General Introduction

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Introduction

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A preliminary study on the growth potential of Colocasia esculenta (Taro) in a natural habitat
1.1.1 Problem statement and fields of interest

The impacts due to the presence of weeds in any productive system involving plants may be viewed at two levels: damage to absolute yield of the product and damage to the value of the product. These are the quantity and quality damage functions of the economist, that in some manner relate weed abundance to loss of financial income. The cosmopolitan occurrence of many such weed species often bear witness to three common characteristics: means of dispersal, colonizing potential and regenerative capacity. These key features tend to ensure their success and elevate them to human attention (Cousens and Mortimer, 1995). The seriousness of the weed menace can be gauged from the fact that in Florida (USA) alone, about US $20 millions were spent just for keeping the prominent weed, water hyacinth spread under control (Abbasi et al., 1988; Ramasamy, 1997). Department of agriculture and rural development, West Africa for the year 2004 - 2005, has reported that the African development fund (ADF) for the control of the invasive aquatic weeds has provided a loan of about US $16.2 millions. Rest of the world also continue with their efforts to control the weeds especially the aquatic / wetland weeds, as they become major environmental nuisance for the water resources (Harouna et al., 2004).
The potential of such weeds to alter ecosystem structure and function has been broadly recognized. Fire, regime, hydrobiological patterns, ecosystem nutrients and energy budgets may also be modified, and the abundance or survival of native species are adversely affected by the weed.

Plant invasions into natural ecosystems are one of the major threats to the conservation of biological diversity across nearly all biogeographical regions on Earth. It is likely that the invasion of weeds into natural areas has been associated with human movements throughout our evolutionary development, but as is now widely recognized, the rate of this process has been recently accelerated considerably. A combination of factors, including developments in transport technology, changes in life-style patterns (particularly in the 'western' world), and a seemingly cosmopolitan interest in the introduction and utilization of exotic plant species, have all been powerful forces in shaping the changing flora of natural areas world-wide. The general trend of an increase in introduced components of natural vegetation accompanied by a decrease in native components has also been greatly assisted by the increasingly extensive exploitation of natural areas, which can alter natural disturbance regimes and thereby provide enhanced opportunities for the colonization and establishment of introduced plants (Adair and Groves, 1998).

The economic impacts are both direct and indirect. Direct impact reflects the effect of the invader and indirect impact implies general effects that are caused by the presence of the invader, which could affect public health. In 2001, Food and agricultural organization (FAO) identified six types of economic impacts of invasion: (i) on production, (ii) on price and market effects, (iii) on trade, (iv) on food security and nutrition, (v) on human health and environment, ecological and economic cost associated, (vi) financial cost impacts (Sharma et al., 2005).

1.1.1.1 Weeds
No single definition of the term ‘weed’ has been coined to universal satisfaction, but most definitions are anthropocentric. In simple terms, weeds are plants, which grow in places where they are not wanted (ICAR, 1997). However, a particular plant is a weed only in terms of human attitude. Before man tilled the soil, the concept of plants out of place had not been conceived; as man developed plants for higher production, weeds seem to have followed so that now we have weeds that are adapted to the same environment as our major crops. Thus, weeds become an important part of our environment and losses from weeds are of several kinds because weeds are undesirable for various reasons (Chandler, 1981).
Weeds by virtue of their characteristics of adaptation under any type of environment compete with crop plants successfully. They shape themselves under changed circumstances. Majority of the weeds are highly aggressive, hardy and able to defy common means of control. Enormous seed production, variation in seed dormancies and power of vegetative propagation makes them almost immortals in agro-ecosystems. Weeds can thrive well even under severe hydro, nutritive and biotic stresses where crop plants cannot survive. The harm done by weeds is both direct and indirect. They cause more losses than insect pests and diseases combined in many ways (Raju, 1998). They increase the expenditure on labour and equipment, render harvesting difficult and reduce the quality and marketability of agricultural products (ICAR, 1997). India has the largest canal network in the world where the velocity of flowing water is reduced by about 30 - 40 percent due to the presence of aquatic weeds; their growth in the rivers render navigation very difficult (Abbasi et al., 1992a; Ramasamy, 1997; Ramasamy and Abbasi, 1999, Gunnarsson and Peterson, 2007).

1.1.1.2 Weed menace
Aquatic weeds are those unabated plants, which grow and complete their life cycle in water and cause harm to aquatic environment directly and to related eco-environment relatively.

