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Effect of Water Hyacinth Media on Yield and Nutrient Uptake of Amaranthus (*Amaranthus tricolor* L.)

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A field experiment was carried out at the Farmer's field in North Kuttanad (Kerala, India), during two consecutive seasons, first in June-July and second in August-September of 2023 to evaluate the efficiency of water hyacinth as media for *Amaranthus* cultivation. The experiment was laid out in Completely Randomized Design (CRD) with six treatments and four replications. The treatments were T_1: Open water culture without medium; T_2: Open water culture with medium; T_3: Hydroponics without medium; T_4: Hydroponics with medium; T_5: Land cultivation with water hyacinth bed alone as medium; and T_6 - Control: soil culture. The nutrients nitrogen, phosphorus and potassium were found to be higher in water hyacinth followed by Hoagland solution whereas, open water had the lowest nutrient concentration initially as well as during different stages of plant growth. The plant nutrient contents at different growth stages and yield of *Amaranthus* varied significantly due to treatments. The plant nutrient content was higher in T_6, followed by T_5. The yield was significantly higher in T_6 (17.21 and 17.14t ha^{-1}), which was on par with T_5 (16.82 and 16.04 t ha^{-1}) during the two consecutive seasons. The water hyacinth media was found to be rich in nutrients with 3363 and 3167.75 ppm nitrogen; 1211 and 1178.5 ppm phosphorus and 3275.5 and 3202 ppm potassium; in season 1 and 2 respectively. The maximum net income and benefit cost ratio (BCR) were obtained in the treatment T_5 (2.6), followed by T_6 (2.05). Therefore, water hyacinth media was found to be as effective as soil cultivation in terms of yield and plant nutrient content as well as profitability in *Amaranthus* cultivation.

(***Key words:*** *Amaranthus, Hydroponics, Nutrient uptake, Open water culture, Water hyacinth,Yield*)

Water hyacinth (*Pontederia crassipes*) belongs to family *Pontederiaceae*. It is a noxious and free-floating major aquatic weed species causing serious problem in Inland water bodies. Water hyacinth alone infests 20 to 25% of India's total usable water supply (Varshney *et al.,* 2008). In Kerala it is widely seen in lakes, streams, rice fields and channels, which makes a vast area non-usable for cultivation and navigation (Jayan and Sathyanathan, 2012). The uncontrollable spread of water hyacinth is due to the eutrophication resulting from the discharge of plant nutrients such as nitrites, nitrates and phosphates from paddy fields in the area. Even after trying different management strategies including the physical, chemical, biological and integrated methods, the complete eradication is very difficult due to the various environmental and financial challenges associated with the management aspects. Initial weed removal, followed by routine, periodic removal of the weeds that have sprouted and grown in the area, along with appropriate use of the weeds gathered as mulch (Singh and Sharma, 2020), animal feed (Agunbiade and Longe, 1999), fiber (Nnaji and Uzuegbunam, 2013), and manure (Akintayo and Adesina, 2000), appear to be workable solutions to this weed problem. They can be used for composting and other uses like, for preparation of floating platform especially for vegetable cultivation, which is widely practiced in Bangladesh. The potential for using water hyacinth as an organic source of plant nutrients is highlighted by the fact that the biomass production of WH (Water hyacinth) is estimated to be 200-300 t ha^{-1} year^{-1} (Verma and Sivappa, 2017). The decomposed water hyacinth which is rich in biomass and organic debris release large amount of essential nutrients that are available for the plant intake (Vidya

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and Girish, 2014). An experiment was planned with an objective to study the effectiveness of utilizing water hyacinth as a growing medium taking *Amaranthus* as a test crop. Water hyacinth which is a good source of nutrients and to be used as a media in floating cultivation being a resilient technology to withstand flood; one of the two major issues of Kuttanad; the other, the invasion of water hyacinth in aquatic bodies. Hence, the study was taken up to compare the efficacy of water hyacinth media, with the hydroponics, open water culture and soil culture for growing *Amaranthus*, a popular leafy vegetable of Kerala. Hydroponics, soil less culture of plants in nutrient media involves heavy investment and hence use of water hyacinth as a growth medium was studied. Also, the open water culture was included in the study as the water is nutrient rich due to the fertilizer residue discharge from the surrounding paddy fields in Kuttanad.

