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COMPARATIVE EFFECT OF HERBICIDAL AND NON-CH[1]EMICAL CONTROL METHODS AGAINST WATER HYACINTH

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ABSTRACT

The invasion of water hyacinth in the fresh water bodies has resulted in tremendous ecological and economic losses globally. In Pakistan water hyacinth is wide spread due to the unawareness of the masses and negligence of the scientific community, causing alteration of ecosystem services, deterioration of aquatic environments and spread of water related diseases. Water hyacinth infestations have also led to enormous economic losses in Pakistan by impeding water flows and hydroelectricity facilities. To investigate the efficacy of different control measures, an experiment was carried out during spring 2014. The experiment was laid out in randomized complete block (RCB) design with three replicates. Eight treatments including (i) 2, 4-D ester @ 1.5 kg a.i. ha^{-1}, (ii) paraquat @ 1.5 kg a.i. ha^{-1}(iii) glyphosate @ 2.0 kg a.i. ha^{-1}, (iv) water extract of Parthenium hysterophrous and (v) water extract of Sorghum bicolor L. @ 1: 10 (w/v), (vi) black plastic, (vii) hand weeding and (viii) a weedy check for comparison. All the variables except species abundance were significantly affected by various methods of weed control. Minimum plant height of water hyacinth (0.00 cm) was recorded in the hand weeding (because of zero re-growth) and 2, 4-D plots (because of 100 % control) followed by dark plastic (5.50 cm) while maximum plant height (43.94 cm) was observed in the control treatment. The lowest density m^{-2}of water hyacinth (0.00 plants m^{-2}) was recorded in the hand weeding, however it was at par with dark plastic plots (1.33 plants m^{-2}) while the highest density m^{-2} (28.33 m^{-2}) was recorded in the control plots. Similarly, minimum fresh weight (0.00 kg m^{-2}) was recorded in the hand weeding, yet it was statically similar with that of dark plastic treatment (1.29 kg m^{-2}), while maximum (7.22) fresh weight was recorded in the control plots. There were zero re-sprouts in the hand weeding and dark plastic plots followed by 2,4-D (1.33 sprouts/ramets m^{-2}) as compared to control (13.00 ramets m^{-2}). Water hyacinth mortality was (100 %) in hand weeding, followed by dark plastic, 2, 4-D and glyphosate (90 % each) while the lowest mortality (5 %) of water hyacinth was obtained in S. bicolor water extract followed by P. hysterophrous (16 %) as compared to control (0.00 %). It was concluded

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from the research findings that hand weeding is the most effective method for the complete eradication of water hyacinth, for small scale and it is environmental friendly but the cost and availability of labor might be a hindrance in some areas, while solarization is very technical and costly too as compared to hand weeding and chemical weed control. So, herbicides can be used for large scale economically with sufficient water hyacinth control but endanger the lives of non-target species and deteriorate the environment if not used sagaciously. Therefore integration of physical removal with the use of herbicide and ecological or cultural techniques depending on the size and severity of infestation is recommended.

Key words: allelopathy, herbicides, water hyacinth, integrated weed control.

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INTRODUCTION

Water scarcity and water pollution are the most important issues of the 21st century. Water conservation for future generations is therefore essential through managing water crisis and solving issues related to deterioration of water quality and destruction of the aquatic ecosystem. Aquatic weeds; the major culprits, deteriorating fresh water, hindering their intended use in various ways; are one of the major factors that disturbs the balance of aquatic ecosystems, deteriorates quality of water and causes water pollution. Pakistan has one of the best canal systems in the world, with scenicand attractive rivers, streams, ponds and dams etc. Fresh water bodies such as dams, barrages, irrigation canals, streams, rivers, drainage ditches, lakes, ponds and rice fields are often infested with aquatic weeds, causing problems and hindering water utilization, reducing crop yield, blocking water flow, making them looking unsightly and affecting water sports (Ramlan, 1991).

