PHYSIOLOGY AND MANAGEMENT OF SUBMERGED WEEDS IN WETLAND RICE ECOSYSTEM

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled "Physiology and management of submerged weeds in wetland rice ecosystem" is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "Physiology and management of submerged weeds in wetland rice ecosystem" is a bonafide record of research work done independently by **Athira K A (2016-11-069)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associate ship or fellowship to her.

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Athira K, A.

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Abbreviations

DO	Dissolved oxygen
TSS	Total suspended salts
%	Per cent
EC	Electrical conductivity
E coli	*Escherichia coli*
UV	Ultraviolet radiation
NRase	Nitrate reductase enzyme activity
IAA	Indole acetic acid
GA	Gibberellic acid
Mg L^{-1}	Milligram per liter
MPN	Most probable number
$CuSO_4$	Copper sulphate
2, 4-D	2, 4- dichlorophenoxy acetic acid
dSm^{-1}	Decisemens per centimeter

INTRODUCTION

1. INTRODUCTION

Rice is the staple food of about half of world's population. It is classified as a semiaquatic plant as rice fields remain under flooded condition for major period of the cultivation cycle of the crop. This aquatic condition provides an ideal habitat for submerged weeds such as algal species and hydrophytes. Submerged weeds are capable of fast growth and multiplication and are very aggressive and compete with rice plants for nutrition. Rao and Chauhan (2015) reported that submerged weeds were increasing in rice fields of Asia. According to a survey report of Central Rice Research Institute, Odisha many species of the family hydrocharitaceae are common weeds of the rice ecosystem (Subudhi *et al.*, 2015).

As per a report of the Zonal Research and Extension Advisory Council (ZREAC, 2016) submerged weeds such as *Chara* and hydrophytes have the most immediate future relevance to Kerala as these species are increasing in the wetland rice ecosystems. Prajeesh *et al.* (2014) observed *Utricularia in* the rice fields of Wayanad.

A sudden spurt in the incidence of submerged weeds can be due to changes in climatic parameters or changes in physico-chemical properties of the soil and water. (Tavechio and Thomaz, 2003) reported that light intensity was an important factor that affected growth of submerged plants. Light and temperature together affect growth and chlorophyll content of aquatic plants (Dar *et al.*, 2014). UV B radiation affects aquatic plant growth negatively (Harder *et al.*, 2007).

Excessive growth of submerged weeds is detrimental to rice crop. It will deteriorate quality of the water and reduce crop growth. Excess application of fertilizers in rice fields tends to enhance weed abundance as the weeds absorb nutrients more than the crop plants. This will lead to low productivity of the main crop. Submerged weeds compete with the crop for same resources and affect the metabolic activity of plants. Considering the likely losses caused by the submerged weeds, their control is important.

For effective management of these weeds, it is important to understand the factors which promote growth of submerged weeds and the effect of local microclimatic factors on the growth of these pants. Hence the present study was initiated with the following objectives:

1. Survey, collection and characterization of the submerged weeds in wetland rice fields of Thrissur, Palakkad and Ernakulam districts of Kerala
2. Identify the physico-chemical properties of the soil and water which promote growth of submerged weeds
3. Study the microclimatic parameters that promote growth of *Utricularia aurea*
4. To develop suitable management practices for *Utricularia aurea*

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Weed infestation is one of the major factors that affects yield of low land rice. The major submerged weeds in rice ecosystem included both hydrophytes and algal species. Sudden spurt in these submerged weeds in rice ecosystem is due to changes in physico-chemical properties of water and also due to changes in microclimatic factors. To manage these weeds, it is essential to find the factors which promote growth of the weeds.

2.1. SUBMERGED WEED PROBLEMS

Rice ecosystem provides favorable environment for growth of various groups of aquatic submerged weeds such as algae and hydrophytes.

The problem due to excessive growth of weeds such as *Hydrilla, Elodea, and Cabomba* has been reported by Varshney (1973). Das (1976) reported that growth of *Chara* and *Nitella* was favored by high temperature (27-30^{0}C) and alkaline water. Vaquer (1984) observed that the biomass of Chlorophyta may reach up to one tonne/hectare after 2 months of submergence of rice field in Camaroon. Chandarsena (1989) reported *Utricularia* and *Hydrilla* to be the most frequently observed weeds in rice fields, based on a survey conducted at Ratnapura and Kurunegala districts of Sri Lanka.

Lancar and Krake (2002) observed that submerged aquatic weeds such as *Chara, Hydrilla, and Najas* etc. grow invasively and compete with rice crop and form a mat which grows below the water surface and causes various problems during cultivation, and reduces growth of the crop. Clayton (1996) observed that control of submerged aquatic macrophytes such as *Egeria* and *Hydrilla* are difficult and costly. Aquatic weed growth is influenced by light and nutrient availability. *Utricularia* and

Najas were identified in rice field based on a survey conducted in Muda rice granary area by Begum *et al.* (2005). Ansari (2007) reported more than 800 aquatic and wetlands plants from India.

2.2. PLANTS OF SUBMERGED ECOSYSTEM

2.2.1. *Spirogyra* sp.

According to Subramanian *et al.* (1965) *Spirogyra* grows abundantly in rice fields. It also forms a thick mat over the water surface and acts as a physical barrier for the rice crop. IRRI (1980) reported that *Spirogyra* reduces growth of rice. Kumar and Sahu (2012) reported *Spirogyra* to be the dominant algal weed in rice fields of Ranchi. Sebastian (2017) observed that presence of *Spirogyra* reduced the seed germination of rice.

Carretero (1988) observed presence of *Spirogyra* in the submerged rice fields of Valencia.

2.2.2. *Chara* sp.

According to Mukherji and Ray (1966) growth of *Chara* will be reduced with increasing UV radiation in the atmosphere. *Chara* and *Nitella* prefer temperatures between 27^0C-35^0C (IRRI, 1985). Carretero (1988) reported frequent occurrence of *Chara* in rice fields. Guha (1991) suggested chemical control measures to control the algal weeds, which contributed to 10-100% yield reduction in kharif rice. He found that control of *Chara* by using oxadiazon and $CuSO_4$ was very efficient. IRRI (1996) reported that *Chara* and *Nitella* can produce 5-10 t fresh weight/ha biomass in the rice field.

Bakker *et al.* (2001) found that UV-B radiation reduced growth of *Chara* spp. John (2002) opined that the weed was mainly found in areas where the water pH was higher. Singh *et al.* (2013) observed that the growth of *Chara* was inhibited if the soluble reactive phosphorus in the water was as low as 15 µg P L^{-1}.

2.2.3. *Nitella* sp.

Nitella was found to be a predominant weed in transplanted rice fields which retarded growth of the rice crop (Mukhophadyay, 1983). Andrews *et al.* (1984) reported that *Nitella* which belongs to the characean family was the largest aquatic macrophyte observed in rice fields. *Nitella* was found to be a common submerged weed in the rice fields of Philippines (IRRI, 1985). John (2002) observed growth of *Nitella* in soft water under low pH condition. Odelu (2015) reported the occurrence of the weed in rice fields of Telangana.

Guha (1991) reported that the weed species can be effectively controlled by $CuSO_4$.

2.2.4. Utricularia sp.

Several species of *Utricularia* were reported from India (IRRI, 1985). Carretero (1988) observed that *Utricularia* sp. was plentiful in the rice fields of Valencia. *Utricularia* was reported as a problem in the rice fields of Sri Lanka (Chandrasena, 1989). Sahid and Ho (1995) reported *Utricularia* as a most dominant weed in dry seeded and wet seeded rice fields. It is a carnivorous plant and it is mostly found in wetland situations (Ellison, 2017). He also identified the presence of *Utricularia aurea* in agricultural fields. It is not commonly seen in intensively cultivated fields. Heckman (2013) reported that *Utricularia* is a submerged weed found in rice fields mainly in the late rainy season. The flowers can be seen above the water surface. Adamec (2014) opined that *Utricularia* coming under the Lentibulariaceae family had under 250 species, of which 50 species grew under submerged condition.

The growth of *Utricularia* was more under low pH (Jha *et al.*, 1978). According to Moeller (1980), growth rate of *Utricularia* was influenced by various factors. It was found to be minimum at high temperature. According to Guisanse (2007) the weed has the ability to tolerate different environmental conditions and nutrient limitations. The weed was found to grow in the EC range of 27 to 394 µS cm^{-1} and pH range of 4.93–9.20, and PO_4–P range of 1.5 to 88 µg l^{-1} (Adamec, 2009). According to Chew and Haron (2011), *Utricularia* will grow well in nutrient poor condition and low pH (3-7). It cannot tolerate high pH. It can grow fast even in nutrient poor environment and these plants can trap P and K from water.

2.2.5. *Elodea canadensis*

Reddy *et al.* (1987) observed presence of *Elodea canadensis* in water channels of Asia, America, New Zealand, South Africa, Europe and Australia. They also reported that *Elodea* removed more nutrients from the water than other macrophytes. *Elodea* is mostly seen in neutral to alkaline condition and is resistant to turbidity (Spicer and Catling, 1988).

Netten (2013) reported that exposure of high temperature together with low pH and low light caused reduction in growth, and leaf tissue mortality. He studied the effect of ammoniacal nitrogen on growth and physiology of *Elodea* and found that high concentration of ammoniacal nitrogen increased photosynthesis in *Elodea nuttalli* while it reduced photosynthesis in *Elodea canadensis.*

2.2.6. *Hydrilla* sp.

Spicer and Catling (1988) stated that *Hydrilla* resembled *Elodea* but the leaf tips were toothed in the case of *Hydrilla*.

According to Haller *et al.* (1976) *Hydrilla* was the most damaging weed plant in Florida Lake. It is a troublesome weed which disturbs the ecosystem function and also blocks waterways and irrigation supplies. Productivity of *Hydrilla* was studied in IRRI and they found that the plant was capable of producing 2. 25 - 4.5 tonne dry matter/hector (IRRI, 1996). Holm *et al.* (1997) observed *Hydrilla* from several parts of the world. *Hydrilla* has reported as a problem in the rice fields of Bangladesh and Myanmar by Lancar and Krake (2002). Balciunas *et al.* (2002) reported that *Hydrilla* was a submerged weed species which grew mainly in warm water and formed mats over the water surface. Heckman (2013) mentioned that *Hydrilla* plant will grow abundantly under water surface in deep water rice. *Hydrilla* increases bacterial population in water (Gordon-Bradley *et al.*, 2014).

Langeland (1996) observed that, *Hydrilla* can grow under a wide range of water quality chemical characters. It can be found both in low and high nutrient concentrations and a wide range of salinity and pH. Mohammed and Al-Kenzawi (2011) observed that increased pH led to the reduction in the growth of *Hydrilla* which led to reduced dissolved oxygen.

2.2.7. *Egeria densa*

Egeria contain 4-5 leaves and are arranged in whorls (Spicer and Catling, 1988). Low light and high temperature promote growth of *Egeria* (Barko and Smart, 1981). Mazzeo (2003) reported that *Egeria densa* was a submerged weed which negatively influenced the growth of the main crop in the temperate zone by light and nutrient limitation.

Egeria densa competes with crops for light and nutrients (Mony *et al.*, 2007). Thiebaut and Dutartre (2009) observed the rapid spread and problem due to *Egeria densa* and studied the effect of temperature and light on growth of this species. Yarrow *et al.* (2009) reported *Egeria densa* as a noxious weed in the aquatic system. Temperature is an important factor affecting the growth of *Egeria* (Dar *et al.*, 2014).

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2.2.8. *Cabomba caroliniana*

Wilson *et al.* (2007) reported that *Cabomba caroliniana* (fanworts) spread rapidly by stem fragmentation and formed thick strands over the water surface. *Cabomba* was found to be resistant to herbicide so integrated management practices were mainly adopted for its control. Thiebaut and Dutartre (2009) observed the occurrence of *Cabomba* species in fresh water ecosystems of France and reported it as an invasive weed species. Menon (2009) reported that *Cabomba caroliniana* was a spreading type of submerged weed causing serious constrains in rice fields and canals in Kerala. *Cabomba* forms a mat over the water surface.

Cabomba caroliniana prefers a pH of 8.4 for growth and development (MDARD, 2015). Luthra (2005) observed that nitrogen will increase growth of this plant. According to Bickel (2012), *Cabomba* growth was more in high nutrient condition. It can tolerate pH above 7.

2.2.9. Najas sp.

Triest and Uotila (1986) observed the dominance of *Najas orientalis* in rice fields of Japan. They reported that *Najas graminea, Najas gracillima* and *Najas minor* as troublesome weeds in rice fields of Japan.

Haller (1974) reported that *Najas* was tolerant to high saline condition. Variation in light and salinity had an influence on the growth of *Najas* (Agami, 1984). *Najas* prefers high salinity.

2.3. PHYSICAL FACTORS THAT INFLUENCE THE GROWTH OF SUBMERGED WEEDS

2.3.1. Light

The effect of season on the appearance of algal species was observed by Bartsch (1954). He opined that differences in light, temperature and nutrient content may be the major factors that account for the spring time appearance of diatom and summer and fall appearance of blue green algae and the reappearance of diatoms in fall and winter. Barko *et al.* (1991) reported that in the seasonal change in the macrophyte community, light may play an important role. Light limits the growth of submerged plants, while some plants adapt to low light condition by adjusting the composition of photosynthetic pigments. Roy *et al.* (1977) stated that light significantly influenced the growth of aquatic plants. *Hydrilla* growth will be more in low light condition (Langeland, 1996). IRRI (1996) reported that light reaching the surface of water will vary at different growth stages of paddy. He also observed that light intensities and changes in temperature and nutrient content of water will affect algal growth.

According to Reut and Fineran (2000), reduced light is preferred by *Utricularia* sp. Lancar and Krake (2002) observed that algal growth and photosynthesis were directly related to light. Increase in light intensity will also increase the growth of algae. The pH, photoperiod and light intensity are the important parameters of algal growth. According to Neid (2006), light significantly affected the growth of aquatic plants and it was an important factor that affected submerged plant growth. Algal growth will be reduced by insufficient light. Light reduces the nutrient demand in *Utricularia* sp.

Al-Qasmi *et al.* (2012) found that light reaching these plants changed the growth patterns. Which were also related to temperature changes. Light and nutrient content in water affected growth. He studied the effect of different light intensities on

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growth of some algae. Voesenek and Sasidharan (2013) opined that some aquatic macrophytes preferred full sunlight while others preferred shaded conditions. Micro algal growth was highly influenced by light and temperature (Singh and Singh, 2015).

2.3.2. Temperature

Variation in temperature changes algal growth (Bartsch, 1954). Algal growth was reduced at high temperature conditions (Subramanian *et al.*, 1965). Barko *et al.* (1991) reported that optimum temperature required for the growth of submerged plants was in the range of 28°C-32°C. According to IRRI (1996), eukaryotic algae prefers low temperature while cyanobacteria prefers high temperature. Influence of temperature on growth of fresh water plants was reported to be more compared to terrestrial plant species (Olesen and Madsen, 2000).

Pezzato *et al.* (2004) observed that high temperature enhanced photosynthesis in *Chara*, *Elodea* and *Egeria*.

Singh and Singh (2015) studied the effect of temperature on the growth of different algae and found that 20°C to 30°C was optimum for the algal growth. Bhateria and Jain (2016) opined that temperature had a significant influence on the growth of aquatic plants as increase in temperature led to increase in pH and decrease in dissolved oxygen which adversely affected growth.

2.3.3. Ultraviolet radiation

A study on the effect of UV radiation on aquatic plants showed that UV light negatively affected plant growth as it created a major stress for the plants by affecting the metabolism (Harder *et al.*, 2007)

UV radiation affects the physiology of the plants. High amount of UV radiation causes reduction in stem elongation (Caldwell, 1968). Larkum and Wood (1993) reported that UV radiation had inhibiting effect on photosynthesis which resulted in a reduction in biomass. Salama *et al.* (2011) explained that UV radiation reduced the length and height of the plants and also brought about changes in the metabolism of the plants which resulted in biomass reduction. According to Kataria *et al.* (2014), UV radiation affects the PS II system leading to a reduction in photosynthetic efficiency.

2.4. PHYSICO-CHEMICAL PARAMETERS OF WATER THAT INFLUENCE WEED GROWTH

Water quality can be accessed by measuring the pH, EC, phosphate, nitrate and dissolved oxygen contents etc. (Bhateria and Jain, 2016). The chemical characteristics of water influenced by the distribution of different aquatic plants (IRRI, 1996). Algae can change their growth rate according to the changing physico-chemical conditions of water (Rai *et al.,* 2015).

2.4.1. pH

pH is an important factor that affects the growth of plants (Vestergaard and Sand-Jensen, 2000). Aquatic life is affected by changes in the pH. Low pH causes leaf tissue mortality in *Elodea canadensis* (Netten, 2013). High pH reduces photosynthetic activity (Bhateria and Jain, 2016).

Dubinsky and Rotem (1974) reported that algal growth was influenced by pH changes of the aquatic system. Algal growth was abundant when the pH was 5-12. CO_2 and pH were found to affect physiological functions such as photosynthesis and growth rate of algae (Chen and Durbin, 1994). pH is the most important factor which influences the growth of algae (IRRI, 1996). Algal growth will be more in neutral to alkaline pH. Leavitt *et al.* (1999) observed that increase in pH to 8.9 -9.9 will reduce algal growth. However some tolerant species can survive in high pH (Bergstrom and Patel, 2007). Venter and Schoonbee (1991) reported that submerged weed growth will be in the pH range of 7-9. Mudge and Haller (2010) observed that *Coontail* can be managed in high pH. A positive correlation between pH and dissolved oxygen was reported by Zang *et al.* (2011).

2.4.2. Electrical conductivity

Conductivity measurement gives a general idea about water quality. This is an indicator of water soluble substances and total dissolved salts (Naiman and Bilby, 2001).

EC is an indicator of the nutrient content of the water (Crossley, 2002). Bhateria and Jain (2016) reported that conductivity of water had a significant correlation with water quality parameters like pH value, alkalinity, temperature, total hardness, total solids, total dissolved solids, calcium and chemical oxygen demand, iron and chloride content of water etc. Presence of chloride, phosphate and nitrate will increase the electrical conductivity of water.