MATERIALS AND METHODS

The field experiment was carried out in the Farmer's field located at 9°41'10" N latitude and 76°25'15" E longitude and an altitude of 6 m above mean sea levelin North Kuttanad (Kerala, India), during two consecutive seasons, in June - July and August - September of 2023 (*Kharif* season) to evaluate the efficiency of water hyacinth as media in *Amaranthus* cultivation. Amaranth variety 'Arun' released from the Kerala Agricultural University was raised for the experiment. The experiment was laid out in Completely Randomized Design (CRD) with six treatments and four replications. The treatments were T_1: Open water culture without medium; T_2: Open water culture with medium; T_3: Hydroponics without medium; T_4: Hydroponics with medium; T_5: Land cultivation with water hyacinth bed alone as medium; and T_6 - Control: soil culture - Kerala Agricultural University (KAU) - package of practices (POP) recommended dose of nutrients. The seedlings were transplanted 15 days after sowing (DAS) with a spacing of 15 cm x 15 cm in styrofoam board (T_1 and T_3), water hyacinth bed (30 cm thickness) (T_2 and T_4), and soil bed (30 cm thickness) (T_6), each with a planting area of 1x1 m^2. T_5 is the treatment in which water hyacinth is used as bed above the soil and a sheet was placed underneath to ensure that the water hyacinth bed did not come into direct contact with the soil. The bed measured 1 m in length and breadth, with a height of 0.5 m. The growth medium used for the study is water hyacinth beds in T_2, T_4 and T_5 and water in T_1, Hoagland nutrient solution in T_3, Hoagland nutrient solution + water hyacinth bed in T_4 and soil with manures and fertilizers [$N:P_2O_5:K_2O$ @ 50:50:50 kg ha^{-1}, namely, Urea (46% N), Rajphos (20% P_2O_5) (ground rock phosphate) and Muriate of potash (60% K_2O)] in T_6. In T_3 and T_4, deep water hydroponics with and without water hyacinth medium in Hoagland nutrient solutionconsists of calcium nitrate, potassium di-hydrogen orthophosphate, potassium nitrate, magnesium sulphate, ferrous sulphate, zinc sulphate, manganese chloride, copper sulphate, boric acid, sodium molybdate and phosphoric acid was tried. Amaranth seeds were sown on 15th June 2023 for trial 1 and on 14th August 2023 for trial 2 and they were harvested at its full maturity, *i.e.*, 45 DAT on 29th July in the trial 1 and on 27th September by uprooting the plants from the entire plot area. The nutrient status of the growing media and plant nutrient content were analyzed at 15, 30 and 45 DAT using alkaline permanganate method (Subbiah and Asija,1956) for available N, Bray No. 1 extraction and spectrophotometer estimation for available P (Bray and Kurtz, 1945) and neutral normal ammonium acetate extraction and estimation using flame photometry (Jackson, 1973) for determining

Table 1. *Initial nutrient status of growing medium*

Treatments	N (ppm)		P (ppm)		K (ppm)	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Water	33.74	32.17	0.33	0.3	46.8	45.09
Water hyacinth	3363	3167.75	1211	1178.5	3275.5	3202
Hoagland solution	152.96	154.21	41.59	42.48	101.9	102.65
Soil	118.8	119.37	16.63	15.72	76.71	75.30

available K. The vegetative yield of the *Amaranthus* was recorded at harvest (45 DAT). The data obtained from the experiment was subjected to statistical analysis using GRAPES (Gopinath *et al.*, 2020). The initial primary nutrient (N, P, and K) status of the different growth media is given in Table 1. The nutrients N, P and K were found to be higher in water hyacinth followed by Hoagland solution and open water had the lowest nutrient concentration.

