MORPHOLOGY, ECOLOGY AND MANAGEMENT OF *Monochoria vaginalis* (Burm. f.) Kunth

By

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(2017-11-017)

THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Morphology, ecology and management of *Monochoria vaginalis* (Burm. f.) Kunth"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Morphology, ecology and management of *Monochoria vaginalis* (Burm. f.) Kunth"** is a bonafide record of research work done independently by **Ms. Athira G. R. (2017-11-017)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Introduction

1. INTRODUCTION

Wetland paddy cultivation is characterized by species richness in associated flora, which often causes tremendous reduction in crop yield and elevated production cost. Knowledge on weed ecology and its interaction with rice plays a key role in weed management, as it is the most important biological constraint in rice cultivation.

Monochoria vaginalis is a typical wetland weed of rice, called as *Karimkoovalam* or *Neelolppalam* in Malayalam, present in all the major rice ecosystems of Kerala. *Monochoria*, an emergent annual hydrophyte, has the ability to grow as a perennial in constantly flooded areas. It is a broad-leaved monocot having fibrous root system, and the stem is modified into a short rhizome from which soft hollow leaf petioles arise. The plant is highly heterogenous regarding its morphology.

Monochoria vaginalis is native to Asia and Western Australia and commonly called as oval-leafed pondweed or heartleaf false pickerelweed. It is a noxious herbaceous semi-aquatic weed in the family Pontederiaceae, present in paddy fields throughout the rice growing areas of the world. *Monochoria* occurs in all systems of rice (except dry land rice) including transplanted, both wet and dry direct-seeded, and in deep water and tidal swamp (Moody, 1989). Many researchers observed that *Monochoria* could survive for long periods through dormancy. *Monochoria* is often gregarious and highly competitive because of its discontinuous germination, rapid growth and high plasticity. Due to its short stature, *Monochoria* may not be a prominent weed in transplanted rice. However, in direct seeded rice, where canopy establishment takes longer time, infestation of the weed may reach problematic proportions.

Germination requirements of weeds may vary with the location and prevailing conditions. The factors affecting weed seed germination have to be thoroughly understood before formulating a weed management strategy. Some cultural methods could be employed to suppress germination, while at other occasions when weed seedlings could be readily controlled, their germination should be encouraged. Weed seed germination is mainly affected by light exposure, soil moisture status, depth of

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burial, flooding, soil pH and temperature. Based on specific requirement of weeds, crop management practices to reduce weed seed germination could be included in integrated weed management programmes.

Though there are several studies on the effect of abiotic factors on the germination of *Monochoria vaginalis*, in many countries, there is very little information on the germination ecology of the weed in the major rice tracts of Kerala, viz, *Kole*, Palakkad, *Pokkali* and *Kuttanad*, between which the plant is seen to vary in morphological characters. Similarly knowledge about the effect of various herbicides on *Monochoria* is insufficient. There are a few reports about the herbicidal activity of 2,4-D, Almix®, ethoxysulfuron, bispyribac, etc. against *Monochoria*.

However, there are several new herbicide molecules which may be effective for the control of broadleaf weeds including *Monochoria*. Optimization of herbicides and their doses helps in developing strategies for effective weed control. Weed management in rice will be effective only if knowledge on weed ecology and their interaction with rice is take into consideration (Labrada, 2002). In this context, the present study was planned with the following objectives:

1) To study the morphological characters of *Monochoria vaginalis* occurring in major rice tracts of Kerala
2) To understand the effect of various ecological factors on germination of *Monochoria vaginalis*
3) To test the efficacy of select herbicides against *Monochoria vaginalis* in pot culture study

Review of literature

2. REVIEW OF LITERATURE

Literature on the distribution, morphology, germination ecology, and management of *Monochoria vaginalis* is reviewed in this chapter.

2.1. Distribution

Monochoria vaginalis (Burm.f) Kunth, a plant species of the family Pontederiaceae, is a noxious herbaceous broad-leaved weed in paddy fields throughout temperate and tropical regions of Asia (Holm *et al*., 1979). Waterhouse (1993) stated *Monochoria* as the worst weed of Southeast Asia, after *Echinochloa colona*.

Gamble (1934) reported two species viz., *M. vaginalis* and *M. hastaefolia* from South India. Christopher (1983) recorded that *M. vaginalis* occurs in all regions of South India from mean sea level to an altitude of 3000 ft.

Monochoria is an emergent aquatic herb commonly found in rice fields throughout India and widely distributed in Asian countries like Japan, China, South Korea, etc. (Zheng *et al*., 2013). Udage and Yakandawala (2017) reported that *Monochoria* is distributed widely in the tropical and warm temperate regions of the Old World, Asia and Australia.

2.2 Morphology of *Monochoria vaginalis*

Wang *et al*. (2004) recorded greater variability in the vegetative morphology of *Monochoria* which might be due to adaptation to different habitats. Li *et al*. (2005) observed high genetic differentiation among the populations over different locations due to limited gene exchange as the plant is self pollinated. Tungmunnithum *et al*. (2016) also observed that *Monochoria vaginalis* exhibits a great variation in its morphology.

The family Pontederiaceae includes six genera and approximately 35 species of aquatic plants and exhibits great variation in morphology, which might be due to fluctuations in water levels. Four morphological patterns were established for the

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family and *Monochoria vaginalis* placed under the pattern II, which had fistulose (with a central hollow) leaf petiole (de Sousa *et al.*, 2016).

Gamble (1934) reported another distinct variety of this species, *M. vaginalis* var. *plantaginea* Solms Laub., which grows only up to a height of 3-6 inches and has smaller narrower leaves and fewer flowers in the racemes. It is not common and is found mixed with *M. vaginalis* and somewhat resembles the smaller plants of this species in size. According to Imaizumi *et al.* (2008), the plant size is heterogenous because *M. vaginalis* germinates intermittently from spring until late summer.

Monochoria is often gregarious and is usually found in inundated places, at the edges of ponds, rivers, irrigation ditches, canals, or in swamps. It is particularly common and almost characteristic of rice fields (Cook, 1989).

Monochoria vaginalis is an annual hydrophyte herb commonly known as oval-leafed pondweed or heartleaf false pickerelweed. It is one of the most heterogenous plants with regard to its size, which ranges in height from 3-5 inches to about 3 ft. Lamid (1981) observed three leaf forms on *Monochoria* plant, namely, sessile-elongated, petiolated-ovate and petiolated-cordate. The plant height, number of leaves and dry weight was greater for early seeded *Monochoria* than late seeded, but the time taken from seeding to flowering decreased progressively as the seeding times were delayed (Park and Kim, 1987).

The plant roots in mud and its upper portion grows above the water (Thomas and Abraham, 1998). The root stock is short and sub-erect and is clothed with brown or purple remains of the old leaf-sheaths. It is having erect or creeping, rhizomatous or stoloniferous stems and shiny ovate-accuminate heart shaped leaves that are radially or spirally arranged. Area of leaf blade is about $2–21 \times 0.8–10\ cm^2$ and the petiole length ranges from 3 cm to 50 cm.

Cook (1989) recorded up to 20 flowers per inflorescences. Inflorescence is spicate, 3-6 cm long and basally opposite the sheath of the floral leaf with a large bract arising from a thickened bundle on the leaf stalk (Guofang *et al.*, 2000). Flowers are bluish purple in axillary racemes with pedicels of 4-25 mm length. Flowers number from 3-25 and open simultaneously or from top to bottom in quick succession. The stamens are six in number and the ovary has a long style.

Capsules are ovoid to ellipsoid, 0.8 -1 cm long and splits between the partitions into three valves. It produces numerous seeds that are egg shaped and longitudinally ribbed (Christopher, 1983). Wang *et al*. (1998) observed that *Monochoria* has both chasmogamous flowers and cleistogamous flowers in one plant and the species is self pollinated before its chasmogamous flowers open.

Among yield components, number of flowers and capsules per plant were the most important factors affecting seed production in *Monochoria* (Park and Kim, 1987).

According to Kataoka *et al*. (1979), the total number of seeds per plant was highly correlated with the foliar growth and could be expressed as a product of seeds per capsule, capsules per inflorescence and inflorescences per plant. They studied the growth and seed production of *Monochoria vaginalis* in paddy fields and accordingly approximately 11 fruits and 1500 seeds per plant were produced when emerged seventeen days after transplanting of rice i.e., seed production was reduced as emergence of the plants was delayed.

Lamid (1981) recorded that a single plant produced an average of 4.45 suckers, 23 spike inflorescences, 235 capsules and 61,195 seeds in a study conducted in Philippines. Wang *et al*. (1997) estimated that there were about 200 fruits and 20,000 seeds per plant growing alone in a pot of 25 cm diameter and 30 cm depth. He observed that the amount of seeds increased with the increase in fertilizer level. Under different shading conditions, maximum seed production occurred when 25 per cent shading was applied 90 days after sowing.

2.2.1. Leaf anatomy

Narayanan and Kaliappan (2014) compared the anatomical features of two emergent aquatic herbs, *Monochoria vaginalis* and *Monochoria hastate*. Both of them were found to be having unique hydromorphic anatomical features related to the

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adaptability of the plant to the aquatic environment. The leaf of *Monochoria vaginalis* is amphistomatic and the median part of lamina contains a horizontal row of wide air chambers, divided by vertical partitions. Vascular bundles are distributed both in the adaxial and abaxial regions and in the vertical partitions. The adaxial epidermis consists of thick rectangular cells and abaxial epidermis possesses cylindrical cells below which a narrow zone of thin, loosely packed palisade cells occurs. The leaf has poorly developed xylem elements and a thick mas of phloem elements enclosed in a less lignified thin layer of sclerenchyma cells.

The mesophyll tissue of mid rib often possesses calcium oxalate crystals in the form of raphides, which is a cylindrical bundle of many thin pointed needles. Occasionally spherical spiny balls of crystals called druses are also observed (Narayanan and Kaliappan, 2014).

Udage and Yakandawala (2017) performed a morphometric analysis to evaluate the diversity of the genus *Monochoria* in Sri Lanka by comparing vegetative, anatomical and reproductive characters. They found that Sri Lankan *M. vaginalis* is a species complex involving more than one taxon, and phenetic groups 2 and 3 had sub-palisade cavities filled with a red coloured liquid. Narayanan and Kaliappan (2014) did not record any sub palisade cavities/glands in their study conducted in India on comparative anatomical characteristics of *M. vaginalis* and *M. hastate*.

2.3. Germination ecology of *Monochoria vaginalis*

2.3.1. Dormancy

Kataoka and Kim (1978) reported that seeds of *Monochoria vaginalis* var. *plantaginea* had weak primary dormancy when first shed from the capsules and it germinated early in the next year when the temperature was sufficient and water is available.

Momonoki (1992) observed that *Monochoria* seeds germinated continually throughout the warm season in paddy fields. Seeds immediately after harvest were dormant even when the embryo was sufficiently developed and the degree of dormancy declines if stored under cold and wet conditions. Takeuchi *et al.* (1995) found that dormancy could be broken by seed coat scarification.

A study conducted by Chen and Kuo (1999) showed that the buried seeds of *Monochoria vaginalis* in paddy fields underwent annual changes in dormant state. *Monochoria* seeds could survive for long periods through dormancy and a large portion of the seeds in soil germinated after March if the soil was well flooded and the seeds were exposed to light. They advised to dry out the soil completely for the interval between two rice crops to induce complete dormancy.

2.3.2. Germination

The broadleaved weed *Monochoria vaginalis* emerged between 15-75 DAT of direct seeded autumn rice, with the peak emergence at 45 DAT (Deka *et al.*, 2009). Nozoe *et al.* (2016) observed that seed density in soil increased the seedling number of *Monochoria* up to a certain level and then reached a plateau to avoid intraspecific competition.

Kim and Chun (1996) studied the effect of rice cultural practices on emergence pattern of *E crus-galli* and *Monochoria vaginalis*. They recorded that seeds of *Monochoria vaginalis* were found at 25 cm depth and occurrence might be erratic during a relatively longer period. However, seed occurrence of *E crus-galli* was restricted up to a depth of 15 cm, and emerged within a short period of cropping season. Although seed population of *Monochoria* was about 4-5 fold greater than *E. crus-galli*, emergence of the latter was about 2.4 fold greater regardless of the cropping pattern employed. They also observed that seed population of *Monochoria* occurred in about 1.6 fold greater number in rainfed field than in irrigated field

A study on the factors affecting germination of paddy weeds by Pons (1982) revealed that *Monochoria* seeds did not germinate under the soil surface due to inadequate light. The influence of depth of submergence on germination of *Monochoria vaginalis* was observed to be little, and the control was difficult by means of inundation as it was adapted to flooded conditions. He also observed that a cover of floating Salvinia filtered the day light, and germination of light sensitive weeds like *Monochoria* underneath was inhibited. He suggested that *Monochoria* could be suppressed using floating beneficial plants like Azolla in paddy field.

Kataoka and Kim (1978) found that it was difficult for the seedlings to emerge from flooded paddy soil when soil cover was more than 2 mm deep. Koarai and Shibayama (2001) investigated the number of *M. vaginalis* seedlings which naturally emerged from a puddled paddy soil and found that more than 90% of total seedlings had emerged from the shallow soil layer of less than 2 mm depth.

Matsuo and Shibayama (2000) observed that the adhering strength of *M. vaginalis* seedlings was more in a saturated puddled soil than in a flooded soil where soil hardness was alleviated by flooded water. So the weed turned out to be a more serious problem under saturated paddy conditions. Germinated seedlings of *M. vaginalis* might be established on a paddy soil surface by geotropic responses of hypocotyl hairs and by their adhering strength to the soil surface. Therefore, water condition and the size of soil particles were considered as important factors for establishment of juvenile seedlings of *M. vaginalis*. They also suggested that greater water depth led to earlier growth of coleoptiles, first leaves, seminal and crown roots of juvenile seedlings.

Wu and Zhou (2002) conducted a series of experiments to evaluate the biological properties of *M. vaginalis* and its effects on rice yield. They observed that germination of *Monochoria vaginalis* enhanced rapidly under saturated moisture condition.

Chisaka and Kataoka (1977) reported that *Monochoria* seeds showed high germination percentage when illuminated by light and incubated under low oxygen (below 1%), and exposed to ethylene (10 ppm) in a glass container.

Kataoka and Kim (1978) concluded that *Monochoria* seeds did not germinate in dark, and greater germination rate was obtained under submerged or anaerobic conditions. They witnessed that no seeds germinated on wet filter paper with atmosphere as the air condition, while seeds in sealed glass tube with a low oxygen (0.2%) level exhibited a high germination percentage.

Germination of *M. vaginalis* seeds was enhanced by ethylene in the presence of light and low concentrations of CO_2, however, other plant hormones did not show any promotive effects (Momonoki, 1992).

Chen and Kuo (1995) investigated germination conditions for non dormant seeds of *Monochoria* in Taiwan and found the following results:

- The seeds did not germinate when exposed to air or incubated in dark, while they germinated under hypoxia condition if illuminated with light
- Germination was saturated at 5 mmol/m^2/day photon dose, above which more light did not influence germination
- The seeds did not germinate when buried beyond 12 mm depth
- Germination reduced significantly below a water potential of - 0.9 MPa
- They germinated rapidly around 30°C within four days
- Germination decreased when temperature dropped below 14°C and rose above 40°C
- The base temperature for sub optimum temperature regime was 12.7°C and ceiling temperature for super optimum regime was 65.8°C

According to Wang *et al.* (1996) seeds of *Monochoria vaginalis* required light for germination and germination percentage decreased with increasing soil depth. They concluded that one of the factors suppressing the germination of *M. vaginalis* in deep soil may have been insufficient light.

