MANAGEMENT AND UTILIZATION OF WATER HYACINTH (*Eichhornia crassipes* (Mart.) Solms)

By

INDULEKHA V. P.

(2013-21-117)

THESIS

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DECLARATION

I, Indulekha V. P. (2013-21-117) hereby declare that the thesis entitled **"Management and utilization of water hyacinth (*Eichhornia crassipes* (Mart.) Solms)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Indulekha

Vellanikkara

Date: 30.08.2018

Indulekha V. P.

(2013-21-117)

CERTIFICATE

Certified that the thesis entitled **"Management and utilization of water hyacinth (*Eichhornia crassipes* (Mart.) Solms)"** is a record of research work done independently by **Ms. Indulekha V. P. (2013-21-117)** 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.

Vellanikkara

Date: 30 Aug. 2018

Dr. C. George Thomas
(Chairperson, Advisory Committee)
Professor (Agronomy)
College of Horticulture, Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Indulekha V.P. (2013-21-117)**, a candidate for the degree of **Doctor of Philosophy in Agriculture**, with major field in **Agronomy**, agree that the thesis entitled **"Management and utilization of water hyacinth (*Eichhornia crassipes* (Mart.) Solms)"** may be submitted by **Ms. Indulekha V.P.** in partial fulfilment of the requirement for the degree.

3/12/18

Dr. C. George Thomas
(Chairperson, Advisory Committee)
Professor and Head (Agronomy)
College of Horticulture, Vellanikkara

Dr. K. S. Anil
(Member, Advisory Committee)
Professor and Head
Dept. of Livestock Production Management
Veterinary College
Kerala Veterinary and Animal Sciences
Mannuthy

Dr. K. M. Durga Devi
(Member, Advisory Committee)
Professor
Dept. of Soil Science & Agricultural Chemistry
College of Horticulture, Vellanikkara

Dr. Meera V. Menon
(Member, Advisory Committee)
Professor
AICRP on Weed Control
College of Horticulture, Vellanikkara

Dr. P. Prameela
(Member, Advisory Committee)
Professor
Dept. of Agronomy
College of Horticulture, Vellanikkara

3/12/18

EXTERNAL EXAMINER
Dr. M. D. Jessy
Joint Director
RRII, Kottayam

Dedicated To my family
and Guide
Dr. C. George Thomas

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LIST OF ABBREVIATIONS

Al	Aluminium
As	Arsenic
B:C ratio	Benefit: Cost ratio
C	Carbon
Cd	Cadmium
CF	Crude fibre
CFU	Colony forming units
cm	Centimetre
cm^2	Square centimetre
Co	Cobalt
CP	Crude protein
Cr	Chromium
Cu	Copper
DAP	Days after planting
DAS	Days after sowing
DAT	Days after transplanting
DMP	Dry matter production
dS/ m	Deci Seimens per metre
EE	Ether extract
et al.	And others
Fe	Iron
Fig.	Figure
g	Gram
ha	Hectare
Hg	Mercury
K	Potash
kg	Kilogram
Kg/ ha	Kilogram per hectare
LAI	Leaf area index
LAR	Leaf area ratio
m	Metre
m^2	Square metre
m^3	Cubic metre
MAC	Months after composting
mg	Milligram
Mg/ kg	Milligram per kilogram
ml/ L	Millilitre per litre

Mn	Manganese
N	Nitrogen
NFE	Nitrogen free extract
Ni	Nickel
P	Phosphorus
Pb	Lead
ppm	Parts per million
SOC	Soil organic carbon
t/ ha	Tonnes per hectare
Viz.	Namely
Zn	Zinc