2.4.3. Phosphorus

Phosphorus application in the rice field will increase growth of algae and aquatic weeds (Roy *et al.*, 1977). Doemel (1975) reported that 0.08-0.10 mg/L phosphate level in water accelerated algal growth. Barko *et al.* (1991) observed that phosphorus had a significant role in aquatic plant growth. According to Babin *et al.* (1989), phosphorus content will increase algal biomass.

Plant growth significantly affected by phosphorus (Rattray *et al.*, 1991). Haller (2009) observed that phosphorus content was less in water with low algal content. Nutrients content in the water led to vigorous growth of aquatic plants (Bornette, 2011). Ghosh and Mondal (2012) stated that increase in phosphorus and nitrogen in water led to growth of aquatic plants and algae. According to Bbalali *et al.* (2013), phosphorus was the major factor that controlled algal growth. Gerardi (2015) explained that phosphorus was very essential for algal growth. Bhateria and Jain (2016) found that the dry weight of algal cells contained up to 3% phosphorus. Hence phosphorus per cent in the water will increase algal blooms, reduce dissolved oxygen and to fish kill.

2.4.4. Potassium

According to Roy *et al.* (1977), use of potassium in rice fields had little or no effect on weed multiplication. IRRI (1996) reported that aquatic plants preferred N, P and K. They grew luxuriant in nutrient rich soils. Wang *et al.* (2013) observed that amount of potassium was directly related to the salt content of water, an important nutrient which affected the growth and metabolism of plants.

According to Shukla and Rai (2007), potassium may inhibit phosphate, and nitrate uptake and thereby prevent mycrocystis bloom (blue green algae). Talling (2010) opined that potassium was an essential plant nutrient. It limits the yield of some algal species including *Chara.* Algal growth in the water leads to depletion of K and the crop suffers nutrient deficiency (Bhateria and Jain, 2016). Gosselin, *et al.* (2018) conducted nutrient studies with *Hydrilla* and explained that growth of *Hydrilla* plant was depressed when potassium concentration was high.

2.4.5. Nitrogen

Nitrogen content in water improved the weed growth and as the weeds competed with the main crops for nitrogen, it resulted in reduced growth of the main crop (Varshney, 1973). Rolland and Tremolieres (1995) reported that aquatic plants used nitrogen for their growth. IRRI (1996) stated that aquatic weeds absorbed 4-5 times more nitrogen than the main crop. According to Haller (2009), algae need nitrogen for their growth. Abundant growth of algae was an indicator of eutrophication. Bhateria and Jain (2016) reported that excessive nitrogen in water bodies will support algae and aquatic plants.

4.6. Dissolved oxygen

Abundant growth of *Utricularia* leads to a decrease in dissolved oxygen (Jha *et al.*, 1978). Submerged weeds and algae change dissolved oxygen content of the water (IRRI, 1996). Mudge and Haller (2010) stated that submerged plants reduced the dissolved oxygen in the water. According to Zhao *et al.* (2014), rice root growth and nitrogen accumulation were significantly affected by dissolved oxygen.

Dissolved oxygen and nitrogen have a significant influence on rice root growth. According to Voesenek and Sasidharan (2013), depletion of oxygen in submerged roots is due to microbial activity. Sylas *et al.* (2015) explained that to understand water quality, dissolved oxygen is an important parameter. Zhu *et al.* (2015) observed that root growth will be more under low nitrogen condition and with high dissolved oxygen content. Bhateria and Jain (2016) opined that algal weed in water significantly reduced the oxygen content of water.

2.4.7. Total suspended solids

Decrease in Dissolved oxygen will lead to an increase in turbidity due to exocellular polymer production (Starkey and Karr, 1984). Naiman and Bilby (2001) reported that TSS was a measure of turbidity. Increased TSS will lead to light scattering and also reduce the dissolved oxygen content. Lancar and Krak (2002) mentioned that invasive growth of weeds depended upon turbidity of water.

Solids present in water include suspended, dissolved and volatile particles, silt, decaying plant matter, stirred-up bottom sediment, or sewage-treatment effluent. High amount of suspended solids in water affects aquatic plant life (Bhateria and Jain, 2016).

2.4.8. *Escherichia coli*

10^5-10^6/ml bacteria were reported in floodwater (IRRI, 1996). Naiman and Bilby (2001) reported that bacterial biomass was dependent on temperature and nutrient factors. It was high in sandy sediments.

According to Byappanahalli *et al.* (2003), *E. coli* in water had a significant correlation with TSS. Which can also help predict the *E. coli* content in the water. Shahab *et al.* (2009) explained that bacteria may synthesize IAA that will lead to the growth of other plants including algae. Exudates of algae are a major source of nutrient for the bacteria. *Cladophora* algae was found to promote *E. coli* in water.

2.5. HORMONES, ENZYMES AND PIGMENTS

2.5.1. Indole acetic acid

Bala and Thukral (2008) reported that IAA increased growth of aquatic weeds.

Jacobs *et al.* (1985) reported that IAA content in algae was very low compared with higher plants. They also studied the rhizoid formation mediated by IAA in *Chara*. According to Leveau and Lindow (2005), major form of auxin is IAA. It controls the main physiological functions of plant. Shahab *et al.* (2009) observed that indole acetic acid had several roles like promotion of adventitious root growth, cell division, light responses etc. Algae also have the capacity to release bioactive forms of auxin. Mohite (2013) reported that IAA is important hormone which has a major role in the metabolism of plants. He also observed that both temperature and pH influenced IAA activity. Acidic pH had a negative effect on IAA activity.

2.5.2. Nitrate reductase

Nitrate reductase is a major enzyme which gives an idea of nitrogen status and gives a measure of plant growth (Srivastava, 1980). Melzer and Kaise (1986) reported that nitrate reductase activity of *Elodea* was comparatively low. According to Berges (1997), changes in nitrate metabolism can be studied by measuring nitrate reductase activity. Nitrate reductase enzyme activity in algae was inhibited by ammonium content in the soil.

Young *et al.* (2007) explained that NRase activity was an indicator to understand the temperature and availability of nutrients. N metabolism and photosynthetic carbon metabolism had a close relationship. He also mentioned the optimum temperature for NRase activity was in the range 10^0C-20°C.

Chamizo-Ampudia (2017) mentioned that nitrate reductase is mainly involved in the signaling and nitrogen acquisition and it had a great influence on nitrogen metabolism. Nitrate percent in the soil was found to improve nitrate reductase activity. According to Ali *et al.* (2011), nitrate assimilation was controlled by light, hormone and nitrogen source.

2.5.3. Phosphatase

Increasing alkaline phosphatase activity will also increase pH of soil. Tarafdar and Jungk (1987) explained phosphatase enzyme activity and phosphorus correlation.

According to Tarafdar and Claassen, (1988), phosphatase activity increased with high inorganic phosphorus. Dick (1980) explained that soil enzymes have various roles for healthy maintenance of soil and also for plant growth. These enzymes indicate the soil changes. He observed that phosphatase enzyme activity and pH had some relationship. Study of the phosphatase enzyme activity helps to understand the liming responses of the soil. Highest activity of phosphatase was identified in *Utricularia* by Adamec *et al.* (2010).

Soil phosphatase activity and the level of mineral phosphorus present in the soil are inversely proportional, because of the increased activity of phosphatases due to the low level of inorganic phosphorus. Nitrogen fertilization had a significant effect on the activity of both alkaline and acid phosphatase. Increase in nitrogen resulted in decreased activity of alkaline phosphatase due to increased nitrogen while the activity of acid phosphatase increased (Lemanowicz, 2011). Phosphatase activity was positively correlated with the algal growth (Xiaoli, *et al.,* 2011).

2.5.4. Gibberellic acid

A study conducted in *Hydrilla verticillata* found that GA had an effect on the growth of the plant (Steward, 1969). Raskin and Kende (1984) reported that gibberellin promoted stem elongation in semi aquatic plants and was of the opinion that hormone manipulation can be adopted for controlling aquatic weeds.

Carole and Micheal (1990) observed that GA had a significant influence on stem growth in *Hydrilla*. In their study GA inhibitors were effectively used for the control of stem elongation.

The growth rate of submerged rice plant is mainly due to GA content. Intercalary meristem development of rice is also a function of GA (Hoffmann-Benning and Kende, 1992).

2.5.5. Chlorophyll

According to Leavitt *et al.* (1999), algal chlorophyll content reduced in alkaline condition. Bbalali *et al.* (2013) explained that chlorophyll was the major pigment in plants and the estimation of chlorophyll is used to access the algal population in water. Chl a will be more than 40 $\mu g\ L^{-1}$ water with algal blooms. They also observed that total nitrogen in the water had an important relation with chlorophyll. If chlorophyll a is low, there will be high amount of nitrogen and algal biomass. Chlorophyll content analysis also helps to understand the photosynthetic efficiency and plant adaptations.

2.6. EFFECT OF CHEMICALS ON THE GROWTH OF WEEDS

2.6.1. 2, 4-dichlorophenoxy acetic acid

2, 4-D and 2, 4, 5-T are used to control submerged weeds (Bartsch, 1954). Mukherji and Ray (1966) reported that 2, 4-D can be used for the control of *Chara* spp. Holm *et al.* (1969) reported that 2, 4-D reduced aquatic weed growth. Dutta *et al.* (1972) opined that the weed density in aquatic system can be controlled by the use of 2, 4-D.

2, 4-D can be used for the effective management of submerged weeds (Rezaul *et al.*, 2004, Haller, 2009). Rao and Chauhan (2015) stated that 1.0 mg L^{-1} 2, 4-D can be used for the control of submerged weeds.

2.6.2. Copper sulphate

$CuSO_4$ is used for the control of algae (Bartsch, 1954). Muchmore (1978) explained the effect of $CuSO_4$ to control algal species. Copper, diquat and endothal can be used for the control of submerged weed (Langeland, 1996). Lancar and Krake (2002) mentioned that $CuSO_4$ was widely used as an algicide @ 1 ppm.

Many copper based compounds like $CuSO_4$ were used widely for algal management (Mc-Comas, 2003). $CuSO_4$ is reported to be effective for the control of submerged weeds and algae. A dose of 0.5-2.0 mg L^{-1} was found to be efficient. Copper containing herbicide can be used for the control of algae and submerged plants in the range of 0.2 to 1 mg/L (Haller, 2009). Rao and Chauhan (2015) explained that $CuSO_4$ can be used for effective management of submerged weeds.

2.6.3. Lime

Bartsch (1954) reported removal of phosphorus by lime. Folkman and Wachs (1973) observed that lime can be used for the control of algae. Haller (1974) studied the effect of salinity on growth of aquatic macrophytes. He observed that increasing salinity reduced the growth of *Hydrilla*, *Najas* and *Vallisinaria*. Lime treatment reduces the growth. It is a cost effective technology which helps to reduce the excessive usage of herbicide in the fields. Liming helps to reduce chlorophyll and total phosphorus content in the water and also improve the dissolved oxygen content (Babin *et al*., 1989). Prepas *et al*. (2001) reported that application of lime reduces phosphorus availability. It also affects the chlorophyll content. This method is cost effective and non-toxic. Owen (2011) observed that N and P availability was limiting at high pH.

MATERIALS AND METHODES

3. MATERIALS AND METHODS

The present investigation entitled "Physiology and management of submerged weeds in the wet land rice ecosystem" aims to characterize the different submerged weed species of the wetland rice ecosystem and to understand the growth and management of submerged weeds. The study constituted survey, identification and morphological characterization of submerged weeds of rice ecosystem of the central zone of Kerala. The effect of environmental conditions on the growth and multiplication of the most common weed, *Utricularia aurea,* and its control were also studied. A brief account of the materials used and methodology adopted in this study are given below.

EXPERIMENT 1 (SURVEY)

3.1. Details of study area

A survey of submerged weeds of rice ecosystem was conducted from April 2017 to March 2018. The survey was carried out on the wetland rice fields in the central zone of Kerala including Thrissur, Palakkad and Ernakulam districts.

Weed survey was conducted in ten locations of each district. Soil and water samples were collected and analyzed from the locations where the weed intensity and diversity were high.

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Plate 1. Survey districtcts

3.1.1. Thrissur

Thrissur lies between the latitude of 10.5276° N and longitude of 76.2144° E. In Thrissur district 10 locations were selected for survey. The sites were Vellanikkara, Alappad, Chirakkekode, Chiyyaram, Puzhakkal, Peechi, Pattikad, Nadavaramba, Pandiparampu and Mala.

The survey in these locations was carried out during March 2017 to August 2017. Soil and water samples were collected from Pandiparampu, Mala and Vellanikkara.

3.1.2. Palakkad

Palakkad lies between the latitude of 10°21' to 11°14' North, and longitudes of 76°02' to 76°45' East. Rice is widely cultivated in Palakkad, which is known as the "rice bowl of Kerala". Anjumoorthy, Pattambi, Chithali, Kuzhalmannam, Vandazhi, Koduvayur, Kollengode, Nenmara, Mangalam, Mudappallur were the survey locations. Among these soil and water samples were collected from Anjumoorthy, Mudappallur, Chithali and Koduvayur.

3.1.3. Ernakulam

Ernakulam lies between the latitude of 9.9816° North, and longitude of 76.2999° East. *Pokkali* cultivation is the major rice cultivation practice in coastal regions of Ernkulam. Thuruthissery, Kottuvally, and Vyttila were selected to study the weed abundance.

3.2. Collection, identification and characterization of weeds

Submerged weed species seen in the rice ecosystem were collected and identified based on the morphological characters.

3.2.1. Identification of weeds

The samples were then sent to the Botanical Survey of India, Coimbatore for confirmation and were also shown to an expert algologist Dr. Jose John, of Thevara College, Ernakulam. Identification was done based on the description provided in the book "A Manual of Aquatic Weeds" (Fasset, 2000).

Plate 2. Weed collection from rice field

Plate 3. Identification of weed plants

The plants were identified based on the following characters.

1. **Leaf characters**
    - Leaf arrangement
    - Leaf margin
    - Leaf petiole
    - Leaf number
2. **Stem characters**
    - Stem colour
    - Stem length
3. **Flower characters**
    - Flower colour
    - Position of flower
4. **Reproductive structures**

3.3. Observations

Water samples collected from ten different locations of each district were subjected to the following analyses based on standard procedure as indicated below (Table 1).

Table 1. Methods used for water analysis

SI. No.	Parameter	Method used
1	Nitrate	Reduction by Devardas alloy and alkali distillation
2	Phosphate	Spectrophotometry
3	Potassium	Flame photometry
4	Total phosphorus	Spectrophotometry
4	Total suspended solids	Gravimetric method
5	*E. coli*	Serial dilution and plate count techniques
6	Dissolved oxygen	Wrinkler's method
7	pH	pH meter
8	Electrical conductivity	Conductivity meter

3.3.1. Physiological parameters of weeds

3.3.1.1. Nitrate reductase

To estimate nitrate reductase enzyme activity in the leaf, the method suggested by Hageman and Flesher (1960) was followed. The nitrite formed was estimated by the method described by Nicholas *et al.* (1976), by measuring the absorbance at 540 nm using a spectrophotometer and expressed in µ moles of NO_2^- formed g^{-1} fresh weight hr^{-1}.

3.3.1.2. Indole acetic acid content (IAA)

IAA oxidase activity was estimated by the method suggested by Parthasaradhy *et al.* (1970) with slight modification, using Garden Weber reagent. Two hundred and fifty milligram plant sample was homogenized in a mortar and pestle using phosphate buffer and centrifuged. Extract was collected and volume made up to 25ml. Ice-cold phosphate buffer and auxin were added to 1ml sample extract taken from 25ml. Absorbance was read at 520 nm and the enzyme activity was expressed as µg of unoxidised auxin g^{-1} h^{-1}.

3.3.1.3. Gibberellic acid content (GA)

The method for the extraction, purification and estimation of endogenous plant hormone gibberellic acid (GA) was modified from that described by Sundberg (1990) and Kojima (1995). One gram of plant sample was homogenized in a mortar and pestle with methanol (ice cold) and kept at 4 °C in dark for four hours. The homogenate was centrifuged, filtered and the solid residue was further extracted twice with the same solvent.

All the methanolic extracts were combined and concentrated to a water residue in vacuum at 50°C for one hour. The volume was adjusted to 10 ml with phosphate buffer and partitioned in a separating funnel with 10 ml diethyl ether by stirring for 3 minutes. The ether phase was discarded and the aqueous phase was adjusted to pH 2.7 with 0.4 M HCl. The partitioned aqueous extract was collected twice with 0.4M $NaHCO_3$. This was then partitioned with 10 ml ethyl acetate. The aqueous phase was decanted and stored at 4°C after adding 2 ml of methanol. This was used for gibberellin estimation by adding zinc acetate (2ml) and potassium ferrocyanide (2ml). It was then centrifuged. The supernatant collected was kept at 20°C for 75 minutes after adding 30 per cent HCl. The absorbance was read at 254 nm using a UV- VIS spectro photometer. GA content was calculated and expressed in $\mu g\ g^{-1}$.

3.3.1.4. Chlorophyll content

Total chlorophyll was estimated by the method suggested by Hiscox and Israelstam (1979). The chlorophyll content was estimated based on spectrophotometer (Model-4001/4 Thermo Spectonic, Thermo Electron Corporation, USA) reading at two wavelengths i.e., 663 nm and 645 nm and expressed as mg g^{-1} fresh weight of plant tissue. The calculation was done by using the following formula and expressed as mg/g

$$\text{Total chlorophyll} = [(20.2 \times A645) + (8.02 \times A663)] \times V/1000 \times W$$

Where,

A = Absorption at the given wavelength
V = Total volume of sample in extraction medium
W = Weight of sample

3.4. Soil analysis

3.4.1. Phosphatase enzyme activity

Phosphate activity was measured as per the procedure of Tabatabai and Bremner (1969). For each sample, four sets of 1 g soil were weighed in 50 ml volumetric flasks. Two sets were taken for the analysis of acid phosphatase and remaining two sets for alkaline phosphatase. Among the two, one was kept as control. Toluene (0.2 ml) and MUB buffer (4ml) (for the acid phosphatase MUB buffer at pH 6.5 and for alkaline phosphatase at pH 11) were added to samples. After that for one set of samples, 1 ml of p- nitro phenyl phosphate solution (p-nitro phenyl phosphate was prepared with MUB buffer 6.5 for acid phosphatase and MUB buffer 11 for alkaline phosphatase) was added. The contents were mixed properly and kept for incubation for 1 h. After incubation, 1 ml $CaCl_2$ and 4 ml of 0.5 M NAOH were added. The contents were swirled for a few seconds for mixing. Para nitro phenyl phosphate solution prepared using respective buffer was added to the remaining set (control) of samples. All the suspension were filtered quickly through Whatman No. 2 filter paper. The yellow colour intensity of the filtrate was measured using spectrophotometer at a wave length of 440 nm.