Kawaguchi *et al*. (1997) recorded 4 percent germination of *Monochoria* seeds in dark when it was soaked in aqueous extract of rice seeds for three days, and suggested that rice seeds might have allelopathic potential. They also observed that pH (7.0 to 9.0) did not influence the germination, while it was suppressed at high electrical conductivity.

Nozoe *et al.* (2012) observed that addition of rice bran to paddy field increased electrical conductivity of soil solution which was associated with production of organic acids and Fe^{2+} in the process of soil reduction. There existed a negative correlation between electrical conductivity and germination of *Monochoria*. Another set of experiments conducted by Nozoe *et al.* (2018) proved that pH and germination of *Monochoria* were in negative correlation, as long as the soil solution pH ranged between 4 and 7.

Putra (2014) studied the effect of salinity and flooding depth on growth and anatomy of *Monochoria*. The result showed that plant height, leaf area and dry weight decreased, and anatomical structures were changed at higher concentration of NaCl and greater flooded depth.

Nozoe *et al.* (2018) observed greater germination of *Monochoria* seeds in soil solution than in distilled water. They concluded that soil solution might promote the germination, if environmental factors like insufficient light, or physiological factor (dormancy), prevailed. The fulvic acid in soil solution and low dissolved oxygen were the factors that promoted germination.

Kim (1983) observed that *Monochoria vaginalis* required a cumulative temperature of 120°C to 150°C from puddling to emergence, and concluded that at least 5 to 7 days are necessary for emergence of annual weeds in a temperate climate. Yamasue and Ueki (1983) stated that the extended period of emergence of *Monochoria* could be explained by the cardinal temperature concept, and non inherent and inherent differences of individual seeds in physiological age and dormancy period. They also observed correlation of seed weight with the depth of emergence in soil.

Park *et al.* (2010) conducted an experiment to predict seedling emergence and early growth of *M. vaginalis* based on Effective Accumulated Temperature (EAT). The study confirmed that at elevated temperature both seedling emergence and initial growth occurred earlier than ambient temperature. The EAT required for 50 per cent of maximum seedling emergence and for four leaf stage was estimated to be 69.3°C and 247°C respectively.

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2.4. Effect of *Monochoria vaginalis* on growth and yield of rice

Smith (1983) listed *Echinochloa crus-galli*, *E. colona*, *Cyperus difformis*, *C. rotundus*, *C. iria*, *Eleusine indica*, *Fimbristylis littoralis*, *Ischaemum rugosum*, *Monochoria vaginalis* and *Sphenoclea zeylanica* as the most important weed species in rice field. According to Moody (1989), *Monochoria vaginalis* was the most predominant annual monocotyledonous broad-leaf weed and occurred in all systems of rice (except dryland rice) including transplanted, both wet and dry direct-seeded, and in deep water and tidal swamp. *Monochoria vaginalis* was listed as noxious weed by the U.S. federal government and by the 46 states (USDA, 2012).

Ahmed (1979) observed a change in weed composition of dry seeded crop compared to transplanted rice crop. The latter had only 5 weed species, in which *Monochoria vaginalis* accounted for 91% weed density and 83.6% of dry weed weight. While, dry seeded crop had 14 weed species where *E. colona* and *L. chinensis* were major weeds. Pablico and Moody (1981) reported that *Monochoria vaginalis* dominated in the harrowed plots while *Echinochloa colona* was the principal weed in zero tilled plots.

Chang (1972) reported that *Monochoria vaginalis* caused more damage to rice if early eradication was not done and yield loss could go up to 31-87%. At low fertilizer rate, it competed more for soil nutrients leading to greater effect on rice. He observed that grain reduction caused by *Monochoria* was more in second season than in first season. Wu and Zhou (2002) estimated the critical density of *M. vaginalis* for severe competition with rice as 60 plants per m^2.

Lubigan and Vega (1971) estimated that *M. vaginalis*, at a density of 366 plants per m^2, reduced rice yield by 35% in Philippines, and in Indonesia a weed density of 150 plants per m^2 reduced rice yield by nearly 25% (Guyer and Koch, 1989). Sattar and Biswas (1991) recorded 17-82 per cent reduction in rice yield depending on weed density. Breen *et al*. (1999) observed that small emerging rice tillers were shaded by the weed foliage, causing carbon deficit and eventually increased tiller abortion. Koarai and Morita (2003) reported that *Monochoria* seeds germinated under suitable conditions and the seedlings competed for water, light and nutrition until rice reached maturity, often causing dramatic reduction in rice yield.

A comparison of broad-leaved weeds in major agro-ecological zones of Kerala showed that *Monochoria vaginalis* was present in all rice ecosystems with high relative importance values. Its abundance was favoured by high organic matter, and could be documented as an indicator plant for high available nitrogen and phosphorus in soil (Vidya, 2003).

Guh and Lee (1974) reported that the number and growth of *Monochoria* increased with increase in soil fertility. Kim and Moody (1980) recorded 67.7 to 98.3% of the weed population was occupied by *Monochoria* at 160 kg N/ha applied, when no nitrogen was applied, it comprised 44.8 to 64.9% of the weed community. They recorded greater plant height, leaf area, dry weight, number of fruits and seeds per plant at high level of applied nitrogen. They also observed that competition for light and yield reduction by *Monochoria* increased with increase in fertility level. It was reported that *Monochoria* predominated when the organic matter content of the soil ranged from 2.1 to 2.8 per cent and the P ranged from 80-110 ppm (Kim, 1991).

Zhu *et al.* (2012) conducted field experiments to study adverse effect of *Monochoria* to rice growth and yield. They recorded 20%, 46% and 11% decrease in plant height, effective ear number and ear length of rice respectively at *Monochoria* density of 80 plants per m^2.

Moon *et al.* (2012) conducted an experiment to model the competition relationships of *Monochoria* with transplanted rice. The weed caused significant reduction in dry weight of rice at 30, 60 and 90 DAT.

Hwang *et al.* (2001) suggested that as *M. vaginalis* was a commonly found serious weed, continuous and intensified application of chemicals contributed to the occurrence of herbicide resistance. *Monochoria* plants escaped the herbicide treatment limited the tillering capacity of rice and caused about 80% yield reduction (Kuk *et al.*, 2003).

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Monochoria vaginalis was reported as secondary weed host for many rice diseases (Table 1).

Table. 1. *Monochoria vaginalis* as alternate host for rice diseases

Disease	Pathogen	Reference
Sheath blight	*Rhizoctonia solani*	Gokulapalan and Nair, 1983
Sheath rot	*Sarocladium oryzae*	Balakrishnan and Nair, 1981 Deka and Phookan, 1992
Rice tungro	Rice tungro virus	Khan *et al*., 1991
Rice grassy stunt	Rice grassy stunt virus	Anjaneyulu *et al*., 1974
Rice ragged stunt	Rice ragged stunt virus	Salamat *et al*., 1987

2.5. Post-emergence herbicides for the management of *Monochoria vaginalis*

Post-emergence herbicides are applied after the emergence of weed. They can be foliar or root absorbed, selective or nonselective, contact or systemic. In rice, 2,4-D and Almix® are used against dicots and sedges. Cyhalofop butyl is used for selective control of grass weeds especially *Echinochloa* spp. Bispyribac-sodium, ethoxysulfuron and penoxsulam have broad spectrum of activity and control against all types of weeds. *Monochoria* could be killed by 2,4-D ethyl ester 4.5% @ 1 kg a.i./ha at 20-25 DAT, Almix® @ 4 g a.i./ha at 3 DAT, ethoxysulfuron 15% WDG @ 12.5-15 g a.i./ha at 10-15 DAT and bispyribac sodium 10% SC @ 20 g a.i./ha at 20 DAS (Choudhury *et al*., 2016).

2.5.1. 2,4-D Sodium salt

2,4-dichlorophenoxyacetic acid is an excellent herbicide used globally for obtaining highly selective, post-emergence control of broadleaved weeds. It appears to work by causing uncontrolled cell division in vascular tissue, causing epinasty.

An investigation on herbicide efficacy against *Monochoria* by Lamid (1981) confirmed that 2,4-D applied at fourth leaf stage killed the weed while application at

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two leaf stage was ineffective. He observed vigorous weed growth on nitrogen application, which did not influence the effect of 2,4-D on *Monochoria*.

Mann *et al.* (2017) conducted pot and field experiments for weed control using auxin herbicides. They used 2,4-D ester (Agri Star®) and 2,4-D DMA (dimethyl ammonium) forms (Weedar®) at different doses. In field DMA @ 560 and 280 g a.e./ha controlled 93.3 % and 6.7% of *Monochoria* respectively. In pot culture, ester forms @ 280 g a.e./ha controlled 89% and 98% of the weed at 16 and 22 days after application.

Atheena (2016) conducted a study to find out the best herbicide that can be tank mixed with cyhalofop-butyl. Almix®, ethoxysulfuron, carfentrazone-ethyl, pyrazosulfuron ethyl, pretilachlor, and pendimethalin were used for both tank mix and sequential application. Complete control of *Monochoria vaginalis* was obtained when Almix® was applied as both tank mix with cyhalofop-butyl, and as follow up application.

2.5.2. Chlorimuron ethyl + metsulfuron methyl

Chlorimuron ethyl + metsulfuron methyl, commonly available as Almix®, is a sulfonyl urea herbicide, having broad spectrum activity, effective in controlling many annual and perennial grasses, sedges and broad-leaf weeds in rice fields.

A comparative study of herbicide efficacy was conducted by Singh *et al.* (2018) in Assam. Weed density and biomass of *M. vaginalis* were highest for weedy check and lowest for pyrazosulfuron ethyl. The weed density was reduced to 3.46 per m^2 in Almix® treated plots, whereas for weedy check it was 10.21 per m^2.

Mahbub *et al.* (2017) evaluated the efficacy of metsulfuron methyl 10% + chlorimuron ethyl 2% WP @ 15, 20 and 25 g ha^{-1} during *Aman*, 2014 and *Boro*, 2014-15. *Cyperus difformis*, *Echinochloa crus-galli*, *Scirpus maritimus* and *Monochoria vaginalis* were the most dominant weeds. Application rates of 20 and 25 g ha^{-1} resulted in more than 80% control of *Monochoria* in both the seasons.

2.5.3. Ethoxysulfuron

Ethoxysulfuron is a post-emergent broad spectrum herbicide, very effective for the control of sedges and broad-leaf weeds in transplanted rice. It belongs to sulfonyl urea group and acts by inhibition of acetolactate synthase.

Ethoxysulfuron @ 20 g a.i./ha controlled 95% of *Monochoria vaginalis* at one-leaf stage and 80% at 3-leaf stage in a pot culture study. *Monochoria* seeds were sown and rice was transplanted at 2-leaf stage into 500 cm^2 pots filled with paddy soil, and water level maintained at 3 cm depth. Herbicides were sprayed and the effects examined after 4 weeks (Endo *et al.*, 2008).

Zhu *et al.* (2012) conducted experiments to evaluate the efficacy of ethoxysulfuron 15% WG against *Monochoria vaginalis* and *Cyperus difformis* in direct seeded rice field. They observed that ethoxysulfuron 15% WG at the dose of 11.25-31.5 g a.i./ha had good control of the main weeds and it significantly reduced their nutrient and water uptake. The control effect against *M. vaginalis* was 90%-100%, and against *C. difformis* 89%-100%.

Tank mix combination of cyhalofop-butyl with ethoxysulfuron gave effective control of *M. vaginalis*, while the sequential application of these two herbicides was not so effective (Atheena *et al.*, 2017).

2.5.4. Bispyribac sodium

Bispyribac sodium is a post-emergence pyrimidinyl carboxy herbicide used for the control of a wide range of weeds, in particular *Echinochloa crus-galli*. The mode of action is inhibition of branched chain amino acid biosynthesis.

Patra *et al.* (2017) studied the efficacy of bispyribac acid 40% EC against weed flora in rice from 2014-15 to 2015-16. Bispyribac sodium 10% SC@ 20 g a.i./ha was used as the standard check. Bispyribac acid 40% SC @ 52.5 g a.i./ha controlled 70.58 % and 67.88% of *Monochoria vaginalis*, whereas 49.97% and 43.44% were the weed control efficiencies of bispyribac sodium @ 20 g a.i./ha in first and second years respectively. The observations were recorded on 60th day after application.

To assess the effectiveness of bensulfuron methyl 12% + bispyribac sodium 18%WP field trials were conducted during *Boro*, 2014-15 and *Aman*, 2015. The herbicide application rates of 125, 150 and 175 g ha^{-1} resulted in 67.46%, 80.51% and 82.50% control of *Monochoria* in *boro* season and 65.30%, 80.78% and 81.73% in *aman* season respectively (Mahbub *et al.*, 2018).

Raj and Syriac (2016) recommended bispyribac sodium + metamifop @ 70, 80 and 90 g/ha for broad spectrum control of weeds, including *Monochoria* in wet direct seeded rice in view of the economics and weed control efficacy. Sequential application of bispyribac sodium after cyhalofop butyl resulted in *Monochoria vaginalis* free plots at 30 days after sowing (Atheena *et al.*, 2017).

A premix product of bispyribac sodium + thiobencarb 915 OD (15 + 900 g a.i./L oil dispersion) was developed by Kumiai Chemical Industry Co., Ltd. to expand the herbicidal spectrum of bispyribac sodium and add residual efficacy. Under greenhouse studies it was verified that this premix product at 1.0 L/ha provided complete control of *Monochoria vaginalis* at 3-4 leaf stage (Kobayashi *et al.*, 2007).

2.5.5. Penoxsulam

Penoxsulam, an ALS inhibitor that belongs to triazolopyrimidine sulphonamides controls *Echinochloa* spp., annual sedges and many broadleaf weeds including *Monochoria*. Penoxsulam (Grasp®) @ 35 g a.i./ha caused 99% of *Monochoria* to develop phytotoxicity symptoms 20 days after application (Mann *et al.*, 2017). Penoxsulam treatment in transplanted rice effectively suppressed grasses, sedges and broad-leaf weeds including *Monochoria vaginalis* over weedy check and it was better than butachlor (Bhat *et al.,* 2013).

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In Maharashtra, penoxsulam 22.5 g/ha applied at 0-3 DAT provided more than 95% control of *Monochoria vaginalis* which was on par with penoxsulam 20 g/ha applied at 8-12 DAT (Kumar *et al.*, 2009).

2.5.6. Penoxsulam + cyhalofop butyl

Cyhalofop-butyl provides good control of many grassy weeds including *Leptochloa chinensis*. This herbicide is an ACCase inhibitor belonging to aryloxy phenoxy propionate group. Combination products containing penoxsulam + cyhalofop-butyl are good at controlling a broad spectrum of weeds with little phytotoxicity to rice plants.

Lap *et al.* (2013) conducted field trials in many locations across ASEAN countries over a 13 year period. They found that pre-mix formulation of penoxsulam 10 g a.i. + cyhalofop butyl 50 g a.i. @ 1, 1.25, 1.5 L/ha provided 95-100% biomass reduction of *Monochoria vaginalis* at 4-18 days after seeding in Philippines and Vietnam.

Yao *et al.* (2013) studied the efficacy of the pre-mix rice herbicide Ricer™ 60 OD containing 10 g a.i. penoxsulam + 50 g a.i. cyhalofop butyl per litre. As a post emergent foliar herbicide, applied at 10-15 days after sowing of rice @ 2-2.5 L/ha, it provided excellent control of a broad spectrum of weeds with no visual phytotoxicity in rice and 2-4 weeks of residual weed control. It showed immediate growth inhibition of susceptible plants and a chlorotic growing tip with some vein reddening. For controlling *Monochoria vaginalis* it was needed at only 60 g a.i./ha.