Aquatic weeds cause substantial economic losses and interfere with water utilization (Julien *et al*., 1999; Charudattan, 2001; Rezene, 2005). Aquatic weeds reduce efficiency of agricultural production systems by slowing down water flowin irrigation canals and water courses, providing unsightly scene of water bodies and interfere with swimming, boating and fishing in fresh waters (Ramlan, 1991). Native aquatic plants are a natural part of fresh water and play an important role in maintaining healthy aquatic ecosystems, protect shorelines from erosion and extract pollutants from water. While plants of exotic or alien nature often become invasive, grow fast and spread quickly across large areas by adapting several ways of reproduction and are capable of surviving in different environmental conditions. They cause huge losses to the national economy and to the environment on large scale (Langeland, 1996). Invasive aquatic weeds like *Salvinia molesta, Hydrilla verticillata, Pistia stratiotes, Lemna, Typha* and *Eichhorniacrassipes* are distributed widespread in Pakistan.

Among them water hyacinth is one of the most problematic invasive species and has been ranked on the top in the list of the world's worst weeds because of its rapid multiplication, dense population and impenetrable mat formation on water surface, destroying fish and wildlife habitats (Center *et al.,* 2002; Howard and Harley,1997). The infestations of water hyacinth in many aquatic systems have reduced native biodiversity, deteriorated ecosystem functioning and services, clogged up lakes and rivers, obstructed navigation, damaged irrigation and hydroelectricity facilities and resulted in colossal economic losses in many regions of the world.

Water hyacinth belongs to family Pontederiaceae is a free floating aquatic plant but can establish roots in the mud like emergent plants when the water level recedes or the water body dries up. It has inflated petioles with bulb like structures in the middle having aerenchyma, helping it in floating on water surface (Hutchinson and Dalziel, 1968).Von Martius, a German naturalist discovered water hyacinth in 1823 while studying the flora of Brazil and named it *Pontederia crassipes*. Later on Solms included it in the genus *Eichhornia* as described by Kuntz in 1829. Itis distributed across the Tropics and Subtropics between 39°N and 39°Scausing huge production and economic losses (Rezene, 2005).

Numerous features make water hyacinth easy to identify, including rosettes of rounded and leathery, waxy, shiny green leaves with abroad, spongy, swollen (in the middle) petioles and dark fluffy roots and attractive purple flowers. The inflorescence is distinctive, with above ground spike growing up to 30 cm, and the fruit consist of a three chambered seed capsule (Langeland and Burks 1998). It is capable of increasing in biomass by up to 12% per day. The time required doubling in number or biomass is variously reported to be from 6 to 15 days (Gopal, 1987). Water hyacinth increases water losses through evapo-transpiration many fold than open water surface and also harms fish production (Irving and Beshir, 1982).

It is a major freshwater weed in most of the frost free zone of the world and is generally recognized as the most troublesome aquatic plant (Holm *et al.*, 1997). It cannot tolerate low temperature and below 12^{o}C it cannot survive. The optimum temperature ranges from 25 to 30^{o}C, while the plant grows its maximum growth at 33^{o}C

(Kasselmann, 1995). Although water hyacinth is excluded from cold climates due to its sensitivity to low temperatures; it does show a degree of frost tolerance. The above water portion when killed by moderate frost is quickly replaced by re-sprouting from under water stem tips which are protected from chilling by water (Langeland and Burks, 1998). In optimum climatic conditions it is capable to cover the entire water body rapidly with thick mats on the water surface, limiting livestock access to water, reducing infiltration of sunlight, alter oxygen levels and pH of water, reducing exchange of gases at the air-water interface, changing water temperature, causing large amount of water loss through transpiration, making the aquatic ecosystem less favorable for the native species and more favorable for the invasive species and providing shelter for insects and snakes.

It degrades water quality by overcrowding the air-water interface and reducing oxygen level below the surface resulting in elimination of aquatic fauna. Water hyacinth seriously reduces biodiversity and eliminates local submerged plants, change emerged plant communities and also change native fauna by destroying their nesting and mating environment and by eradicating indigenous plants on which these animals depend upon for their food and shelter (Gowanloch, 1944).