RESULTS AND DISCUSSION

Nutrient status of growing media

The N status of different growth medium for both seasons is presented in Table 2. There was a significant difference between treatments with regard to N content of growing media. The N content at 15, 30 and 45 DAT in the first season was significantly higher in T_5: Land cultivation with water hyacinth bed alone as medium (3142.75 ppm, 2661 ppm and 1722.25 ppm) followed by T_4: Hydroponics with medium (3136.5 ppm, 2544.5 ppm and 1689.55 ppm) and T_2: Open water culture with medium (3128.5 ppm, 2468.75 ppm and 1648.75 ppm). The treatment T_6: Control: with recommended dose of nutrients (152 ppm, 168.88 ppm and 126.5 ppm) ranked next. The T_1: Open water culture without medium (32.96 ppm, 29.34 ppm & 28.21 ppm) recorded lower N content at all stages and similar trend was observed in second season. The higher concentration of N in water hyacinth media is due to higher root surface area, root biomass and root activity of water hyacinth that resulted in enhanced rate of removal of N from the water. Similar results of higher N content in water hyacinth was reported by Q in *et al.* (2016). A reduction in N from the initial status in all treatments except in case of soil culture (T_6) where, N fertilization was carried out as per the recommended dose.

Significantly higher P content (Table 2) was recorded in T_5 (Land cultivation with a bed of water hyacinth alone as medium) which was followed by T_4 (Hydroponics with medium) and T_2 (Open water culture with medium) and the lowest P content was observed in T_1 (Open water culture without medium) during the growth period. The high P content in the water hyacinth is due to the higher rate of absorption of P by the water hyacinth from the water bodies they grow. Zhang *et al.* (2014), Gao *et al.* (2015) and Victor *et al.* (2016) also reported a higher rate of accumulation of P by water hyacinth plants from the water bodies where they grow. Similar to N, there is a reduction in P from the initial status in all treatments except in case of soil culture (T_6) where P fertilization was carried out as per the recommended dose.

The K content of the growing media in different growth stages in both seasons is given in the Table 2. The highest K content (3168 ppm and 3128.25 ppm) was obtained in treatment with water hyacinth bed as media in land cultivation (T_5) followed by T_4 and the lowest K content was observed in T_1 in both the seasons at 15 DAT. In 30 and 45 DAT, there was a decrease in the K content of the growth medium in both the seasons and the highest content in both stages was observed in T_5 (1571.5 ppm and 861.75 ppm) and the lowest was in T_1 (43.78 ppm and 42.33 ppm). The high rate of K content in water hyacinth is due to the high rate of absorption of K from the water bodies by the plant as in the case of N and P. Similar results was observed by Beegum (2016). The water hyacinth is a bio accumulator of nutrients with the capacity to absorb large quantities of nutrients that occur as inflow to the water bodies through leaching of fertilizers from nearby paddy fields and other sources in North Kuttanad. Similar to N and P, there was a reduction in K from the initial status in all treatments except in case of soil culture (T_6) where P fertilization was carried out as per the recommended dose.

The N, P and K content of growing media drastically decreased from the early stages of crop growth towards the harvest in all treatments due to the removal of nutrients by the crop. However, in T_1 the open water was always replenished with the nutrients from the flowing natural water body and hence the content of nutrients remained constant. In T_3 also this reduction in nutrients was not so drastic because of the addition of nutrients to the Hoagland media at 15 days interval.