The above review broadly covers the research carried out on *Monochoria vaginalis*. However, very little information is available on the ecological requirements of the plant and its adaptation to various rice ecosystems. Specific response of *Monochoria* to commonly used herbicides is also not known. The present investigation strives to fill the gaps in knowledge so as to arrive at a viable management strategy.

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Materials and methods

3. MATERIALS AND METHODS

The research programme was carried out during 2017-2019 to study the morphological characters of *Monochoria vaginalis* occurring in major rice tracts of Kerala. It was also aimed to understand the effect of various ecological factors on germination of the weed, and to test the efficacy of select herbicides against it. The whole research work consisted of three parts:-

Part I: Morphological characters of *Monochoria vaginalis* occurring in major rice tracts of Kerala were studied. The seeds were collected from each location along with soil samples and sown in pots, and observations on growth and morphological characters were recorded.

Part II: The following experiments were conducted to study the effect of environmental factors like light and temperature, pH, salinity, depth of burial, flooding depth and duration on the germination of *Monochoria vaginalis.*

Part III: Efficacy of post-emergence herbicides on *Monochoria vaginalis* - Pot culture study

3.1. Details of study area

The study was focused on major rice tracts of Kerala, viz., *Kole*, Palakkad *Pokkali* and *Kuttanad.*

3.1.1. *Kole* lands

The *Kole* lands are spread over Thrissur and Malappuram districts and cover over 13,000 ha. The area lies between the latitudes of 10°20' to 10°40' North, and longitudes of 75°58' to 76°11' East and is located 0.5 m to 1 m below mean sea level. The soil pH ranges from 2.6 to 6.3, and the electrical conductivity from 0.16 to 15 dS m^{-1} and the texture varies from sandy loam to clayey. The *Kole* lands are highly productive. The soil is high in organic carbon and available phosphorus, and medium in nitrogen and potassium. Rice is cultivated only in one season, *i.e.*, September-

October to February- March, and the land remains submerged for the rest of the year. However, in favorable locations, farmers raise a second crop during the period from February to April.

3.1.2. Palakkad rice tract

Palakkad rice tract known as the rice granary of Kerala, is located between the latitudes of 10°21' to 11°14' North, and longitudes of 76°02' to 76°45' East. The soil is laterite and low in available nitrogen, phosphorus, potassium and organic carbon. The pH of the soil is around 5. The rice lands in Palakkad plains are double cropped. The first crop is mainly grown under semi-dry situation. In second season, the system followed is transplanted rice under puddled condition. It depends on canal irrigation water from Malampuzha, Vaalayar, Mangalam, Pothundi, Gayathri and Chithrapuzha irrigation projects.

3.1.3. *Kuttanad*

Kuttanad is the rice bowl of Kerala, and lies in Alappuzha and Kottayam districts. The area is serviced by four rivers viz., Achenkovil, Pampa, Manimala and Meenachil together with the Vembanad lake. The area is located at a latitude of 9°27' North and a longitude of 76°25' East, and is around 0.5 to 2 metres below mean sea level. *Kuttanad* soils are grouped into three categories viz., *kari*, *karappadom* and *kayal* soils based on their chemical characteristics. The soil texture is silty clay, with a pH of around 3.5 to 4.5. The soil is of low fertility status, but is rich in organic matter. In wetlands, rice is cultivated in two seasons, viz., May- June to September- October, and November-December to March-April.

3.1.4. *Pokkali*

The *Pokkali* lands are situated in the coastal lines of Ernakulam and Alappuzha districts. *Pokkali* soils are acidic in reaction with a pH range of 3.1 to 4.8 and the texture is clay loam. The soil is high in organic matter, low in available phosphorus and high in available potassium. Rice is cultivated in these soils during the rainy season

(June-October). During summer months, saline water inundates the *Pokkali* fields and thus they become saline with electrical conductivity ranging between 10 to 18 dS m^{-1}. Mounds of 1 m diameter and 0.5 m height are formed in summer after draining the field so that salts are leached by the pre-monsoon and south-west monsoon showers. Thus, the electrical conductivity of these soils is brought down to 4 to 7 dS m^{-1}. Sprouted seeds of the saline tolerant rice varieties are sown on the mound tops. After 25 to 30 days the mounds are dismantled along with the seedlings attached to a clod of earth. This technique ensures the speedy establishment of the seedlings in this acid saline soils.

3.2. Climate and weather

Palakkad district, *Kuttanad*, *Pokkali* and *Kole* lands have tropical monsoon climate with more than 80 per cent of the rainfall distributed through south-west and north-east monsoon showers. During 2018 August, the state received about 27.5% more rainfall than usual and faced its worst floods in nearly 100 years.

3.3. Experiments

3.3.1. Part 1: Morphological study of *Monochoria vaginalis*

Surveys were conducted to identify *Monochoria* infested areas in *Pokkali* during September 2018 to November 2018, and in Palakkad, *Kole*, and *Kuttanad* regions during December 2018 to February 2019. At least five locations were inspected from each rice tract. From each location, important morphological observations at flowering stage were recorded, and seed and soil samples were collected (Plate 1).

Seeds were sown in pots and observations on growth and morphological characters were recorded. The soil samples were analysed to determine major physical and chemical characters, and nutrient contents.

Kole

Palakkad

Plate 1. Survey and sample collection in different locations

Observations

a) Morphological characters in the field

1. **Plant height**: Height of five plants from each location were measured from the base of the plant to the tip of the tallest leaf at the flowering stage and recorded in centimeters
2. **Number of leaves per plant**: Total numbers of leaves per plant were counted at the flowering stage. Observations were recorded from five plants in each location.
3. **Leaf area** (cm^2): Leaf area were determined using graph paper method
4. **Length of pedicel** (cm): Pedicel length in centimeters was measured
5. **Number of flowers per plant**: Number of flowers per plant was recorded from 5 plants in each location.
6. **Number of seeds per plant**: No. of seeds per pod, no. of pods per plant and individual pod weight were measured. From this total no. of seeds per plant was derived.
7. **Dry matter per plant** (g): Uprooted plants were first air dried for three days and then oven dried at 70±5°C to constant weight. Dry weight was recorded in grams.
8. **Seed weight** (g): Seeds from five plants were pooled in each location and 1000 seed weight was recorded
9. **Leaf anatomy**: Free hand sections of the leaves were taken and stained with saffranine and mounted after washing. The sections were observed under microscope and photographs were taken.

b) Soil chemical properties in the field

Soil samples were collected from each location and analysed in the laboratory. The methods used for physico-chemical analysis of soil are detailed in Table 2.

Table 2. Methods for soil physico-chemical analysis

Sl. No.	Soil property	Method used
1	pH	1: 2.5 soil: water ratio, Potentiometry (Jackson, 1958)
2	EC	1: 2.5 soil: water ratio, Conductometry (Jackson, 1958)
3	Organic C (%)	Walkley and Black method (Jackson, 1958)
4	Available N (kg/ha)	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg/ha)	Bray-1 extractant ascorbic acid reductant method (Watnabe and Olsen, 1965)
6	Available K (kg/ha)	Neutral normal ammonium acetate extractant flame photometry (Jackson, 1958)

c) Morphological characters in pot culture

1. Germination percentage

For germination test, 25 seeds each were placed in petri dishes of 9 cm diameter lined with a piece of Whatman No.1 filter paper, which was moistened with distilled water. It was also carried out by soaking 100 seeds in distilled water in 25 ml glass vials.

Seeds with a visible protrusion of radicle were considered to have germinated. The number of germinated seeds were counted daily for 14 days after the start of the experiment. The mean germination per cent was then worked out.

2. Days to emergence: Seeds collected from *Kole,* Palakkad, *Pokkali*, and *Kuttanad* were sown on the surface of respective soils. The mean time required for the shoot to reach the soil surface was recorded and indicated in days.

3. Plant phenophases: Mean number of days taken from emergence to flowering, flowering to seed formation and for seed maturation were noted

4. No. of leaves per plant: The number of leaves produced in five mature plants were counted and the mean number was worked out

5. No. of flowers and seeds per plant: The number of flowers and seeds produced in five mature plants were counted and the mean number was worked out

3.3.2. Part 2: Germination ecology of *Monochoria vaginalis*

Germination test: Germination of *Monochoria vaginalis* collected from the *Kole* area was evaluated by placing 25 seeds evenly in Petri dishes containing Whatman No.1 filter paper and 5 ml distilled water. Another method in which 100 seeds were immersed in distilled water in 25 ml glass vials was also used.

The number of germinated seeds were counted daily for 14 days after the start of the experiment, with the visible protrusion of the radicle being the criterion for germination. The mean germination percentage was then worked out.

The following experiments were conducted (Plate 2) to study the effect of environmental factors on germination of *Monochoria vaginalis*:

a) Effect of depth of burial on germination: Germination were tested by keeping seeds buried at 0, 5, 10 and 15 cm depth in pots. 12 pots were filled with soil collected from the *Kole* area which had been solarised for one month. Seedling emergence were observed for one month from sowing. Mean germination percentage at different depths of burial was worked out.

b) Effect of light and temperature on germination: Fully matured seeds were incubated in germinator at 28°C, 33°C, and 38°C temperature in both light/dark and continuous dark regimes. Germination was observed as in the germination test. Mean germination percentage was calculated.

a) Germination test in glass vial - Inside seed germinator

b) Germinated seedlings in glass vial

Plate 2. Experiments on germination ecology

Plate 3. View of the experiment on herbicide efficacy

c) Effect of pH on germination: Solutions with pH ranging from 4 to 9 were made using 4, 7 and 9.2 buffer capsules. These solutions were used to moisten 100 seeds each in 25 ml glass vials and germination was recorded as in the germination test and mean germination percentage was noted. Unbuffered distilled water was used as control.

d) Effect of salinity on germination: Sodium chloride amounting to 0, 0.146, 0.242, 0.584, 0.877, 1.169, and 1.461 g was dissolved in 0.1 L water to obtain final NaCl concentrations of 0, 25, 50, 100, 150, 200 and 250 mM, respectively. Seeds of *Monochoria vaginalis* were placed in dishes containing 5ml solutions of 0, 25, 50, 100, 150, 200 and 250 mM NaCl and germination were recorded as in the germination test. Mean value for germination percentage were calculated.

e) Effect of flooding depth and duration on germination: Twenty seeds were sown on the surface of soil. The pots were filled with solarized soil collected from the *Kole* area. Four flooding depths (0, 2, 5 and 10 cm) and three flooding durations (flooding for 2, 4 and 7 days) were adopted. After 2 weeks, emerged seedlings were counted and mean values worked out.

All the above experiments were laid out in completely randomized design with three replications each, and each experiment was done twice.

3.3.3. Part 3: Evaluation of efficacy of post-emergence herbicides on *Monochoria vaginalis* by pot culture study

The experimental design was CRD with three replications and was conducted under wet seeded condition. Earthen pots of 50 cm diameter and 25 cm height were used (Plate 3). Soil in the pots were puddled, seeds sown and then flooded. Of the emerged seedlings, five were retained in each pot and post-emergence herbicides were applied 20 days after emergence. The quantity was measured by micropipettes, and using 100 ml hand sprayer, herbicides were applied as per treatments detailed in Table 3.

Table 3. Post-emergence herbicide treatments

Sl. No.	Herbicide	Trade name	Formulation	Dose (kg/ha)	Quantity in 100 ml spray volume
1	2,4-D Sodium salt	Agan™	80 WP*	0.800	0.200 g
2	Chlorimuron ethyl 10% + metsulfuron methyl 10%	Almix®	20 WP	0.004	0.004 g
3	Ethoxysulfuron	Sunrice®	15 WDG**	0.015	0.020 g
4	Bispyribac sodium	Nominee Gold®	10 SC***	0.025	0.050 ml
5	Penoxsulam	Riceup™	2.67 OD****	0.025	0.187 ml
6	Cyhalofop butyl 5.1% w/w + penoxsulam 1.02% w/w	Vivaya™	6 OD	0.150	0.500 ml
7	Control	–	–	–	–

* WP- Wettable powder ** WDG - Water dispersible granule

*** SC- Soluble concentrate **** OD- Oil dispersions

Observations

Observations were recorded on:

1. Phytotoxicity symptoms of *Monochoria* plants after spraying herbicides
2. Percentage of seedlings survived
3. Dry weight of remaining plants which survived the herbicide application

Phytotoxicity rating at two weeks after spraying

Effects of herbicides on weeds were done visually by taking into consideration weed kill, injury to weeds and growth reduction by each herbicide. The rating was done according to the toxicity scale of Thomas and Abraham (2007) as shown in Table 4.

Table 4. Phytotoxicity rating

Rating	Effects on weeds
0	None
1	Slight
2	Moderate
3	Good control
4	Very good control
5	Complete control

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R_2T_4	R_1T_6	R_2T_6	R_3T_7	R_2T_3	R_1T_4	R_3T_5
R_1T_5	R_3T_2	R_1T_7	R_3T_6	R_1T_2	R_2T_2	R_1T_3
R_1T_1	R_3T_4	R_2T_1	R_2T_7	R_3T_3	R_3T_1	R_2T_5

Fig. 1. Layout of the experiment 'Efficacy of post-emergence herbicides'

T_1- 2,4-D Sodium salt

T_2- Chlorimuron ethyl + metsulfuron methyl

T_3- Ethoxysulfuron

T_4- Bispyribac sodium

T_5- Penoxsulam

T_6- Cyhalofop butyl + penoxsulam

T_7- Control

Statistical analysis

The data generated from the experiments were tabulated and morphological and soil parameters were statistically analysed using Microsoft Excel spread sheet. The correlation studies and the germination experiment with factorial CRD design was analysed by the data analysis tool 'OPSTAT'.

Results

4. RESULTS

The thesis programme entitled 'Morphology, ecology and management of *Monochoria vaginalis* (Burm. f.) Kunth' was taken up from September 2018 to June 2019. Survey, pot culture and lab experiments were conducted to study the morphology, germination ecology, and to test the efficacy of select herbicides against *Monochoria vaginalis*. Statistically analysed results from the recorded data are presented in this chapter.

4.1 Part I: Morphological study of *Monochoria vaginalis* in major rice tracts of Kerala

Surveys were conducted in the main rice tracts of Kerala viz., *Kole*, *Kuttanad*, Palakkad and *Pokkali* from September 2018 to February 2019. Plate 4 shows locations covered in the survey. Matured seeds and five plant samples were collected from each location. Soil samples from each location were also collected and analysed in the laboratory.

4.1.1 Morphological study in field

Monochoria vaginalis was found to occur in all the surveyed locations (Plate 5). The weed inhabited cultivated rice fields and irrigation channels, but was not observed in drier parts of the surveyed area. The observations taken from each location are furnished in Tables 5, 6, 7, 8 and 9.

4.1.1.1 Vegetative characters

Monochoria plants grew more vigorously in *Pokkali* areas compared to all other locations, and the weed in Palakkad rice tract registered lowest vegetative growth. *Pokkali* and Palakkad infesting plants recorded greatest (69 cm and 5.7 g) and lowest (25.8 cm and 1.72 g) plant height and dry matter respectively (Table 5). Number of leaves and leaf area were also low for *Monochoria* seen in Palakkad. The plants growing in *Kole* had more number of leaves than all the others. Leaf area of the weed was similar in *Pokkali* and *Kole* lands (Table 6). The vegetative characters differed in the four locations surveyed.