Whenever the spread of such aquatic weeds are not controlled or reach a stage beyond the control, due to limited resources or other reasons they rapidly spread over the water bodies and surrounding marshy land areas in those regions (Plate I). Such weeds, in general, have good growth rate, for example, the aquatic weeds such as water hyacinth has an average annual productivity of 50 - 60 dry (ash free) tonnes per hectare per year. This attribute - of explosive growth rate - helps the weed to cover large water surfaces faster than most other plants (Abbasi and Ramasamy, 2001). Such colonization of weeds diminishes the quantity and quality of water in wetlands - eventually causing the loss of wetlands (Gajalakshmi et al., 2001a). Based on the reports of Department of agriculture and rural development, West Africa for the year 2004 - 2005, it was estimated that the annual losses due to such weeds in the West African region vary from US $ 28 to 56 millions for fisheries, from US $ 4 to 6 millions for health, from US $ 7 to 14 millions for hydro-energy, and from US $ 36 to 72 millions for agriculture. Consequently, the total annual losses would vary from US $ 75 to 150 millions (Harouna et al., 2004).
1.1.1.3 Weed management strategies

Historically, weed control measures have been pursued to minimize the damage done by weeds. The weed control practices involved periodic habitat disturbance, typically the virtual destruction of plant biomass. These measures were often applied regardless of the size of the weed infestation and may have become part of a cultural heritage. In spite of the constantly changing agricultural practices, mechanical, biological or chemical methods of weed control employed separately are but minor forces towards accomplishing the objective of most weed control programmes (Slife, 1981). The efforts of chemical or biological control methods are fraught with three basic disadvantages:

- The costs are high.
- The introduction of chemical or bioagents on a large-scale has the serious risk of environmental pollution. The chemicals may cause toxicity to non-target organisms while bioagents may proliferate beyond their demographic level and become major pests themselves, and
- Most important of all, the destruction of one weed invariably paves the way for another of such quality or more problematic weed with greater resistance than the prevailing weeds for chemical or biological agent (Abbasi and Nipaney, 1984).

Unfortunately, the advent of chemicals and their large-scale application in the name of fertilizers and biocides has drastically changed the structure of the soils and in most cases eliminated the soil organisms (Ismail, 1997).

1.1.1.4 Colocasia esculenta

*Colocasia esculenta* is a widely distributed food crop and is locally important in many parts of the humid tropics and sub-tropics. It fits well into multiple tree cropping and agroforestry systems. Some types adapt well to multiple habitats such as marginal lands and swamps while others are grown under intensive cultivation as starch crops. The centers of its diversity are in Northeast India, Southeast Asia and Malaysia. Debate and research continue on the centers of origin of this global crop. Northeast India and Malaysia are the possible separate centers of origin and domestication. It is commonly known as ‘Taro’, ‘Dasheen’, ‘Potato of the tropics’, ‘Elephant ears’, ‘Eddoes’, ‘Malanga’, and ‘Cocoyam’ in the Caribbean and West Africa (Tanimoto *et al*., 1983).

Taro, a common herb, wild or cultivated is found in almost all districts of Kerala, India. It is a rooted emergent type of plant, spreads all over the marshy places on the banks of small streams, canals, ponds etc. (Plate II). When it occurs in the wild, this is
Plate I: *Colocasia esculenta* found in marshy areas

Plate II: *Colocasia esculenta* found near streams and canals
considered a nuisance weed. *C. esculenta* locally known as ‘Kattuchembu’ is fast emerging as one of the troublesome weeds in Kerala (Bindu and Ramasamy, 2005, 2007, 2008).

The wild progenitor of the crop is unknown in literature. The wild form has stolons, semi-stolons or tubers with mother corms of variable sizes and shapes. These occur widely in Kerala and in some parts of Karnataka and Tamil Nadu as swarms in waterlogged areas, wastelands and along drains (Sivarajan and Mathew, 1997; Ghosh, 2005). They are very aggressive colonizers, propagating quickly by stolons. Their thick vegetation causes harm to water bodies, irrigation canals; sewage-ditches in the same way as water hyacinth harm the aquatic environment. When *C. esculenta* spreads on marshy or surrounding land areas where soil moisture is prevalent—especially during monsoon and post monsoon seasons - they develop into thick bushes harbouring insect pests and poisonous creatures like scorpions and snakes. When they spread over marshy wetlands, they become breeding ground for mosquitoes and other disease vectors (Plate I).

