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Aquatic weeds management through chemical and manual integration to reduce cost by manual removal alone and its effect on water quality

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ABSTRACT

Dlapat sagar reservoir is one of the prominent aquatic bodies in Jagdalpur of Bastar region of Chhattisgarh state in India. The reservoir was severely infested by aquatic weeds for last many years. An experiment was done to evaluate the integration of herbicides and manual/mechanical approaches to reduce the cost in comparison to manual removal alone. The experiment comprised of 8 treatments, *viz.* glyphosate 2.0 and 1.0 kg/ha (41 SL), paraquat 2.0 and 1.0 kg/ha (24 SL) and 2,4-D (amine salt 58% SL) 2.0 and 1.0 kg/ha dissolving in 500 litre water, manual removal and control was laid out in randomized block design with three replications at reservoir located at $19^0$5'41"N and $82^0$0'43"E with elevation of 563 m MSL during 2016 and 2017. The aquatic body was covered with thick mat of different weeds entangled with each other. Herbicides were sprayed to loosen the entangled weed biomass followed by manual and mechanical removal after 25 to 30 days. Glyphostae, 2,4-D and paraquat were mixed with sticker (Latron AG-98) and were sprayed in three replications by power spray machine (1HP HTP MAK ASPEE) mounted on the boat. The pH of water was gradually increased from 6.79 to 7.09 while EC and TDS from 0.33 to 0.30 (mS/cm^2) and 101 to 207 (mg/l), respectively. The minimum density and dry matter was recorded with manual/mechanical removal followed by application of glyphosate 2.0 kg/ha, which was significantly superior over control and lower dose of other two herbicides and found statistically at par with 2,4-D amine salt 58% SL and applied at higher dose (2.0 kg/ha) during both the years. Glyphosate (2.0 kg/ha) was found effective in controlling weeds with the cost of ` 19,660/- and ` 18080 per hectare during 2016 and 2017, respectively with weed control efficiency of 86.4, 84.3; 79.1, 82.2 and 83.8, 88.3 % for water hyacinth, lotus and alligator weeds during 2016 and 2017, respectively.

INTRODUCTION

Aquatic weeds are those unwanted plants, growing in water and complete at least a part of their life cycle in water. Aquatic weeds can be classified as submerged weeds, emerged weeds and dispersed weeds, shoreline and ditch weeds, bank weeds, marshland and swamp weeds. (Gupta 1987). Out of about 140 aquatic weeds, following weeds are of primary concern in India: *Alternanthera philoxeroides, Chara* spp., *Ipomoea* spp. *Eichhornia crassipes, Hydrilla verticillata, Nelumbo nucifera, Nitella* spp. *Nymphaea stellata, Salvinia molesta, Typha angustata, Vallisnaria* spp. (Labrada 1996, Gopal and Sharma 1981). Among these, *Eichhornia crassipes*, alligator weed and lotus are of primary concern in India and world over. In general, it is estimated that 20-25% of the total utilizable water in India is currently infested with *Eichhornia crassipes* (water hyacinth), while in the state of Assam, Kerala, West Bengal, Orissa and Bihar, more than 40% water bodies are infested with water hyacinth (Sushilkumar 2011, Sushilkumar and Pradhan 2018). In Kuttanad region of Kerala, water hyacinth problem has taken a serious view, which has compelled Kerala Government to take immediate action to manage it, but problem still persists. By 1980, alligator weed (*Alternanthera philoxeroides*) was not considered a problem in India, but now it has become growing menace in water bodies, which necessitated to find out its management through various approaches including chemical management (Sushilkumar 2003). Holm *et al.* (1991) reported that in India under Chambal Project, submerged aquatic weeds had cut the flow of water by 80% in the canals. Likewise, lotus has also become a nuisance in many aquatic bodies in India and many other countries (Sushilkumar 2003, 2011). In lack of suitable biological control options for alligator and lotus weed and high cost of labour involved in manual removal, attempts were made to manage aquatic weeds in severely infested water bodies, first through herbicide application over the weed mat to get it loosened and thereafter to remove them manually and mechanically.