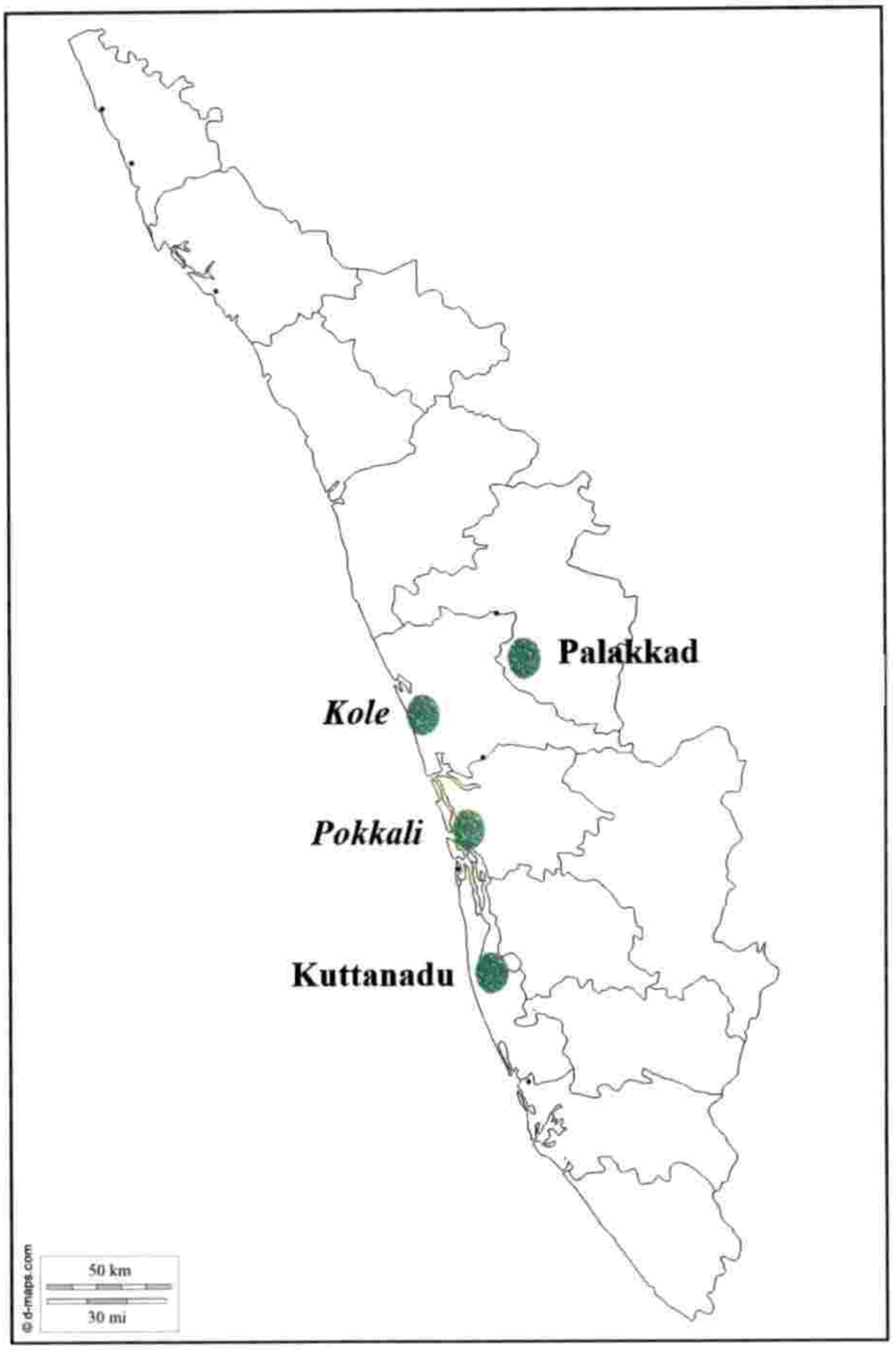

Plate 4. Map of surveyed locations

Kole

Palakkad

Pokkali

Kuttanad

Plate 5. Infestation of *Monochoria vaginalis* in major rice tracts of Kerala

Table 5. Plant height and dry matter of *Monochoria* in different locations

	Location	Plant height (cm)		Dry matter/plant (g)	
		Mean	Range	Mean	Range
Kole	Alappad 1	56.8±2.63	49-64	4.95±0.29	3.98-5.73
	Alappad 2	56.2±2.71	47-63	4.93±0.26	4.16-5.63
	Manakodi 1	56.0±2.57	49-64	4.57±0.24	3.95-5.20
	Manakodi 2	54.4±2.79	47-63	4.66±0.28	3.72-5.22
	Manakodi 3	55.4±2.23	50-62	4.77±0.17	4.28-5.34
Palakkad	Chethali 1	37.2±2.75	28-45	2.60±0.15	2.20-3.10
	Chethali 2	34.8±1.96	28-40	2.48±0.24	1.90-3.20
	Chethali 3	36.2±2.87	30-47	2.70±0.24	2.30-3.60
	Kavasseri 1	26.2±1.74	22-32	2.33±0.17	1.72-2.75
	Kavasseri 2	25.8±1.36	22-30	2.32±0.16	1.89-2.80
Pokkali	*Pokkali* 1	58.6±5.39	38-69	4.68±0.40	3.80-5.70
	Pokkali 2	56.2±2.59	47-62	4.72±0.18	4.20-5.20
	Pokkali 3	53.6±3.87	42-64	4.78±0.29	3.80-5.60
	Pokkali 4	57±3.05	47-65	5.00±0.19	4.50-5.50
	Pokkali 5	56.4±2.27	49-63	4.92±0.30	3.90-5.60
Kuttanad	Kidangara	41.2±1.53	38-46	4.07±0.17	3.62-4.60
	Muttar	40.2±0.86	38-43	3.97±0.12	3.62-4.35
	Veeyapuram	39.6±1.72	36-46	3.94±0.25	3.28-4.51
	Edathua	39.6±1.72	36-46	3.92±0.16	3.34-4.24
	Changagari	38.4±2.71	30-46	4.01±0.14	3.60-4.38

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Table 6. Leaf characters of *Monochoria vaginalis* in different locations

	Location	No. of leaves/plant		Leaf area (cm^2)	
		Mean	Range	Mean	Range
Kole	Alappad 1	13.4±1.1	10-16	64.6±5.32	49.0-73.5
	Alappad 2	13.6±1.0	10-16	63.7±4.36	50.3-72.0
	Manakodi 1	12.2±0.7	10-14	61.3±3.16	51.5-69.4
	Manakodi 2	12.4±1.0	10-16	63.4±3.12	55.3-72.0
	Manakodi 3	12.2±0.8	10-14	61.7±3.01	53.3-71.6
Palakkad	Chethali 1	7.6±0.81	6-10	20.7±2.16	15.8-28.0
	Chethali 2	6.8±1.11	5-11	18.4±2.10	14.3-26.8
	Chethali 3	7.2±1.24	5-12	19.2±2.73	15.8-30.0
	Kavasseri 1	9.8±0.73	8-12	11.1±0.77	8.5-13.3
	Kavasseri 2	10.2±0.6	9-12	11.3±0.84	8.8-14.0
Pokkali	*Pokkali* 1	11.2±1.0	8-13	62.4±1.67	59.5-68.8
	Pokkali 2	11.2±0.7	9-13	62.7±1.50	58.8-67.3
	Pokkali 3	11.2±1.1	8-14	65.0±1.78	59.0-69.8
	Pokkali 4	11.6±0.8	9-13	65.0±1.78	59.0-69.8
	Pokkali 5	11.0±0.7	9-13	62.5±1.04	59.3-65.2
Kuttanad	Kidangara	9.0±0.32	8-10	37.3±4.04	27.5-51.5
	Muttar	11.8±1.1	9-15	38.3±3.18	29.3-48.8
	Veeyapuram	10.6±0.8	8-13	38.0±4.28	26.6-52.3
	Edathua	8.8±0.86	7-12	38.6±3.07	32.3-50.0
	Changagari	11.2±0.9	9-14	37.2±2.59	27.8-42.8

4.1.1.2 Flower characters

The flowers of *Monochoria vaginalis* were bluish purple in colour and borne on an inflorescence axis. There were 4-6 flowers per inflorescence in *Monochoria* plants of Palakkad, while in all other locations more than six flowers per inflorescence were seen. Number of inflorescences per plant was also less in Palakkad.

The greatest number of flowers per plant was recorded in *Pokkali*, and lowest in Palakkad. In *Pokkali* it ranged from 34-48, and for Palakkad the range was 6-38. *Monochoria* grown in *Kole* and *Kuttanad* had 24- 46 flowers per plant. The length of pedicel was similar for all the locations and it ranged from 0.3 cm to 1.6 cm (Table 7).

4.1.1.3 Seed characters

Monochoria vaginalis has the ability to produce numerous seeds from a single plant. The seeds are very small and longitudinally ribbed, and enclosed in capsules.

A single capsule contained up to 359 seeds in *Pokkali* and the capsules weighed 0.10 8-0.236 g. Even though the capsule weight was less (ranging from 0.04-0.06 g) in Palakkad, it enclosed about 123-266 seeds. The capsule weight and number of seeds per capsule were 0.07-0.12 g and 80-168 in *Kole*, and 0.08-0.14 g and 100-197 in *Kuttanad* respectively (Table 8 and 9).

The total number of seeds per plant was higher for *Monochoria* seen in *Pokkali*, where a single plant produced more than ten thousand seeds. The mean number of seeds per plant was comparable for *Kole*, *Kuttanad*, and Palakkad. However, there was a wide range in seed number per plant in all the four surveyed locations.

The 1000 seed weight was very low for *Monochoria* growing in Palakkad rice tract, *i.e.*, 0.3 g. In all the other locations the 1000 seed weight ranged from 0.6-0.9 g.

Table 7. Flower characters of *Monochoria vaginalis* in different locations

	Location	No. of flowers/plant		Length of pedicel (cm)	
		Mean	Range	Mean	Range
Kole	Alappad 1	34.4±2.3	28-40	0.84±0.15	0.3-1.2
	Alappad 2	36.0±2.3	28-42	0.94±0.19	0.4-1.6
	Manakodi 1	35.2±2.9	24-40	0.84±0.10	0.6-1.2
	Manakodi 2	36.0±1.7	32-42	0.86±0.16	0.4-1.4
	Manakodi 3	35.2±2.1	28-40	0.82±0.12	0.5-1.2
Palakkad	Chethali 1	20.8±3.3	14-32	0.72±0.14	0.4-1.2
	Chethali 2	20.0±5.3	6-38	0.78±0.14	0.4-1.2
	Chethali 3	20.0±4.0	8-32	0.80±0.18	0.3-1.4
	Kavasseri 1	18.0±2.0	12-24	0.76±0.09	0.5-1.0
	Kavasseri 2	18.4±1.7	14-24	0.70±0.08	0.4-0.9
Pokkali	*Pokkali* 1	40.8±2.1	36-48	0.94±0.18	0.4-1.4
	Pokkali 2	41.6±2.0	36-48	0.76±0.09	0.5-1.0
	Pokkali 3	40.4±1.7	36-46	0.88±0.12	0.5-1.2
	Pokkali 4	40.0±2.3	34-46	0.80±0.15	0.4-1.3
	Pokkali 5	40.4±1.2	38-44	0.94±0.13	0.6-1.4
Kuttanad	Kidangara	35.6±3.1	24-42	0.62±0.06	0.5-0.8
	Muttar	35.6±4.2	24-46	0.64±0.07	0.5-0.9
	Veeyapuram	38.0±2.8	28-42	0.60±0.08	0.4-0.9
	Edathua	35.6±3.3	24-42	0.62±0.04	0.5-0.7
	Changagari	34.8±3.2	24-42	0.76±0.07	0.5-0.9

Table 8. Seed characters of *Monochoria vaginalis* in different locations

	Location	No. of seeds/capsule		No. of seeds/plant	
		Mean	Range	Mean	Range
Kole	Alappad 1	116.6±12.6	80-154	3902.8±216	3200-4370
	Alappad 2	131.8±10.1	112-168	4768.8±578	3892-7056
	Manakodi 1	131.0±11.0	97-159	4648.0±622	2904-6042
	Manakodi 2	133.8±8.0	115-161	4819.2±360	3910-5796
	Manakodi 3	136.0±7.9	118-162	4806.0±473	3976-6480
Palakkad	Chethali 1	179.0±22.0	132-252	3567.2±414	2156-4536
	Chethali 2	176.8±17.8	123-226	3742.4±1308	972-8588
	Chethali 3	196.4±20.3	157-266	4072.0±992	1256-6976
	Kavasseri 1	181.8±16.7	138-219	3349.2±563	1788-4488
	Kavasseri 2	181.0±14.4	132-221	3400.8±513	1848-4608
Pokkali	*Pokkali* 1	258.2±19.9	196-302	10594.0±1072	7056-12768
	Pokkali 2	243.4±44.5	151-354	9981.6±1737	7040-15576
	Pokkali 3	277.0±32.1	174-359	11332.0±1703	6960-16514
	Pokkali 4	271.2±16.7	228-325	10886.0±1029	8208-14300
	Pokkali 5	240.0±33.2	163-337	9552.4±1073	7172-12806
Kuttanad	Kidangara	143.8±16.8	107-197	4971.6±448	3852-6600
	Muttar	138.0±10.4	107-160	5037.2±869	2568-7268
	Veeyapuram	141.6±14.4	107-189	5426.8±786	3852-7938
	Edathua	141.4±16.2	100-196	5096.0±748	2400-6664
	Changagari	153.8±5.6	137-170	5342.4±532	3864-7140

Table 9. Capsule weight and seed weight of Monochoria in different locations

	Location	Capsule weight (g)		1000 seed weight (g)	
		Mean	Range	Mean	Range
Kole	Alappad 1	0.093±0.007	0.07-0.11	0.814±0.03	0.71-0.90
	Alappad 2	0.098±0.005	0.09-0.11	0.748±0.02	0.67-0.80
	Manakodi 1	0.102±0.006	0.08-0.12	0.785±0.02	0.73-0.85
	Manakodi 2	0.103±0.004	0.09-0.11	0.771±0.02	0.70-0.82
	Manakodi 3	0.105±0.003	0.09-0.11	0.774±0.02	0.70-0.84
Palakkad	Chethali 1	0.048±0.004	0.04-0.06	0.276±0.02	0.24-0.32
	Chethali 2	0.048±0.004	0.04-0.06	0.275±0.01	0.26-0.31
	Chethali 3	0.052±0.004	0.04-0.06	0.268±0.01	0.23-0.31
	Kavasseri 1	0.050±0.004	0.04-0.06	0.280±0.01	0.26-0.30
	Kavasseri 2	0.049±0.005	0.04-0.06	0.271±0.01	0.23-0.29
Pokkali	*Pokkali* 1	0.139±0.020	0.11-0.19	0.672±0.06	0.53-0.87
	Pokkali 2	0.169±0.020	0.13-0.23	0.585±0.04	0.48-0.68
	Pokkali 3	0.166±0.020	0.12-0.22	0.619±0.07	0.47-0.84
	Pokkali 4	0.161±0.020	0.11-0.21	0.590±0.03	0.50-0.65
	Pokkali 5	0.168±0.020	0.13-0.24	0.711±0.04	0.61-0.87
Kuttanad	Kidangara	0.112±0.010	0.09-0.13	0.794±0.04	0.67-0.92
	Muttar	0.113±0.005	0.10-0.12	0.828±0.03	0.77-0.91
	Veeyapuram	0.112±0.007	0.09-0.13	0.801±0.03	0.69-0.88
	Edathua	0.112±0.010	0.08-0.14	0.802±0.03	0.70-0.91
	Changagari	0.121±0.003	0.11-0.13	0.786±0.013	0.76-0.83

4.1.2 Leaf anatomy

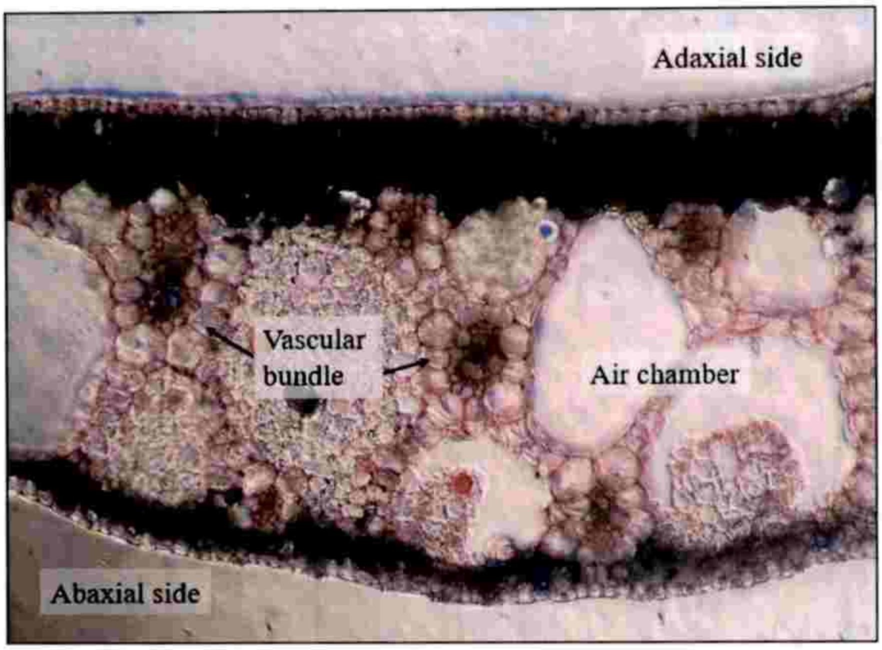
The transverse sections of *Monochoria* leaf from the four surveyed locations were taken and images (Plate 6 and 7) were obtained with a capturing device attached to light microscope using Leica Application Suite (LAS) software for image digitization.