3.4.2. Nitrate reductase activity

Nitrate reductase enzyme activity was estimated according to the procedure of Kandler (1996). 5g of fresh soil was treated with 10 ml of solution containing NO_3-N and incubated at 28^0C for 24 hours. After 24 hours, 40 ml 2.5 M KCl solution was added. The contents were shaken for one hour and the contents filtered using Whatman No 42 filter paper. To one ml of aliquot, 1 ml of diazotizing reagent was added and mixed for 5 minutes. One ml of coupling reagent was added, mixed and allowed to stand for 20 minutes. The volume was made up to 50 ml and read at 540 nm and expressed in μNO_2-N/g^{-1}soil 24h^{-1}.

3.4.3. Indole acetic acid

Auxin content in the soil was estimated colorimetrically. As per Wohler (1997), soil samples were treated with phosphate buffer (pH 7.5) with glucose (1 g glucose per 100 ml phosphate buffer) and 4 ml of 1 percent L-tryptophan. The samples were incubated at 37 °C for 24 hours in dark. After the incubation, 2 ml of 5% trichloroacetic acid solution was added followed by addition of 1 ml of 0.5 M $CaCl_2$ solution to inactivate the IAA oxidase enzyme. After filtering (Whatman No.2), 3 ml of the filtrate was taken in a test tube, and to this 2 ml of salper solution (2 ml 0.5 M FeCl3 and 98 ml 35% $HClO_4$) was added. This mixture was incubated for 30 minutes at 25 °C in the dark. Absorbance of the red solution was measured with a spectrophotometer at a wavelength of 535 nm. From the 100 ppm stock solution, made different concentration and draw standard graph. The auxin concentration of the soil was calculated and expressed as auxin equivalents (μg of auxin g-1 of soil).

3.5. Experiment 2

The most common submerged weed in the rice ecosystem was *Utricularia aurea* and hence this weed was selected for further studies. Three separate experiments were carried out. To study the effect of light and UV radiation on the growth and multiplication *Utricularia aurea,* completely randomized design (CRD) with three treatments and five replications was used.

Pots of size 30 cm height × 30 cm diameter were used for the study. The pots were filled with 6 kg soil and filled to the brim with water. Twenty centimeter long *Utricularia aurea* filaments were kept in each pot. The details of the experiments are given below.

3.5.1. Effect of light on the growth and multiplication of *Utricularia aurea*

The experiment consisted of three treatments as below.

T_1: Open condition with ambient light

T_2: Pots covered with green coloured shade nets which allowed 75% light Infiltration

T_3: The pots covered with shade nets which allowed only 50% light infiltration

3.5.2. Effect of UV light on the growth and multiplication of *Utricularia* sp.

The following treatments were used.

T_1- Normal UV- Normal UV was measure under open condition

T_2: Zero UV (Mylar film)

T_3: 80% UV (Poly ethylene sheet)

The experiment was conducted in ventilated polyhouse of size 42.75 m^2. The polyhouse was compartmentalized in two parts of equal size. One compartment was clad with 0.3 mm thick polyester, which transmitted 80% full spectrum radiation excluding UV-B and provided zero UV condition. The second compartment roof was covered with UV transparent polythene sheet which transmitted 80% UV.

UV radiation was measured with a UV meter (model – 3414F, field scout, Spectrum technology, len, USA) and expressed in W/m^2.

3. Effect of chemicals on degradation of *Utricularia aurea*

Three chemicals viz. $CuSO_4$, 2, 4-D and lime each of three levels were tried to study the rate of degradation of *Utricularia aurea* after one month of their application. The levels of chemicals are detailed below (Table 2).

Table 2. Chemical application rate

$CuSO_4$	2, 4-D	Lime
1 ppm	1 ppm	100 ppm
2 ppm	2 ppm	200 ppm
3 ppm	3 ppm	300 ppm

3.5.2. Observations

Twenty centimeter long filaments of *Utricularia aurea* were introduced into pots containing 6 kg soil. Water level was maintained at 25 cm. Growth of the plant was observed at 10 days intervals up to one month and the following observations were taken.

3.5.2.1. Rate of multiplication

Rate of multiplication was measured at 10 days interval by recording the number of branches.

3.5.2.2. Filament length after one month

Length of the filament was taken at 10 days intervals up to a period of one month.

3.5.2.3. Fresh weight

Fresh weight of the sample were noted after one month. The plant was taken out from water. The excess water was removed by tissue paper. Weight was measured immediately for all the treatments.

3.5.2.4. Dry weight

To estimate the dry weight, the samples were kept for drying under shade for two days and kept in oven at 80^0C in paper covers.

3.5.2.5. Temperature and UV radiation measurement

Air and water temperature in the experiment were measured and expressed in degree Celsius. UV radiation was measured by UV meter and expressed in W/m^2.

3.5.3. Statistical analysis

Statistical analysis was done using WASP developed by ICAR. For the pot culture study each treatment was analyzed separately to understand the effect of UV on weed growth, effect of shading on weed growth and effect of chemicals on weed growth.

Plate 4. Providing shade nets

Plate 5. Field layout of experiment two

RESULTS

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4. RESULTS

A survey was conducted in the central zone of Kerala to identify the major submerged weeds in rice ecosystem. A pot culture study was then initiated to find the factors influencing weed growth and also develop control measures. Results of the survey and the pot culture study are detailed below.

4.1. Survey, identification and characterization of submerged weeds in rice fields

The survey was conducted during April 2017 to March 2018 in ten different locations in Thrissur, Palakkad and Ernakulam districts. Locations of survey area are given in plate 6. Submerged weeds from the rice fields were collected along with soil and water samples. The weeds were then identified and the soil and water samples were analyzed.

4.1.1. Important weeds in rice fields

Studies revealed that the submerged weeds of the rice ecosystem belonged to two categories, (1) algae and (2) hydrophytes. The major algal species observed were *Spirogyra, Chara* and *Nitella*. The major hydrophytes observed were *Utricularia aurea, Utricularia exoleta, Elodea canadensis, Hydrilla verticillata, Egeria densa, Cabomba* sp. and *Najas* sp. Among the hydrophytes, *Utricularia* was found to be the most dominant species in rice ecosystems. The details of the survey locations, and weeds observed are given below.

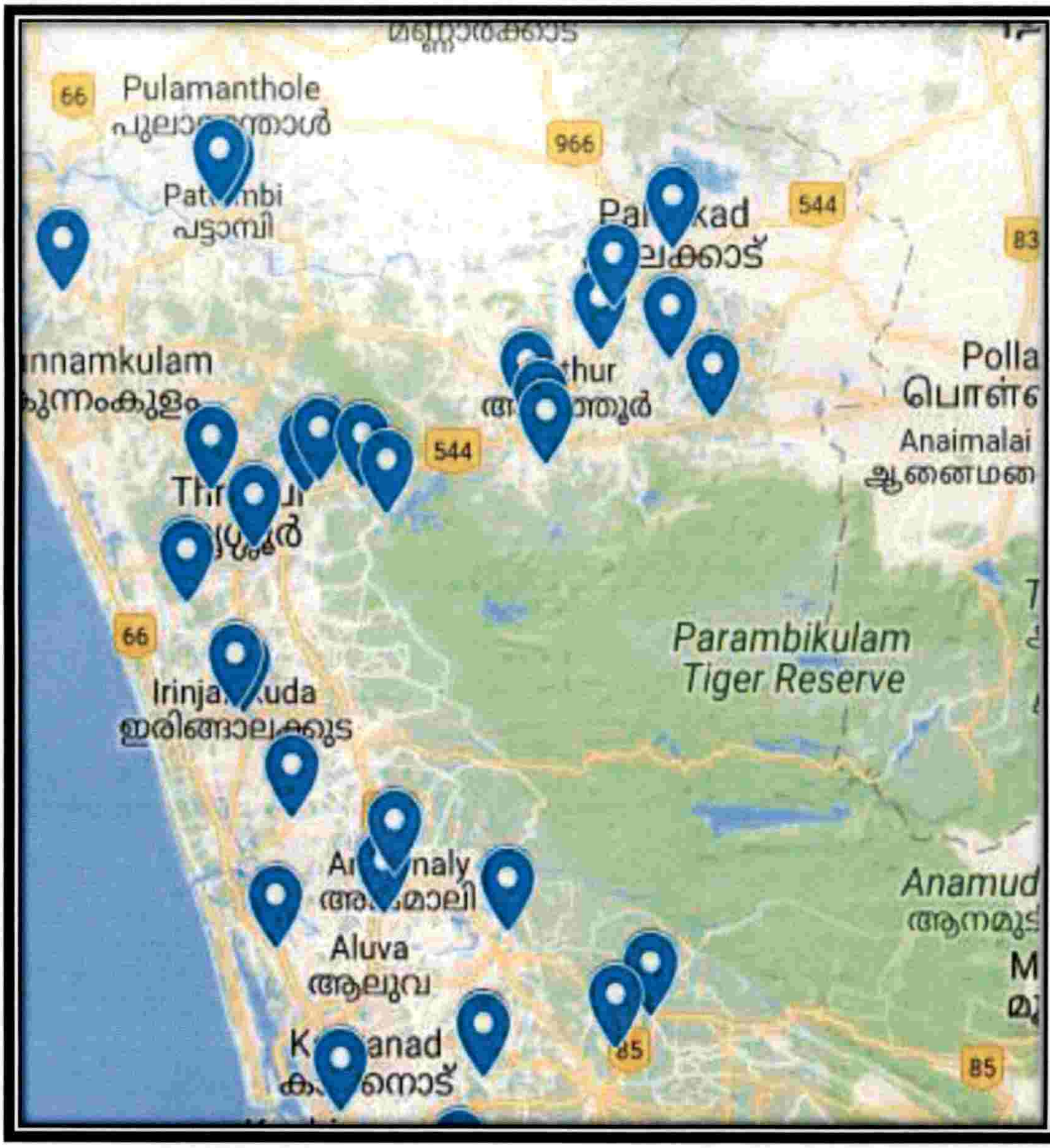

Plate 6. Location map of the study area

Table 3. Difference between algae and hydrophytes

Algae	Hydrophytes
Sub kingdom Cryptogamae	Subkingdom Phanerogamae
True root stem and leaves are absent	True root stem and leaves are present
No vascular system	Vascular system present
Class thalophyta	Class gymnospermae or angiospermae
Soft body	Comparatively hard body

4.1.1.1.Weed species observed in Palakkad

In Palakkad district weed species were collected from 10 location viz. Anjumoorthy, Pattambi, Chithali, Kuzhalmannam, Vandazhi, Koduvayur, Kollengode, Nenmara, Mangalam and Mudappallur. Among the algal species *Spirogyra* was observed in five out of the ten locations. *Nitella* was the only other algal species seen in Palakkad and it was in Mudappallur. The most common hydrophyte was *Utricularia aurea,* which was found in five out of ten locations. The other hydrophyte seen were *Cabomba*, which was observed in three locations, which *Hydrilla* was seen only in Kollengode region.

Table 4. Weed species observed in Palakkad district

District	Locations	Algal weeds	Hydrophytes
Palakkad	Anjumoorthy	*Spirogyra*	*Utricularia aurea*
	Koduvayur	Nil	*Cabomba* *Utricularia aurea*
	Mudappallur	*Nitella sp.*	Nil
	Chithali	Nil	*Utricularia aurea*
	Pattambi	*Spirogyra*	Nil
	Kuzhalmannam	*Spirogyra*	*Utricularia aurea*
	Vandazhi	*Spirogyra*	Nil
	Kollengode	*Spirogyra*	*Hydrilla verticillata*
	Nenmara	Nil	*Cabomba*
	Mangalam	Nil	*Utricularia aurea*

4.1.1.2. Weed species observed in Thrissur district

Ten locations were selected for survey in Thrissur district. These locations were Vellanikkara, Alappad, Chirakkekode, Chiyyaram, Puzhakkal, Peechi, Pattikad, Nadavaramba, Pandiparampu and Mala. Among these, three locations were selected for further study. Maximum diversity of submerged weeds was noticed in Thrissur district. Seven different hydrophytes and two different algal species were observed in the region. Among the algal species, *Spirogyra* was the most dominant species seen in five out of ten locations, while *Chara* species was seen in two locations, Peechi and Mala. The hydrophyte observed in the location were *Utricularia aurea,* which was seen in six out of ten locations, viz. Chirakkekode, Chiyyaram, Nadavaramba, Pattikad and Vellanikkara. *Hydrilla verticillata* was seen in 4 locations. *Elodea canadensis* was seen in Pandiparampu, while in Mala region *Egeria densa* was observed.

Table 5. Weed species observed in Thrissur district

District	Locations	Algal weeds	Hydrophytes
Thrissur	Vellanikkara	*Spirogyra sp.*	*Hydrilla verticillata*
			Utricularia aurea
	Alappad	*Spirogyra sp.*	*Cabomba sp.*
	Chirakkekode	Nil	*Utricularia aurea*
	Chiyyaram	Nil	*Utricularia aurea*
	Puzhakkal	*Spirogyra sp.*	Nil
	Peechi	*Chara* sp.	*Utricularia aurea*
	Pattikad	*Spirogyra sp.*	*Utricularia aurea*
	Nadavaramba	Nil	*Utricularia aurea*
			Hydrilla verticillata
	Pandiparampu	*Spirogyra sp.*	*Utricularia exoleta*
			Elodea canadensis
			Hydrilla verticillata
	Mala	*Chara*	*Egeria densa*
			Najas sp.
			Hydrilla verticillata

4.1.1.3.Weed species observed in Ernakulam

Weed species were collected from 10 locations in Ernakulam district viz. Vyttilla, Kottuvally, Thuruthissery, Angamali, Perumbavoor, Kothamangalam, Mulavoor, Arakunnam, Pallikara and Kadayiripu.

Four different hydrophytes and one algal species were observed in Ernakulam. *Spirogyra* was the only alga which has observed from four locations (Kottuvally, Angamali, Perumbavoor and Pallikara) out of ten locations. The hydrophytes observed were *Najas*, *Utricularia aurea, Hydrilla* and *Cabomba. Utricularia aurea* was the most dominant hydrophyte observed in this region, which was seen in four (Kottuvally, Thuruthissery, Arakunnam and Kadayiripu) out of the 10 locations. The other hydrophyte seen were *Cabomba*, which was observed in Mulavoor. *Hydrilla* was seen in both Kothamangalam and Mulavoor region. *Najas* was seen only in Vyttilla.

Table 6. Weed species observed in Ernakulam

District	Locations	Algal weeds	Hydrophytes
Ernakulam	Vyttilla	Nil	*Najas* sp.
	Kottuvally	*Spirogyra* sp.	*Utricularia aurea*
	Thuruthissery	Nil	*Utricularia aurea*
	Angamali	*Spirogyra* sp.	Nil
	Perumbavoor	*Spirogyra sp.*	Nil
	Kothamangalam	Nil	*Hydrilla*
	Mulavoor	Nil	*Cabomba* sp. *Hydrilla verticillata*
	Arakunnam	Nil	*Utricularia aurea*
	Pallikara	*Spirogyra* sp.	Nil
	Kadayiripu	Nil	*Utricularia aurea*

4.1.2. Identification of weed plants

Weeds collected were identified by the botanical survey of India, Coimbatore and also with the help of an expert algologist Dr. Jose of Thevara College, Ernakulam.

Plate 7. Collection of weeds from different rice fields

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4.1.3. Characterization of submerged weeds

The plants were identified based on the morphological characters specific to each species, which are detailed below.

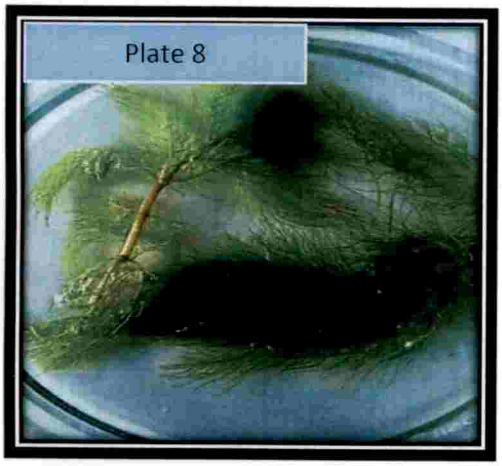

Plate 8

Scientific name: *Utricularia aurea*

Family: Lentbulareaceae

Common name: Bladderwort

Locations: Vellanikkara, Anjumoorthy, Koduvayur, Chithali, Kottuvally and Thuruthissery

Habit: Submerged plant

Morphological characters: It is a carnivorous plant without true root. Root like rhizoids. Alternate or whorled leaves are present. Bladder present in the stem

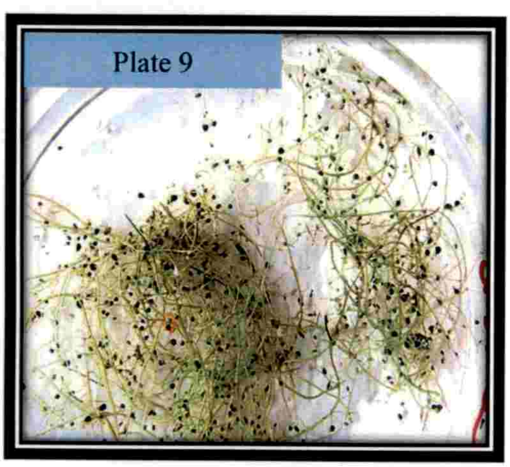

Plate 9

Scientific name: *Utricularia exoleta*

Family: Lentbulareaceae

Common name: Bladderwort

Location: Pandiparampu

Habit: Submerged plant

Morphological characters: Light green stem without leaves. Black colored bladder is present to trap the insects.