LIST OF SYMBOLS

%	:	Per cent
µg	:	Micro gram
^{0}C	:	Degree Celsius
@	:	At the rate of
&	:	And

INTRODUCTION

1. INTRODUCTION

Most aquatic weeds interfere with the normal functioning of water bodies, besides causing several harms to the environment. Among the aquatic weeds, *Eichhornia crassipes* (Mart.) Solms, commonly known as water hyacinth is considered as the world's worst aquatic weed. Water hyacinth also known by the names 'Bengal terror' and 'lilac devil' is a native of Brazil. It was introduced to India in the 1890s as an ornamental plant and spread throughout the country. It is estimated that 20-25 per cent of the total utilizable water in India is infested with water hyacinth alone (Varshney *et al.*, 2008). Recognized by its lavender flowers and shinning bright leaves, water hyacinth is prolific in growth and is one of the most productive plants on earth. The growth rate of the plant is so high that it can double its population just within 12 days (AERF, 2005). The plant is adapted to both fresh and saline waters hence, it has invaded backwaters too. The plant is also a serious threat to biodiversity as it prevents the growth of other aquatic plants. Other adverse effects on water bodies are by blocking canals and motor pumps, providing convenient breeding sites for mosquito, and interfering with fishing and fish culture.

Water hyacinth is widely seen in Kerala in rice fields, lakes, streams, and channels, which makes large areas uncultivable, inaccessible and non-navigable (Jayan and Sathyanathan, 2012). High pollution by plant nutrients such as nitrates, nitrites and phosphates has contributed to the spread of water hyacinth. Various strategies have been tried to manage water hyacinth including physical, chemical, biological, and integrated management methods. Complete eradication of water hyacinth is, however, not possible because of various environmental and financial challenges associated with these methods. A novel approach is to use aquatic weeds such as water hyacinth as a raw material in various applications, thus projecting their management by large scale utilization as an attractive approach. Turning this weed to productive use would be desirable, if it would partly offset the costs involved in mechanical removal.

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Many aquatic weeds have been found to extract heavy metals from polluted water thereby assisting in the control of water pollution. Aquatic macrophytes such as *Eichhornia crassipes, Typha latifolia, Pistia stratiotes, Lemna* spp., *Alternanthera philoxeroides,* and *Phragmites karka* have proved to be efficient in phytoremediation of polluted water. For example, one hectare of *Eichhornia crassipes* produces about 600 kg dry matter per day, which potentially removes about 300 g of heavy metals from one hectare of polluted water bodies per day (Sushilkumar and Deka, 2015). Water hyacinth was found to be the dominant weed in most canals and abandoned paddy fields of acid sulphate wetlands of Kuttanad, Kerala and it was found to be a good phytoextractor of Fe, Zn, Cu, Al, Cd and Pb from the *Kari* soils (Thampatti and Beena, 2014). In addition to the possibility of using them for phytoremediation of heavy metals and pollutants, there are several other options. They can be used for composting and vermicomposting, as food for humans, feed for animals and fish, biofuel production, and for various medicinal and other uses.

For the safe and quick disposal of aquatic weeds, composting is a good technique. As water hyacinth produces large quantities of biomass, it would be a viable technology for the production of good organic manure and the problem of disposal of these weeds can be solved largely. Water hyacinth based compost used as an organic fertilizer showed good analysis of macronutrients, micronutrients and also microorganisms that would support plant growth (Viveka and Grace, 2009). When considering the option for compost making, the best options –the vermicompost, the Bangalore compost, the Indore compost, and the phospho-compost with water hyacinth has to be worked out.

Some aquatic weeds are excellent feed for both ruminants and non-ruminants. Livestocks are reluctant to eat water hyacinth in fresh form. Tham (2012) reported that improved silage could be made from water hyacinth by the use of additives such as molasses and rice bran. Molasses is a universal additive to silage but not easily available to common people. Lowilai *et al.* (1993) reported

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the use of cassava flour instead of molasses as an additive. Little bag silage in polythene bags is a viable option for small holders as traditional silos such as bunker, trench or tower silos are not feasible for them. As there is acute shortage of feed resources for livestock in Kerala, it is hoped that a standardized silage production method from water hyacinth would be of much help to dairy farmers.