As cited, like all other weeds *C. esculenta* is also bestowed with excellent growth potential. The high productivity of such weeds can be an asset only if ways and means are found to utilize them profitably. Otherwise, the weeds become a major nuisance to the environment (Gupta, 1979; Abbasi and Nipaney, 1986; Ramasamy, 1997; Ramasamy and Abbasi, 1999) and they cause immense harm to the water resources by occupying lakes, ponds and canals and thus reducing the carrying capacity of these water bodies (Abbasi and Ramasamy, 1999a).

Ethnobiological studies reveal that specific socio-cultural and use factors underlying distinct selection pressures on Taro germplasm, maintained genetic diversity (Mathews, 1997). The wild form also possess characteristics of the typical weed and can be considered to have co-evolved with the crop from a common ancestor if limited gene exchange can be proved to exist in nature (Velayudhan *et al*., 1991).

### 1.1.1.5 Weed utilization - A feasible managerial practice

It has been found that chemical or biological control of weeds poses several problems to not only the plants, human beings but also to the livestock. At this particular juncture, a viable option in order to control the spread of these weeds is ‘weed utilization’. Long-term control of the weed requires heavy initial clearance followed by regular periodic removal of the regrown weeds. If the cost of this periodic harvesting of the weeds can be offset by proper utilization, the mechanical or manual removal of the weeds may provide an answer to the weed infestation problem in an environmentally safe manner.
(Abbasi and Nipaney, 1993; Ramasamy, 1997; Abbasi and Ramasamy, 1999a, 2001; Bindu and Ramasamy, 2005, 2007, 2008; Kurien and Ramasamy, 2006).

The major weed utilization options available are listed below:

1. **As bioagent in wastewater treatment**

In spite of the various negative characteristics of weeds, the high productivity and nutrient removal capability has created substantial interest in their photosynthetic and physiological characteristics and in their potential use for beneficial purposes like wastewater treatment (Reddy and DeBusk, 1984, 1985). The natural processes associated with living plants make them ideal for use in the remediation of selected contaminants in soil and water. Plants can be used to contain, uptake and / or mineralize toxic organic compounds.

‘Phytoremediation’ may be defined as the utilization of vascular plants, algae and fungi to control, breakdown, or remove wastes, or to encourage degradation of contaminants in the rhizosphere, or root region of the plant (McCutcheon and Schnoor, 2003). This may be more cost-effective than any other engineered intensive systems, in remediating contaminants that are dispersed over a large area and / or they are at low levels.

2. **As source of energy**

Several highly developed technologies are available for converting biomass into energy. Of these options, thermal and thermo-chemical conversions are widely used for obtaining energy from terrestrial biomass, especially woody material. Amongst fermentation based technologies, aerobic fermentation is used on a large-scale for obtaining alcohol from sugarcane juice and other carbohydrate rich agricultural products. However, these options are unsuitable for a wetland / aquatic biomass mainly because the water content of the aquatics is very high - 60 to 95 %. Drying these to a level at which they can be used in thermal and thermo-chemical processes are too costly to be practicable. Likewise, the sugar content of these weeds is too low to make them attractive as raw material in alcohol productions. The most appropriate and feasible process for energy production from aquatic biomass is anaerobic digestion (Abbasi et al., 1988; Abbasi et al., 1992b; Ramasamy, 1997; Abbasi and Ramasamy, 1999b; Asha et al., 2007; Bindu and Ramasamy, 2005, 2007, 2008).

3. **As source of compost and vermicompost**
These weeds can also undergo an aerobic decomposition process commonly referred to as ‘composting’ in which the entire organic matter is stabilized. It may be defined as ‘the bioconversion of organic wastes into an amorphous dark brown to black colloidal humus like substance under conditions of optimum temperature, moisture and aeration’ (Abbasi and Ramasamy, 2001). The process requires three to six months for completion, depending on the temperature and amount of turning. Due to the hygroscopic nature of these weeds, this compost has high retention properties. It is an excellent organic soil supplement for sandy soils (Abbasi and Ramasamy, 2001).

Weeds can also be subjected to vermicomposting: either directly as fresh harvested plants or after partially composting it (Ramasamy, 1997; Abbasi and Ramasamy, 1999b; Gajalakshmi et al., 2002a; Kurien and Ramasamy, 2006; Bindu and Ramasamy, 2005, 2008).