The micrograph from the four location were similar with wide air chambers in the middle of the lamina. They were partitioned by transverse diaphragms. Vascular bundles were observed both in the adaxial and abaxial regions and in the vertical partitions. The upper epidermis was made of 3-4 layers of rectangular cells and the lower epidermis consisted of cylindrical cells. The spongy parenchyma consisted of aerenchyma chambers, some of which were filled with bundles of parenchyma cells or contained idioblasts. Calcium oxalate crystals in the form of raphides (cylindrical bundle of many thin pointed needles) were present in idioblasts or in specialised cells.

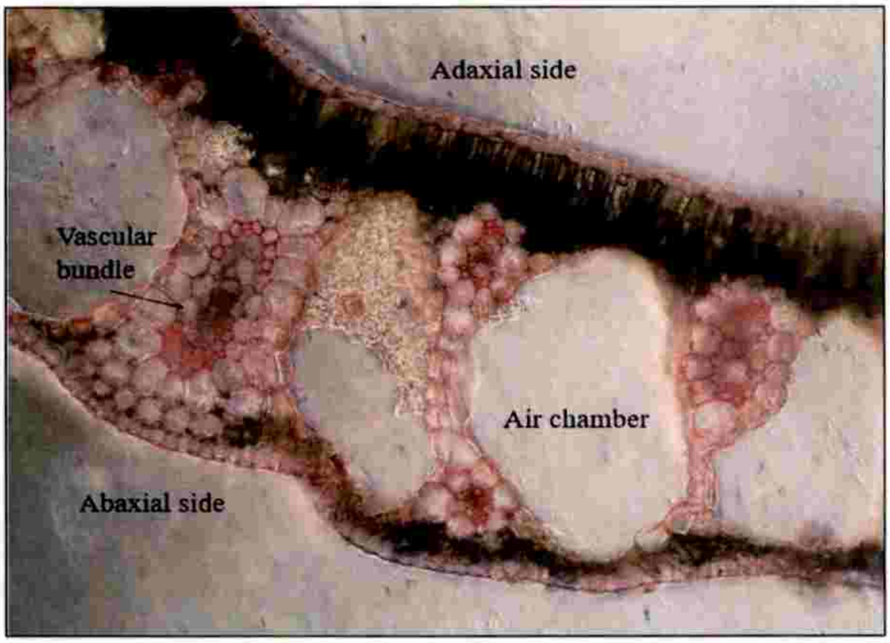
4.1.3 Soil chemical properties

All of the surveyed area had an acidic soil pH and, the soil from *Kole* and Palakkad rice tracts recorded higher (6.02-6.65) pH. The acid saline and the acid sulphate soils of *Pokkali* and *Kuttanad* registered lower pH (4.16-4.28). Electrical conductivity was highest for *Pokkali* (1.64 mS/m) soil and lowest for Palakkad soil (0.001 mS/m).

The soil collected from *Kuttanad* was rich in organic carbon (4.43 per cent), while it was less than one per cent for Palakkad soil. The highest available nitrogen content was recorded from Kidangara region (526.4 kg/ha) in *Kuttanad*, but the other locations in *Kuttanad* registered a low to medium range of available nitrogen (201.6-347.2 kg/ha). The *Pokkali* soil had a medium range of available nitrogen (380.8-425.6 kg/ha) and was high in available potassium (463.7-535.4 kg/ha), whereas the Palakkad soil was observed to be low in available nitrogen (100.8-156.8 kg/ha) and available potassium (87.4-294.6 kg/ha). Except for *Pokkali* soil (56.21-74.58 kg/ha), the available phosphorus content was in medium range (10-20 kg/ha) for all the surveyed locations (Table 10).

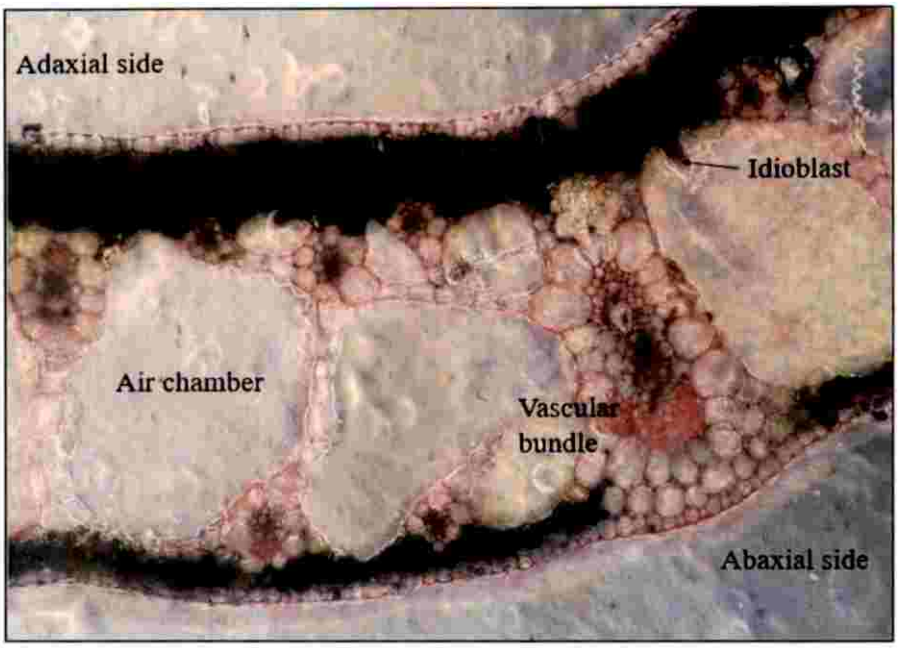


A. Kole

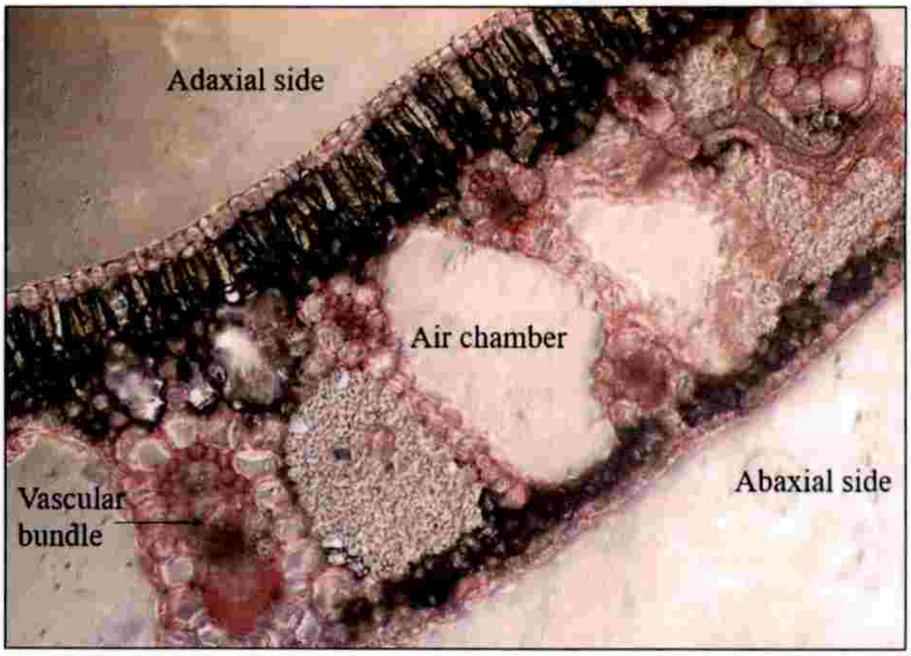


B. Palakkad

Plate 6. A. Micrograph of transverse section of *Monochoria* leaf from *Kole* and Palakkad

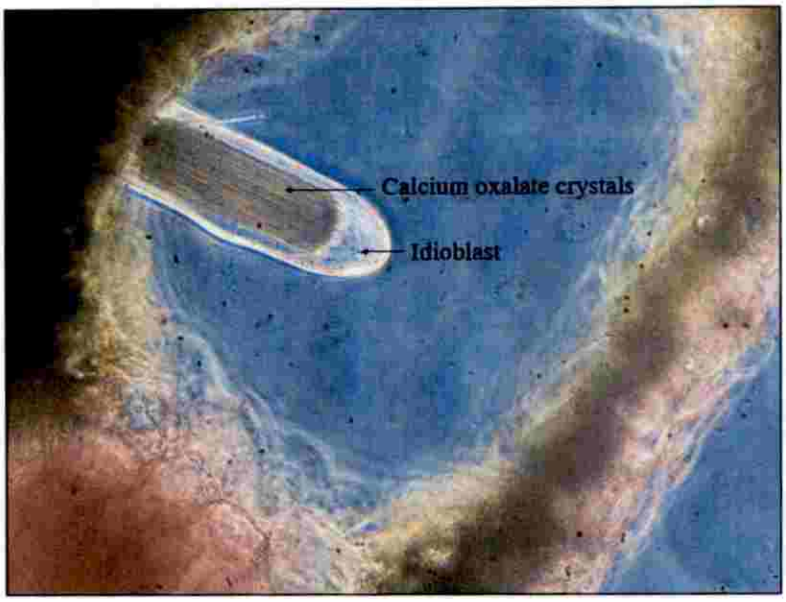


C. Pokkali

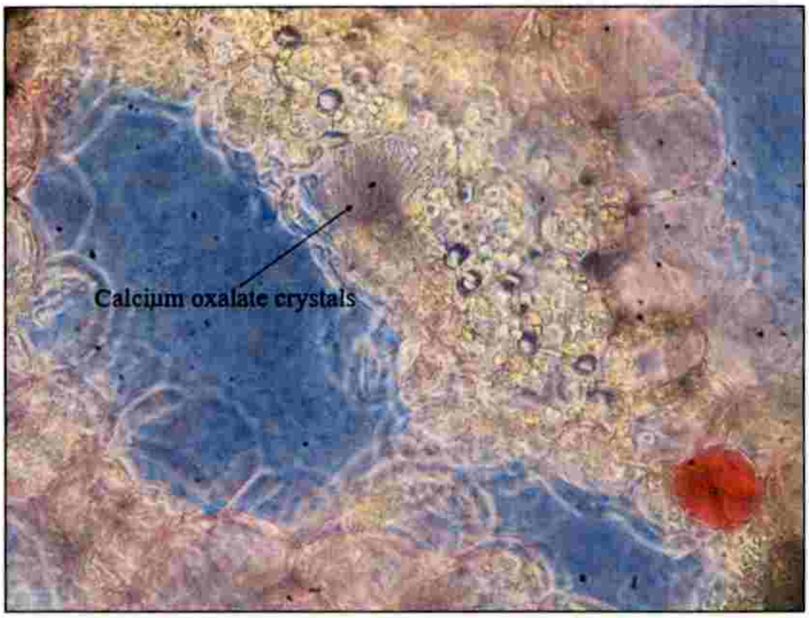


D. *Kuttanad*

Plate 6. B. Micrograph of transverse section of *Monochoria* leaf from *Pokkali* and *Kuttanad*



a. Raphides in idioblast



b. Raphides freely in the cell

Plate 7. Calcium oxalate crystals in *Monochoria* leaf

Table 10. Chemical properties of soil of surveyed locations

Location	pH	EC (mS/m)	Organic carbon (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Kole						
Alappad 1	5.02	0.32	1.67	201.6	12.25	178.4
Alappad 2	4.99	0.33	1.68	235.2	12.30	189.6
Manakkodi 1	5.99	0.53	2.22	246.4	13.74	252.0
Manakkodi 2	6.02	0.54	2.13	235.2	10.24	241.9
Manakkodi 3	5.85	0.52	2.26	246.4	11.49	264.3
Palakkad						
Chethali 1	5.58	0.035	0.52	100.8	17.74	87.4
Chethali 2	5.80	0.047	0.62	112.0	18.49	91.8
Chethali 3	5.57	0.038	0.58	100.8	20.74	88.5
Kavasseri 1	6.65	0.001	0.89	156.8	14.74	271.0
Kavasseri 2	6.26	0.001	0.90	156.8	15.49	294.6
Pokkali						
Pokkali 1	4.63	1.42	1.78	425.6	58.46	463.7
Pokkali 2	4.77	1.64	2.14	403.2	56.21	535.4
Pokkali 3	4.16	1.31	2.06	392.0	74.58	483.8
Pokkali 4	4.26	1.43	2.12	414.4	70.95	478.2
Pokkali 5	4.25	1.41	1.87	380.8	72.33	495.0
Kuttanad						
Kidangara	4.38	0.171	4.43	526.4	11.25	222.9
Muttar	4.28	0.145	4.03	201.6	12.25	191.5
Veeyapuram	4.37	0.189	3.56	246.4	13.50	213.9
Edathua	4.33	0.161	4.12	347.2	11.25	687.9
Changagari	4.43	0.166	3.92	313.6	11.37	213.9

4.1.4 Correlation between morphological characters and soil chemical properties

The results revealed that pH was negatively correlated with all the morphological characters studied and the coefficient was statistically significant for dry weight, number of flowers and seeds per plant, capsule weight and seed weight.

Except for number of leaves and seed weight, electrical conductivity had statistical significance with all the morphological traits, and they were positively correlated. Soil organic carbon had negative correlation with pedicel length and number of seeds per capsule and positive correlation with number of flowers per plant, capsule weight and seed weight (Table 11).

Available N, P and K in soil had positive correlation with morphological characters, except in the case of seed weight and soil P. The coefficient was statistically non significant for number of leaves with respect to all the soil properties studied.