Mulching with water hyacinth is another option for its removal. Its feasibility has to be tested in crops, which require heavy mulching. In turmeric, mulching is an important cultural practice, and mulching immediately after planting with green leaves and subsequently after 50 days is recommended (KAU, 2011). Initial growth of turmeric is slow, and if weeds are not controlled properly, it may cause considerable yield reduction. The commonly used mulch materials in turmeric are jack leaves and coconut leaves but during the planting time of turmeric, shortage of enough mulch materials is common. It is hoped that using water hyacinth as a mulch will be a blessing for the farmers as well as the public because of the conversion of a menace for a good cause. Having considered all the possible options, a study has been designed and conducted to utilize water hyacinth with the following objectives:

- To assess the phytoextraction capacity of water hyacinth
- To manage water hyacinth by eco-friendly means such as composting, silage making, and mulching

REVIEW OF LITERATURE

2. Review of Literature

In this chapter the review of literature pertaining to the utilization aspects of huge biomass of water hyacinth is presented.

Aquatic weeds grow profusely in lakes and water bodies all over the world, and in recent decades their negative effects have been exasperated by human's intensive use of such water bodies. Most aquatic weeds are aggressive colonizers with flexible habitat requirement having the ability to out compete native species. Proliferation of aquatic weeds block canals and motor pumps in irrigation projects, provide convenient breeding sites for mosquitoes, interferes with fishing and fish culture, and retard river flows. They also reduce the volume of water storage by way of high evapotranspiration. Among the aquatic weeds, a few are highly damaging; for example, it is reported that 20-25 per cent of the total utilizable water in India is infested with water hyacinth alone (Varshney *et al.*, 2008).

Attempts to control problem aquatic weeds with chemical, biological and mechanical means have failed throughout the world on a long term basis (Bindu and Ramasamy, 2005). These methods succeed only in keeping weed infestations in check at enormous costs (Gajalakshmi *et al.*, 2001). Alternatively, the initial clearance of the weed followed by regular, periodic removal of the regrown weeds, coupled with proper utilization of the harvested weeds seems to be a viable solution to the weed menace. Utilizing the high productivity of weeds such as water hyacinth can be made a part of integrated management of troublesome aquatic weeds.

2.1. Phytoremediation potential of water hyacinth

Contamination of water resulting from anthropogenic activities is a matter of concern worldwide. A number of chemicals, heavy metals, and industrial effluents are released into the water bodies contributing to a variety of toxic effects on living organisms by way of bioaccumulation and biomagnification (Arora *et al.*, 2008). Physical and chemical methods for clean-up and restoration of heavy metal contaminated water have serious limitations like high cost, destruction of native flora and fauna, and creation of secondary pollution problems. Therefore, phytoremediation - a low cost technology using green plants for the removal of contaminants is projected as a better solution to the problem. It is a novel, efficient, eco-friendly, and solar energy driven remediation strategy (Landmeyer, 2011).

Phytoremediation basically refers to the use of plants and associated soil microbes to reduce the concentrations or toxic effects of contaminants in the environments (Greipsson, 2011). It can be used for removal of heavy metals and radionuclides as well as for organic pollutants (such as, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, and pesticides). Mechanism of phytoremediation could be phytostabilization, rhizodegradation, rhizofiltration, and phytodegradation, phytostabilization, phytoaccumulation and phytovolatalization (Smits, 2005).

2.2 Expression of phytoextraction efficiency

The efficiency of phytoextraction can be quantified by calculating bioconcentration factor (BCF) and translocation factor (TF). Bioconcentration factor indicates the efficiency of a plant species in accumulating a metal into its tissues from the surrounding environment (Ladislas *et al.*, 2012). It is calculated as, Bioconcentration Factor (BCF) = C_{tissue}/C_{medium}, where C_{tissue} is the concentration of the target metal in the plant tissue and C_{medium} is the concentration of the same metal in the water (substrate) (Zhuang *et al.*, 2007).