Dalpatsagar Reservoir in Jagdalpur city of Bastar district in Chhattisgarh state of India is one of the prominent big reservoirs spreading over 137.77 ha (340.44 acres). It was constructed by King Dalpat Deo Kakatiya over 400 years ago with the objective of harvesting rain water, but off late it became famous for its fishing and livelihood related activities for the inhabitants. Mild infestation of aquatic plants like water hyacinth, lotus and alligator weeds was started in 2005 and gradually spread in whole water body over the years due to draining of city sewage into reservoir, which favoured severe growth of aquatic weeds especially water hyacinth, lotus and alligator weed. By 2016, more than 80% surface water turned as green carpet and caused big challenge for fishing, navigation and other vital use. This compelled local administration to manage the weeds for the benefit of residents for their livelihood. In view of densely interlocked weed mat over the water surface, manual removal was experienced difficult and costly. Biological control option was available only for water hyacinth, but it was considered time taking method while other weeds would not be controlled. Therefore, it was thought to loosen the weed mat by using herbicides followed by manual and mechanical removal to reduce the cost of operation by manual method alone. Looking to the importance, an experiment was conducted to find out the suitability of the method for controlling the weeds in Dalpat sagar reservoir.

MATARIALS AND METHODS

Dalpat sagar reservoir situated at northern side of Jagdalpur city in Chhattisgarh state, India coordinating 19°5’413 N 82°0’433 E with elevation of 563 m MSL was severely infested with many type of aquatic weeds. Weed were collected and identified before applying treatments. The experiment was conducted during 2016 and 2017 at infested locations of reservoir comprising of 8 treatments namely glyphosate 41 SL at 2.0 and 1.0 kg/ha, paraquat 24 SL at 2.0 and 1.0 kg/ha, 2, 4-D (amine salt 58%) at 2.0 and 1.0 kg/ha, manual removal and control under randomized block design with three replications. Manual/mechanical removal was done by cutting of weed mat and dragging the weeds manually by boats to the bank side and from there to remove and upload on tractor trolley by JCB machine. Spraying of herbicides was done over weed mat dissolving into 500 litre water and adding with sticker 20 ml (Latron AG-98). The chemical spray was done with power spray machine (1HP HTP MAK ASPEE) mounted on the boat. The experimental area was equally divided into 24 plots of 10 x 10 m by piling bamboo poles at corners of each plot and separated by net. The gap between two plots was kept 10 meter. Herbicide spraying was done on 15th and 17th June, 2016 and 2017, respectively. After spray of herbicides, weed biomass was loosened and upper leaves were dried, but weed mat was still interlocked, which was cut and dragged manually upto bank side by the labours using the boats, ropes and bamboos. Likewise, untreated weed mat was also cut, dragged and removed using labours and machine only.

Water samples of Dalapat sagar reservoir were collected before spraying and at 10 days interval after spraying upto 30 days from each plot under different treatments. The samples were analysed for physio-chemical properties such as pH, EC and TDS using standard procedure (Jackson 1967).

Different types of aquatic weeds were collected and identified. Weed counts (no./m^2) was recorded by placing a quadrate (1.0 m^2) at three random spots in each plot before and after 25 days after spray (DAS). Roots were separated from aerial portion for taking dry weight of weed. Dry weight (g/m^2) was recorded after oven drying at 60±5^{o}C for 72 hours and weed control efficiency was calculated following the standard method. Economics of each treatment was calculated taking into consideration the cost of hiring the boat, machine and labours. Data on density and dry weight of weeds were transformed using square root transformation ($\sqrt{x+0.5}$) before statistical analysis as suggested by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Weed flora

Major aquatic weeds of Dalpat sagar reservoir were *Eichhornia crassipes* (Mart.) Solms, *Echinodorus grisebachii* Small, *Nymphaea alba* L., *Nelumbo nucifera* Gaertn., *Nymphaea rubra* Roxb. ex Andrews, *Nymphaea indica* (L.) Kuntz, *Cyperus javanicus* Houtt. Houttuyn, *Oxalis corniculata* L., *Ipomoea aquatica* Forssk, *Ipomoea carnea* Jace., *Oryza nivara* S.D. Sharma & Shastry, *Alternanthera philoxeroides* R.Br.exDC, *Potamogeton crispus* L., *Lemna minor* L., *Potamegaton amplifolius* Tuckerman and *Ceratophyllum demersum* L. Among these aquatic flora, *Eichhornia crassipes, Alternanthera philoxeroides and Nelumbo nucifera* were prominent weeds and most of the water surface was covered with these flora.