4.1.5 Pot culture study

The soil collected from *Kole*, Palakkad, *Pokkali* and *Kuttanad* were filled in pots, and seeds from respective locations were sown. The germination percentage of the seeds were tested in the laboratory before sowing, and it was around 20 per cent for all the locations (Table 13).

Seeds collected from *Pokkali* during September to November 2018 failed to germinate immediately after harvest, but started to germinate after January 2019. Seeds collected during December 2018 to February 2019 from *Kole*, Palakkad and *Kuttanad* germinated after March. But seeds matured after March germinated within one week of shedding. Hence the pot culture experiments were started in February 2019 for *Pokkali* and from March 2019 for all other locations (Plate 8).

Seeds from all the areas started to germinate after 2 days and the emergence continued for one week. *Monochoria* from all the location took more than 50 days for first flowering. Days required for flowering ranged from 69-82 and 60-72 days in plants from *Pokkali* and Palakkad respectively. The time period needed was less for the plants of *Kole* (53-65) and *Kuttanad* (50-65) origin (Table 12).

Table 11. Correlation between morphological characters of *Monochoria vaginalis* and soil chemical properties

	pH	EC	Organic carbon	N	P	K
Plant height	-0.359	0.749**	0.088	0.508*	0.492*	0.362
No. of leaves	-0.160	0.377	0.236	0.270	0.103	0.181
Leaf area	-0.424	0.735**	0.229	0.573**	0.467*	0.435
No. of flowers	-0.728**	0.704**	0.597**	0.781**	0.469*	0.568**
Pedicel length	0.107	0.537*	-0.499*	0.072	0.472*	0.097
Dry weight	-0.549*	0.678**	0.406	0.652**	0.412	0.445*
Capsule weight	-0.753**	0.854**	0.471*	0.836**	0.724**	0.708**
No. of seeds/capsule	-0.303	0.763**	-0.305	0.415	0.934**	0.533*
Seed weight	-0.561*	0.226	0.785**	0.543*	-0.056	0.270
No. of seeds/plant	-0.621**	0.946**	0.110	0.731**	0.938**	0.707**

Kole

Pokkali

Palakkad

Kuttanad

Plate 8. Pot culture of *Monochoria* from different locations

All the plants took about 20 days after flowering for seed maturation, irrespective of their original location. The seed formation and maturation were delayed for plants in *Pokkali* condition (84-94 days) compared to other groups of plants (Table 12).

Table 12. Phenophases of *Monochoria vaginalis* in pot culture study

Phenophases	Location	Range	Average	SEm (±)
Days to emergence	*Kole*	2-6	3.60	0.678
	Palakkad	2-7	4.20	0.860
	Pokkali	2-6	4.00	0.707
	Kuttanad	2-6	3.40	0.748
Days to first flowering	*Kole*	53-65	58.40	2.088
	Palakkad	60-72	67.60	2.064
	Pokkali	69-82	76.40	2.182
	Kuttanad	50-65	56.00	2.530
Days taken for seed formation	*Kole*	65-78	71.20	2.267
	Palakkad	69-82	75.40	2.337
	Pokkali	77-91	84.40	2.358
	Kuttanad	61-77	69.00	2.828
Days taken for seed maturation	*Kole*	77-85	83.00	2.000
	Palakkad	79-89	83.00	1.822
	Pokkali	89-99	94.00	1.612
	Kuttanad	75-83	80.00	1.844

The average number of leaves (13.2), flowers (45.6) and seeds (12,196) per plant was observed to be the highest for *Pokkali* condition simulated in pot culture. The plants raised from seeds of Palakkad tracts recorded the lowest mean value for number of leaves (9.8), number of flowers (24.6) and number of seeds (4318) per plant (Table 13).

Table 13. Germination percentage and biometric characters of *Monochoria* in pot culture study

Location	Germination %	No. of leaves/plant	No. of flowers/plant	No. of seeds/plant
Kole	20.2±1.07	12.4±0.75	31.2±1.36	4424.6±291.9
Palakkad	20.4±0.93	9.8±0.58	24.6±1.08	4318.6±352.1
Pokkali	19.8±1.02	13.2±0.49	45.6±2.14	12196.4±947.6
Kuttanad	20.4±1.08	10.6±0.60	32.0±1.41	4564.8±194.4

4.2. Part 2: Germination ecology of *Monochoria vaginalis*

Monochoria seeds collected from Kole lands were used to study the germination ecology. Germination tests were done by two methods. No seed germination occurred in Petri plates lined with Whatman No. 1 filter paper, both in open condition and with lid. The mean germination percentage was observed to be 20 in glass vial with distilled water.

The effect of depth of burial, light and temperature, pH, salinity, and flooding depth and duration on germination of *Monochoria* were studied. All the experiments were repeated twice and the observations were seen to be similar both times. Therefore the data were pooled, and the mean germination percentage of each experiment are presented separately in Tables 14, 15, 16, 17 and 18.

4.2.1 Effect of depth of burial on germination

Seeds placed at 5, 10 and 15 cm depth of soil failed to emerge and the same result was obtained when the experiment was repeated. Seeds sown on soil surface germinated and the mean germination percentage was 23.5.

Table 14. Effect of depth of burial on germination

Depth of burial (cm)	Germination %
0	23.5
5	0
10	0
15	0

4.2.2 Effect of light and temperature on germination

The experiment was conducted in a seed germinator in which the light, temperature and humidity conditions could be maintained. *Monochoria* seeds kept at continuous dark condition failed to germinate irrespective of the temperature provided. The seeds maintained at 28°C and 33°C did not germinate in all the three light conditions.

The seeds germinated only at a temperature of 38°C and the mean germination percentages were 20.67 and 22.17 in continuous light, and alternate light and dark conditions respectively.

Table 15. Effect of light and temperature on germination

Temperature	Mean germination %		
	Continuous light	Continuous dark	Alternate light and dark
28°C	0	0	0
33°C	0	0	0
38°C	20.67	0	22.17

65

4.2.3 Effect of pH on germination

The seeds germinated in solutions of pH 6 and 7, and the mean germination per cent was 22.5 and 24.5 respectively. The seeds placed in buffered solutions of pH 4, 5, 8, and 9 did not germinate in both the experimental runs.

Table 16. Effect of pH on germination

pH	Germination %
4	0
5	0
6	22.5
7	24.5
8	0
9	0

4.2.4 Effect of salinity on germination

The mean germination percentage was 21 for the seeds immersed in 0 mM NaCl solution. The experiment was done twice and it was observed that the seeds did not germinate in concentrated saline solutions in both the runs.

Table 17. Effect of salinity on germination

Salinity (mM NaCl)	Germination %
0	21
25	0
50	0
100	0
150	0
200	0
250	0

4.2.5 Effect of flooding depth and duration on germination

The result showed that seed germination in *Monochoria* was significantly influenced by flooding depth and duration. The germination percentage recorded under 0, 2 and 5 cm of flooded depth were 23.50, 24.67 and 21.83 respectively, which were significantly higher than that under 10 cm water column (7.33).

The germination percentage recorded for 4 and 7 days of flooded duration were 19.88 and 20.33 respectively, which were on par and significantly higher than that of 2 days' duration (17.79).

Considering the interaction effect, it was seen that highest germination percentage (26.83) was obtained when seeds were immersed in 2 cm depth of water for 4 days. This was on par with germination percentage of the combinations, 2 cm for 7 days and 0 cm for 7 days (*i.e.*, no flooding). All other combinations were on par, except 10 cm flooded depth for 2, 4 and 7 days.

Table 18 A. Effect of flooding depth and duration on germination

Treatments	Germination percentage
Flooding depth (cm)	
0	23.50
2	24.67
5	21.83
10	7.33
CD (0.05)	1.598
Flooding duration (days)	
2	17.79
4	19.88
7	20.33
CD (0.05)	1.384

Table 18 B. Interaction of flooding depth and duration on germination

	Flooding duration (days)		
Flooding depth (cm)	**2**	**4**	**7**
0	21.67	23.50	25.33
2	21.67	26.83	25.50
5	23	20.33	22.17
10	4.83	8.33	8.33
CD (0.05)	2.768		

4.3 Part 3: Efficacy of post-emergence herbicides on *Monochoria vaginalis* - Pot culture study

Phytotoxicity scoring based on visual symptoms

Scoring was done visually based on the toxicity symptoms on weeds at two, five, seven, and 14 days after spraying (Table 19). Toxicity scale described by Thomas and Abraham (2007) was used for scoring. The scores 1 and 2 indicated slight and moderate control respectively. The scale ranging from 3-5 specified good to complete control of weeds.

Application of 2,4-D sodium salt @ 0.8 kg/ha on plants resulted in epinasty, *i.e.*, stem twisting and bending within two days of spraying (Plate 9. A), and penoxsulam + cyhalofop butyl application @ 0.15 kg/ha resulted in yellowing of leaves after five days (Plate 9. B). Both the herbicides completely killed *Monochoria* after one week of application.

Almix® @ 0.004 kg/ha caused slight discoloration of leaves and petioles (Plate 10. A), and ethoxysulfuron @ 0.015 kg/ha applied plants exhibited partial drying (Plate 10. B), after seven days of spraying. In bispyribac sodium sprayed (@ 0.025 kg/ha) plants, lower leaves dried up and upper leaves started to dry from the tip within seven days (Plate 10. C). Penoxsulam @ 0.025 kg/ha also resulted in tip burning of leaves after one week of application (Plate 10. D).

All the tested herbicides were found to be very effective in controlling *Monochoria* after two weeks of application, and no plant escaped. However, 2,4-D sodium salt caused severe injury on the weed immediately after application and brought about complete kill within one week of application. The premix herbicide, penoxsulam + cyhalofop butyl, was also good at killing *Monochoria* within a short period.

Table 19. Phytotoxicity scoring at two, five, seven, and 14 days after spraying

Treatments	Score			
	2 days	**5 days**	**7 days**	**14 days**
T_1R_1	2	4	5	5
T_1R_2	3	3	5	5
T_1R_3	2	4	5	5
T_2R_1	0	2	2	5
T_2R_2	0	0	1	5
T_2R_3	0	2	3	5
T_3R_1	0	2	2	5
T_3R_2	0	0	3	5
T_3R_3	0	1	2	5
T_4R_1	0	2	2	5
T_4R_2	0	1	1	5
T_4R_3	1	1	2	5
T_5R_1	0	2	2	5
T_5R_2	0	1	2	5
T_5R_3	0	2	2	5
T_6R_1	0	3	5	5
T_6R_2	0	3	5	5
T_6R_3	0	3	5	5
T_7R_1	0	0	0	0
T_1R_2	0	0	0	0
T_1R_3	0	0	0	0

A) 2, 4-D sodium salt - 2 DAA

B) Penoxsulam + cyhalofop butyl - 5 DAA

C) 2, 4-D sodium salt - 7 DAA

D) Penoxsulam + cyhalofop butyl - 7 DAA

Plate 9. Phytotoxicity symptoms

A. Almix®

B. Ethoxysulfuron

C. Bispyribac sodium

D. Penoxsulam

Plate 10. Phytotoxicity symptoms - 7 days after application

Discussion

5. DISCUSSION

Monochoria vaginalis, a serious weed of wet land paddy was seen in all the major rice ecosystems of Kerala. Knowledge on the habit and influence of environmental factors on germination and growth could help in formulating better management practices for the weed. The outcome of the research programme entitled 'Morphology, ecology and management of *Monochoria vaginalis* (Burm. f.) Kunth' presented in chapter IV is discussed hereunder based on the available literature.

5.1 Part I: Morphological study of *Monochoria vaginalis* in major rice tracts of Kerala

Monochoria coexisted with rice and occupied the irrigation channels in all the four surveyed locations, but was not seen in drier parts. Vidya (2003) studied weed dynamics in major agro-ecological zones of Kerala and found that *Ludwigiua parviflora* and *Monochoria vaginalis* were the two most common broad leaved weeds seen in all the major rice ecosystems of Kerala viz., *Kole*, *Pokkali*, Palakkad, Chittur and *Kuttanad*. She recorded the Relative Importance Values (RIV) of 1.64 and 6.84 for *Monochoria* in first and second crop season respectively in Palakkad and concluded that the weed preferred water stagnation.

5.1.1 Morphology and vegetative characters

Monochoria vaginalis is a fleshy emergent semi-aquatic annual herb, which has the potential to grow perennially through rhizomes. It inhabits constantly flooded areas like paddy fields. It is a broad-leaved monocot having fibrous root system, and the stem is modified into a short rhizome from which soft hollow leaf petioles arise. *Monochoria* showed great variation with location in morphology (Plate 11), and the traits were analysed quantitatively by recording characters like plant height, leaf area, number of leaves, flowers and seeds per plant, length of pedicel and dry weight. The variation in morphological characters might have emerged due to the ecological situation including soil factors prevailing in the tracts.

Plate 11. Variation in size of *Monochoria* plants from different locations

A) Juvenile stage

B) Flowering and vegetative stage

Plate 12. Leaf forms in *Monochoria*

The plant height varied from 10 to 60 cm (Fig. 2), number of leaves from 5 to 16 (Fig. 5), and leaf area from 10 to 70 cm^2 (Fig. 4). According to Chiang (1983) number of leaves per plant was 13 at 60 DAS in the first season, and plant height was less than 40 cm. Dry weight of plants was around 0.2 g at 60 DAS in his experiment, while here the dry weight ranged from 1.92 g to 5.7 g (Fig. 3).

In juvenile stage, leaf was narrow or linear (Plate 12. A) and then leaf form changed to narrowly ovate or lanceolate. Still older plants had leaves with sharply acuminate apex and cordate base (Plate 12. B). Lamid (1981) also observed three leaf forms on *Monochoria* plant namely sessile-elongated, petiolated-ovate and petiolated-cordate.

5.1.2 Flower characters

Inflorescence was a spike arising from leaf petiole opposite to the floral leaf. The flowers were violet or lilac blue coloured, and pedicellate, and the number varied from 4 to 9 per inflorescence (Plate 13. B). The total number of flowers per plant ranged from 6 to 48 (Fig. 6). The flowers opens simultaneously or in quick succession in morning hours and afterwards were spirally contorted (Plate 13. C). Inflorescence bent downwards after flowering and capsules (Plate 14) were formed. At maturity they split into three valves and released numerous seeds that were longitudinally ribbed (Plate 15).

5.1.3 Propagation

Monochoria is mainly propagated through seed. The mean number of seeds per capsule ranged from 116 to 277 (Fig. 8), total number of seeds per plant from 3400 to 11,300 (Fig. 9) and 1000 seed weight from 0.27 g to 0.82 g (Fig. 11). Chiang (1983) recorded around 140 seeds per capsule and thousand seed weight was about 0.19 g, and the seed production capacity was estimated to be 47,000 to 55,000 per plant. *Monochoria* could also propagate by vegetative means through rhizomes (Plate 16).