Translocation factor indicates the efficiency of the plant in translocating the accumulated metal from its roots to shoots. It is calculated as Translocation Factor (TF) = C_{shoot}/C_{root}, where C_{shoot} is concentration of the metal in plant shoots and C_{root} is concentration of the metal in plant roots (Padmavathiamma and Li, 2007). Both BCF and TF are important in screening hyperaccumulators for

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phytoextraction of heavy metals. Translocation factor value greater than 1 indicates the translocation of the metal from root to above-ground part (Jamil *et al.*, 2009). According to Yoon *et al.* (2006), only those plant species with both BCF and TF greater than 1 have the potential to be used for phytoextraction. Hyperaccumulators have BCF greater than 1, sometimes reaching 50-100 (Cluis, 2004).

2.3. Phytoremediation effects of water hyacinth on water quality

Rezania *et al.* (2016) observed that BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), ammoniacal nitrogen and total dissolved solids of water decreased and quality of domestic waste water improved after treatment with water hyacinth for 14 days. Waste water treated with water hyacinth and water lettuce decreased 58.87 per cent ammonium, 50.04 per cent phosphate, 82.45 per cent COD, and 84.91 per cent BOD and concentration of metal in water reduced from 6.65 to 97.56 per cent by water hyacinth and 3.51 to 93.51 per cent by water lettuce (Victor *et al.*, 2016). Qin *et al.* (2016) from a study to assess the phytoremediation capability of water hyacinth revealed that nitrogen content of domestic sewage water decreased by 58.64 per cent. He also reported that water hyacinth is better than water lettuce for removal of nitrogen from water because of its higher root surface area, root biomass, root activity and net photosynthetic rate. Water lettuce removed phosphorus more efficiently because of its rhizofiltration ability.

Gao *et al.* (2015) studied phytoremediation of contaminated water by employing water hyacinth and found that COD, total phosphorus, total nitrogen and ammonium nitrogen decreased by 66-75 per cent, 64.65-91.72 per cent, 37.55-79.89 per cent and 61.27-97.58 per cent respectively in 18 days of treatment. Remediation of total nitrogen was slower than COD and total phosphorus. When water hyacinth was used to treat waste water from fish farming by 50 per cent, 75 per cent and 100 per cent plant cover for 24 hours. Rubim *et al.*

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(2015) observed that nitrite and total phosphorus decreased by 86.8 per cent and 69 per cent respectively, when 50 per cent plant cover was maintained.

Municipal waste water was treated using water hyacinth by Madan and Verma (2011) using 50 per cent and 100 per cent waste water and reported that turbidity, hardness, total dissolved solids, BOD, and COD of waste water decreased considerably and total nitrogen reduced from 3.5 mg/L to 1.5 mg/L in 50 per cent concentration and 5.6 mg/L to 2.8 mg/L in 100 per cent concentration. Adsorption of N and P from eutrophic water under various hydraulic loadings was studied by Yong *et al.* (2011) and reported that with increase of hydraulic loadings, N and P accumulation by the plant increased. Water hyacinth removed N and P at the rate of 42.33 per cent to 46.44 per cent and 68.10 to 95.26 per cent respectively at low hydraulic loading and N and P accumulation was more in leaves and shoots compared to roots.

There is a strong positive correlation between accumulated N and P assimilation and water hyacinth biomass. Biomass of water hyacinth in eutrophic water increased by 41.03-47.12 kg/m^2 at average growth rate of 0.096-0.262 $kg/m^2/day$ and total N and P removal by water hyacinth were 43.06-71.16 and 8.68-16.63 g/m^2 respectively (Yong *et al.* , 2010). Water hyacinth hyper-accumulated 21.1 kg nitrogen from 6000 tonnes of eutrophicated water. Reduction of total nitrogen from 2.1 to 0.5 mg/L occurred after 44 days of treatment and ammonium concentration reduced to half and nitrite concentration approached to below detection limit after 14 days. (Ying *et al.*, 2007).