4. As livestock feed

Perhaps the most important management practice, what could be termed good husbandry, also includes proper grazing practices besides other means (Slife, 1981). Some of our domestic animals, particularly cow, sheep and goats have long been used for weed control.

Although the nutrient rich biomass shows great promise as a cattle feed supplement, to date no economical drying facility for large-scale dehydration of the aquatic/wetland weeds has been designed which will work efficiently in humid climates (Frank, 1976). This is due to the hygroscopic nature of the plant. The moisture content of these weeds must be reduced from an initial value ranging 60-95% to less than 15% in order to prevent rapid spoilage.

1.1.2 Present work

The present study explores the possibility of weed utilization as a management option. *C. esculenta* commonly known as ‘Taro’ and locally known as ‘Kattuchembu’ is fast emerging as one of the troublesome weeds in Kerala. An attempt was made in this study to utilize this weed in various ways so that the utilization becomes a viable weed management option. *C. esculenta* was used as a bioagent in aquatic macrophytes-based treatment system (AMS) treating domestic, synthetic as well as industrial wastewater. The mature and grown up plants harvested from such AMS/natural water bodies were subjected to anaerobic digestion for the recovery of energy as biogas. The spent weed
ensuing from the anaerobic reactors was further subjected to composting and vermicomposting. Thus, the troublesome weed, *C. esculenta* was completely and effectively utilized for the recovery of energy and manure. Besides the cited utilization options, an attempt was also made to study the potential of this weed as animal fodder.

**1.1.3 Objectives**

1. To explore the potential of *C. esculenta* as a bioagent in remediating wastewater individually as monoculture and in combination with a few other aquatic weeds as polyculture in different types of aquatic macrophytes-based wastewater treatment systems (AMS).
2. To study the efficiency of diphasic anaerobic systems in extracting a mixture of volatile fatty acids (VFAs) from *C. esculenta* and subsequently converting the VFAs into methane rich biogas using a biomethaniser.
3. To investigate the effectiveness of high-solids anaerobic digestion (HSAD) systems with *C. esculenta* as feedstock in producing clean fuel-methane.
4. To evaluate the potential of a novel combination of phase separation and HSAD systems in anaerobic multiphase high-solids digestion systems (AMHDs) - in converting *C. esculenta* into biogas rich in methane.
5. Bioconversion of the spent weeds from the anaerobic digesters – into manure through composting and vermicomposting.
6. To assess the suitability of the weed, *C. esculenta* as animal fodder.

**1.1.4 Organization of the thesis**

This thesis consists of six parts:

Part I - gives a general introduction to weeds, weed menace and weed control options. The growth potential of *C. esculenta* in a natural habitat has also been detailed.

Part II - describes *C. esculenta* as a bioagent in wastewater treatment. This part consists of seven chapters. Chapters I and II include a general introduction to wastewater treatment and literature review. Remaining chapters deal with the different types of treatment systems and different kinds of wastewaters used in the study. Summary and conclusion to this part has also been included as a separate chapter.
Part III - evaluates the possibilities of deriving methane rich biogas from *C. esculenta* through anaerobic digestion using different types of anaerobic digesters.

Part IV - details the bioconversion of spent weed mass ensuing from the anaerobic digesters into nutrient rich manure using composting and vermicomposting.

Part V - explores the potential of *C. esculenta* as animal fodder.

Part VI - gives an overall summary of the work with findings and conclusions drawn out of it.
1.2.1 Introduction

*Colocasia esculenta* (L.) Schott is a wetland herbaceous plant. It is an important edible tuber crop used as tuber vegetable and as a secondary staple food in many countries. However, when it occurs in the wild, it becomes a nuisance weed. Its abundance in the wetlands, marshy lands, banks of streams, canals as well as in the sewerages carrying domestic wastewater has been well documented (Mbuligwe, 2004; Kurien and Ramasamy, 2006; Bindu and Ramasamy, 2005, 2007, 2008). However, only little informations are documented on the growth and abundance of Taro when it occurs in the wild. The available published literature on the topic are mostly based on wetland crop grown over a period of 12-15 months in Hawaii. In Kerala, India, Taro is grown mostly on upland situations either on dry land or in paddy fields. The taro varieties grown in Kerala mature within 5 to 6 months. Because of the shorter life cycle, the growth and development of Taro under such situations are different from that of wetlands as in Hawaii (Mohan Kumar and Sadanandan, 1989).