Physio-chemical properties of water body

The pH of the reservoir was influenced by weed management practices. In general, there was no difference in pH until the chemicals were applied and weeds were removed, but it increased gradually from 10 to 30 DAS during both the years. In two years of experimentation, pH was higher in the year 2017 as compared to 2016; TDS and EC were increased during 2016 than 2017 (**Table 1**). Among weed management treatments, pH in glyphosate 2.0 kg/ha (6.67, 6.97, 6.85 and 6.75 7.05, 7.01 at 10, 20 and 30 DAS in 2016 and 2017, respectively) treated plots were found significantly higher than remaining treatments except 2,4-D amine salt 2.0 kg/ha, which was at par with glyphosate 1.0 kg/ha at 10, 20 and 30 DAS (**Table 1**). The lowest TDS (105 mg/l) was noticed in control before spray during 2016, which increased at 10, 20 and 30 days after herbicide spray, while in glyphosate 1.0 kg/ha treated plots it was at par with 2,4-D 1.0 kg/ha. TDS increased gradually from 10 to 30 DAS corresponding to the deterioration of weeds. The significant differences of EC were not observed among the treatments at 10 days after spray. Significantly higher EC was observed in application of glyphosate 2.0 kg/ha (0.33, 0.30, 0.26 and 0.35,0.27, 0.24 (mS/cm^2) at 10 20 and 30 DAS during 2016 and 2017, respectively), which was at par with 2,4-D 1.0 kg/ha (0.28, 0.35, 0.29 and 0.27, 0.22, 0.28 at 10, 20 and 30 DAS during 2016 and 2017, respectively) whereas in rest of treatments, EC was found less (**Table 1**). Similar finding was reported by Kannan and Karthiresan (2002) for effective control of water hyacinth with glyphosate 2.20 kg/ha without much reduction of water quality in term of pH. Glyphosate and 2,4-D ethyl-ester 2.0 kg/ha were found effective to control lotus in a pond at Jabalpur with no mortality of fish (Sushilkumar *et al.* 2003). However, they observed decrease in pH and dissolve oxygen after 15 days of herbicide spray on lotus and interpreted this decrease with the decomposing of leaves of lotus due to action of chemicals. In the present study also, no fish mortality was observed after herbicide spray. This might be happened because all the herbicides fell down on dense mat of weeds and therefore there was no direct mixing of herbicide with the water.

Effect of herbicides on density of weeds

The maximum density was recorded with alligator weed followed by water hyacinth and lotus. In control, no significant difference was observed in density of weeds before imposing treatments, but significant changed was recorded in the treated plots after 25 DAS (days after spray). The density of water hyacinth in control varied from 8.98 to 9.51 and 5.76 and 6.37 per m^2 during 2016 and 2017, respectively. The lotus density in control was recorded 2.37 to 2.62 m^2 and 1.44 to 1.67 m^2 during 2016 and 2017, respectively. The alligator density in control varied from 9.97 to 10.03 and 6.4 to 7.04 m^2 during 2016 and 2017, respectively. The overall density in all the treatments was found reduced in 2017 in control, which reflected that control action taken during 2016