Mahmood *et al.* (2005) from a study to utilize water hyacinth for textile effluent treatment reported that pH of water reduced to 7, BOD and COD reduced by 40-70 per cent and total suspended solids decreased by 50 per cent. Heavy metals such as Cr, Zn and Cu decreased by 94.78 per cent, 96.88 per cent and 94.44 per cent respectively. Nyanti *et al.* (2010) reported that suspended solids, oxygen demand, nitrogen, phosphorus and ammonia nitrogen in shrimp pond waste water reduced from 1.8 mg/L to 0.2 mg/L in 48 hours when the water surface was fully covered by water hyacinth. Zimmels *et al.* (2007) reported that water hyacinth decreased BOD by 86.3 per cent, COD by 66.6 per cent, ammonia by 97.8 per cent and phosphorus by 65.0 per cent from polluted water within 11 days of treatment.

Rizzo *et al.* (2012) stated that water hyacinth reduced total N, total P, BOD, COD, total dissolved salts and heavy metals such as Pb, Zn, and Cr from polluted water, and biomass of the plant increased largely during the treatment. Accumulation of N and P from eutrophic water by water hyacinth was 109 per cent and 17 per cent more than that by *Hydrilla verticillata.* Total nitrogen and total phosphorus content of water decreased considerably compared to control without plants (Zhi *et al.,* 2013). Jayaweera and Kasturiarchchi (2004) observed 100 per cent accumulation of total nitrogen (TN) and total phosphorus (TP) by water hyacinth from industrial waste water after 9 weeks of treatment and the main mechanism for removal of total nitrogen and total phosphorus was assimilation by plants. For a batch type constructed wetland, 6 weeks old plants were suitable for removal of TN and TP and 3 weeks of hydrological retention time was required.

Hua *et al.* (2014) reported that total nitrogen and total phosphorus reduction by water hyacinth from Dianchi lake were from 13.47 mg/L to 2.93 mg/L for TN and from 1.34 mg/L to 0.1mg/L for TP. Snow and Ghaly (2008) studied nutrient removal by water hyacinth, water lettuce and parrot's feather and reported that all the plants reduced pollution by reduction of COD by 71.1-89.5 per cent, ammonium nitrogen 55.9-76 per cent, nitrite nitrogen 49.6-90.6 per cent, nitrate nitrogen 34.5-54.5 per cent and phosphates 64.5-76.8 per cent. Yan *et al.* (2015) reported that water hyacinth accumulated more phosphorus when pH ranged from 6-9 and TP concentration decreased by 0.03-0.27 mg/L and removed 73.12 per cent to 79.06 per cent phosphorus from the system. However at higher pH (10.5) water hyacinth could not survive.

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Ayyasamy *et al.* (2009) from an experiment to study the removal of nitrate from synthetic medium and ground water using aquatic macrophytes such as water hyacinth, water lettuce and salvinia observed 64 per cent reduction in nitrate level in synthetic medium when it contained 100 mg/L nitrate. The efficiency increased to 80-83 per cent when the concentration was raised to 200-300 mg/L but reduced at higher concentration of 400-500 mg/L. Water lettuce and salvinia accumulated less nitrate than water hyacinth and nitrate removal from ground water was negatively affected by sulphate and phosphate, which reduced nitrate removal by water hyacinth. Reddy *et al.* (2015) studied phytoremediation capabilities of aquatic weeds in the treatment of sugar industrial water effluents. All the test plants effectively reduced almost all the physical, chemical and biological parameters of the sugar industry effluent water to a significant level. *Eichhornia crassipes* lowered BOD, COD, total dissolved solids, chlorides and sulphates compared to effluent treated with other plants.

Kumar *et al.* (2012) studied phytoaccumulation capacity of water hyacinth *in vitro* for 18 days of hydrological retention time for decreasing the pollution parameters in paper industry effluent. BOD, COD, total P, total N and heavy metal content of water decreased with the treatment. Water hyacinth plants were cultured in modified Hoagland solution containing 0, 40, 80, 100, 150, 200, and 300 ppm of nitrogen in order to study their N accumulation potential by Fox *et al.* (2008). N removal by the plant was 60-85 per cent and the plant had maximum net productivity (calculated from dry matter gain) at 80 ppm and beyond this concentration, the dry matter level did not vary much. Total N removal by the plant was directly related to dry matter gain or canopy cover.