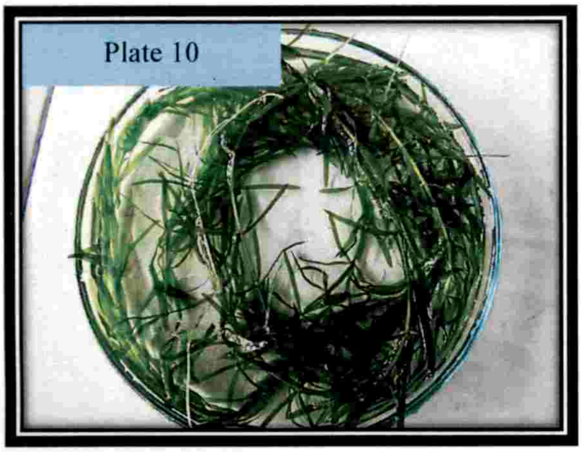
Plate 10

Scientific name: *Egeria densa*

Family: Hydrocharitaceae

Common name: Brazilian water weed

Location: Mala

Habit: Submerged plant

Morphological characters: 4-8 Leaves are produced in whorls. Pointed leaf tips.

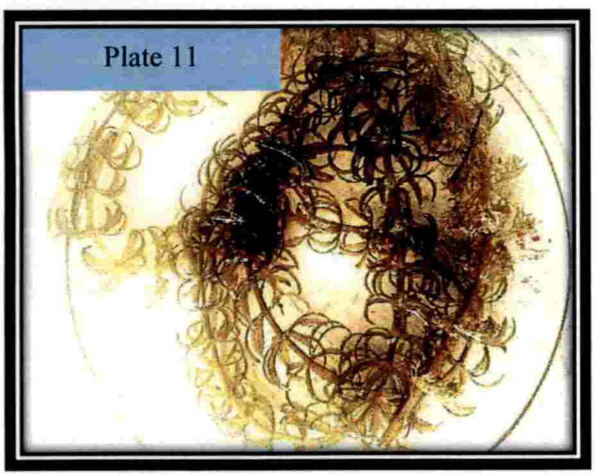
Plate 11

Scientific name: *Elodea canadensis*

Family: Hydrocharitaceae

Common name: Canadian pond weed

Location: Pandiparampu

Habit: Submerged plant

Morphological characters: Long and slender stem. Leaves are arranged in whorls. Stalk less leaves with minutely toothed margin. Crowded leaves in tips.


Plate 12

Scientific name: *Hydrilla verticillata*

Family: Hydrocharitaceae

Common name: Hydrilla

Locations: Mala, Pandiparampu, Vellanikkara

Habit: Submerged plant

Morphological characters: Long and slender stem. Leaves are arranged in whorls. Stalk less leaves with minutely toothed margin

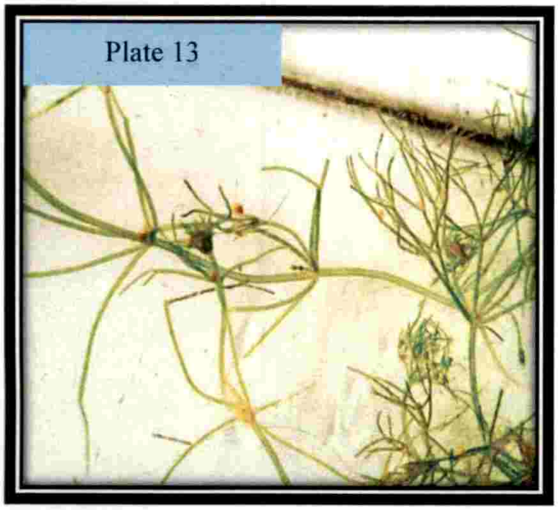

Plate 13

Scientific name: *Chara* sp.

Family: Characeae

Common name: Stonewort

Location: Mala

Habit: Submerged plant

Morphological characters: Light green colored leaves are arranged in whorles. 4-7 leaf like structure in each whorl. Orange colored globule present.

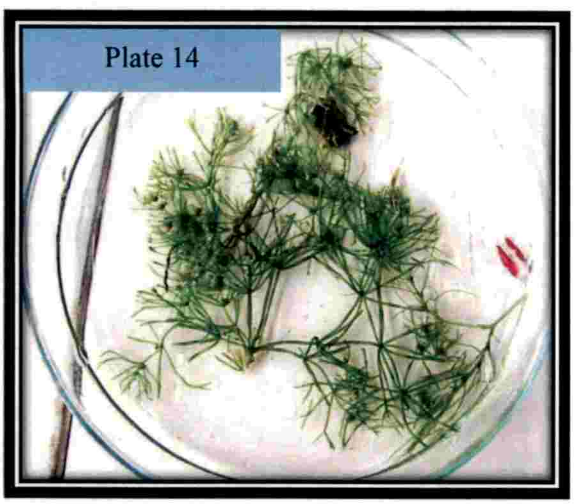

Plate 14

Scientific name: *Nitella* sp.

Family: Characeae

Common name: Stonewort

Location: Mudappallur

Habit: Submerged plant

Morphological characters: Dark green, forked bushy branches. Several branches coming from the main stem. The dark, ball-like structures seen on the branches.

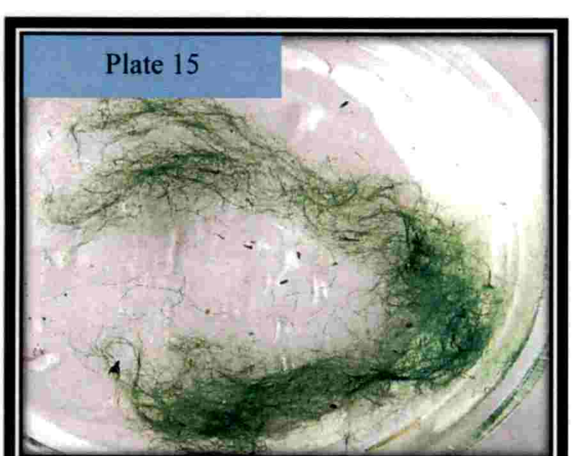

Plate 15

Scientific name: *Spirogyra* sp.

Family: Zygnematophyceae

Common name: Blanket weed

Locations: Pandiparampu, Vellanikkara, Anjumoorthy, Kottuvally

Habit: Submerged plant

Morphological characters: Green slimy filamentous algae. Form mat over the water surface

Plate 16

Scientific name: *Najas* sp.

Family: Hydrocharitaceae

Common name: Water nymph

Locations: Vyttilla, Mala

Habit: Submerged plant

Morphological characters: Needle shaped leaves with plumose appearance. Leaves with 0.5 mm thick. 5-8 cm length

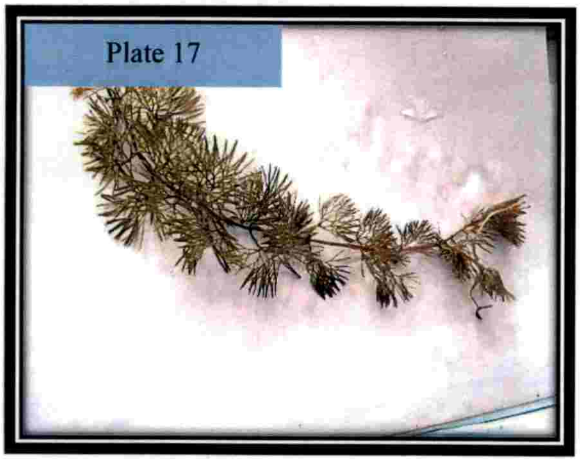

Plate 17

Scientific name: *Cabomba* sp.

Family: Cabombaceae

Common name: Fanwort

Location: Koduvayur

Habit: Submerged plant

Morphological characters: Dimorphic leaves. Red coloured flower.

***Utricularia* bladder**

Leaf margin of *Hydrilla verticillata*

Chara sp.

Spirogyra sp.

Plate 18. Microscopic image of weed species

4.1.4. Water quality at the locations

Water samples were collected from the ten locations and the following parameters were analyzed (Table 7). It was found that the dissolved oxygen content ranged from 0.028 to 0.9 mg/L. Nine locations had less than 0.9 mg/L DO. Highest DO was recorded in Mudappallur of Palakkad (0.9). Anjumoorthy of Palakkad (3) had the highest TSS followed by Vellanikkara of Thrissur (2) and Koduvayur of Palakkad (1.91). Location 3, 8 and 9 (Chithali (0.41), Vyttilla (0.325), Kottuvally (0.325)) had almost same TSS. pH ranged from 7.2 to 8.3. The value of EC was found to be higher in Kottuvally (1423), Vyttilla (1250) and Thuruthissery (1005) all of Ernakulam district. Highest *E. coli* was observed in Anjumoorthy (1100) followed by Vellanikkara (460).

Table.7. Water quality parameters of water samples of selected areas

SI.No.	District	Locations	EC (dS/m)	pH	TSS (mg/L)	DO (mg/L)	*E. coli* (MPN)
1	Palakkad	Anjumoorthy	233	7.2	3	0.028	1100
2		Mudappallur	249	8.3	0.19	0.9	4
3		Chithali	225	7.8	0.41	0.071	4
4		Koduvayur	302.6	7.3	1.91	0.039	4
5	Thrissur	Mala	150.7	7.7	0.35	0.06	9
6		Pandiparampu	93	7.5	0.04	0.04	4
7		Vellanikkara	114	7.3	2	0.037	460
8	Ernakulam	Vyttilla	1250	8.02	0.325	0.03	4
9		Kottuvally	1423	8.13	0.325	0.07	4
10		Thuruthissery	1005	8.17	0.21	0.08	4

65

4.1.4. Nutrient content of water samples of selected location

Nutrient content was measured from ten water samples (Table 8). Highest PO_4 and total phosphorus was measured in Mala (0.09) and Vellanikkara of Thrissur (0.08), Chithali of Palakkad (0.06) and Vyttilla of Ernakulam (0.06). In Anjumoorthy (0.01), Mudappallur (0.01) and Koduvayur (0.02) of Palakkad had the lowest phosphorus content. Potassium was more in Mudappallur of Palakkad (4.52), Thuruthissery (1.31) and Kottuvally (1.21) of Ernakulam. Lowest potassium was measured in Koduvayur of Palakkad (0.25), Mala of Thrissur (0.25) and Chithali of Palakkad (0.66). Nitrate content was more in Vyttilla of Ernakulam (3.36) followed by Anjumoorthy of Palakkad (2.28). Lowest nitrate was found in the Pandiparampu (0.56) and Mala of Thrissur (1.12) and Chithali of Palakkad (1.12). There was no nitrate detected in Mudappallur.

Table 8. Nutrient content of water samples of selected areas

Sl.No.	District	Locations	Phosphate (mg/L)	Total phosphorus (mg/L)	Potassium (mg/L)	Nitrate (mg/L)
1	Palakkad	Anjumoorthy	0.01	0.038	0.41	2.8
2		Mudappallur	0.01	0.038	4.52	Nil
3		Chithali	0.06	0.187	0.66	1.12
4		Koduvayur	0.02	0.058	0.25	2.33
5	Thrissur	Mala	0.09	0.278	0.25	1.12
6		Pandiparampu	0.03	0.091	0.95	0.56
7		Vellanikkara	0.08	0.245	0.31	1.12
8	Ernakulam	Vyttilla	0.06	0.183	0.66	3.36
9		Kottuvally	0.04	0.128	1.24	2.21
10		Thuruthissery	0.06	0.183	1.31	2.24

Analysis of soil samples

Phosphatase enzyme activity, nitrate reductase activity and indole acetic acid was measured in 10 soil samples and results are detailed below (Table 9).

Acid phosphatase activity, nitrate reductase activity and IAA of these soil samples were analyzed. Acid phosphatase was more in Pandiparampu of Thrissur (46.49) followed by Mala (33.23) and Vellanikkara (29.76) of Thrissur. Lowest acid phosphatase activity was found in Kottuvally (17.02) and Thuruthissery (16.88) of Ernakulam.

Nitrate reductase was more in Mudappallur of Palakkad (29.24) followed by Pandiparampu (28.01) and Vellanikkara (22.91) of Thrissur. In Vyttilla (17.25), Anjumoorthy (18.42) and Kottuvally (18.52) showed the low value of nitrate reductase.

IAA was found to be high in Anjumoorthy (7.84), Pandiparampu (7.33) and Mala (7.15). Thuruthissery (4.01), Vyttilla (4.25) and Mudappallur had the lowest IAA.

Table 9. Enzymes and the hormone IAA in soil samples of selected areas

Locations	Acid phosphatase (mg P-Nitro phenol/g^{-1} soil h^{-1})	Nitrate reductase (μNO_2-N/g-^{1}soil 24h^{-1})	IAA (µg g-1 of soil)
Anjumoorthy	17.63	18.42	7.84
Mudappallur	17.42	29.24	4.28
Chithali	18.59	19.02	4.76
Koduvayur	18.24	20.59	6.25
Mala	33.23	18.82	7.15
Pandiparampu	46.49	28.01	7.33
Vellanikkara	29.76	22.91	6.75
Vyttilla	17.48	17.25	4.25
Kottuvally	17.02	18.84	4.98
Thuruthissery	16.88	18.52	4.01

4.1.7. Physiological parameters of the weeds

Different physiological parameters of weeds were analyzed. The enzyme nitrate reductase was higher in *Najas* (150) followed by *Cabomba* (75), *Egeria* (72), *Nitella* (68), *Utricularia aurea* (66), *Utricularia exoleta* (65), *Chara* (62), *Eodea* (61) and *Spirogyra* (60) It was seen that chlorophyll content was more in *Utricularia* aurea (4.74 followed by *Hydrilla* (4.211), *Cabomba* (3.914) and *Utricularia exoleta* (1.69). Chlorophyll content was found to be low in *Chara (0.85), Nitella (0.81) and Spirogyra* (0.97). IAA content was highest in *Hydrilla* (2.05) followed by *Utricularia aurea* (1.9), *Spirogyra* (1.45), *Chara* (0.990), *Elodea* (0.850), *Utricularia exoleta* (0.810), *Cabomba* (0.800), *Nitella* (0.770), *Egeria* (0.730) and *Najas* (0.720) respectively. GA was more in *Utricularia* (89) followed by *Spirogyra* (41.3), *Chara* (32), *Nitella* (31.3), *Najas* (29), *Cabomba* (19), *Elodea* (19) and *Egeria* (15.3).

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Table 10. Physiological parameters of different submerged weeds

Parameters	*Chara* sp.	*Spirogyra* sp.	*Nitella* sp.	*Utricularia aurea*	*Cabomba* sp.	*Hydrilla* sp.	*Najas* sp.	*Elodea* sp.	*Egeria* sp.	*Utricularia exoleta*
Nitrate reductase ($\mu g\ NO_2\ g^{-1}$)	62	60	68	66	75	70	150	61	72	65
Chlorophyll(mg/g)	0.85	0.97	0.81	4.7	3.91	4.21	1.3	1.21	1.52	1.69
IAA (mg/g)	0.99	1.45	0.77	1.9	0.8	2.05	0.72	0.85	0.73	0.81
GA (mg/g)	32	41.3	31.3	89	19	19.2	29	17	15.3	21

4.2. EXPERIMENT 2 (Pot culture)

4.2.1. Effect of UV radiation on growth and development of *Utricularia*

The weed *Utricularia aurea* was grown under three different UV conditions (open UV, minimum UV and 80 % UV). The fresh weight, dry weight and increase in filament length were measured after one month. The rate of multiplication was recorded at 10 days interval.

4.2.2. Effect of UV radiation on filament length of *Utricularia aurea*

The filament length of *Utricularia aurea* under different UV light intensities is given in the Table 11. Results indicate that *Utricularia aurea* grown under minimum UV had a filament length of 90.2 cm after one month, which was significantly superior to open condition (66.2) and 80% UV (61.2) which showed on par values.

Table 11. Effect of UV radiation on filament length after one month

Treatments	**Filament length after one month (cm)**
Open	66.2^{b}
Zero UV	90.2^{a}
80 %UV	61.2^{b}
CD (0.05)	22.21

70

4.2.3. Rate of multiplication after ten days interval

The multiplication rate of *Utricularia* aurea was measured after 10, 20, 30 days and the results are given in table 12. The multiplication rate of *Utricularia* measured after 10 days showed higher multiplication rate with zero UV radiation (3.01) and open condition (2.78) which were statistically on par. The lowest value was observed in 80% UV radiation (1.294).

In the second observation (after 20 days), all the treatments were significant. Highest value was observed in zero UV treatments which was 0.68 followed by 3.6 in open condition. The lowest value was observed in 80 % UV radiation (0.46).

The third observation (after 30 days) was found to be statistically non-significant.

Table 12: Effect of UV radiation on the rate of multiplication at different interval

Treatments	Rate of multiplication(cm/day)		
	10 days	20 days	30 days
Open	2.7^{a}	0.3^{ab}	0.7
Zero UV	3.0^{a}	0.6^{a}	2.0
80% UV	1.2^{b}	0.4^{b}	1.8
CD (0.05)	1.2	0.4	NS

4.2.4. Fresh weight and dry weight after one month

4.2.4.1. Fresh weight after one month

Fresh weight of the weed recorded after one month is given in the Table 13. Results indicated that there was significant variation in the treatments. Among the treatments, zero UV radiation had the highest fresh weight (16.6) followed by open condition (11.4). Lowest value was recorded for 80 % UV radiation (8.2).

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Table 13. Effect of UV exposure on the fresh weight after one month

Treatments	Fresh weight (g/plant)
Open	11.4^{b}
Zero UV	16.6^{a}
80% UV	8.2^{b}
CD (0.05)	5.02

4.2.4.2. Dry weight after one month

Table 14 indicates the dry weight of *Utricularia aurea* under different UV conditions. The treatments were found to be non-significant.

Table 14. Effect of UV exposure on the dry weight after one month

Treatments	Dry weight (mg/plant)
Open	157
Zero UV	260.4
80 % UV	153
CD	NS

4.2.5. Effect of shade on the growth and development of *Utricularia aurea*

To understand the effect of light on the growth of *Utricularia aurea,* they were grown under three different conditions (open condition, 75% light and 50% light). After one month, fresh weigh, dry weight and filament length were measured. Rate of multiplication was also recorded at 10 days interval.

4.2.6. Effect of shade on filament length of *Utricularia aurea*

The filament length of *Utricularia aurea* under different shade conditions is given in the Table 15. Results indicate that *Utricularia aurea* grown under three different shade condition had a variation in filament length after one month. However it was statistically non-significant.