Table1. Physio-chemical properties of Dalpatsagar reservoir

Treatment	Year	pH				TDS(mg/litre)				EC (mS/cm^2)			
		Before spray	10 DAS	20 DAS	30 DAS	Before spray	10 DAS	20 DAS	30 DAS	Before spray	10 DAS	20 DAS	30 DAS
Glyphosate 41 SL 2.0 litre/ha	2016	6.09	6.65	6.97	6.85	102	143	193	204	0.31	0.33	0.3	0.26
	2017	6.23	6.75	7.05	7.01	112	139	189	199	0.28	0.35	0.27	0.24
Glyphosate 41 SL1.0 litre/ha	2016	6.1	5.98	6.19	6.37	110	129	174	183	0.3	0.29	0.2	0.23
	2017	5.44	6.02	6.08	5.98	115	124	165	178	0.29	0.29	0.24	0.20
Paraquat 24 SL 2.0 litre/ha	2016	5.95	5.73	5.94	6.11	105	123	166	176	0.28	0.28	0.26	0.21
	2017	6.02	5.79	6.01	6.18	106	124	168	178	0.28	0.28	0.26	0.21
Paraquat 24 SL 1.0 litre/ha	2016	5.81	5.5	5.7	6.86	101	128	160	169	0.29	0.26	0.25	0.21
	2017	5.98	5.86	6.01	6.25	113	126	165	171	0.31	0.34	0.31	0.24
2,4-D Amine Salt 58% SL 2.0 kg/ha	2016	6.07	6.73	6.89	7.09	104	145	195	207	0.3	0.32	0.3	0.23
	2017	6.80	7.54	7.72	7.94	116	132	218	232	0.34	0.36	0.34	0.26
2,4-D Amine Salt 58% SL 1.0 kg/ha	2016	6.08	6.05	6.27	7.18	111	130	176	186	0.3	0.29	0.23	0.22
	2017	6.83	6.81	6.78	6.91	118	137	186	201	0.34	0.32	0.29	0.26
Manual removal	2016	6.00	5.89	6.01	7.19	106	125	168	178	0.29	0.28	0.24	0.21
	2017	6.12	6.02	6.17	7.21	112	131	172	182	0.32	0.31	0.25	0.24
Control	2016	5.98	5.87	5.77	5.63	105	117	122	171	0.28	0.27	0.25	0.28
	2017	6.64	5.89	6.01	6.09	117	118	110	190	0.32	0.35	0.28	0.32
LSD (p=0.05)	2016	NS	0.67	0.73	0.72	NS	19.5	14.4	12.3	NS	0.03	0.03	0.02
	2017	NS	0.76	0.86	0.76	NS	20.1	15.2	13.8	NS	0.03	0.04	0.02

DAS=Days after spray; mS/cm =millisiemens per centimeter caused reduction in density in aquatic weeds in 2017. The severe reduction in density of water hyacinth was observed with spraying of glyphosate 2.0 kg/ha followed by 2,4-D amine salt 2.0 kg/ha and paraquat 2.0 kg/ha (**Table 2**). Lower doses of tested herbicides were not significantly effective with each other. Manual/mechanical removal was significantly superior in reduction of density over the rest of treatments. Density of all three type of weeds were found significantly increased in control than the herbicidal and manual control treatment. Aquatic weeds were effectively controlled by manual and mechanical removal, but it was costlier than the chemicals (Bhan and Sushilkumar 1996). Glyphosate at 2.0 kg/ha was found superior in controlling weeds than other herbicidal treatments except higher dose (2.0 kg/ha) of 2,4-D amine salt, which were at par with glyphosate 2.0 kg/ha (**Table 2**). Similar finding was of glyphosate quoted by Muniyappa *et al.* (1995) at 2 ml per litre of glyphosate for alligator weed in reduction of density. Obyleye *et al.* (1993) obtained most effective and economic method of control for *E. crassipes* by application of 2,4-D amine salt and fish species composition also improved qualitatively and quantitatively.