In Pakistan, there is a great problem of water hyacinth in all water bodies and no concrete steps have been taken for their management. In the studied area, most of the water bodies especially drainage ditches and water streams are fully infested with water hyacinth and the rest of water bodies are prone to further infestation at a rapid speed, if no proper check and management plan is implemented. The studied area is plain where the water movement is slow and chance of siltation is more, making conducive environment for the invasion of water hyacinth. All these conditions necessitate a comprehensive management plan for this noxious weed. Therefore, an experiment was designed with the objectives to find out an easy and economical control method for water hyacinth management and to compare weed control efficiency of various methods in managing the water hyacinth infestations.

MATERIALS AND METHODS

Experimental site description

An experiment was conducted to evaluate "comparative effect of herbicidal and non-chemical control methods against water hyacinth in drainage ditches previously infested with heavy mats of water hyacinth in the District Swabi, Khyber Pakhtunkhwa, Pakistan" during spring 2014. The study site was situated at 34° 13'00.32" N latitude and 72°16'00.30" E longitude with an altitude of 1055 ft.

Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD), replicated three times with eight treatments.The treatments used in the experiment were;

T_1 = 2, 4-D ester (2, 4-dichlorophenoxy acetic acid,) @ 1.5 kg a.i. ha^{-1}

T_2 = Paraquat (1. 1-Dimethyl-4, 4-bipyridinium dichloride) @ 1.0 kg a.i. ha^{-1}

T_3 = Glyphosate (N-(Phosphonomethyl) glycine) @ 2.0 kg a.i. ha^{-1}

T_4 = *Parthenium hysterophrous* water extract (WE) @ 1: 10 (w/v)

T_5 = *Sorghum bicolor* water extract (WE) @ 1: 10 (w/v)

T_6 = Dark plastic (Solarization)

T_7 = Hand weeding (physical control)

T_8 = Control (Weedy check)

The size of each experimental unit was (2x2) m^2. Recommended doses of the above mentioned herbicides were applied post-emergence as foliar spray on water hyacinth infestation in a drainage ditch with an average water depth of 52.65 cm on March 25, 2014 with a Knapsack manual sprayer. Control treatment was kept weedy for the whole season. In hand weeded treatment water hyacinth was removed completely with the help of a simple three-tine fitch fork with crooked frongs thoroughly during the experiment and the accumulated biomass of water hyacinth was dumped on land, away from the water body to dry up and wither. Re-growth (ramets m^{-2}) from the mother plants was observe done month after treatments application. Solarization method was used by covering the water hyacinth infestation with dark plastic to alter the micro-environment for the water hyacinth, to deprive it from sunlight.

During the course of experiment the data was recorded on water hyacinth plant height (cm) by measuring height of ten plants in each treatment selected randomly from water surface to the tip of the leaves by using measuring rod and then average plant height was calculated for each treatment. Density of water hyacinth (m^{-2}) was recorded before and after treatments application with the help of ($0.5x0.5m^2$) quadrate. Density was recorded three times at equal interval and then average was calculated. To know about the other species associated with the stands of water hyacinth and to find out the affect of control strategies on these plants species abundance (%) data were calculated. The data was taken after the treatments application with the help of ($0.5x0.5m^2$) quadrate. For fresh weight of water hyacinth (kg m^{-2}) each treatment was weeded out thoroughly and was weighed after one month of treatments application. The fresh biomass was collected in plastic bags and then weight with the help of electronic balance.The data recorded on water hyacinth mortality (%) was based on visual rating of each treatment compared to control treatment. Scale of 1-5 was used for recording water hyacinth mortality (%), where 1 means 0-20, 2 means 21-40, 3 means 41-60, 4 means 61-80 and 5 means 81-100 % water hyacinth mortality % caused by the concerned treatments. Such data were recorded at the end of the experiment. Data on numbers of re-sprout/ramets m^{-2} was recorded in each treatment after one month of treatments application.