Plant nutrient content

Plant samples collected at 15, 30 and 45 DAT were analyzed for the nutrient content (Table 3). In the initial stages of growth, the N, P and K content in plant was higher in T_6 - Control: soil culture with recommended dose of nutrientsfollowed by T_5: Land cultivation with water hyacinth bed alone as medium. Significantly lower nutrient content was obtained in treatment with

T_1: Open water culture without medium. The higher nutrient content in the treatment with soil as medium is due to the fact that, the nutrients will be readily available for plant uptake from the inorganic NPK fertilizer. These results are in agreement with the findings of Chaturvedi and Chandel (2005) and Amit *et al.* (2010). In later stages the primary nutrient content was higher in the T_5, this might be due to the decomposition of water hyacinth which resulted in the release of nutrients which are essential for plant growth. This is in conformity with the findings of Ntanos and Koutroubas (2002). Such increase in nutrient content in crops grown in water hyacinth medium was reported by Kumar *et al.* (2010). Chemical fertilizers provided nutrients that instantly become available to plants because they dissolve easily in soil solutions. Microbial activity which allows nutrients from organic sources to be available is a slow and steady process. This is might be the suitable reason for higher nutrient content in the plants grown in T_6 in the early stages and the same was found to increase in T_5 towards the later stages. Similar result was reported by Rakshit *et al.* (2008).

Plant nutrient uptake

The nutrient uptake was analyzed after harvest and data of both seasons are depicted in Fig. 1. Significantly higher N and P uptake in first and second season was obtained in T_6 - Control: soil culture with recommended dose of nutrients, followed by T_5: Land cultivation with water hyacinth bed alone as medium and the least uptake was recorded by T_1: Open water culture without medium. The K uptake was significantly higher in T_6 (55.66 kg ha $^{-1}$), which was significantly superior to all the treatments and was followed by T_5 (53.65 kg ha $^{-1}$). The lowest uptake was registered in T_1 (4.28 kg ha $^{-1}$). In the second season, the highest uptake was observed in T_5 (50.29 kg ha $^{-1}$) which was on par with T_6 (49.98 kg ha $^{-1}$) and the least uptake was in T_1 (4.16 kg ha^{-1}). Significantly higher plant nutrient uptake in soil media is attributed to continuous and steady supply of available nutrients throughout the crop growth period because of the application of inorganic inputs (Tewari *et al.,* 2007) and in treatments with water hyacinth media, the uptake of nutrients was improveddue to the richness of the water hyacinthin plant nutrients (Atere and Olayinka, 2019). The nutrient uptake was higher in treatments with soil as media than treatments with water hyacinth as media which might be due to the readily availability of nutrients from the inorganic fertilizer compared to water hyacinth where nutrient is released after proper decomposition (Osoro *et al.,* 2014).

Crop yield

The growing media had significant effect on crop yield. The total yield of *Amaranthus* in first and second season (Table 4) varied from minimum of 1.20 and 1.22 t ha^{-1} under T_1 to a maximum of 17.21 and 17.14 t ha^{-1} in T_6 in season 1 and season 2, respectively. However, the highest yield recorded by the treatment T_6 was on par with that of T_5 under both the seasons. The increase in yield of T_6 (Control: soil culture - Kerala Agricultural University (KAU) - package of practices (POP) with recommended dose of nutrients) is due to better availability of nutrients in the soil. The availability of N in inorganic fertilizer stimulates plant vegetative growth, the nutrient having a role in boosting photosynthetic area, root development, and nutrient uptake in plants, as well as in facilitating photosynthate translocation that leads to improved sink development (Noor *et al.,* 2008). The higher yield in T_5 (land cultivation with water hyacinth bed as medium) can be explained by the release of considerable amount of nutrients from water hyacinth to the plants, especially N and P, which resulted in better photosynthesis, plant growth and yield (Kamanu *et al.,* 2012) and also K which increases the efficiency of plants in the production and distribution of photosynthates leading to higher yields (Mashavira *et al.,* 2015). The treatments with water hyacinth as growing medium T_2 (Open water culture with medium), followed by the T_4 (Hydroponics with medium) ranked next in *Amaranthus* yield. Improvement in yield of vegetables by growing in water hyacinth medium has been reported by Baran *et al.* (2022). The lowest growth, growth attributes and yield recorded in open water culture (T_1) and hydroponics (T_3), where no water hyacinth medium was used for the cultivation, could be due to the poor root growth, poor nutrient availability and uptake. Even though media of water hyacinth was used to grow vegetables in the open water (T_2) and hydroponics (T_4), the presence of water in the root zone throughout the growth period soon after planting due to the fast shrinking of the water hyacinth bed resulted