Plate 13. A. Inflorescence emergence

Plate 13. B. Inflorescence in full bloom

Plate 13. C. Inflorescence when contorted

Plate 14. Capsules of *Monochoria*

Plate 15. Seeds of *Monochoria vaginalis*

Plate 16. Propagation through rhizomes

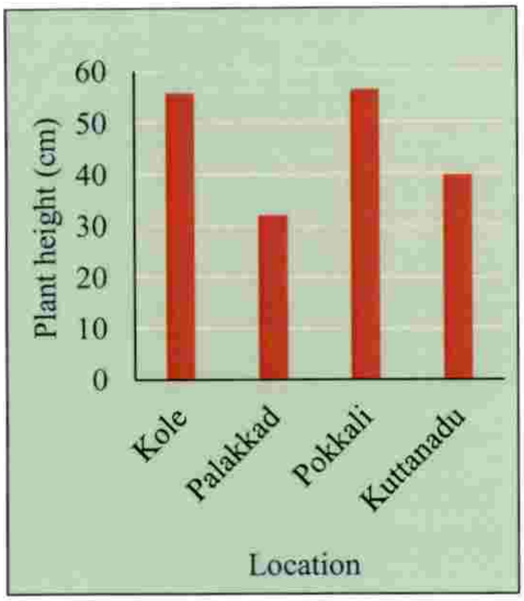


Fig. 2. Variation in plant height in different locations

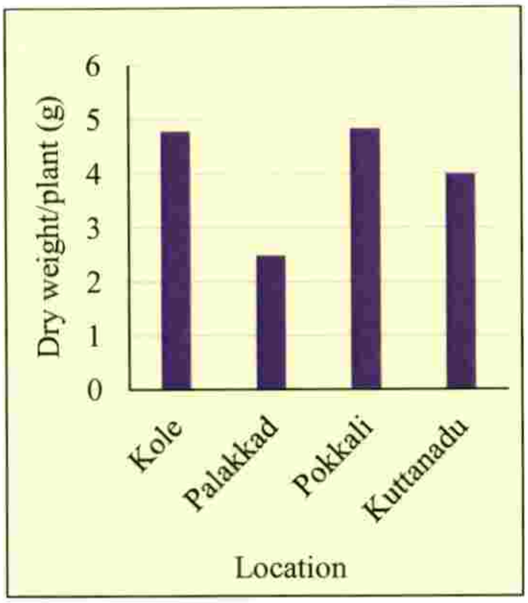


Fig. 3. Variation in dry weight in different locations

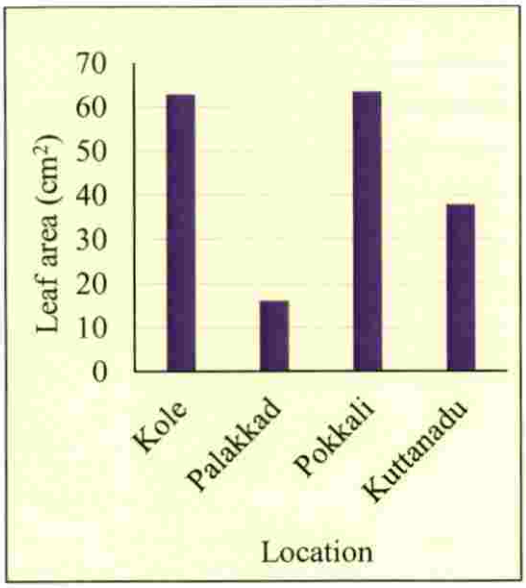


Fig. 4. Variation in leaf area in different locations

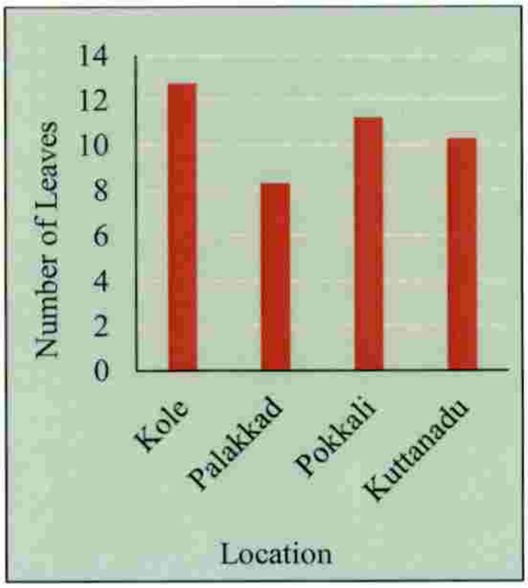


Fig. 5. Variation in number of leaves in different locations

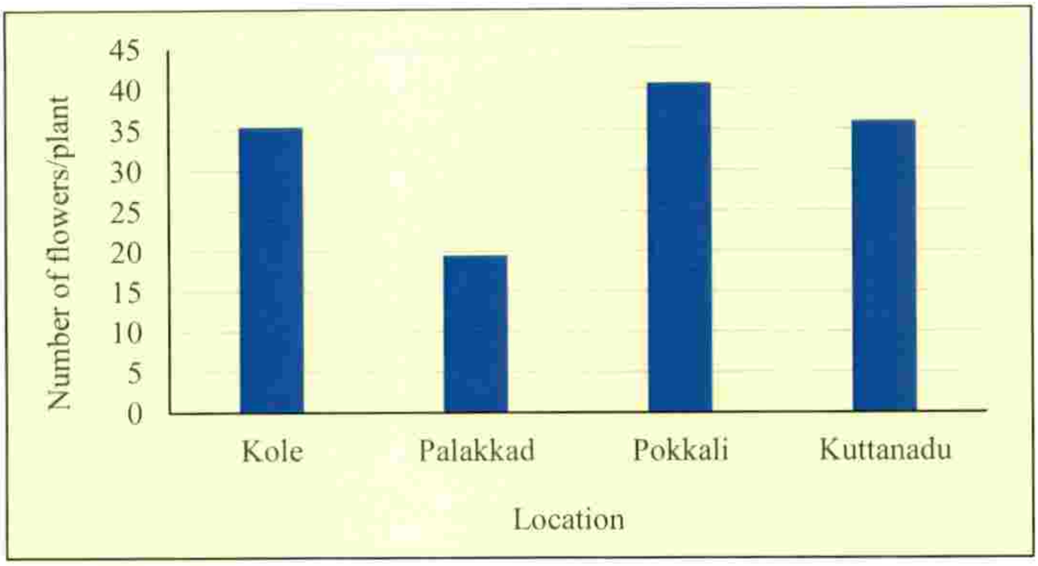


Fig. 6. Variation in no. of flowers per plant in different locations

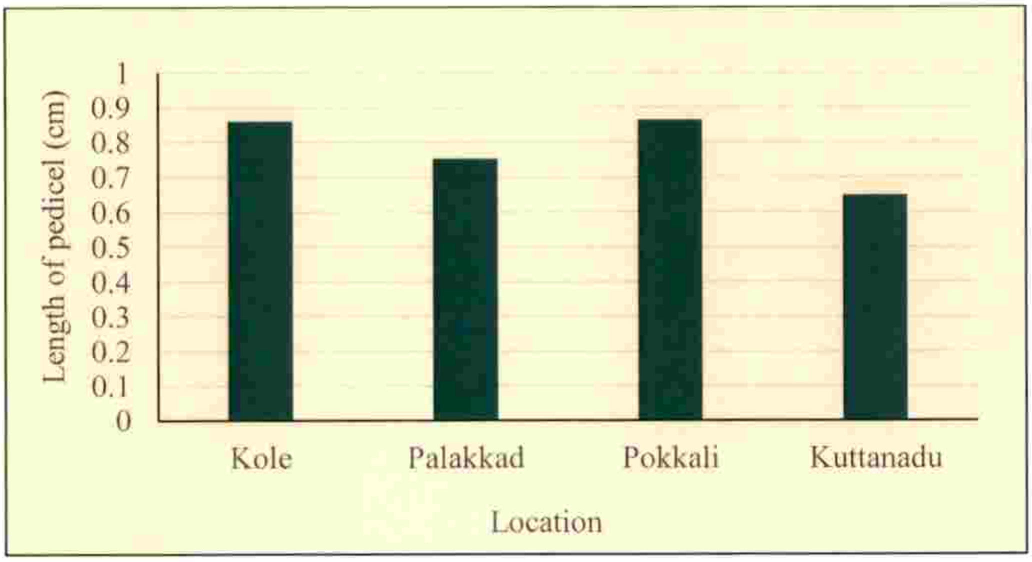


Fig. 7. Variation in length of pedicel in different locations

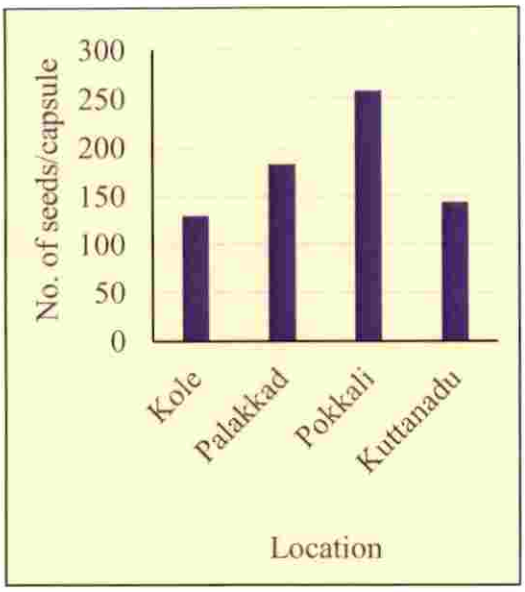


Fig. 8. Variation in no. of seeds per capsule in different locations

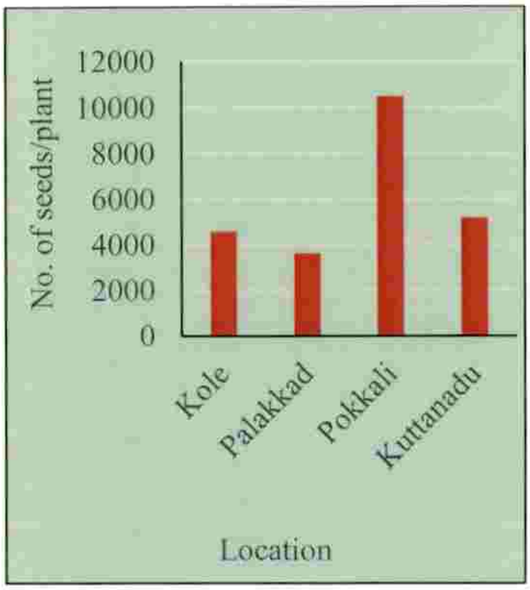


Fig. 9. Variation in no. of seeds per plant in different locations

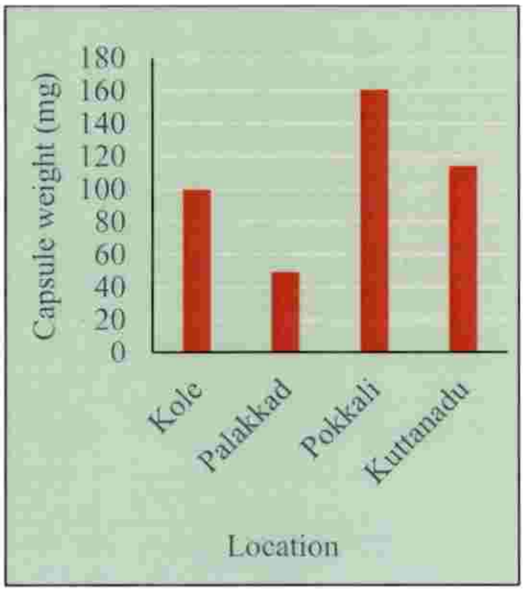


Fig. 10. Variation in capsule weight in different locations

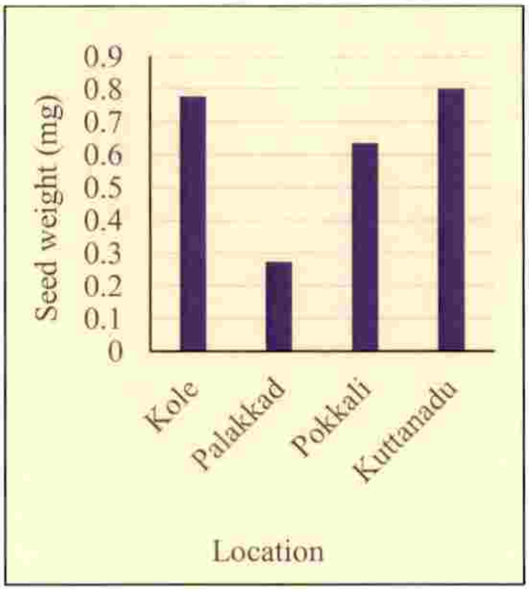


Fig. 11. Variation in seed weight in different locations

Table 20. Morphological description of *Monochoria vaginalis*

Characteristics	Description
Habit	Annual, semi-aquatic, emergent with potential to grow perennially through rhizomes
Habitat	Wet land paddy fields and irrigation channels
Stem	Modified into short rhizomes
Leaves	Arise at the end of long hollow petioles. Narrow elongated lamina at juvenile stage, which changed to lanceolate, and older plants had broad cordate leaves with acuminate apex
Inflorescence	Spike, opposite to the sheath of the floral leaf with a large bract, 4 to 9 flowers per inflorescence
Flower	Violet or lilac blue coloured, pedicellate, open in morning hours and close in afternoon
Fruit	Capsules with numerous seeds
Seed	Very small, weight less than 1 mg, longitudinally ribbed
Propagation	Mainly through seeds, and vegetative propagation by rhizomes
Seed dispersal	Capsules splits between the partitions into three valve and release the seeds when matured

5.1.4 Phenology

The pot culture experiments were started after March except for *Pokkali* condition, which were started in February, as the September to January collected seeds showed dormancy. But the seeds matured after March did not show any dormancy, and started the germination from the second day of sowing, indicated that season had an effect on germination. Many researchers reported that *Monochoria* seeds were dormant immediately after harvest (Kataoka and Kim, 1978; Momonoki, 1992; Chen and Kuo 1999).

Germination of *Monochoria* commenced within 2-7 days in all the germination experiments. This result was comparable with the findings of Chiang (1983), who documented that *Monochoria* emerged within 5 days in first season and in 2 days in second season in Taiwan.

The mean days taken for flowering ranged from 56 to 76, and seed matured in about 20 days from flowering, while Chiang (1983) observed 40 and 80 days for flowering in second and first seasons respectively and seed maturity in 14-28 days from flowering.

5.1.5 Correlation between morphological characters and soil chemical properties

From the result it was clear that *Monochoria* grew vigorously with increased soil fertility and favoured slightly acidic condition. Electrical conductivity was positively correlated with plant growth in a narrow range, but *Monochoria* could not tolerate salinity at high levels. It was observed that *Monochoria* plants dried up on saline water inundation in *Pokkali* region.

Guh and Lee (1974) reported that growth of *Monochoria* proliferated with increase in soil fertility. Kim and Moody (1980) recorded greater plant height, leaf area, dry weight, number of fruits and seeds per plant at high level of applied nitrogen. They also observed that yield losses due to *Monochoria* increased with fertility level. It was reported that *Monochoria* predominated when the organic matter content of the soil ranged from 2.1 to 2.8 per cent and the P ranged from 80-110 ppm (Kim, 1983). Vidya (2003) observed that *Monochoria* was dominant in plots with high amount of organic matter, and available N and P.

5.1.6 Leaf anatomy

The major portion of leaf lamina was occupied by air chambers, partitioned by transverse diaphragms. The upper epidermis was made of 3-4 layers of rectangular cells and the lower epidermis consisted of cylindrical cells. Vascular bundles were observed both in the adaxial and abaxial regions and in the vertical partitions. These observations were in conformity with findings of Narayanan and Kaliappan (2014). They found that the middle part of *Monochoria* leaf contained a horizontal row of wide air chambers, divided by vertical partitions. Vascular bundles were seen on both adaxial and abaxial epidermis, which consisted of thick rectangular and cylindrical cells respectively. de Sousa *et al.* (2016) observed air spaces divided by vertical partitions in leaf petiole, reproductive axis, inflorescence bract petiole and peduncle of Pontederiaceae family members. Jackson and Armstrong (1999) explained that increased number and size of air spaces in angiosperms was due to soil submergence.

The spongy parenchyma consisted of aerenchyma chambers, some of which were filled with bundles of parenchyma cells or contained idioblasts. Pereira *et al.* (2017) reported similar leaf anatomy in *Eichhornia crassipes*.