The data recorded individually for each parameter were analyzed statistically by using analysis of variance techniques in Microsoft Excel 2007, appropriate for randomized complete block design and the results were confirmed by reanalyzing through Statistix 8.1 software. Means were compared by using Least Significant Difference (LSD) test at 0.05 level of probability (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Plant height (cm)

Statistical testing of data revealed that integration of different treatments had significant ($p \leq 0.05$) effect on the plant height of water hyacinth. Data regarding plant height is presented in Table-1. The data showed that zero plant height was recorded in hand weeding plots and 2, 4-D followed by minimum plant height in the dark plastic treatment (5.50 cm), glyphosate (7.87 cm) and paraquat (12.70 cm) as compared to control (43.94 cm). While maximum plant height (33.44cm) was observed in *Sorghum bicolor* water extracts followed by *Parthenium hysterophrous* (28.19 cm) water extracts, respectively. Our results are inline with Carlock, (2003) who stated that the use physical /mechanical control for water hyacinth is a good and alternative approach to the conventional chemical control. Herbicide 2,4-D application for plant suppression is excellent, the plants were completely wilted and zero plant heightwas recorded. Solarization technique was also best for the control of water hyacinth but it showed less control than hand weeding and 2, 4-D because the average water depth data was recorded 48 cm. If the water hyacinth plants were attached to the hydro-soil, complete decomposition would have occurred in the absence of oxygen and temperature would have raise significantly, then there would be complete decomposition of water hyacinth.

Glyphosate as a trans-located herbicide show less injury symptoms than 2,4-D, because of low dose and fully mature water hyacinth weeds in their flowering stage, while paraquat shows contact injuries and may recover after 1 to 2 weeks of spray. In allelopathic water extracts treatments *Parthenium hysterophrous* give and *Sorghum bicolor* give plant height (28.19 cm) (33.44 cm), respectively. If we increase the concentration of *P. hysterophrous* and *S. bicolor* we might get the better control of water hyacinth.

Density (m^{-2}) of water hyacinth

Data on density (m^{-2}) of water hyacinth was recorded one month after treatments applications. Statistical analysis of data revealed that treatments had highly significant effect on density of water hyacinth. Data regarding density (m^{-2}) of water hyacinth is presented in the Table-1.The highest water hyacinth density m^{-2} (28.33) was recorded in the control treatment while minimum density (0.00 plants m^{-2}) was observed in the hand weeding plots. However, it was statistically at par with that of plastic mulch (1.33 m^{-2}), 2,4-D (2.33 m^{-2}) and followed by glyphosate (5.33m^{-2}) treatments, respectively. Paraquatas contact herbicide significantly affected water hyacinth foliage but most of the plants recovered and regenerated with the passage of time from the protected buds that have escaped from the herbicide contact. While the water extracts of the allelopathic plants *P. hysterophrous* (19.667 m^{-2}) and *S. bicolor* (21.33m^{-2}) both had minimum effect on the density of the water hyacinth.

As per our results, hand weeding proved the best control method for complete eradication of the whole biomass of water hyacinth. These results are similar to those of (Julien *et al*., 1999) who stated that in developing countries, manual removal is still productive. In case of chemical control of water hyacinth our results are in conformity with those of Gopal (1987) who reported that water hyacinth is very susceptible to herbicides like 2,4-D, glyphosate, diquat and paraquat. Furthermore, Chinnusamy *et al*. (2012) stated that the use of glyphosate at the rate of 10 ml L^{-1} can suppress the water hyacinth density. In the current experiment best control of water hyacinth was achieved in 2,4-D treated plots followed by glyphosate treatments, because of the trans-located nature of the herbicides and optimum growing stage of the water hyacinth at the flowering stage.

Table-1. Plant height (cm) and density (m^{-2}) of water hyacinth as affected by different treatments

Treatments	Plant height (cm)	Density (m^{-2})
2, 4-D ester	0.00 d	2.33 e
Paraquat	12.70 c	8.00 c
Glyphosate	7.87 c	5.33 d
Parthenium hysterophrous (water extract)	28.19 b	19.66 b
Sorghum bicolor (water extract)	33.44 b	21.33b
Dark plastic (solarization)	5.50 cd	1.33 ef
Hand weeding	0.00 d	0.00 f
Control (weedy check)	43.94 a	28.33 a

LSD value for plant height (cm) of water hyacinth at 0.05 alpha level =7.22

LSD value for weed density (m^{-2}) of water hyacinth at 0.05 alpha level =1.80

Species abundance (%)

Statistical analysis of the data depicted that the data on species abundance was non-significantly affected by the application of different control methods Table-2. However maximum plant species were observed in control (7.00) while the lowest plant species were observed in hand weeding (0.00) and dark plastic (0.00) followed by *P. hysterophrous* water extract (0.66) and 2, 4-D (1.00) treatments.