Table 15. Effect of shade on filament length after one month

Treatments	Filament length after one month (cm)
Open	66.2
75% light	79
50% light	70
CD (0.05)	NS

4.2.7. Rate of multiplication after ten days interval

The multiplication rate of *Utricularia* was measured after 10, 20, 30 days interval and the results are given in table 16. Rate of multiplication was recorded in all treatments at 10 days interval. The treatments are found to be non-significant in all observations.

Table 16. Effect of shade on rate of multiplication at different interval

Treatments	Rate of multiplication (cm/day)		
	10 days	20 days	30 days
Open condition	2.78	0.36	1.1
75% light	1.0	1.8	1.6
50% light	1.52	0.56	1.64
CD (0.05)	NS	NS	NS

4.2.8. Effect of shade on fresh and dry weight after one month

4.2.8.1. Fresh weight after one month

Fresh weight measured after one month is shown in table 17. It was more in 75 % light (14.4), followed by open condition and 50% light (11.4 and 10.4 respectively). These 3 treatments were found to be statistically non-significant.

Table 17. Effect of shade on fresh weight after one moth

Treatments	Fresh weight (g/plant)
Open	11.4
75% light	14.4
50% light	10.4
CD	NS

4.2.8.2. Dry weight after one month

Dry weight after one month was taken in each treatments. It is given in the table 18. Dry weight was more in 75% light (160.6) followed by open condition (157) and 50% light (153.6). It was found to be statistically non-significant.

Table 18. Effect of shade on dry weight after one month

Treatments	Dry weight (mg/plant)
Open	157
75% light	160.6
50% light	154
CD (0.05)	NS

4.2.9. Effect of chemicals on weed degradation

Effect of $CuSO_4$ (1ppm, 2ppm and 3ppm), 2, 4-D (1ppm, 2ppm and 3ppm) and lime (100 ppm, 200 ppm and 300 ppm) on weed growth reduction was measured visually and degradation of weed after one month was measured (Table 19).

$CuSO_4$ effect on weed growth was measured after one month. One ppm, 2 ppm and 3 ppm $CuSO_4$ was sprayed and percentage reduction in weed after one month was visually estimated. Weed degradation rate was more in 3 ppm treatment (69) followed by 2 ppm (55). Lowest weed reduction was noticed in 1 ppm treated pots (50).

Maximum degradation of 69% was observed in 3 ppm 2, 4-D followed by 2 ppm (65). The lowest degradation of weed was observed when only 1 ppm of 2, 4-D was given.

Effect of lime on the weed growth was measured. Weed degradation was more in 300 ppm lime (75) followed by 200 ppm (73). Lowest degradation was found in 100 ppm lime (70).

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Table 19. Weed degradation percentage after one month

Chemical	Rate	Percentage degradation after one month (%)
$CuSO_4$	1 ppm	50
	2 ppm	55
	3 ppm	69
2, 4-D	1 ppm	60
	2 ppm	65
	3 ppm	69
Lime	100 ppm	70
	200 ppm	73
	300 ppm	75

4.3. Air and water temperature

Air temperature (Table 20) and water temperature (Table 21) were also measured for one week during the pot culture study. Temperature was highest in 80% UV treated pots followed by open condition, 75% light and 50% light respectively. The lowest temperature was noticed in zero UV treated pots.

Table 20. Daily air temperature in pot culture study (°C)

Treatments	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Open	34.8	34.9	33.6	34.2	34.6	33.9	34.6
75% light	32.1	32.5	31.8	32.1	32.8	33.1	32.8
50% light	31.8	31.2	31.1	31.0	32.1	32.8	32.1
Zero UV	31.2	31.0	31.0	30.0	31.6	31.5	31.6
80% UV	36.3	35.8	34.8	33.9	33.8	34.2	34.8

Table 21. Daily water temperature in pot culture study

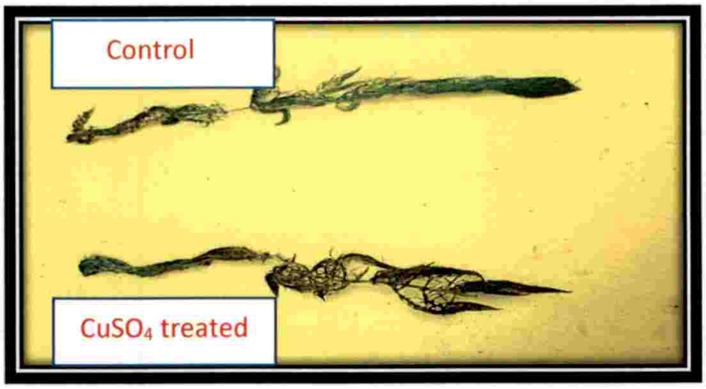
Treatments	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Open	34.8	34.7	34.0	34.5	34.6	34.2	34.6
75% light	32.9	32.6	32.0	32.2	33.1	33.5	32.8
50% light	32.0	31.3	31.5	31.8	33.0	33.5	32.8
Zero UV	31.4	31.2	31.0	30.2	31.5	31.5	31.9
80 % UV	36.5	35.9	34.5	33.8	33.9	34.4	34.8

4.5. UV radiation measurement

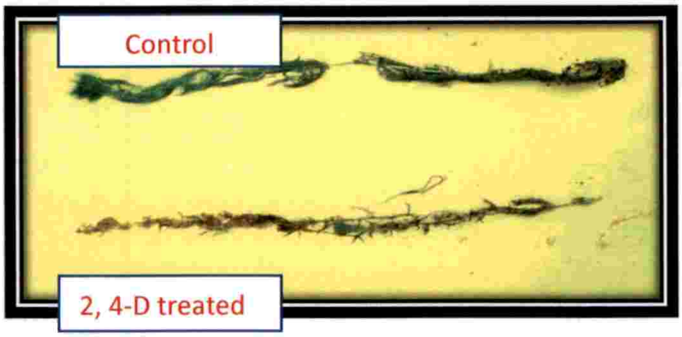
UV radiation was measured with UV meter and expressed in W/m^2. UV radiation was more in open condition (3.4 to 4.7) followed by 80% UV (1.5 to 3.5). Zero UV was observed in the polyhouse clad with mylar film (Table 22).

Table 22. Daily UV radiation in pot culture study (W/m^2)

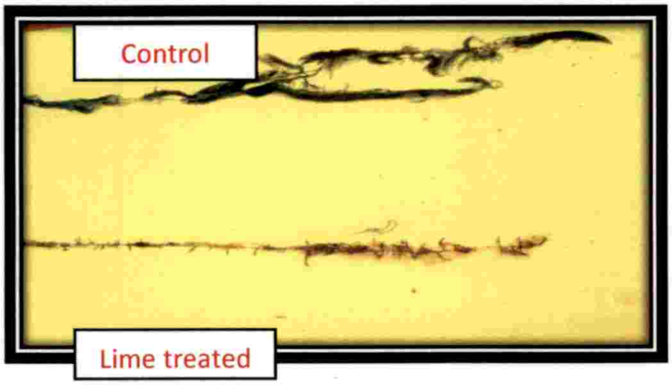
Treatments	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Open	3.4	3.9	4.7	2.9	3.3	3.8	3.1
Zero UV	0	0	0	0	0	0	0
80% UV	2.5	2.8	3.5	1.5	2.7	3.01	2.4



Effect of CuSO4 on weed degradation



Effect of 2, 4-D on weed degradation



Effect of lime on weed degradation

Plate 19. Effect of chemicals on weed degradation

DISCUSSION

5. DISCUSSION

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The present study has been undertaken to identify the major submerged weeds in rice fields in districts of Kerala and the factors which influence their growth and development. Results obtained from the survey and pot culture as part of the thesis programme entitled "Physiology and management of submerged weeds in wetland rice ecosystem" are presented in chapter 4. The details pertaining to the various findings are discussed in this chapter.

Excessive growth of submerged weeds can be detrimental for rice cultivation. They grow invasively and compete with rice crop and cause various problems during cultivation, and also affect growth of rice crop. In this study an attempt has been made to identify submerged weed species commonly seen in the rice ecosystem of *kole* lands, Palakkad and Ernakulam districts of Kerala and also to evaluate probable soil and water characters that contribute to their sudden spurt in population in these areas.

The major submerged weeds in the rice ecosystem included both hydrophytes and algal species. Seven hydrophytes were collected from the region, while only three species of algae were commonly distributed in the region. The major hydrophytes were *Utricularia aurea, Utricularia exoleta, Elodea canadensis, Hydrilla* sp., *Egeria densa, Cabomba* sp. *and Najas* sp. while the common algal species were *Spirogyra, Chara* and *Nitella.*

5.1. Part 1: Survey and identification of different weed species in rice fields of central zone of Kerala

The survey was undertaken to identify the submerged weed plants in wetland rice ecosystems of central zone of Kerala (Thrissur, Palakkad, and Ernakulam districts). Soil and water samples were collected along with weed samples during the period of April 2017 to March 2018. The samples collected were analyzed in the laboratory for different physico-chemical properties. Details of the observed weed samples along with quality parameters of water and soil samples were analyzed to find out the factors which promote weed growth. The results thus obtained are discussed below.

A survey of 30 different locations of Palakkad, Thrissur and Ernakulam districts revealed that the most dominant hydrophyte was *Utricularia aurea* which was seen in 15 out of 30 locations surveyed. The other hydrophytes observed in these locations were *Hydrilla, Cabomba, Najas, Utricularia exoleta, Elodea canadensis, and Egeria densa* according to the order of abundance (Fig. 1)

The most widely seen algal species was *Spirogyra* which was observed in 14 out of the 30 locations surveyed. The other algal species observed in these locations were *Chara* and *Nitella* according to the order of abundance (Fig. 2). The per cent incidence of weed species observed from the survey is depicted below.

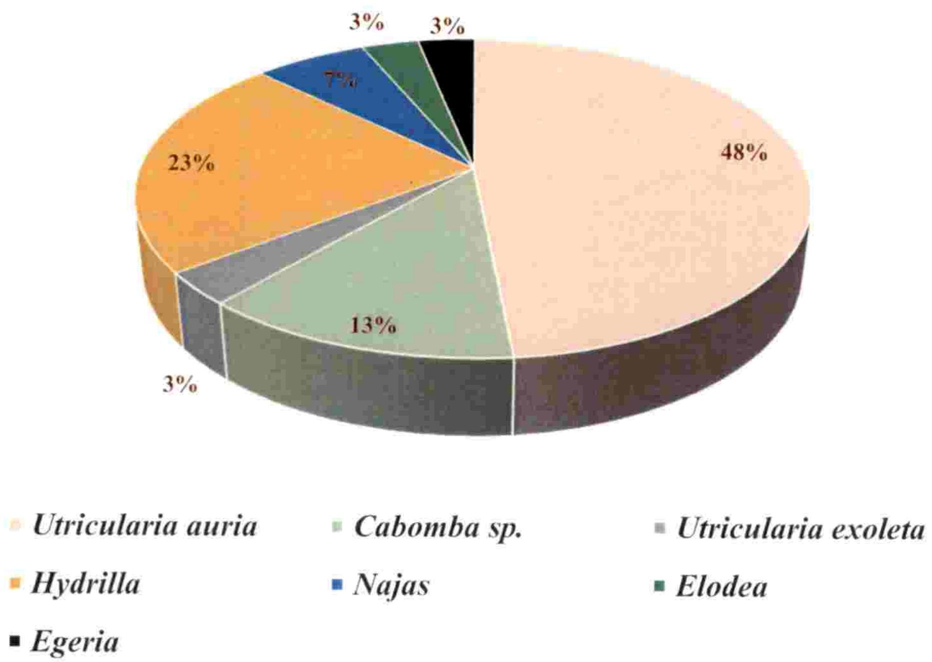

Fig 1. Per cent incidence of hydrophytes in rice fields

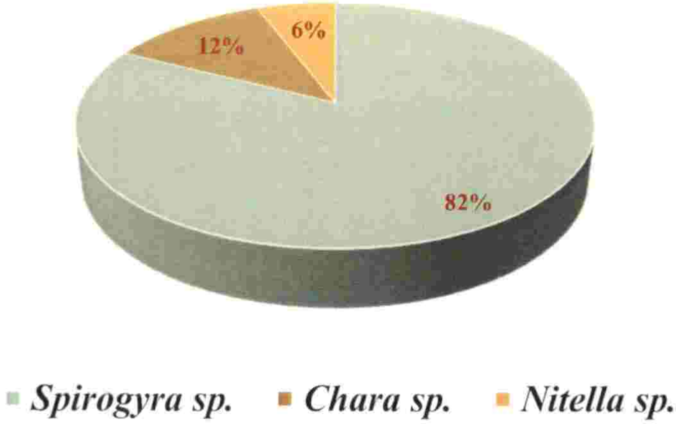

Fig 2. Per cent incidence of algae in rice fields

5.1.1. Physico-chemical properties of water affecting weed growth

The physico-chemical properties of water tested from ten locations where the weed growth was abundant indicated that pH, EC, dissolved oxygen content and TSS of the water had a profound influence on the growth of the weeds.

The pH of the water collected from 10 locations ranged from 7.2-8.3(fig.3) which indicates that abundant weed growth is seen when the pH of the water is neutral to alkaline. This is in accordance with the findings of Venter and Schoonbee (1991), who reported that submerged weeds prefer a pH range of neutral to slightly alkaline. In all the locations, the most commonly observed weed was *Utricularia aurea.* Generally there was decrease in weed abundance when the pH was very low, this was evident from the study of Singh *et al.* (2013).

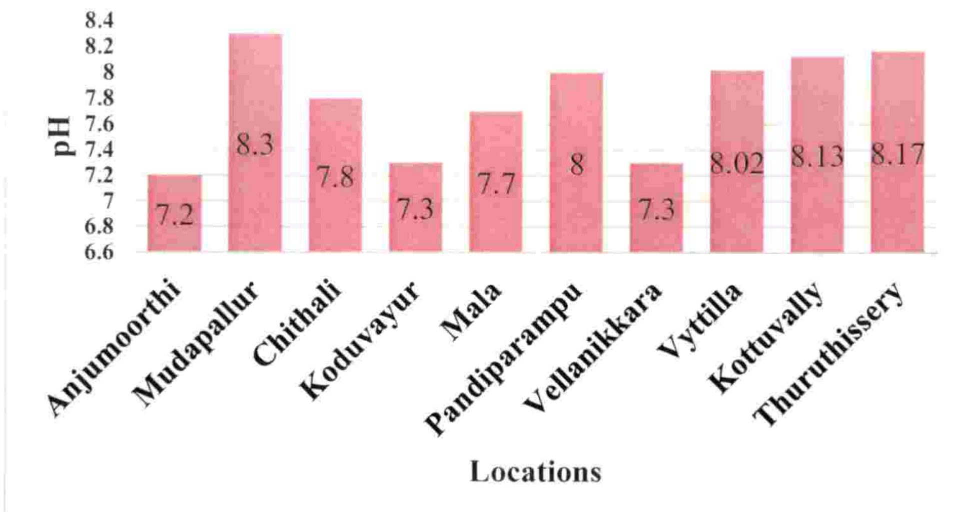

Fig. 3. pH of water samples collected from different locations

In Mudappallur, Kottuvally and Thuruthissery when the pH range was above 8 (8.13-8.3) (Fig.3) only *Utricularia* and *Spirogyra* were observed. This might be due to the ability of these two weeds to tolerate a wide pH range. Adamec (2009) has reported that *Utricularia* is capable of growing in a pH range of 4.93-9.20. Among the algal species *Spirogyra* can tolerate a pH range of 7.2-8.17.

Electrical conductivity is a measure of the concentration of charged ions in water. The EC values of the location studied ranged from 93 to 1423 dS/m (Fig.4). High EC was recorded from Kottuvally followed by Vyttilla and Thuruthissery, all of Ernakulam district (Table 6). This may be due to high salt content in the water. The only hydrophytes seen in these locations were *Utricularia* and *Najas*, and algal species was *Spirogyra.* Halter *et al.* (1974) has reported that the hydrophyte *Najas* is capable of tolerating saline condition. Adamec (2009) found that *Utricularia* can tolerate an EC level of 27 – 394 dS/cm, whereas our study shows that it can tolerate up to 1423 dS/cm. The hydrophytes *Utricularia exoleta, Elodea canadensis* and *Hydrilla verticillata* were observed in Pandiparampu (Table.5). This location had high pH range of 8 and lowest EC (93). Highest number of hydrophytes was observed in Pandiparampu.