Calcium oxalate crystals in the form of raphides (cylindrical bundle of many thin pointed needles) were present in idioblasts or in specialised cells. Narayanan and Kaliappan (2014) got the same results in *Monochoria*. It was also observed by de Sousa *et al.* (2016) that plants in Pontederiaceae family possessed idioblasts containing phenolic compounds or raphide crystals in leaf petiole.

Franceschi and Nakata (2005) suggested that calcium oxalate crystals had a role in tissue calcium regulation, heavy metal detoxification and protection from herbivores. Some studies proposed that these crystals might be involved in water stress (Doupis *et al.*, 2016, Tooulakou *et al.*, 2016).

5.2 Part 2: Germination ecology of *Monochoria vaginalis*

Effects of environmental factors on germination of *Monochoria vaginalis* was investigated in lab conditions and as pot culture studies. Germination tests were conducted and the mean germination percentage was found to be 20 in glass vial with distilled water, while no germination occurred in Petri plates. Kataoka and Kim (1978) witnessed that no seeds germinated on wet filter paper with atmosphere as the air condition, while Chisaka and Kataoka (1977) reported that seeds incubated under low oxygen level exhibited a high germination percentage. According to Chen and Kuo

(1995), germination test for *Monochoria* seeds should be carried out by top paper method of ISTA with some modifications *i.e.*, the water level should be maintained at 2 to 6 mm above seed surface with a light period of 8 hours/day and a light intensity of 0.3-0.5 mol/m^2/day.

Monochoria seeds germinated on soil surface but not when placed below 2 cm depth (Plate 17). Many workers reported that *Monochoria* seedlings had emerged from the shallow soil layer, of less than 2 mm depth (Kataoka and Kim, 1978; Chen and Kuo, 1995; Koarai and Shibayama 2001). It was concluded that one of the factors suppressing the germination of *M. vaginalis* in deep soil might have been insufficient light (Pons, 1982, Wang *et al*., 1996).

Monochoria seeds kept in continuous dark condition failed to germinate irrespective of the temperature provided. It was concluded that *Monochoria* seeds required light for germination as confirmed by the findings of Chisaka and Kataoka (1977), Kataoka and Kim (1978), Chen and Kuo (1995), and Wang *et al*. (1996).

The seeds kept in solution of pH 6 and 7 germinated and no germination took place in pH 4, 5, 8 and 9. Kawaguchi *et al*. (1997) also observed that pH of 7.0 to 9.0 did not influence the germination. But in field conditions, pH and germination of *Monochoria* were in negative correlation, as long as the soil solution pH ranged between 4 and 7 as substantiated by Nozoe *et al*. (2018).

Saline solutions ranging from 25 to 250 mM NaCl inhibited the germination and the seeds germinated only in 0 mM NaCl concentration. Putra (2014) observed that at high concentration of NaCl, the growth of *Monochoria* reduced. Nozoe *et al*. (2012) observed a negative correlation between electrical conductivity and germination of *Monochoria*.

The seeds germinated at a temperature of 38°C in continuous light, and alternate light and dark condition, but did not germinate at 28°C and 33°C in any of the light conditions provided. The result was in contrast to the findings of Chen and Kuo (1995), who observed 30.4°C as the optimum temperature for germination. Park

a) 0 cm

b) 15 cm

Plate 17. Germination of *Monochoria* at different depth of burial after 2 week

a) 5 cm flooding for 2 days

b) 10 cm flooding for 2 days

Plate 18. Germination of *Monochoria* at different flooding depth and duration after 2 week

et al. (2010) observed that both seedling emergence and initial growth occurred early at elevated temperature (28°C) than ambient temperature (25°C) as the Effective Accumulated Temperature (EAT) was obtained early in elevated temperature.

The results showed that seed germination in *Monochoria* is significantly influenced by flooding depth and duration. Greater germination was obtained when seeds were kept at saturated and low flooded depth for more than 4 days. Increased flooding depth decreased the germination percentage, but growth of germinated plants was more (Plate 18). Pons (1982) observed that *Monochoria* plant had adaptation to flooded condition. Matsuo and Shibayama (2000) obtained results that water condition and size of soil particles were important factors for establishment of juvenile seedlings of *M. vaginalis*, and adhering strength of seedlings was more in a saturated puddled soil than in a flooded soil where soil hardness was alleviated by flooded water. It was observed that in field conditions, plant height, leaf area and dry weight of *Monochoria* decreased, and anatomical structures were changed at greater flooded depth (Putra, 2014).

From the current investigation, it was clear that *Monochoria vaginalis* germinated only in light condition under anaerobic, saturated or submerged condition. In paddy field the germination required slightly acidic pH, but growth was retarded under saline conditions. Elevated temperature up to 38°C favoured the germination.

5.3 Part 3: Efficacy of post-emergence herbicides on *Monochoria vaginalis* - Pot culture study

All the tested herbicides namely, 2,4-D sodium salt, Almix®, ethoxysulfuron, bispyribac sodium, penoxsulam and penoxsulam + cyhalofop butyl, were found to be very effective in controlling *Monochoria* after two weeks of application, and no plant survived. These results are in conformity with the findings of Atheena (2016) who observed complete control of *Monochoria* when cyhalofop-butyl + Almix, cyhalofop-butyl *f.b.* Almix, ethoxysulfuron and bispyribac sodium were applied at 30 DAS of rice.

Lamid (1981) and Mann *et al.* (2017) observed that 2,4-D applied at fourth leaf stage completely killed *Monochoria*. Application of metsulfuron methyl 10% + chlorimuron ethyl 2% WP effectively controlled the weed (Mahbub *et al.*, 2017, Singh *et al.*, 2018). Endo *et al.* (2008) and Zhu *et al.* (2012) recorded good control of *Monochoria* on ethoxysulfuron 15% WG application. Bispyribac-sodium in combination with bensulfuron methyl (Mahbub *et al.*, 2018), metamifop (Raj and Syriac, 2016) and thiobencarb (Kobayashi *et al.*, 2007) provided complete control of *Monochoria*. Patra *et al.* (2017) recorded 70 per cent weed control efficiency for bispyribac acid 40% EC @ 52.5 g a.i./ha. Choudhury *et al.* (2016) also reported the kill of *Monochoria vaginalis* by 2,4-D ethyl ester, Almix®, ethoxysulfuron and bispyribac-sodium.

Penoxsulam @ 35 g a.i./ha caused 99% of *Monochoria* to develop phytotoxicity symptoms 20 days after application (Mann *et al.*, 2017) and 20 g/ha applied at 8-12 DAT provided 95% control (Kumar *et al.*, 2009). The premix, penoxsulam 10 g a.i. + cyhalofop butyl 50 g a.i., @ 60 g a.i./ha at 10-15 DAS effectively controlled *Monochoria* (Yao *et al.*, 2013) and when applied @ 1, 1.25, 1.5 L/ha provided 95-100% control of *Monochoria* (Lap *et al.*, 2013).

From this study it is concluded that all the six post-emergence herbicides tested can be recommended to control *Monochoria vaginalis* in rice at 20 DAS.

The present investigation provided information on the biology and ecology of *Monochoria vaginalis* in the rice ecosystems of Kerala and its chemical control. The efficacy of new generation herbicides for controlling the weed need to be confirmed in field conditions. Also the prospects of utilizing the weed as vegetable, cattle feed and for compost making needs to be explored.

Summary

6. SUMMARY

The research programme entitled 'Morphology, ecology and management of *Monochoria vaginalis* (Burm. f.) Kunth' was taken up from September 2018 to June 2019 at the Department of Agronomy, College of Horticulture. Survey, pot culture and lab experiments were conducted to study the morphology, germination ecology, and to test the efficacy of select herbicides against *Monochoria vaginalis*.

Surveys were conducted in the main rice tracts of Kerala viz., *Kole*, Palakkad, *Pokkali*, and *Kuttanad*. *Monochoria vaginalis* was found to occur in all the four locations. *Monochoria* coexisted with rice and occupied the irrigation channels, but was not seen in drier parts of surveyed locations.

Monochoria vaginalis was observed to be a broad-leaved monocot having fibrous root system, and the stem was modified into a short rhizome from which soft hollow leaf petioles arose. The plant height varied from 10 to 60 cm, number of leaves from 5 to 16, leaf area from 10 to 70 sq. cm, and the dry weight ranged from 1.92 g to 5.7 g per plant. *Monochoria* at flowering stage had shiny ovate-accuminate heart shaped leaves, while the plants at juvenile stage had somewhat narrow elongated leaves. The micrograph of the transverse section of leaf showed that the middle portion of leaf lamina was occupied by wide air chambers. The leaf contained calcium oxalate crystals in the form of raphides in idioblasts or in specialised cells.

The flowers of *Monochoria vaginalis* were bluish purple in colour and pedicellate, and borne on a spicate inflorescence arising from leaf petiole opposite to the floral leaf. The number of flowers varied from 4 to 9 per inflorescence and the total number of flowers per plant ranged from 6 to 48. The flowers opened in morning and afterwards were spirally contorted. Inflorescence bent downwards after flowering and capsules were formed. At maturity they split into three valves and released numerous seeds that were longitudinally ribbed.

Monochoria propagated mainly through seed. The mean number of seeds per capsule ranged from 116 to 277, total number of seeds per plant from 3400 to 11,300 and 1000 seed weight from 0.27 g to 0.82 g. It could also propagate by vegetative means through rhizomes.

Monochoria vaginalis was more proliferate in *Pokkali* areas compared to all other locations, and the weed in Palakkad rice tract registered lowest vegetative growth. The plant showed great variation with location in morphology, which might have emerged due to the ecological situation including soil factors prevailing in the tract. *Monochoria* grew vigorously with increased soil fertility and favoured slightly acidic condition, but could not tolerate electrical conductivity at high levels.

The seeds of *Monochoria vaginalis* showed dormancy immediately after harvest in September to February. The germination commenced within 2-7 days in all the germination experiments done after March, by which time dormancy was broken. The mean number of days taken for flowering ranged from 56 to 76, and seed matured in about 20 days after flowering.

The findings of the experiments on germination ecology of *Monochoria* is summarised below:

- *Monochoria* seeds germinated on soil surface, but not when placed below 2 cm depth.
- The seeds germinated in solutions of pH 6 and 7, but did not germinate when immersed in buffered solutions of pH 4, 5, 8, and 9.
- Saline solutions with concentrations ranging from 25 to 250 mM NaCl inhibited the germination, and the seeds germinated only in 0 mM NaCl concentration, or non-saline solutions.
- Seeds kept in continuous dark condition failed to germinate irrespective of the temperature provided.

- The seeds germinated at a temperature of 38°C in continuous light, and alternate light and dark condition, but did not germinate at 28°C and 33°C in any of the light conditions provided.
- Seed germination in *Monochoria* was significantly influenced by flooding depth and duration.
- Greater germination was obtained when seeds were kept in saturated soil condition and low flooding depth (*i.e.*, less than 5 cm) for more than 4 days.
- Increased flooding depth decreased the germination percentage, but increased growth of germinated plants.

The experiment on efficacy of post-emergence herbicides on *Monochoria vaginalis* brought out the following findings:

- Application of 2,4-D sodium salt @ 0.8 kg/ha resulted in epinasty within two days of spraying.
- Almix® @ 0.004 kg/ha caused slight discoloration of leaves and petioles after one week.
- Plants exposed to ethoxysulfuron @ 0.015 kg/ha exhibited partial drying after one week of application.
- Bispyribac sodium @ 0.025 kg/ha caused drying of leaves from the tip within seven days.
- Penoxsulam @ 0.025 kg/ha resulted in tip burning of leaves after one week of application.
- Penoxsulam + cyhalofop butyl application @ 0.15 kg/ha resulted in yellowing of leaves after five days.
- All the tested herbicides were effective in causing kill of *Monochoria*.

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MORPHOLOGY, ECOLOGY AND MANAGEMENT OF *Monochoria vaginalis* (Burm. f.) Kunth

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ABSTRACT OF THE THESIS

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ABSTRACT

Knowledge on biology and ecology of weeds and its interaction with rice plays a key role in weed management. In the research programme entitled 'Morphology, ecology and management of *Monochoria vaginalis* (Burm. f.) Kunth', *Monochoria vaginalis*, a broad-leaved monocot weed of wet land paddy was seen to occur in all the major rice ecosystems of Kerala *viz.*, *Kole*, Palakkad, *Pokkali*, and *Kuttanad*, but was not seen in drier parts. It is an emergent annual hydrophyte herb, and has the potential to grow perennially through rhizomes. The plant showed great morphological variation with location, due to the prevailing ecological situation including soil factors. *Monochoria* grew vigorously with increased soil fertility and favoured slightly acidic condition, but could not tolerate high salinity.

Monochoria vaginalis was observed to have fibrous root system, with the stem modified into a short rhizome from which soft hollow leaf petioles arose. The plant height varied from 10 to 60 cm, number of leaves from 5 to 16, leaf area from 10 to 70 cm^2, and the dry weight ranged from 1.92 g to 5.70 g per plant. The leaf shape changed from narrow in the juvenile stage to cordate in the mature stage and the major portion of leaf lamina was occupied by air chambers.

About 4 to 9 bluish purple coloured flowers were borne on spicate inflorescences and the total number of flowers per plant ranged from 6 to 48. The flowers opened in the morning and were spirally contorted later. Inflorescence bent to form capsules, which split into three valves at maturity and released numerous longitudinally ribbed seeds. *Monochoria* is propagated mainly through seeds, and showed dormancy immediately after shedding, which may be influenced by the season. The mean number of seeds per capsule ranged from 116 to 277, total number of seeds per plant from 3400 to 11,300 and 1000 seed weight from 0.27 g to 0.82 g.

The effect of depth of burial and flooding depth and duration on germination of *Monochoria vaginalis* was studied by two separate pot culture

experiments. *Monochoria* seeds germinated on soil surface, but when placed below 2 cm depth, germination was inhibited due to lack of light. The seed germination in *Monochoria* was significantly influenced by flooding depth and duration. Greater germination was obtained when seeds were kept at saturated and low flooded depth of less than 5 cm for more than 4 days. Increased flooding depth decreased the germination percentage.

Influence of environmental factors like light and temperature, pH, and salinity on germination of *Monochoria vaginalis* was investigated separately in lab conditions. The seeds kept in solutions of pH 6 and 7, germinated while no germination took place in solutions of pH 4, 5, 8 and 9. Saline solutions with concentrations ranging from 25 to 250 mM NaCl inhibited the germination, and the seeds germinated only in 0 mM NaCl concentration, or non-saline solutions.

Influence of light and temperature was studied in a seed germinator, in which light, temperature, and humidity conditions could be regulated. Seeds kept in continuous dark condition failed to germinate, irrespective of the temperature provided. Germination was observed at a temperature of 38°C in continuous light, and alternate light and dark condition, but did not germinate at 28°C and 33°C in any of the light conditions provided. From the current investigation, it was clear that *Monochoria vaginalis* germinated only in light condition under anaerobic, saturated or submerged situation.

All the tested herbicides namely, 2,4-D, Almix®, ethoxysulfuron, bispyribac sodium, penoxsulam and cyhalofop butyl + penoxsulam, were found to be very effective in controlling *Monochoria* by two weeks after application. However, 2,4-D caused severe injury on the weed immediately after application and brought about complete kill within one week of application. The premix herbicide, cyhalofop butyl 5.1 % + penoxsulam 1.02 %, was also good at killing *Monochoria* within a short period. From this study it is concluded that all the six post-emergence herbicides tested can be recommended to control *Monochoria vaginalis* in rice at 20 DAS.