As the treatments were applied to a natural habitat with natural species composition of water hyacinth along with other aquatic plants i.e. *Nastursium officinale* and *Persicaria hydropipper* at various spots along the drainage ditch, different numbers of species were there in each respective treatment plots. For example in *P. hysterophrous* and *S. bicolor* plots there is only pure stands of water hyacinth while the remaining treatments have various number of species, that is why the results are non-significant throughout the experimental plots.

Fresh weight (kg m^{-2}) of water hyacinth

Statistical analysis of data showed that different integrated control treatments had significantly affected biomass (kg m^{-2}) of water hyacinth (Table-2). The maximum fresh weight kg m^{-2}(7.22) was recorded in the control treatments, while the minimum fresh weight kg $m^{-2}$was noted in hand weeding plots (0.00) followed by dark plastic (1.29), 2, 4-D (1.55) and glyposate (2.53). Paraquat had a significant effect (3.01) on water hyacinth biomass but having less efficacy, although was far better than the *P. hysterophrous* (4.25 kg m^{-2}) and *S. bicolor* (6.49 kg m^{-2}) treatments.

Hand weeding is the best for the removal of complete biomass rather than those of chemical or any other control measures where the left over biomass of decaying plants in water create water pollution. Yet hand weeding cannot be carried out on large scale due to labor availability, high cost of weed control and inaccessibility in certain situation and can only be adopted on small area like small drainage water channel. Whereas, in case of very huge infestation integrated control would be the best option. Mallya *et al*. (2001) also stated that integrated control of water hyacinth was more effective than individual methods. Dark plastic showed best result followed by 2,4-D showed completely wilting of water hyacinth. Chinnusamy *et al*. (2012) also stated that 2, 4-D at 6g L^{-1} and 8g L^{-1} showed wilting in the early stage and cause death of water hyacinth. Glyphosate having optimum control of water hyacinth and the results are in line with Lopez, (1993) who stated that glyphosate at the rate of 5 L ha^{-1} can reduce 95 % biomass of water hyacinth, while paraquat at earlier stage of application showed best results thanplant extracts of sorghum and parthenium. However, at later stage paraquat, *P. hysterophrous* and *S. bicolor* water extracts treated plots showed recovery symptoms.

Table-2. Specie abundance and fresh weight (kg m^{-2}) of waterhyacinth as affected by different treatments

Treatments	Specie abundance	Fresh weight (kg m^{-2})
2, 4-D ester	1.000 ab	1.5533 e
Paraquat	3.667 ab	3.01 d
Glyphosate	2.667 ab	2.53 d
Parthenium hysterophrous (water extract)	0.667 b	4.27 c
Sorghum bicolor (water extract)	2.667 ab	6.49 b
Dark plastic (solarization)	0.000 b	1.29 e
Hand weeding	0.000 b	0.00 f
Control (weedy check)	7.000 a	7.22 a

LSD value for species abundance at 0.05 alpha level =6.341
LSD value for fresh weight of water hyacinth at 0.05 alpha level=0.635

Water hyacinth ramets/re-sprouts (m^{-2})

Statistical analysis of data revealed that different treatments had significant effect on ramets (m^{-2}) of water hyacinth (Table-3).The maximum ramets m^{-2} (13.00) was recorded in the control treatment, while the minimum ramets m^{-2}(0.00), (0.00) and (1.33) in the hand weeding, dark plastic and 2,4-D treatments respectively, which are statistically at par with each other followed by glyphosate (4.66) and paraquat (7.00) ramets(m^{-2}). *Sorghum bicolor* showed little effect on ramets m^{-2} of water hyacinth.