Chavan and Dhulap (2012) used water hyacinth for sewage treatment of Solapur city. Dissolved oxygen level enhanced by 1.9 mg/L and total dissolved solids, chlorides, BOD, and COD decreased by 66.75 per cent, 17.99 per cent, 86.63 per cent, 48.69 per cent and 54.38 per cent respectively. Contents of heavy metals like Cu, Ni, Co and Fe also decreased. Dune *et al.* (2013) used water hyacinth to remediate water from oil field at Niger, Nigeria and reported that

BOD, COD and oil/grease content of water decreased by 3.35mg/L, 53.75mg/L and 1.10mg/L respectively. Heavy metals such as Fe, Zn, Mg, Ni, Cu and Pb reduced by 0.82 mg/L, 1.31 mg/L, 0.18 mg/L, 1.15mg/L, 0.045 mg/L and 0.021 mg/L respectively. Ismail *et al.* (2015) reported that nitrate reduction by water hyacinth and water lettuce was 72 per cent and 83 per cent respectively and phosphate reduction was 55 per cent and 60 per cent respectively in a phytoremediation experiment in which the plants were grown in 68 litres of domestic waste water for 21 days.

Moyo *et al.* (2013) reported that water hyacinth decreased total dissolved solids, sulphates, phosphates, hardness and electrical conductivity by 26 per cent, 45 per cent, 33 per cent, 37 per cent and 25 per cent respectively. Water hyacinth was more effective for treatment of domestic waste water than water morning glory (*Ipomoea aquatica*). The efficiency for reduction of TSS by water hyacinth and water morning glory were 37.8 per cent and 53.3 per cent, for COD 44.4 per cent and 53.4 per cent, phosphates 56.7 per cent and 61.4 per cent and ammonium 26.8 per cent and 32.6 per cent respectively (Loan *et al.*, 2014). Water hyacinth reduced COD (69.27%-74.15%), TP (69.20%-83.61%) and ammonia nitrogen (64.26%-94.50%) within 18 days (Xia *et al.,* 2013). COD, BOD, total suspended solids, TN, TP, and total coliform of waste water from pig pens reduced greatly by the treatment with water hyacinth (Manh *et al.,* 2014).

2.4. Trace and heavy metal remediation by water hyacinth

Environmental pollution by heavy metals has become a serious problem in the world. Unlike organic substances, heavy metals are non-biodegradable and therefore accumulate in the environment. Heavy metals have adverse effect on human health and therefore heavy metal contamination of food chain deserves special attention. Harmful effects of selected heavy metals on human health are summarized in Table 1.

Table 1. Harmful effects of heavy metals on human health

Heavy metal	Harmful effect	References
As	Interfere with cellular processes	Tripathi *et al.* (2007)
Cd	Carcinogenic, renal failure, chronic anaemia	Salem *et al.* (2000)
Cr	Damage kidney, hair loss	Salem *et al.* (2000)
Cu	Brain and kidney damage, liver cirrhosis and chronic anaemia, stomach and intestinal irritation	Salem *et al.* (2000)
Hg	Impaired motor function, depression, memory loss, vision disturbances	Ainza *et al.* (2010)
Ni	Allergic dermatitis known as nickel itch	Mishra *et al.* (2010)
Pb	Learning disability, mental retardation in children	Salem *et al.* (2000)
Zn	Fatigue and dizziness	Salem *et al.* (2000)

Kamal (2011) from a study on the extent of aquatic pollution in Vellayani lake identified some potential phytoremediators for various heavy metals. *Eichhornia crassipes* was found to be a good phytoextractor for Fe, Cu, and Cd; *Pistia stratiotes* for Zn, Cu, and Pb; and *Nymphaea odorata* for Cu and Cd. Similarly, *Typha latifolia* and *Phragmites karka* tested in the experimental wetlands at Water Technology Centre, IARI showed encouraging pollutant removal efficiencies for municipal waste water. The wetland treated waste water was found to have 93 per cent less turbidity, 67 per cent less chromium, and 70 per cent less lead (Khankhane and Kaur, 2015).