When compared to many other exotic and invasive species of aquatic macrophytes like water hyacinth, *Salvinia*, *Pistia* etc., the literature on the growth potential of *C.esculenta* is very scarce. Besides a few works on Taro by Mohan Kumar and
Sadanandan (1989) and Asokan and Vikraman, (1984), the scarcity of literature has urged us to make a study on the growth rate of *C. esculenta* in a natural habitat.

### 1.2.2 Materials and methods

#### 1.2.2.1 Sampling site

The study was conducted from May to November 2004, in the instructional farm (Plate III) at a latitude of 9° 39' 13" N and 76° 31' 53" E, in close proximity to the School of Environmental Sciences, Mahatma Gandhi University, Kottayam. The study area experienced a well balanced tropical climate, varying little from season to season. The ambient temperature ranged from 27-31°C.

#### 1.2.2.2 Sampling technique: Collection and preservation

The experiment was laid out at random in 1x1m quadrates, confounded split plot design, with three replications and the representative plants were harvested above sediment surface once in every thirty days of the study period. Total number of plants present in the plot was counted, marked, recorded and about 3-6 representative plant samples were harvested every month. The harvested plants belong to different categories such as mature, medium and young ones. The categorization was done based on the plant height. In the next thirty days, another permanent quadrate among the three replicates was used for counting the number of plants.

Population changes were studied by measuring the number of plants, plant height, diameter of the petiole, total numbers of leaves, leaf area and leaf area index (LAI) as per the methods of Kvet and Marshall (1971). Leaf area was calculated by tracing the outline of the fully expanded leaves.

The density of the stand at each site was determined by counting the total number of plants and dividing it by the number of quadrates studied in the field every month. Plants were separated into young, medium and mature ones. The biomass and density of the plants in each class was determined during the study period.

Dry matter production was estimated by the periodic harvest (Vollenweider, 1974). At each harvest, the plants were separated into belowground (BG) and aboveground (AG) organs. BG organs include the roots and the rhizomes, while the AG organs include petiole and leaves. Different fractions were washed thoroughly in running water, separated and dried to constant weights at 105°C. Dry weight of a single plant was calculated from the total dry weight per metre square divided by the number of plants.
Part III: Growth study area of C. esculenta
Growth rate studies are valuable when discussing the different strategies used by plants to achieve their productivity and to compete (Kvet, 1971; Still, 1996). The crop growth rate (CGR), was computed by dividing the biomass change by days. The mean relative growth rate (RGR) was calculated from the formula

\[ \text{RGR} = \frac{\ln(D_f / D_i)}{t} \]

where ‘\(D_i\)’ is the initial biomass (per sq.m or per plant)
‘\(D_f\)’ is the biomass after \(t\) days

Soil samples were collected in polythene bags from rooting depth (up to 20 cm) using an auger. The samples were generally processed immediately with only a few exceptional cases, where the processing was delayed for 2-3 days, during such occasions, the samples were refrigerated. The samples were refrigerated to minimize the nutrient loss. The samples were first air-dried under shade for 30 min and subsequently oven dried at 80°C over night and sieved through 5 mm mesh. The sieved samples were subsequently oven dried at 105°C for 24 h, then powdered and sieved.

Chemical analysis of the soil samples for nitrogen (N), phosphorus (P) and potassium (K) were done as per the methods of Jackson (1973) and APHA (1998).

1.2.3 Statistical analysis
Statistical analysis for the growth rate was done by two-way analysis of variance (ANOVA) in order to find out the statistical significance of the results (Snedecor and Cochran, 1980).

A comparative study on the nutrient status of the soil and the growth rate was also done by the analysis of variance.

1.2.3 Results and discussion
Marked seasonal patterns of plant growth and senescence were observed in the study area. Active growth was not observed during the latter period of the study (October-November).

The vegetative growth phase of the plants was completed by the end of September.

1.2.3.1 Plant analysis
Part I

General Introduction

Studies on the potential of Colocasia esculenta (L.) Schott in wastewater treatment and recovery of energy

i) Plant height

The data on the plant height on various months of the growth study is presented in Table 1.2.1. The increasing trend was observed from the month of May and reached a peak in July (from 34.01 to 50.05 cm), and thereafter the height increment was found less during the following months.

ii) Plant diameter

It was noticed in the present study that as the height increased the diameter also tended to increase from the month of May (1.18 cm), attaining a maximum of 1.97 cm in July and then declined (Table 1.2.1).

iii) Leaf area, leaf area index (LAI) and number of leaves

Similar were the observations in leaf area and LAI with that of plant height and diameter (Table 1.2.1). The values attained maximum during the month of July and thereafter decreased.