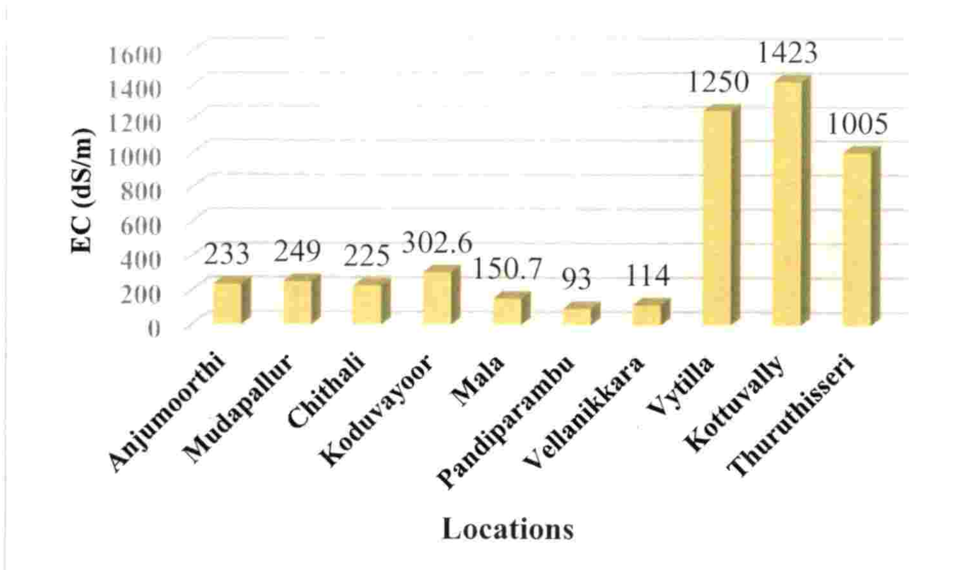

Fig 4. Electrical conductivity of water samples collected from different locations

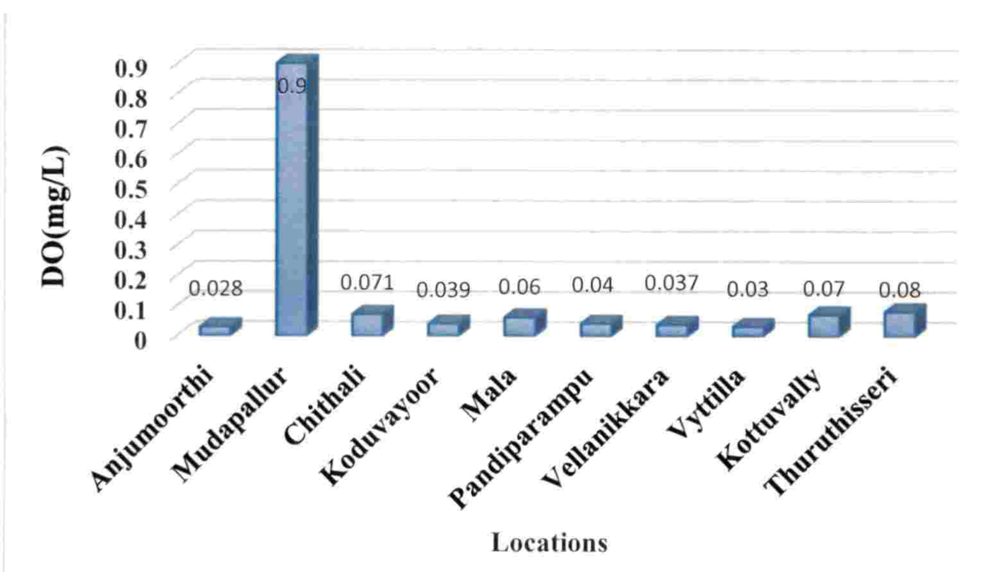

Fig.5. Dissolved oxygen content of water samples collected from different locations

Dissolved oxygen is one of the major indicators of water quality. Rice requires sufficient amounts of oxygen dissolved in water to survive (Zhao *et al.*, 2014). Dissolved oxygen depletion can occur due to several naturally occurring reasons. The primary cause of oxygen depletion in a water body is due excessive growth of algae and phytoplankton driven by high levels of phosphorus and nitrogen (Gupta *et al.*, 1976). Algae or hydrophytes present in the water reduce the dissolved oxygen content of the water. Dissolved oxygen was more in Mudappallur than in Thuruthissery and Kottuvally (Fig.5). Weed growth was comparatively low in these three locations may be due to high pH. pH had a negative influence on the growth of submerged weeds (Bhateria and Jain, 2016)

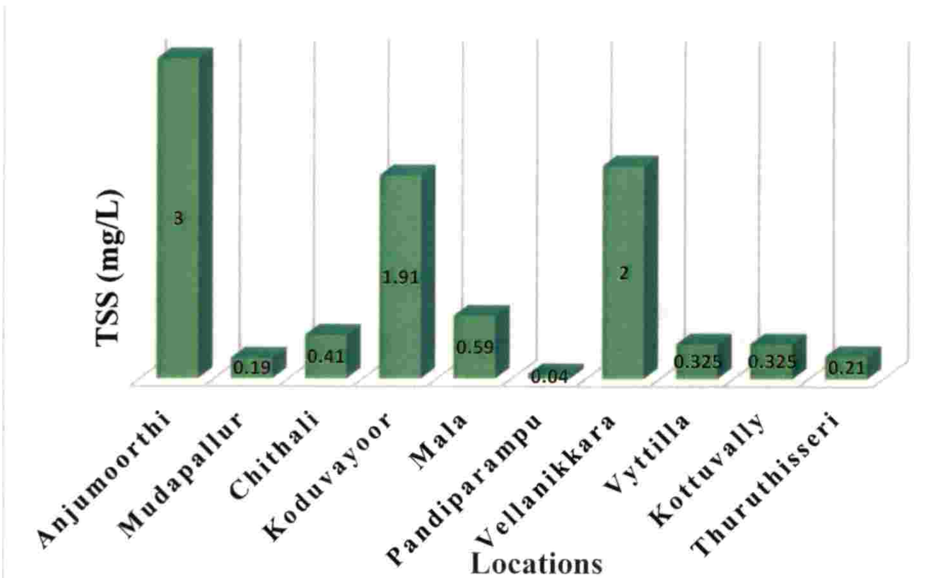

Fig. 6. TSS of water samples collected from different locations

Total suspended salts is a measure of turbidity. The TSS value of the locations observed ranged from 0.04 mg/L to 3 mg/L (Fig.6). High TSS was seen at Anjumoorthy of Palakkad followed by Vellanikkara (Thrissur) and Koduvayur (Palakkad). The weeds found in these areas were *Spirogyra, Utricularia aurea, Cabomba and Hydrilla* (Table.4 & 5). The density of weeds was also higher in these locations, indicating that weed growth might promote the content of TSS in the water. Similar findings have been reported by Lancar and Krak (2002). Increased TSS will lead to reduction in dissolved oxygen content (Naiman and Bilby, 2001).

A positive relationship between growth of *E. coli* and TSS was reported by Byappanahalli *et al.* (2003). According to the present study maximum content of *E. coli* in water was observed in Anjumoorthy (Fig. 7) which also recorded the highest TSS content in water. Shahab *et al.* (2009) found a relationship between the prevalence of *E. coli* and algal presence in the water. In Anjumoorthy *Spirogyra* was the algal species observed (Table.4). Our studies confirm a relation between algal growth and *E. coli.* Algal growth was more in Anjumoorthy, Vellanikkara and Mala (Table.4&5). *E. coli* was also found to be higher in these locations. *Spirogyra, Utricularia aurea, Hydrilla, Najas and Egeria* were seen in water with high *E. coli* content.

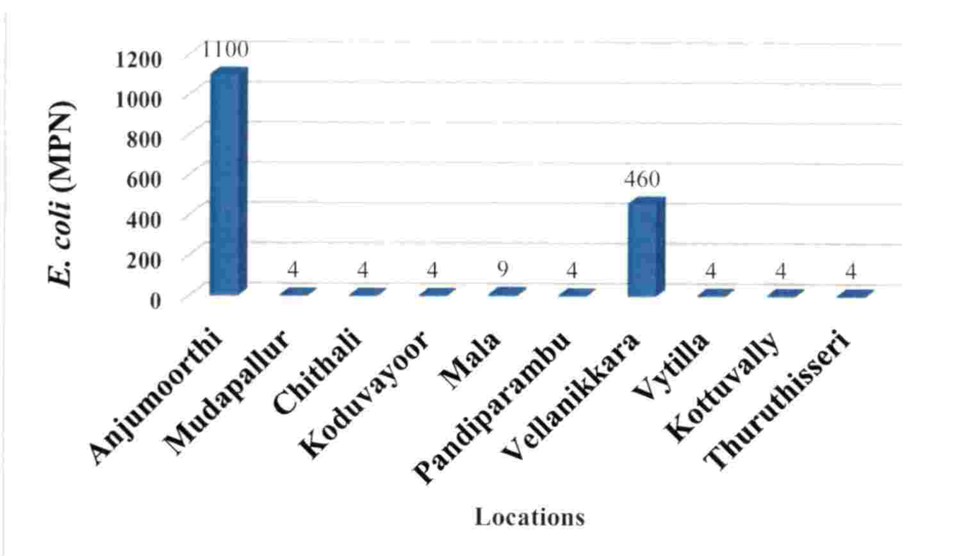

Fig. 7. *E. coli* of water samples collected from different locations

The result of the study indicates that among the physico-chemical parameters of water, pH has the highest influence on growth of submerged weed species. The maximum weed growth was observed within pH range of neutral to alkaline, between7.2 to 8.3. The presence of submerged weeds reduce dissolved oxygen content of water and increases the content of TSS and promotes growth of *E. coli* adversely affecting water quality and supply of oxygen to rice root (Fig. 8).

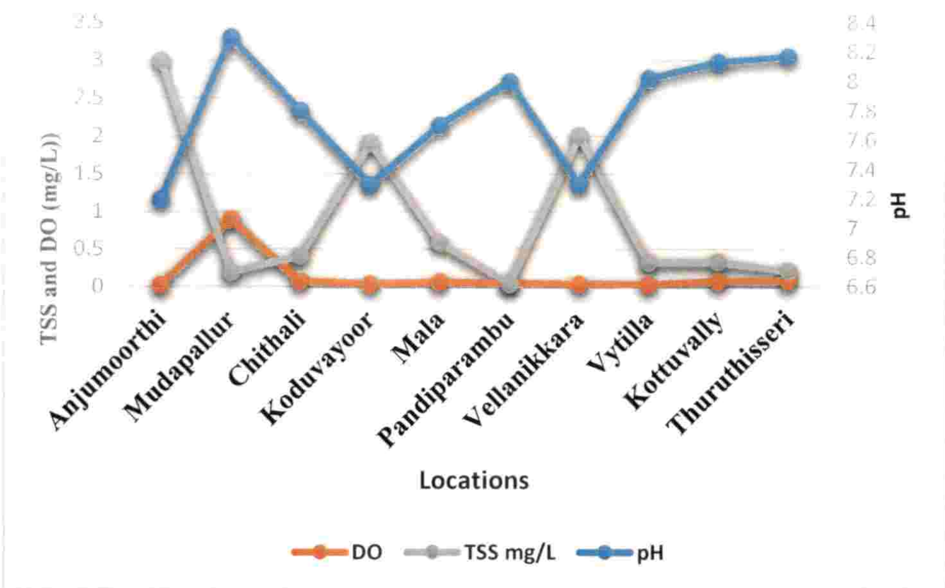

Fig. 8. Relation between pH, DO and TSS

5.1.1.2. Nutrient content of water and weed growth

The low nitrate content of water in Mudappallur (Fig.9) might have contributed to the low weed growth in the location accounting for higher dissolved oxygen content in water and lower TSS value. The only weed observed in this location was *Nitella* which is reported to grow under low nutrient concentration (Ravan, 1981).

Though the nitrogen content was higher in Vyttilla, Kottuvally and Thuruthissery, the pH of these locations was high due to salinity. This might be the reason for lower weed growth in these locations. The saline tolerant *Najas* was seen extensively in Vyttilla region (Table.6). *Utricularia aurea* was the weed observed in Kottuvally and Thuruthissery (Table.6) and of the algal weeds, only *Spirogyra* was seen in these locations.

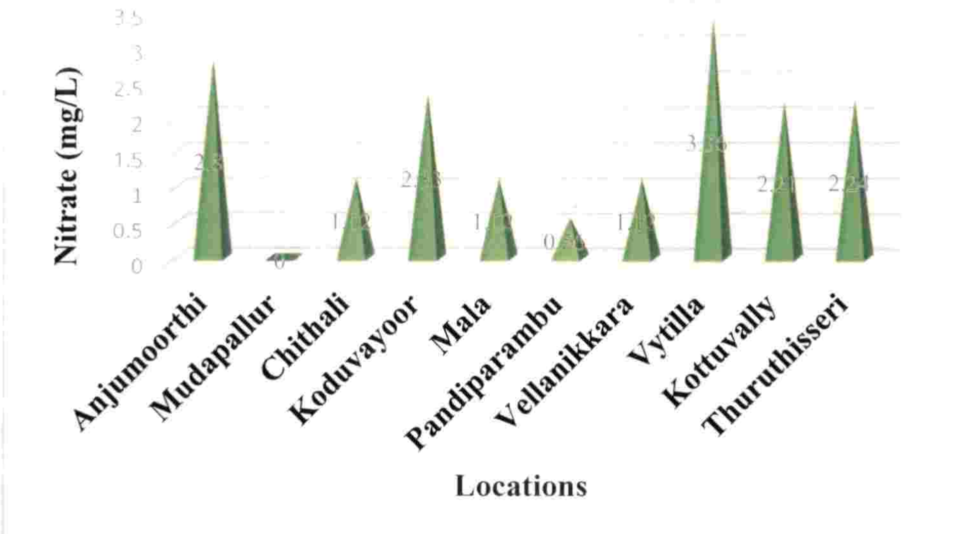

Fig.9. Nitrate content of water samples collected from different locations

Phosphate (Fig.10) and total phosphorus contents (Fig.11) were more in Mala, Vellanikkara, Chithali and Vyttilla. The study does not indicate any special relation between phosphate content and the growth of submerged weeds.

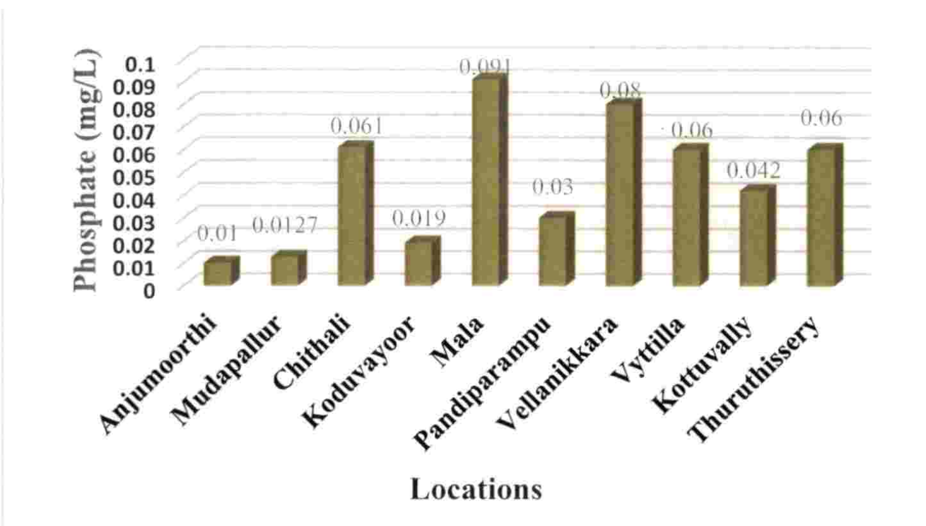

Fig 10. Phosphate content of water samples collected from different locations

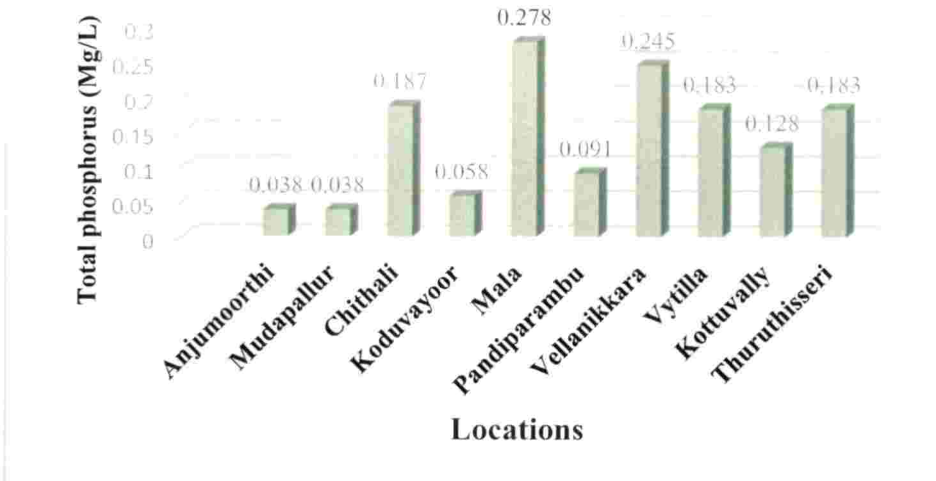

Fig 11. Total phosphorus content of water samples collected from different locations

Potassium was more in Mudappallur, Thuruthissery and Kottuvally (Fig.12). The weed growth was comparatively low in these three locations. This might be because of the ability of potassium to inhibit the uptake of phosphorus and nitrogen which are nutrients required for growth of submerged plants. Similar findings have been reported by Shukla and Rai (2007). According to Dhote and Dixit (2007), *Hydrilla verticillata* accumulates potassium. This might be the reason for the low potassium content in water samples collected from Vellanikkara, Mala and Pandiparampu which had high incidence of the weed (Table 5).

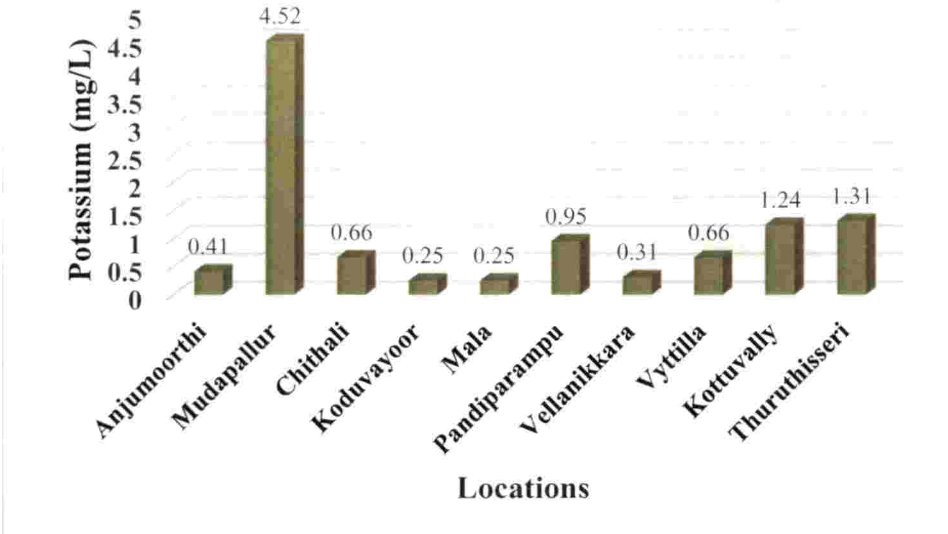

Fig. 12. Potassium content of water samples collected from different locations

5.1.1.3. Effect of soil enzymes and hormones on weed growth

Phosphatase is a broad group of enzymes involved in the hydrolysis of esters and anhydrides of H_3PO_4 (Schmidt and Laskowski 1961). They have an important role in P mineralization. The phosphatase enzyme is classified into acid phosphatase and alkaline phosphatase.