Water hyacinth ramets emerged after 2 weeks from the mother plants, it depending on the environmental conditions especially temperature while the environmental condition was more suitable for water hyacinth growth. Maximum water hyacinth sprouts (13m^{-2}) where recorded in the control treatment. Hand weeding and dark plastic were at par with each other resulted optimum control of water hyacinth followed by 2,4-D and glyphosate. In paraquat, *P. hysterophrous* and *S. bicolor* treated plots ramets (m^{-2}) emerged after one week of application where the parent plants might have recovered from herbicidal or allelopathic effect while the remaining treatment showed no symptoms of plant recovery and ramets m^{-2}.

Water hyacinth mortality (%)

The data on water hyacinth mortality (%) was recorded on visual observations of each treatment. Scale of 1- 5 was used for recording weeds mortality as mentioned in the material and methods section. Statistical analysis of data revealed that treatments had significant affect on water hyacinth mortality (Table-3). The data showed that maximum water hyacinth mortality 5 which is 100 %, was recorded in hand weeding and dark plastic treatments followed by 2,4-D and glyphosate having values of 4.66 and 4.33 % respectively. The minimum water hyacinth mortality of 0.66, 1.66 and 3.66 % was recorded in the paraquat, *P. hysterophrous* and *S. bicolor*plots respectively.

In the hand weeding plots the complete biomass was removed therefore, 100 % mortality was achieved. Our results are in line with Carlock, (2003) who stated that physical removal is the best approach for complete removal of water hyacinth to a limited area. Dark plastic achieved best results with conformity to those of Ogari and Knap (2002) who also stated that after a period of three weeks full decomposition (100%) of water hyacinth occurs and plants were dead. The results of 2, 4-D and glyphosate are in line with Chu *et al.* (2006) who reported that herbicides 2, 4-D and glyphosate were used for the best control of water hyacinth in the past decades in China. Gopal, (1987) also reported that herbicides 2, 4-D, glyphosate and paraquat are best for the control of water hyacinth but paraquat as a contact herbicides showed recovery symptoms. In case of allelopathic extract application of *P. hysterophrous* showed best result than *S. bicolor* with no or very little mortality. Our results are in conformity to those of Pandey *et al*., (1993) who reported that *P. hysterophrous* extract applied @0.50% w/v caused wilting from the margins of the leaves. They further stated that mortality of water hyacinth depends upon the concentrations of the allelopathic plant extract as well as on the growth rate and growth stage of the target plant. Plant extract have exerted little effect on water hyacinth mortality and suggested that the efficacy might be enhanced if the extracts were used at seedling stage of water hyacinth with higher concentrations.

Table-3. Ramets m^{-2} (re-sprouts) and mortality % of water hyacinth as affected by different treatments

Treatments	Ramets m^{-2}	Mortality %
2, 4-D ester	1.333 d	4.6667 ab
Paraquat	7.000 c	3.6667 c
Glyphosate	4.667 c	4.3333 b
Parthenium hysterophrous (water extract)	10.000 b	1.6667 d
Sorghum bicolor (water extract)	12.667 a	0.6667 e
Dark plastic (solarization)	0.000 d	4.6667 ab
Hand weeding	0.000 d	5.00 a
Control (weedy check)	13.000 a	0.00 f

LSD value for ramets (m^{-2}) of water hyacinth at 0.05 alpha level=2.406
LSD value for mortality (%) of water hyacinth at 0.05 alpha level=0.557

CONCLUSION

Hand weeding is best for the control of water hyacinth to a limited area like small ponds or a village drains. Solarization method resulted in maximum control of water hyacinth, but for a large scale it is costly, technical and sensitive to the climatic conditions. 2,4-D and glyphosate showed best results, while paraquat give poor control due to regeneration of water hyacinth from the protected buds which escaped herbicidal contact due to dense canopy structure. Immense care should be taken to avoid entry to the areas and water bodies presently free from the menace of water hyacinth. Application of 2,4-D and glyphosate resulted in sufficient control of water hyacinth but due to decomposing biomass water pollution is created, therefore hand weeding for small water bodies like ponds is recommended. Chemical weed control or mechanical control capable of dumping the weed biomass out of water would be better option for large scale while for drainage ditches, trans-located herbicides is enough without integration with mechanical method.

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