When assessing the leaf count during the study period, it was noticed that their number was highest during the initial month of May, tended to decrease during the following months and again increased during the month of November (Table 1.2.1).

iv) Plant density

The density varied from 24.33 to 60.67 per sq.m between May to November.

The maximum average plant density of 60.67 plants / sq.m was observed in May, which declined to 50.33 plants / sq.m in July and became the least in September with an average density of 24.33 plants / sq.m. This trend slightly improved thereafter and attained 42.0 plants / sq.m in November. However, as the plant density in these quadrates was above 10 in different months they were grouped as high-density quadrates.

v) Dry matter production

The live biomass was low during the start of the study (Table 1.2.1), but it improved significantly during the month of July with an average mass of 0.605 g/g (dry /fresh weight) and then slightly declined (0.405 g/g) in September, but it was the least during November (0.074 g/g).
vi) Growth rate

On an average, the relative growth rate was calculated to be 0.01 g/g d\(^{-1}\) (0.424 g/m\(^2\) d\(^{-1}\)) from May to November, 2004.

The growth rate of *C. esculenta* is close to that of some of the fast growing aquatic weeds. A recent study conducted by the Ministry of Environment and Forests (MoEF), Government of India, on the assessment of explosive aquatic weed growth and their impact on the Kuttanad wetland ecosystem, Kerala, India has found that of the 126 species studied, 50 of them were distributed in the whole Kuttanad wetlands. *C. esculenta* was one among the dominant taxa present in that area (MoEF, 2007).

<table>
<thead>
<tr>
<th>Months</th>
<th>Height (cm)</th>
<th>Diameter (cm)</th>
<th>Leaf area (cm(^2))</th>
<th>LAI</th>
<th>Dry matter (g/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AG</td>
<td>BG</td>
<td>Total</td>
<td>AG</td>
<td>BG</td>
</tr>
<tr>
<td>May</td>
<td>4.01</td>
<td>1.18</td>
<td>61.02</td>
<td>61.02</td>
<td>0.054</td>
</tr>
<tr>
<td>June</td>
<td>37.52</td>
<td>1.59</td>
<td>70.00</td>
<td>65.21</td>
<td>0.195</td>
</tr>
<tr>
<td>July</td>
<td>50.05</td>
<td>1.97</td>
<td>78.08</td>
<td>78.08</td>
<td>0.184</td>
</tr>
<tr>
<td>August</td>
<td>41.56</td>
<td>0.71</td>
<td>64.41</td>
<td>69.70</td>
<td>0.247</td>
</tr>
<tr>
<td>September</td>
<td>34.55</td>
<td>0.55</td>
<td>48.08</td>
<td>48.08</td>
<td>0.197</td>
</tr>
<tr>
<td>October</td>
<td>25.98</td>
<td>0.59</td>
<td>35.56</td>
<td>32.30</td>
<td>0.057</td>
</tr>
<tr>
<td>November</td>
<td>21.23</td>
<td>0.64</td>
<td>21.57</td>
<td>21.57</td>
<td>0.015</td>
</tr>
</tbody>
</table>

*All values are the averages of three replicates*

1.2.3.2 Associated plant species

Associated plant species were also noted down in the permanent site. *Pandanus fascicularis*, a wetland plant was found associated more than any other plants. *Cyperus hespan* was also located with other wetland species like *Polygonum* sp., *Acrostichum* etc.

1.2.3.3 Soil analysis

Nutrient status of soil

The growth rate of *C. esculenta* observed with different months from May to November coincides with the differential nutrient status of soil in which the plants are growing. For instance, high growth rate in July coincides with the high nitrogen, phosphorus and potassium values of that month (Table 1.2.2).
### Table 1.2.2: Changes in the nutrient content of the soil during the study period