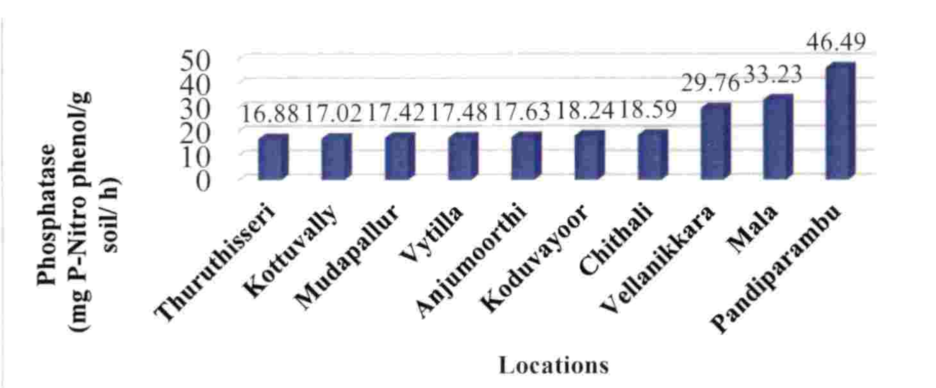

Fig. 13. Phosphatase enzyme content of soil samples collected from different locations

The acid phosphatase activity of the location studied ranged from 16.88 to 46.49 (mg P-Nitro phenol/g^{-1} soil h^{-1}) (Fig.13). High phosphatase activity was recorded from Pandiparampu followed by Mala and Vellanikkara all of Thrissur district (Table.5). This may be due to high phosphorus content in these locations. According to Tabatabi and Bremner (1969), phosphatase activity will increase with high phosphorus content in the soil. Phosphorus content of the water had a positive relationship with the *E. coli* content. This has been reported earlier by Parks (1974). In the present study the *E. coli* content was higher at Vellanikkara and Mala where the phosphorus content of the water was also high.

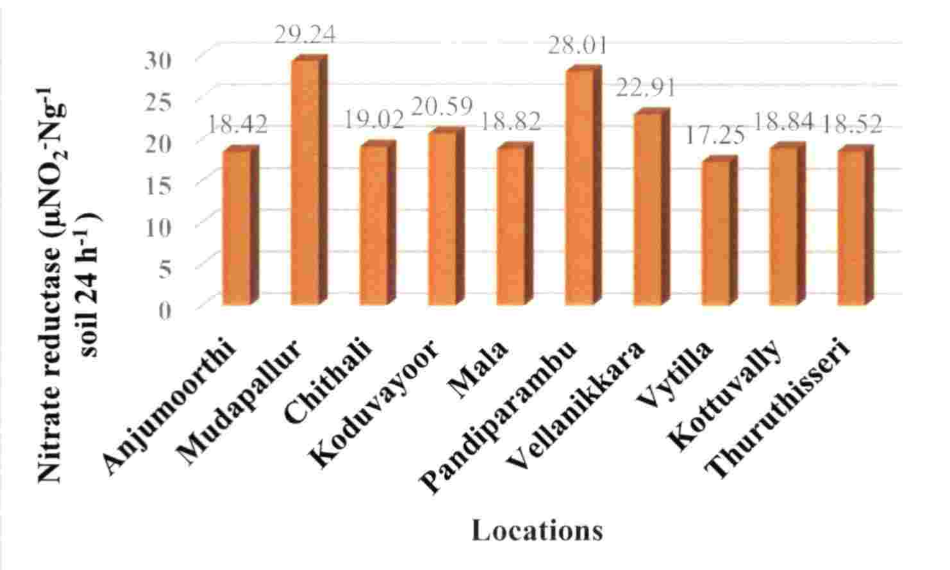

Fig. 14. Nitrate reductase enzyme content of soil samples collected from different locations

Nitrate reductase activity of the locations studied ranged from 17.25 to 29.24 (μNO_2-N/g-^{1}soil 24h^{-1}) (Fig 14). High nitrate reductase was recorded from Mudappallur followed by Pandiparampu and Vellanikkara. This might be the reason for the low Nitrogen content in these locations (Fig.9). High nitrate reductase activity will lead to reduction in nitrate content of the soil as the nitrate is converted to ammonia by the activity of the enzyme (Mccarty and Bremner, 1993). These locations had a variety of algae and hydrophytes (Table 4 &5)

IAA content of soil was more in Anjumoorthy followed by Pandiparampu and Mala (Fig.15). This might be the reason for high weed growth in these areas (Table 4&5).

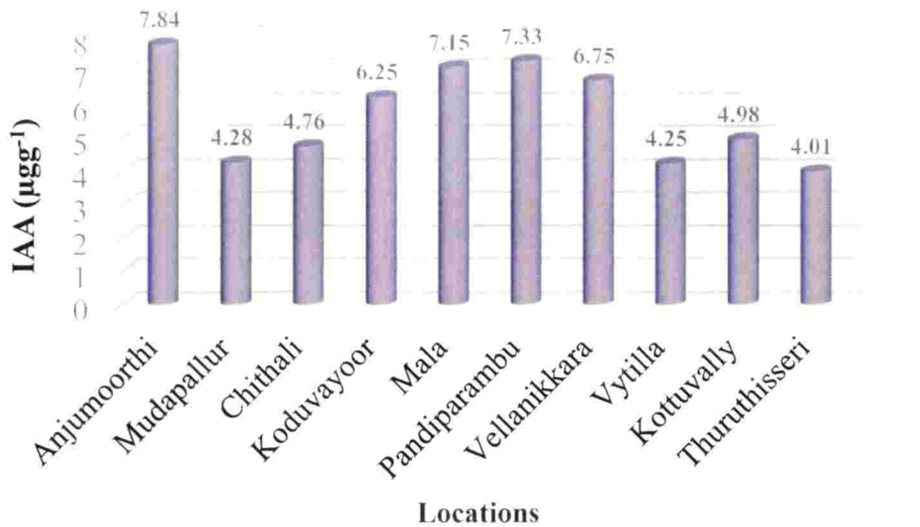

Fig 15. IAA content of soil samples collected from different locations

5.1.1.4. Physiological parameters of weeds

Physiological parameters such as chlorophyll content, NRase activity, IAA and GA content of the submerged weed species were estimated.

Chlorophyll a is biological indicator for monitoring and assessing the levels of organic pollution in aquatic ecosystem. The high concentration of chlorophyll in water plants reported to significantly affect the penetration of light in to the system (Krause-Jensen and Sand-Jensen, 1998).

Chlorophyll contents of algal species *Chara*. *Spirogyra* and *Nitella* (Fig. 16) were lower than those of the hydrophytes (Fig 17). Among the hydrophytes *Utricularia, Cabomba* and *Hydrilla* had higher chlorophyll content than *Najas, Elodea, Utricularia exoleta, Egeria* and *Nitella.*

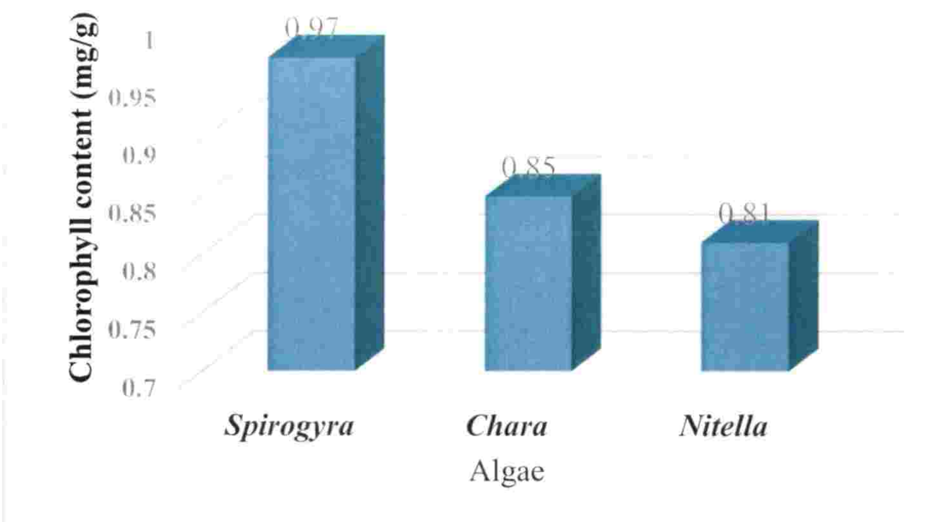

Fig 16. Chlorophyll content of algal species

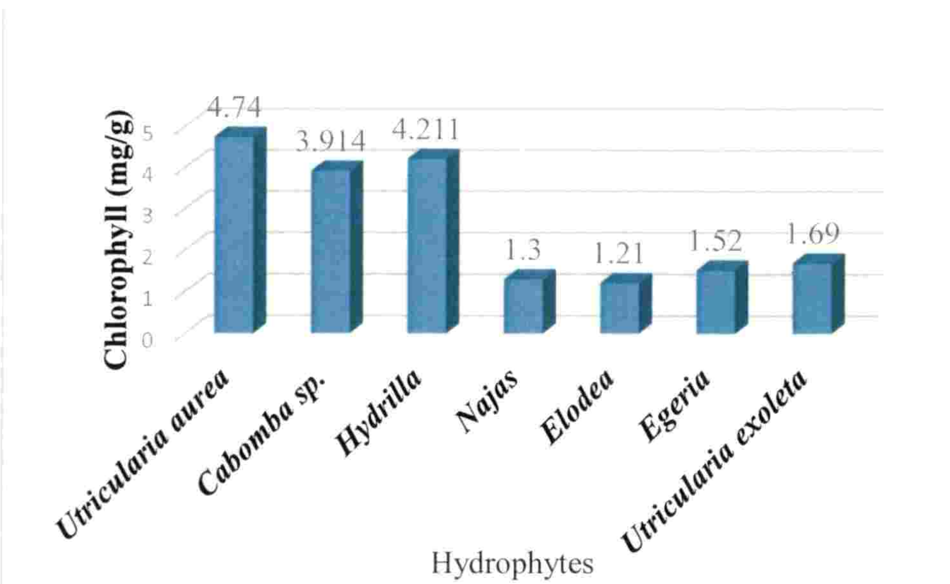

Fig 17. Chlorophyll content of hydrophytes

The NRase enzyme activity of hydrophyte *Najas* was high (Fig 18). Among algae, *Nitella* contained high amount of nitrate reductase and this was found in low nitrogen area. It might be due to the increased nitrogen uptake by *Nitella*.

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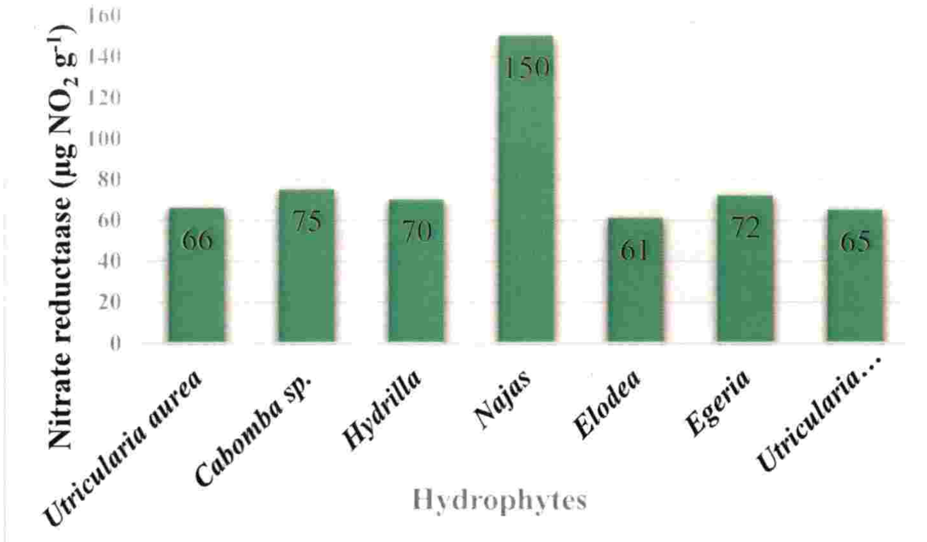

Fig 18. Nitrate reductase content of hydrophytes

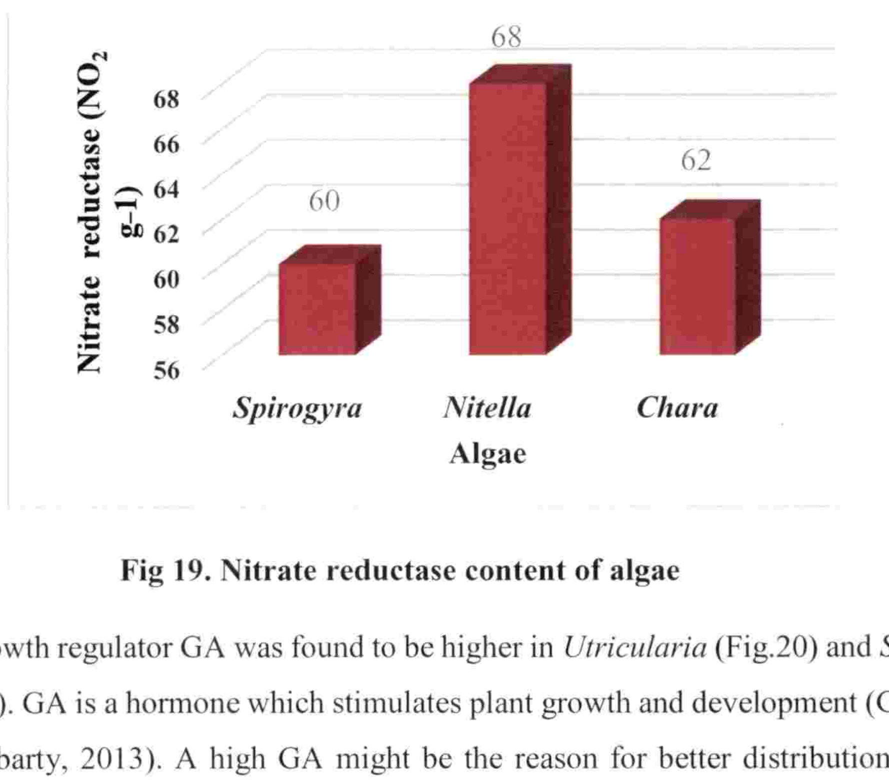

Fig 19. Nitrate reductase content of algae

The growth regulator GA was found to be higher in *Utricularia* (Fig.20) and *Spirogyra* (Fig.21). GA is a hormone which stimulates plant growth and development (Gupta and Chakrabarty, 2013). A high GA might be the reason for better distribution of these weeds.

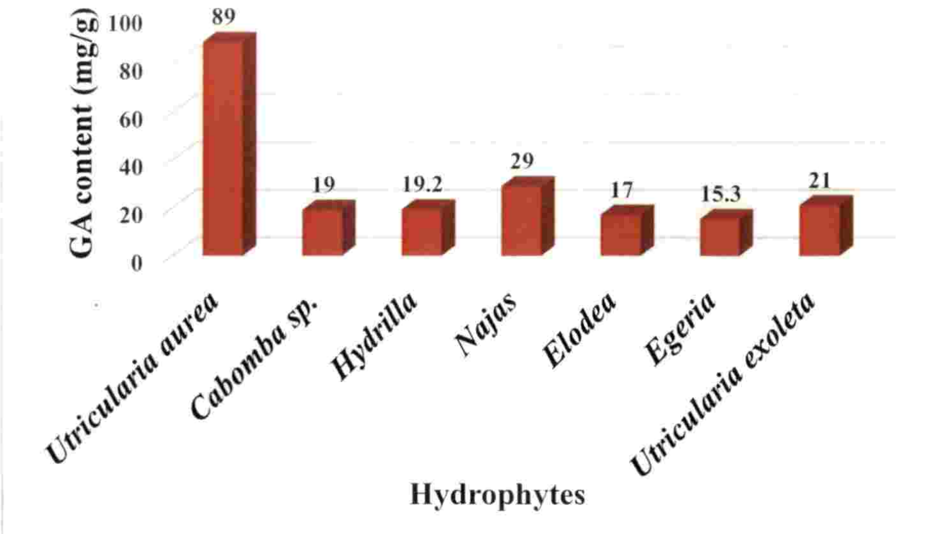

Fig.20. GA content of hydrophytes

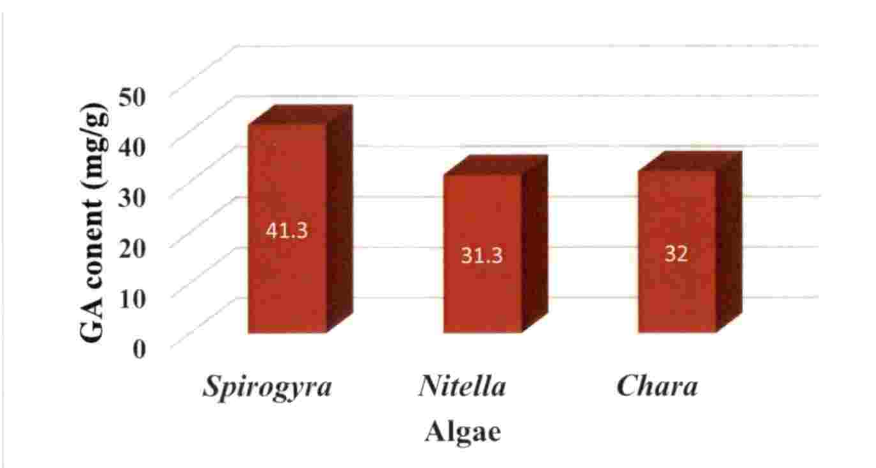

Fig.21. GA content of algae

The IAA content of *Utricularia*, *Hydrilla* (Fig.22) and *Spirogyra* (Fig. 23) was found to be high. This might be the reason for the abundance of these weeds in water. There was a positive correlation between IAA and plant growth. The finding was in accordance with the finding of Rayle *et al.* (1970). Auxin has a profound influence on of plant growth and development (Zhao, 2014).