Table 2. *Nutrient (N, P and K) content of different growing media*

Treat-ments	N (ppm)						P (ppm)						K (ppm)					
	Season 1			Season 2			Season 1			Season 2			Season 1			Season 2		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
T_1	32.96	29.34	28.21	33.94	30.87	33.45	32.96	29.34	28.21	33.94	30.87	33.45	0.32	0.29	0.32	0.31	0.29	0.31
T_2	3128.50	2468.75	1648.75	2916.75	2288.50	1456.50	3128.5	2468.75	1648.75	2916.75	2288.50	1456.50	913.00	708.00	321.00	893.00	693.00	312.50
T_3	139.10	97.61	86.61	130.50	100.44	89.40	139.10	97.61	86.61	130.50	100.44	89.40	35.39	31.53	26.87	35.64	30.66	27.05
T_4	3136.50	2544.50	1689.55	2941.25	2349.25	1500.00	3136.5	2544.50	1689.55	2941.25	2349.25	1500.00	942.50	734.25	356.75	916.25	728.75	348.00
T_5	3142.75	2661.00	1722.25	2950.50	2470.00	1530.75	3142.75	2661.00	1722.25	2950.50	2470.00	1530.75	954.75	755.00	373.25	923.25	733.25	352.50
T_6	152.00	168.88	126.50	146.03	158.19	126.10	152.00	168.88	126.50	146.03	158.19	126.10	33.00	40.75	28.00	29.36	37.51	26.08
SEm±	1.81	2.67	3.83	9.17	9.07	8.59	1.81	2.67	3.83	9.17	9.07	8.59	3.76	1.96	1.99	2.44	0.71	0.76
CD (P=0.05)	5.47	7.92	11.41	27.23	26.93	25.52	5.47	7.92	11.41	27.23	26.93	25.52	11.17	5.83	5.91	7.25	2.12	2.26

[N: nitrogen; P: phosphorus; K: potassium; DAT: Days after transplanting] (T_1: Open water culture without medium; T_2: Open water culture with medium; T_3: Hydroponics without medium; T_4: Hydroponics with medium; T_5: Land cultivation with water hyacinth bed alone as medium; and T_6- Control: soil culture- Kerala Agricultural University (KAU)-package of practices (POP) recommended dose of nutrients)

Table 3. *Effect of different growing media on nutrient (N, P and K) content in plant*

Treatments	N (%)						P (%)						K (%)					
	Season 1			Season 2			Season 1			Season 2			Season 1			Season 2		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
T_1	1.52	1.68	1.94	1.44	1.63	1.85	0.023	0.117	0.131	0.023	0.12	0.13	0.53	0.91	1.13	0.52	1.05	1.09
T_2	1.84	1.99	2.46	1.76	1.85	2.41	0.032	0.131	0.186	0.026	0.12	0.18	0.63	1.25	1.75	0.61	1.14	1.45
T_3	1.54	1.75	2.05	1.53	1.73	1.93	0.029	0.12	0.138	0.026	0.11	0.14	0.56	1.06	1.15	0.54	0.92	1.13
T_4	1.67	1.86	2.17	1.67	1.82	2.16	0.027	0.119	0.178	0.024	0.12	0.18	0.61	1.09	1.57	0.56	1.09	1.45
T_5	1.97	2.53	2.95	1.87	2.57	2.72	0.048	0.137	0.225	0.046	0.14	0.22	0.68	1.35	2.15	0.76	1.34	2.09
T_6	2.35	2.47	2.89	2.07	2.23	2.60	0.052	0.279	0.354	0.05	0.27	0.35	0.88	1.26	1.99	0.86	1.19	1.86
SEm±	0.055	0.020	0.018	0.010	0.016	0.014	0.001	0.001	0.001	0.001	0.002	0.002	0.011	0.013	0.011	0.007	0.009	0.014
CD (P=0.05)	0.17	0.061	0.053	0.03	0.05	0.042	0.004	0.004	0.004	0.004	0.006	0.006	0.032	0.038	0.032	0.02	0.03	0.04

