	4.46	4.12
M_5	3.91	4.39	4.73	4.34	3.81	4.25	4.60	4.22	3.86	4.32	4.66	4.28
Mean	3.80	4.30	4.57	4.22	3.65	4.19	4.46	4.10	3.73	4.24	4.52	

CD (0.05)	Seed size (L)	Depth (D)	L×D	Doses (M)	M×D	M×L	M×L×D
	0.05	0.04	NS	0.07	NS	0.12	NS

dry weight was recorded in M_3D_1 (1.53 g) which was significantly superior to all other combinations while minimum was recorded in M_1D_2 (1.10 g).

At an interval 90 DAS in seed size categories, maximum total dry weight was observed in L_3 (2.94 g) which was significantly superior to all other seed categories, while minimum total dry weight was recorded in L_1 (1.99 g). Among two sowing depths, depth D_1 recorded higher total dry weight (2.53 g) than depth D_2 (2.41 g). Effect of organic manure doses showed that maximum total dry weight was recorded in M_3 (2.67g) which was statistically at par with M_5 (2.63g) while minimum total dry weight was recorded in M_1 (2.14 g). Interactions between seed size and sowing depth (L×D), maximum total dry weight was recorded in D_1L_3 (3.04 g) while minimum was recorded in D_2L_1 (1.94 g). Among interactions between organic manures and seed size categories (M×L), maximum total dry weight was recorded in M_3L_3 (3.25 g) which was statistically at par with M_5L_3 while minimum was recorded in M_1L_1 (1.74 g).

At an interval of 120 DAS in seed size categories, maximum total dry weight was observed in L_3 (4.52 g) which was significantly superior to all other seed categories, while minimum was recorded in L_1 (3.73 g). Among sowing depths, depth D_1 recorded significantly higher total dry weight (4.22 g) than depth D_2 (4.10 g). Among different organic manure doses, maximum total dry weight was recorded in M_3 (4.38 g) which was significantly superior to all other organic manure doses while minimum total dry weight was recorded in M_1 (3.87 g). An interaction between organic manures and seed size categories (M×L) maximum total dry weight was recorded in M_3L_3 (4.71 g) which was statistically at par with M_5L_3 while minimum total dry weight was recorded in M_1L_1 (3.33 g). Seedling biomass production of *Sapindus mukorossi* viz., shoot dry weight, root dry weight and total dry weight significantly influenced by seed size categories, sowing depth and different organic manure doses and their interactions (Tables 1-3).

Seedling biomass has good positive relationship with seed size and weight. Similar trend of biomass production 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).Chima *et al*. (2017) found that seedling biomass were also affected by seed size with the large seed size class performing best, followed by the medium seed size class in *A. muricata*. 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 and dry matter production, maternal plant size was positively associated with improved seed quality and seedling performance in Polylepis tree.

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 and seedling biomass. 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 fresh root-shoot weight, dry root-shoot weight and dry matter production. Nabi *et al*. (2011) who in their studies on cotton (*Gossypium* spp) and faba beans (*Vicia faba* L.) respectively, reported that germination rate and seedling biomass 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 4 cm and 6 cm 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 and dry matter production 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 seedling biomass 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 growth over time and that small seeds attained the seedling biomass irrespective of the 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) reported that secondary branches, shoot root weight, root-shoot ratio 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 weight and root weight. 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 dry matter (%) was recorded in FYM in *Sapindus mukorossi* (Bali and Chauhan 2021). Application of organic manure at various doses yielded better growth, biomass and seedlings quality of *Tamarindus indica* as compared to NPK (15:15:15) and Urea fertilizer (Dachung and Kalu 2019).

CONCLUSION

The seedling biomass parameter like 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 seedling biomass 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 @ 10 t /ha showed better root dry shoot weight, dry root weight and total dry weight. 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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