Weed control efficiency (WCE)

The weed control efficiency was significantly highest under manual and mechanical removal than other treatments except glyphosate 2.0 kg/ha, which was at par with this treatment. 2,4-D 2.0 kg/ha was the second most effective herbicides to loosen the compact weed mat and was at par with glyphosate 2.0 kg/ha. In paraquat treatment, upper leaves started to dry by 24 hours after spray and it appeared that it will quickly control the weeds, but within a week, leaves gradually started to regain its green colour from the lower side of the plant. Higher WCE was recorded during 2017 in comparison to 2016 (**Table 3**), which might be due to the past experience of labour in applying of herbicides followed by cutting and dragging of weed biomass to the bank side. Raju and Reddy (1988) suggested that lowest WCE was noticed when 2,4-D amine salt 58% SL was applied at 0.5 kg/ha due to more reduction of dry matter, which led to higher WCE. Sushilkumar (2011) recorded

Table 2. Effect of weed control treatments on density (no./m^2) of the aquatic weeds

Treatment	Water hyacinth				Lotus				Alligator weed			
	2016		2017		2016		2017		2016		2017	
	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS
Glyphosate 41 SL 2.0 kg/ha	9.93	4.25	6.37	2.46	2.62	1.46	1.67	0.94	11.03	4.19	7.04	2.69
	(98.09)	(19.73)	(61.25)	(10.57)	(6.35)	(1.62)	(4.08)	(1.05)	(121.09)	(17.05)	(76.12)	(10.92)
Glyphosate 41 SL1.0 kg/ha	8.98	5.09	5.76	3.27	2.25	1.73	1.44	1.11	9.97	5.18	6.40	3.32
	(80.06)	(25.43)	(45.21)	(14.25)	(4.55)	(2.50)	(2.91)	(1.61)	(98.83)	(26.31)	(62.13)	(16.87)
Paraquat 24 SL 2.0 kg/ha	9.08	5.67	5.82	3.35	2.29	1.76	1.47	1.13	10.08	5.41	6.46	3.71
	(81.93)	(26.78)	(51.27)	(17.18)	(4.74)	(2.61)	(3.05)	(1.66)	(101.15)	(27.70)	(64.89)	(17.78)
Paraquat 24 SL 1.0 kg/ha	9.18	5.88	5.78	3.64	2.33	1.97	1.50	1.26	10.20	5.79	6.54	3.39
	(83.85)	(26.56)	(53.79)	(16.79)	(4.93)	(3.38)	(3.16)	(2.16)	(103.51)	(27.48)	(65.44)	(17.62)
2,4-D Amine Salt 58% SL 2.0 kg/ha	9.29	4.12	5.89	2.89	2.37	1.56	1.51	1.00	10.32	4.57	6.62	2.91
	(85.81)	(16.48)	(54.23)	(11.25)	(5.13)	(1.94)	(3.28)	(1.23)	(105.94)	(20.41)	(66.96)	(13.10)
2,4-D Amine Salt 58% SL 1.0 kg/ha	9.40	5.91	6.03	3.79	2.41	1.77	1.55	1.14	10.44	6.01	6.70	3.86
	(87.82)	(34.42)	(55.62)	(20.91)	(5.33)	(2.63)	(3.41)	(1.69)	(108.42)	(35.61)	(69.75)	(22.83)
Manual removal	9.51	3.10	6.10	1.99	2.46	1.18	1.58	0.78	10.56	3.02	6.77	2.03
	(89.88)	(9.09)	(56.47)	(5.80)	(5.53)	(0.89)	(3.55)	(0.57)	(110.95)	(9.40)	(72.15)	(6.03)
Control	9.41	10.40	6.04	6.64	2.42	3.32	1.55	2.13	10.84	10.63	6.95	6.81
	(87.98)	(107.64)	(55.46)	(68.95)	(5.34)	(10.51)	(3.43)	(6.74)	(116.95)	(112.58)	(74.56)	(71.25)
LSD (p=0.05)	NS	1.40	NS	0.81	NS	0.14	NS	0.19	NS	1.17	NS	0.95

Table 3. Effect of weed control treatments on weed control efficiency and economics