<table>
<thead>
<tr>
<th>Months</th>
<th>pH</th>
<th>Nitrogen (kg/ha)</th>
<th>Phosphorus (kg/ha)</th>
<th>Potassium (kg/ha)</th>
<th>Organic carbon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>4.40</td>
<td>50.91</td>
<td>23.36</td>
<td>100.56</td>
<td>1.40</td>
</tr>
<tr>
<td>June</td>
<td>5.21</td>
<td>74.89</td>
<td>20.87</td>
<td>149.80</td>
<td>0.90</td>
</tr>
<tr>
<td>July</td>
<td>4.40</td>
<td>115.32</td>
<td>19.20</td>
<td>172.40</td>
<td>0.87</td>
</tr>
<tr>
<td>August</td>
<td>4.58</td>
<td>114.56</td>
<td>19.55</td>
<td>165.42</td>
<td>0.95</td>
</tr>
<tr>
<td>September</td>
<td>3.69</td>
<td>82.00</td>
<td>18.17</td>
<td>138.11</td>
<td>1.08</td>
</tr>
<tr>
<td>October</td>
<td>4.15</td>
<td>67.36</td>
<td>17.62</td>
<td>100.45</td>
<td>1.12</td>
</tr>
<tr>
<td>November</td>
<td>4.01</td>
<td>47.89</td>
<td>17.63</td>
<td>75.75</td>
<td>1.05</td>
</tr>
</tbody>
</table>

### Discussion

In the present study, above ground live plants were present throughout the study period. Plant height, as mentioned earlier, increased to a maximum during the month of July and then decreased (Fig. 1.2.1 A). Studies by Mohan Kumar and Sadanandan (1989) on the growth of Taro have shown that levels of nitrogen in the soil significantly increased the height of the plant up to 120th day after planting and then tend to decrease. This type of growth pattern in Taro suggests that for early vegetative growth, higher levels of nitrogen are required. The influence of nitrogen on vegetative growth of any plant is a well-established phenomenon. At 150th day after planting, the plant has reached the maturity stage and as such, the vegetative growth has ceased. By this time, all the early-formed bigger leaves have started withering and drying, leaving only the short late-formed leaves, which result in a reduction in plant height.

The change in diameter of the plant might also be due to the reasons attributed to the increase in plant height (Fig. 1.2.1 B). Changes in the number of leaves during the study period were shown in Fig. 1.2.1 C.

Studies with dry matter production of Taro showed a gradual increase from the initial month of the study and reached its peak on the 90th day (30.42 g / sq.m) and on the 150th day (3.12 g/sq.m) there occurred a reduction as a result of senescence (Fig. 1.2.1 D). Similar were the observations made by Mohan Kumar and Sadanandan (1989) on Taro. It may be emphasized here that the dry matter production is regulated by a number of physico-chemical; macro- and micro-climatic factors and stand characteristics. Therefore, the high values of production possible under optimal culture conditions are rarely obtained in the field.
Wolverton and McDonald (1977) estimated a daily biomass production rate of 72 g/m² from April through October for water hyacinth (density about 1100 g/m²) grown in sewage effluents while Reddy and DeBusk (1984) observed average growth rates ranging between 25.7 and 36.6 g/m² for the period March through December. A high growth rate of 52 g/m² was recorded during June - July; a maximum value of 64 g/m² was obtained over a period of second week in July.

Data on the leaf area and LAI (Fig. 1.2.1E) were comparable with other works on Taro. Mohan Kumar and Sadanandan (1989) had shown that the levels of nitrogen had significant contributions to the increase in leaf area and LAI. The same observation has been reported in many other crops.

In most cases, the LAI was found to be maximum at 80 kg N/ha. Presence of phosphorus did not show any significant effect on LAI, but was increased significantly by increasing levels of potassium. Maximum LAI was observed at 150 kg K₂O/ha but was on par with 100 kg K₂O/ha (Mohan Kumar and Sadanandan, 1989).

Changes in plant density have been presented in Fig.1.2.1 F.

Relation between plant height and growth rate

From Fig.1.2.1 G, it has been found that the growth rate in terms of biomass was noticed to be maximum during the month of July where the plant height was also the highest (Fig.1.2.2 A). This may be due to the fact that in July, all the young and medium plants turned mature, hence the maximum height and biomass was obtained in that particular month.

The relation between plant height and growth rate has statistically proved to be significant (p < 0.001), but they have no significance during the different months of the study period (Fig. 1.2.2 A).