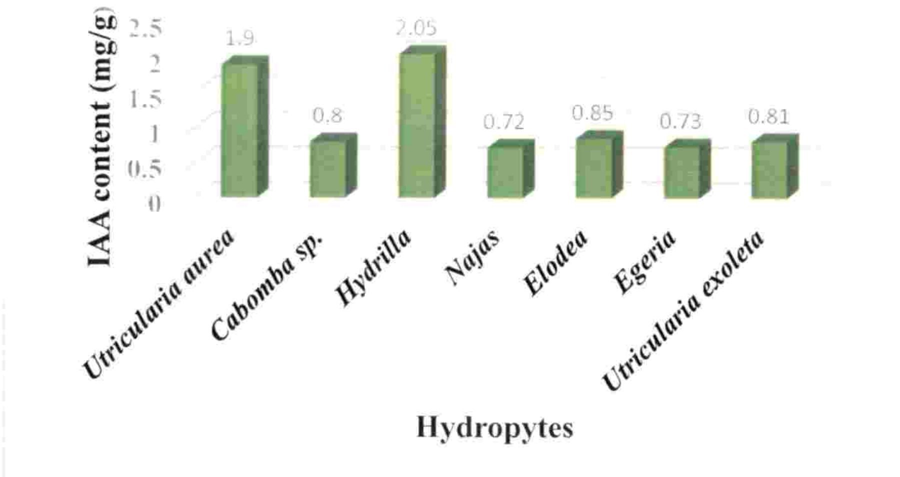

Fig.22. IAA content of hydrophytes

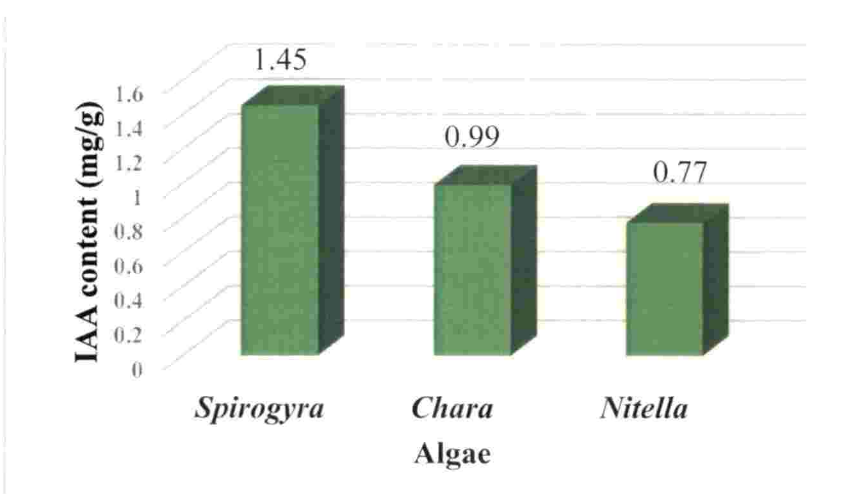

Fig. 23. IAA content of algae

5.2. Experiment 2

Effect of weather factors on weed growth

In the present study, an attempt was made to understand the effect of weather parameters such as light, UV radiation and temperature on growth of submerged weed *Utricularia aurea* which is seen to be spreading in the rice ecosystems of Kerala with a likelihood of becoming a concern for rice farming. Changes in these parameters not only affect the fauna and flora of the terrestrial ecosystem but can also contribute to changes in the aquatic ecosystem (Bhateria and Jain, 2016).

Climate change has contributed to increase in UV radiation (Heggelin and Shepherd, 2009) and rise in temperature. Nishanth *et al.* (2011) has reported that UV-B in Kannur and Palakkad districts of Kerala has increased constantly from 2000-2010.

Temperature data collected during the period (Table.20) shows that higher air temperature contributed to increase in water temperature. According to Lee *et al.* (2007), the optimum growth temperature for tropical and subtropical species of aquatic plants is in the range between23°C to 32°C. Higher water temperatures are reported to influence the physiological processes such as growth rate, reproductive pattern and distribution of submerged weed flora. Studies with *Utricularia* indicate that growth and multiplication rate of the weed is maximum when the temperature is around 30-31.6°C and with minimum UV light indicating that both UV and high temperature have a negative effect on the growth of *Utricularia.* However the lowest growth and multiplication rate were observed at 33.9°C to 34.8°C, though the UV level was reduced by 20%, indicating that temperature has greater influence than UV light on the growth and multiplication of the weed. Kosiba (1992) reported that high temperature affects growth of submerged weed. Salama *et al.* (2011) found that UV light contributed to reduction in growth of submerged weeds. According to Zuk-Golaszewska and Upadhyaya (2003), high UV reduces photosynthetic ability thereby resulting in reduced biomass production. Hence changes in climatic parameters can have profound impacts on growth of submerged weeds like *Utricularia* in the rice ecosystem.

The growth of the weed did not alter with shading indicating that light intensity was not a limiting factor weed growth. Light can significantly affect the growth of submerged plants (Neid, 2006). However, the shade levels employed in the current study was not small enough to inhibit weed growth.

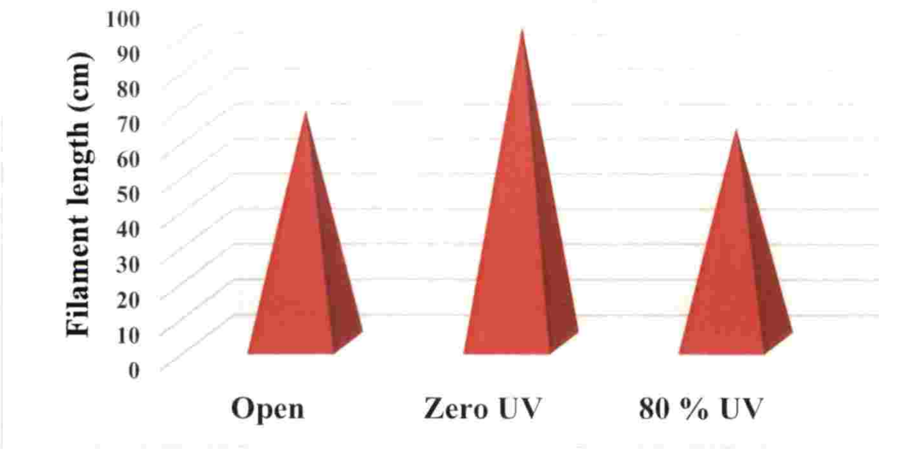

Fig.24. Filament length under different UV condition

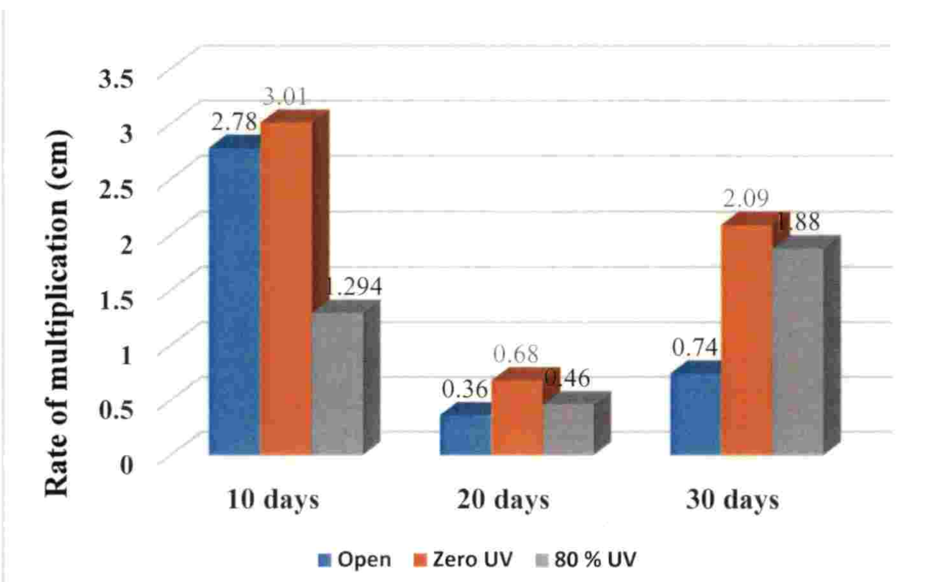

Fig.25. Rate of multiplication of under different UV condition

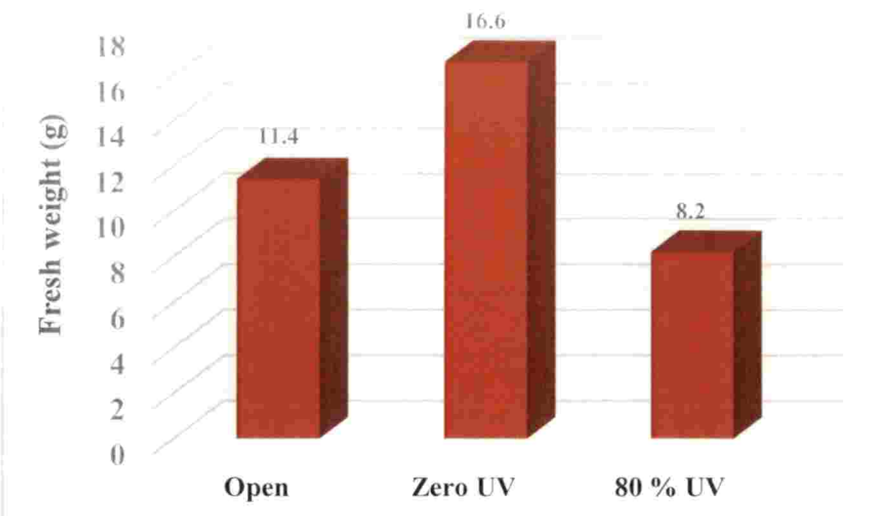

Fig.26. Fresh weight of under different UV condition

5.2.1.3. Effect of chemicals on weed growth

Effect of a few chemicals with herbicidal activity on the control of *Utricularia aurea* was evaluated. All the chemicals tried, 2, 4-D, $CuSO_4$ and lime were found to be effective in controlling *Utricularia aurea.*

Reduction in weed growth to the tune of 50-69% was observed when treated with $CuSO_4$. Higher concentration of $CuSO_4$ gave better results than lower concentration. The positive influence of $CuSO_4$ on the control of submerged weeds such as algae has been reported by Haller (2009).

Better control was obtained with higher concentration of all three chemicals tried. Three ppm of $CuSO_4$, 2, 4-D and 300 ppm lime gave better results. Since it is not advisable to use 2, 4-D in aquatic system, the use of the chemical cannot be recommended.

This experiment was done under controlled conditions in a confined area. The practical utility of the chemicals has to be tested in actual field situation and the amount of chemicals to be used has to be standardized taking into consideration the density of the weed, the area to be covered, environmental impact etc.

A sudden spurt in the incidence of submerged aquatic weeds in the rice ecosystems of Kerala is a cause of concern. A plethora of 10 different species viz. *Utricularia aurea, Utricularia exoleta, Elodea Canadensis, Hydrilla* sp., *Egeria densa, Cabomba* sp. *and Najas* sp. *Spirogyra, Chara* and *Nitella* was collected from the rise fields of Ernakulam, Palakkad and Thrissur districts. Among these the common species observed were the hydrophyte *Utricularia aurea* and the algal spices *Spirogyra*. These two species were found to adapt to a wide range of pH and EC conditions of water making them potentially noxious weeds.

Proliferation of these weeds had an effect on water quality, in terms of TSS, dissolved oxygen of water and *E. coli* content which intern can affect the growth of the rice plant.

Presence of dissolved nutrients such as nitrate in the water may be a major reason for the high incidence of these weeds. Climatic factors such as temperature and light were found to affect the multiplication rate and growth of the weeds. Soil enzymes and hormones also positively influenced their growth.

It was observed that *Elodea canadensis* reduced the TSS of the water and improved the DO. *Nitella* was found in low nitrogen areas (Mudappallur). *Utricularia aurea* adapted to wide range of water quality parameters and nutrient levels. *Najas* was observed in areas with high nitrate content.

Application of $CuSO_4$ and lime can be recommended for the control of the weed after further validation in the field. Further studies are required to standardize the dose, time of application in the rice filed etc.

SUMMARY

6. SUMMARY

The present study was conducted on "Physiology and management of submerged weeds in wetland rice ecosystem" from April 2017 to March 2018. A survey was conducted at 30 locations of Palakkad, Thrissur and Ernakulam districts (central zone of Kerala) to identify and morphologically characterize submerged weeds in the rice ecosystem. Soil and water samples were collected along with weed samples from ten locations where weed growth was more. The water and soil samples were analyzed to assess the relation of water quality parameters, nutrients and hormone with weed growth. Effect of environmental conditions on growth and multiplication of the common weed, *Utricularia aurea* and its control were also studied.

Utricularia aurea was the most abundant weed observed in 15 out of the decreasing 30 locations surveyed. The other hydrophytes observed were *Hydrilla, Cabomba, Najas, Utricularia exoleta, Elodea canadensis* and *Egeria densa* according to the decreasing order of their distribution of occurrence.

The most widely seen algal species was *Spirogyra*. The other algal species were *Chara* and *Nitella* according to the order of distribution.

According to the present study, growth of the submerged weeds was affected by water quality parameters like TSS, *E. coli* and pH. pH range of neutral to alkaline was found to promote growth of submerged weeds. Highly alkaline and acidic water did not favor growth of these weeds. However among the hydrophytes *Utricularia aurea* and among the algal species *Spirogyra* were found to tolerate a wide range of pH and EC.

The nitrogen content of the water and soil enzymes like nitrate reductase and hormone IAA were higher in locations where the submerged weeds were present.

Weed growth increased the total suspended solids in water. Increased TSS reduced the dissolved oxygen content of water which may adversely affected the rice crop. A positive relationship between *E. coli* and TSS was also observed in the present study.

Nitrate content of water to promoted weed growth while potassium was inhibited growth of submerged weeds, may be by inhibiting phosphate and nitrate uptake.

Phosphatase enzyme activity of the soil had a positive relation with phosphate content of ambient water. High nitrate reductase activity of soil had a negative relation with the nitrate content of water. This might be due to the conversion of nitrate to ammonia which is easily absorbed by weeds for growth.

Physiological parameters such as chlorophyll content, NRase activity, IAA and GA content of the submerged weed species was estimated. The chlorophyll content of algal species was lower than those of the hydrophytes. Among the hydrophytes *Utricularia, Cabomba* and *Hydrilla* had higher chlorophyll content as compared to other hydrophytes. Higher nitrate reductase activity was observed in *Najas* which is an indicator of the ability of the plant to fix N_2 for its growth. *Najas* can grow in low nutrient and high saline conditions. Growth regulators GA and IAA were found to be higher in *Utricularia aurea* and *Spirogyra* which might be the reason for the spread of these species in aquatic ecosystems.

Climatic parameters such as UV radiation and temperature were found to have significant influence on the growth of submerged weed species.

Higher water temperatures influenced physiological processes such as growth rate, and multiplication rate of *Utricularia aurea*. Studies indicated that, both these parameters were maximum when the temperature was around 30-31^{0}C with minimum UV light. UV radiation and high temperature seem to have a negative effect on the growth of the weed.

Chemicals such as $CuSO_4$, 2, 4-D and lime were found to be effective in controlling the weed growth. The higher concentration of these chemicals gave better result, *viz*. 3 ppm $CuSO_4$, 3 ppm 2, 4-D, and 300 ppm of lime. However further studies are required for standardizing the concentration, time of application of the in the rice field for the management of the weed, environmental impact assessment etc.

Future line of wok

- Standardize the concentration and time of application of chemicals, environmental impact
- Assess the water purifying potential of certain weeds like *Hydrilla, Najas* and *Elodea*

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Abstract

PHYSIOLOGY AND MANAGEMENT OF SUBMERGED WEEDS IN WETLAND RICE ECOSYSEM

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ABSTRACT OF THE THESIS

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ABSTRACT

The present investigation entitled "Physiology and management of submerged weeds in the wetland rice ecosystem" aimed to identify and characterize the different submerged weed species of wetland rice ecosystem, understand their growth pattern and evolve possible management practices. The study consisted of survey, identification and morphological characterization of submerged weeds of rice ecosystem of the central zone of Kerala. The effect of environmental conditions on growth and multiplication of the most common weed, *Utricularia aurea* and its control were also studied.

Weed survey was conducted in ten locations each in Thrissur, Palakkad and Ernakulam districts of Kerala. Submerged weeds from the rice fields were collected along with soil and water samples from ten locations for further studies. The major submerged weeds in the rice ecosystem included hydrophytes and algal species. Seven hydrophytes and three species of algae were commonly seen in the region. The major hydrophytes were *Utricularia aurea, Utricularia exoleta*, *Elodea canadensis*, *Hydrilla* sp., *Egeria densa, Cabomba* sp. and *Najas* sp. while the common algal species were *Spirogyra*, *Chara* and *Nitella*.

The water and soil samples collected were analyzed in the laboratory for different physico-chemical properties such as pH, electrical conductivity (EC), total suspended solids (TSS), dissolved oxygen (DO), *E. coli* content, soil enzymes and hormones which affect growth of the rice plant. pH had the larger influence on growth of submerged weed species. Highest weed growth was observed between pH range of. 7.2 to 8.01 (neutral to alkaline). The presence of submerged weeds reduced the dissolved oxygen content of water and increased the content of TSS and *E. coli,* adversely affecting water quality and supply of oxygen to rice root. The presence of dissolved nitrate in the water may be a major reason for high incidence of these weeds. Soil enzymes and hormones also positively influenced their growth.

The physiological parameters such as chlorophyll content, nitrate reductase activity, indole acetic acid (IAA) and GA contents of the weeds were also studied.

It was found that IAA, GA and chlorophyll promoted weed growth. High nitrate reductase was observed in *Nitella*. *Elodea canadensis* had the capacity to purify the water by reducing the TSS and improving the dissolved oxygen content.

The most common submerged weed in the rice ecosystem was *Utricularia aurea* and hence this weed was selected to study the effect of light, UV radiation and chemicals on growth and multiplication.

Effect of light on weed growth was studied by using different shade nets which allowed 50 per cent and 75 per cent light infiltration. Effect of UV radiation was studied by growing the plants under polyhouse cladded with mylar film which allowed zero UV and polyethylene sheet which allowed 80 per cent UV radiation. Growth and multiplication of *Utricularia aurea* in the open condition and different light and UV levels were compared. Zero UV and temperature in the range of 30-31^{0}C was found to be ideal for weed growth. Both high water temperature and high UV were detrimental. Growth of the weed was not altered with shading, indicating that moderate shade not affect the weed growth.

Effect of $CuSO_4$ (1ppm, 2ppm and 3ppm), 2, 4-D (1ppm, 2ppm and 3ppm) and lime (100 ppm, 200 ppm and 300 ppm) on growth of *Utricularia aurea* was measured by recording the rate of degradation of the weed one month after application in pot culture study. Good control was obtained with higher concentrations of all the three chemicals tried. Three ppm of $CuSO_4$, 2, 4-D and 300 ppm lime gave better results. Lime was found to be more effective in the control of *Utricularia aurea.*