Treatment	Weed control efficiency (%)						Cost of control (x10^3 `/ha)	
	Water hyacinth		Lotus		Alligator weed			
	2016	2017	2016	2017	2016	2017	2016	2017
Glyphosate 41 SL 2.0 litre/ha	86.4	84.2	79.1	82.2	83.7	88.3	19.66	18.08
Glyphosate 41 SL1.0 litre/ha	81.7	81.1	74.9	79.2	80.5	82.3	20.41	19.10
Paraquat 24 SL 2.0 litre/ha	68.0	62.2	61.3	60.3	66.1	67.2	24.12	24.57
Paraquat 24 SL 1.0 litre/ha	62.1	61.3	56.0	54.7	62.6	65.6	22.26	22.31
2,4-D Amine Salt 58% SL 2.0 kg/ha	81.7	78.3	67.7	78.2	74.9	82.6	21.33	20.41
2,4-D Amine Salt 58% SL 1.0 kg/ha	75.3	74.0	66.2	71.2	73.8	79.2	20.78	19.40
Manual removal	91.6	90.1	88.4	91.2	91.0	92.3	59.36	57.52
Control	0	0	0	0	0	0	0	0
LSD (p=0.05)	8.1	6.1	7.5	14.0	16.0	10.6	1.87	2.08

highest weed control of water hyacinth by 2,4-D 2.kg/ha (82.8%) followed by glyphosate 2.0 kg/ha (75.4%) and by paraquat (75.6%) at 21 days after herbicide spray, however they observed highest regrowth of water hyacinth in paraquat treatment after 3 months of spray followed by 2,4-D and glyphosate. Sushilkumar *et al.* (2003) also recorded higher weed control of lotus by glyphosate 2.0 kg/ha (82.7%) followed by 2,4-D (ethyl ester) 2.0 kg/ha (77.5%). Sushilkumar *et al.* (2008) recorded that 2,4-D (1.5 kg/ha) and glyphosate (2.0 kg/ha) caused almost 100% superficial killing of terrestrial form of alligator weed at 15 DAS, however, regrowth occurred after 60 days. They observed that repeat application of same herbicides after 90 days of first application revealed no significant difference in regrowth at 30 DAA, however significant difference appeared at 60 and 90 DAS.

Economics

The maximum cost of weed control was associated with manual-cum-mechanical removal because of engagement of labours with highest WCE (91.56, 90.15,88.45 and 81.25, 91.04, 92.35% for water hyacinth, lotus and alligator weeds during 2016 and 2017, respectively). Glyphosate (2.0 kg/ha) was found most effective with cost of ` 19660 and ` 18080 per hectare with WCE of 86.4 and 84.3% for water hyacinth during 2016 and 2017, respectively (**Table 3**). Paraquat 24 SL and 2,4-D amine salt 58% SL were less costlier than glyphosate applied at higher dose, but weed control efficiency was not parallel to glyphosate. Lower dose of glyphosate was effective than lower dose of paraquat and 2,4-D in context to weed control efficiency, which were 76.4,80.2, 67.7 and 71.2, 74.9, 79.5% for water hyacinth, lotus and alligator weeds during 2016 and 201. The cost of treatments *of* 2,4-D amine salt at 1.0 kg/ha and paraquat 1.0 kg/ha for controlling weeds was found to be ` 20780 and 19400 and ` 22260 and 22310 per hectare during 2016 and 2017, respectively, which was about 61% lower than that of manual removal cost of ` 59360 and 57520 per hectare during 2016 and 2017, respectively. Reduction in cost in second year was possible due to experience gained during previous year to spray the chemical and to remove the weed subsequently. Sharma *et al*. (1989) obtained that an expenditure of ` 30324.00 was incurred in manual removal of *E. crassipes* from four experimental ponds, which had an area of 18.18 hectare after the removal of *E. crassipes* mechanically over manual control. In our experiment, we removed aquatic weeds after loosening the weed mat using both manual and mechanical approaches due to which cost of removal has come down appreciably than the manual approach alone.

It was concluded that in case of sever infestation of complex of aquatic weeds, we can reduce the cost of manual or mechanical removal appreciably without disturbing water quality by first employing the herbicide over the weed mat to loosen the entangled weed biomass and thereafter to remove them manually/mechanically after a gap of 25 to 30 days.

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