[N: nitrogen; P: phosphorus; K: potassium; DAT: Days after transplanting] (T_1: Open water culture without medium; T_2: Open water culture with medium; T_3: Hydroponics without medium; T_4: Hydroponics with medium; T_5: Land cultivation with water hyacinth bed alone as medium; and T_6 - Control: soil culture- Kerala Agricultural University (KAU)-package of practices (POP) recommended dose of nutrients)

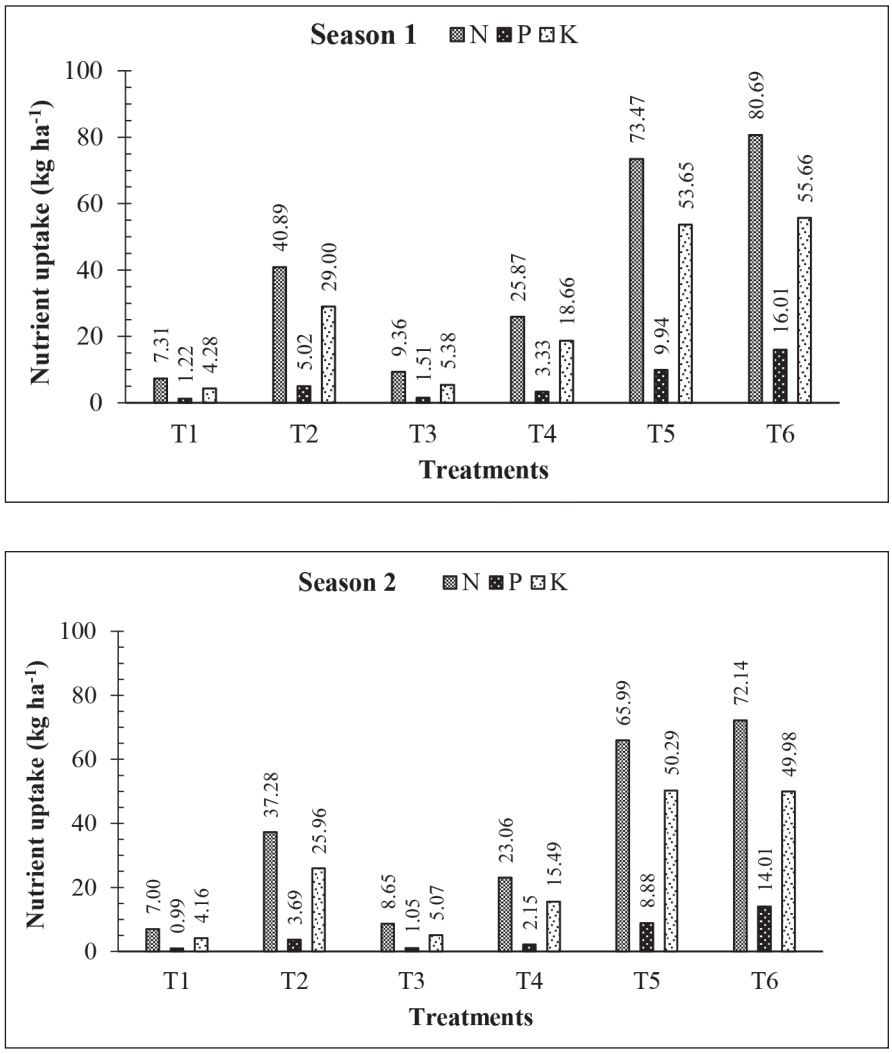

Fig. 1. Effect of different growing media on plant nutrient uptake (kg ha^{-1})