Relation between density and growth rate

The average plant density as explained earlier was found to be maximum during May, was the least during September, and then increased in November. This might be due to the fact that initially the young and medium plants compared to the mature ones contributed more to the density in each quadrat. However, after this the trend was apparently declining as these plants turned mature. This seemed to continue until September and then onwards, the more young and medium plants were again recruited into the population (Unni et al., 1990).
Fig.1.2.1: Changes in plant growth parameters during different months of the study period.
The density when related to the biomass production or the growth rate (Fig.1.2.2 B) has shown that initially when the density was high in May due to the number of young and medium plants, the biomass appeared to be less (7.53 g/m²). Nevertheless, when the young and medium ones turned mature during the subsequent months from July to September, the biomass was within the range of 9.86 to 30.42 g/m². Again when the density shoted up in the month of November, the biomass declined (3.12 g/m²). This very well explains the fact that the mature ones mainly contribute to the biomass. Similar were the results obtained by Unni et al. (1990) on the growth and productivity of *Typha augustata*.

In water hyacinth, the specific growth rate decreases linearly with an increase in density, while the maximum biomass was obtained at intermediate densities (Reddy and DeBusk, 1984; DeBusk and Reddy, 1987).

The data on the relation between plant density and growth rate has proved to be statistically non-significant.

**Relation between LAI and growth rate**

The data on the LAI showed that it was 61.02 in May, 78.08 in July, 48.08 in September and 21.57 in November. This when compared to the biomass production in the respective months, showed that the biomass production was also high in the months where the LAI was high (Fig.1.2.2 C). For instance, in July, the LAI and growth rate was 7.81 and 30.42 g/m² respectively. Assuming the photosynthesis proportional to the leaf area and respiration to weight, plants with maximum lamina area: weight ratio would be most productive (highest growth rate). Petioles of leaves are not important in photosynthesis because of low stomatal frequency and shading despite significant chlorophyll content. This very well explains the least biomass production in the month of November where the LAI was also low (Sharma and Gopal, 1977; Unni et al., 1990).

The statistical analysis of the data on the relation between LAI and growth rate proved to be significant (p < 0.05) but no significance was observed between the different months of the study period.
Studies on the potential of *Colocasia esculenta* (L.) Schott in wastewater treatment and recovery of energy

**Part I**

**General Introduction**

Studies on the potential of *Colocasia esculenta* (L.) Schott in wastewater treatment and recovery of energy

**Fig. 1.2.2:** Relation between various plant growth factors to the growth rate during different months of the study period

**Relation between soil nutrients and plant growth rate**

The availability of nitrogen and potassium are considered essential for the better growth of *C. esculenta*. Studies by Ashokan and Vikraman (1984) revealed that levels of nitrogen concentration have significant effect on the growth of *C. esculenta*.

In the present study, the plant density was found low while the soil nutrients and plant growth rate was high in July. This indicates that the available nutrients need to be shared by lesser number of plants. On the contrary, growth rate seemed to decline during other months of the study (Fig.1.2.3 A,B,C). Therefore, it can be inferred that during the month of July, the soil nutrients and other conditions were optimal for a
better growth rate than other months. Even though these changes in soil nutrients and growth rate during different months of the present study period proved to be statistically insignificant individually, there was a significant difference – (p < 0.05), (p < 0.001) and (p < 0.05) for soil nitrogen, phosphorus, and potassium respectively with respect to growth rate.

In the light of the above study, it was obvious that *Colocasia esculenta* is apparently a noxious weed having a moderate growth rate (Table 1.2.3). Undoubtedly, this weed is gradually establishing itself everywhere and if early steps are not taken to eradicate this plant, it may become noxious as *Salvinia, Eichhornia, Typha* etc.

**Fig. 1.2.3**: Relation between nutrient content of the soil and growth rate during different months of the study period
Studies on the potential of *Colocasia esculenta* (L.) Schott in wastewater treatment and recovery of energy

### Table 1.2.3: Comparison of present work with similar works cited in literature, in terms of growth rate

<table>
<thead>
<tr>
<th>Species</th>
<th>Growth rate (g/g d⁻¹)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Salvinia molesta</em></td>
<td>0.04 – 0.09</td>
<td>Mitchell and Tur (1975)</td>
</tr>
<tr>
<td><em>Eichhornia crassipes</em></td>
<td>0.053</td>
<td>Wotten and Dodd (1976)</td>
</tr>
<tr>
<td><em>Nymphaea nouchali</em></td>
<td>0.043</td>
<td>Wotten and Dodd (1976)</td>
</tr>
<tr>
<td><em>Nymphoides indica</em></td>
<td>0.047</td>
<td>Wotten and Dodd (1976)</td>
</tr>
<tr>
<td><em>Colocasia esculenta</em></td>
<td><strong>0.010</strong></td>
<td><strong>Present work</strong></td>
</tr>
</tbody>
</table>

*Source : Gopal (1976)*