Table 4. *Effect of different growing media on yield (t ha^{-1}) of Amaranthus*

Treatments	Total yield (t ha^{-1})	
	Season 1	Season 2
T_1	1.20	1.22
T_2	8.25	7.60
T_3	1.81	1.72
T_4	3.78	3.64
T_5	16.82	16.04
T_6	17.21	17.14
SEm±	0.62	0.42
CD (P=0.05)	1.85	1.26

(T_1: Open water culture without medium; T_2: Open water culture with medium; T_3: Hydroponics without medium; T_4: Hydroponics with medium; T_5: Land cultivation with water hyacinth bed alone as medium; and T_6 - Control: soil culture - Kerala Agricultural University (KAU) - package of practices (POP) recommended dose of nutrients)

in lesser root growth and nutrient availability and lesser yield.

Economics of cultivation

The economics of cultivation in both of the seasons are worked out for unit plot size of 1x1 m^2 (Table 5). The treatment T_5 was most profitable followed by T_6 and T_2. The highest B:C ratio was obtained under T_5 followed by T_6 and T_2. The highest gross income was obtained by the treatment T_6 (₹ 72.66) for a unit plot size of 1 x 1 m^2. The maximum net return (₹ 41.4) and maximum BCR (2.6) were obtained by the treatment T_5. It was followed by T_6 with a net income of ₹ 41.14 which recorded a BCR of 2.05. The higher yield obtained with these treatments has reflected in their gross income. The result revealed that T_5 (Land cultivation with a bed of water hyacinth alone as medium) recorded the highest net returns and benefit-cost ratio because of the reduced cost of cultivation. Compared to T_6 where, soil cultivation requires tillage, intercultural operations like weeding, manuring, plant protection measures, the land cultivation in a bed of water hyacinth required no such cultural practices. The plants were free from soil borne diseases and weeds as well. All these reduced the cost of cultivation drastically compared to soil culture.

Table 5. *Effect of different growing media on economics of cultivation ofAmaranthus*

Treatments	Cost of cultivation (₹ m^{-2})	Trial 1			Trial 2		
		Gross returns (₹ m^{-2})	Net returns (₹ m^{-2})	B:C ratio	Gross Returns (₹ m^{-2})	Net returns (₹ m^{-2})	B:C ratio
T_1	167.2	5.17	-132	0.031	5.1	-162	0.03
T_2	25.8	34.86	9.06	1.35	31.93	6.12	1.24
T_3	758.6	7.56	-751	0.01	7.2	-751.4	0.01
T_4	767.6	15.96	-751.64	0.021	15.28	-752.3	0.02
T_5	25.8	67.2	41.4	2.6	67.38	41.58	2.6
T_6	34.99	72.66	37.67	2.08	71.98	36.99	2.05

CONCLUSION

From the result, *Amaranthus* cultivation in soil culture supplemented with nutrient was found to give the highest yield but water hyacinth as the growing media was equally effective as soil culture. Water hyacinth being a rich source of nutrients compared to open water and hydroponic solution and as effective as cultivation in soil supplied with nutrients with respect to yield andplant nutrient content and uptake of *Amaranthus*. The water hyacinth decomposes faster and releases the nutrients within a short period of time. Also, *Amaranthus* cultivation in land using water hyacinth as growing media proved to be more profitable compared to soil culture because of the reduced cost of cultivation. In North Kuttanad, the aquatic weed water hyacinth is available in plenty and also is a menace to the aquatic ecosystem and navigation. Hence, utilizing the weed as a medium at a lower cost for *Amaranthus* cultivation can be an advantage for the weed management strategies.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest

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