Beegum (2016) reported that *Eichhornia crassipes* could be effectively used for phytoremediation of acid sulphate soils of *Kuttanad* ecosystem. Heavy metal content in tested plants were in the order of Fe>Mn>Al>Zn>Cr>Cu>Pb.

Thampatti *et al.* (2007) found that plants like *Hydrilla verticillata, Eichhornia crassipes*, and *Cyperus pangora* possess hyper accumulation capacity for Fe, Mn, Zn, Cu, and Al in the wetlands of *Kuttanad.* A study on phytoremedial capability of water hyacinth was done by Sasidharan *et al.* (2013) at the Regional Agricultural Research Station, Kumarakom. Concentration of heavy metals was higher in the plant tissue compared to their concentration in sediment and lake water. While Cd, Pb and Ni concentration in the lake water was higher than Cu and Zn, their content in *E. crassipes* was lesser than Cu, Cr and Zn.

A phytoremediation study was carried out at Pariyej Reservoir, an internationally important wetland in Gujarat by Kumar *et al.* (2008) to ascertain the degree of heavy metal contamination. *Eichhornia crassipes* had maximum concentration of Co, Ni, Pb, and Zn, while *Ipomoea aquatica* contained maximum concentration of Cd. Cu was maximum in *Nelumbo nucifera.* Khankhane *et al.* (2014) assessed heavy metal accumulation in weeds found in various ponds of Jabalpur. The heavy metals exhibited the sequence of their concentration in pond water as Fe > Cd > Mn >Ni >Cu. There were marked differences in metal uptake among weed species growing on the ponds. *Eichhornia crassipes* accumulated higher concentration of cadmium, nickel, iron and manganese in their roots than shoots, whereas *Alternanathera philoxeroides* accumulated higher metals in shoots than roots.

Prasad and Maiti (2016) observed that leaves of water hyacinth can be used for bio-monitoring surveys in pond ecosystem and bioaccumulation factor for Cu, Mn, Pb, and Cd were 428-3205, 285-1100, 242-506, and 7-130 respectively. Water hyacinth was planted in Hoagland solution containing 15 or 25 mg Cu/L under greenhouse condition by Melignani *et al.* (2015) and found more Cu concentration in roots and the highest accumulation was 23, 38.72 mg/ka in 25 mg Cu/L and very low quantity of Cu was translocated to leaves.

Ashok *et al.* (2014) tested the growth of water hyacinth in 20 ppm Cr, Pb, Cd and Zn separately and observed that 63 per cent reduction of heavy metals

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occurred on the 10^{th} day of treatment. He *et al.* (2013) revealed that Fe and Mn content in waste water were reduced by 97 per cent and 83 per cent by water hyacinth and the metals were accumulated more in shoot. Verma *et al.* (2005) reported that Pb and Zn accumulation was higher (80.32 and 73.4% respectively) at 20 per cent effluent concentration after 20 days of treatment and absorption of metals were time dependent. Chabukdhara and Nema (2012) observed that plants such as water hyacinth and *Nelumbo* sp. accumulated heavy metals such as Cd, Cu, Cr, Mn Zn, Pb and Ni from river Hindon in different plant parts.

Aquatic plants such as *Eichornia crassipes, Nymphoides indica, Nelumbo nucifera* and *Nymphaeae* sp. accumulated heavy metals such as Fe, Cd, Cu without any toxic effects and the order of accumulation was Fe followed by Cd and Cu. Plants decreased the metal content by 65-95 per cent (Begum, 2009). Zhu *et al.* (1999) stated that water hyacinth accumulated more Cd and Cr than Cu and the bio-concentration factor for Cd, Cr, and Cu was 2150, 1823 and 595 respectively. Absorption of Ni and As was comparatively low and heavy metal accumulation was more in roots than shoots. Water hyacinth, water lettuce and *Salvinia cucullata* could absorb heavy metals from industrial effluents and uptake of metals increased with increased effluent concentration compared to control. Accumulation of Cr, Cd, Cu, Ni, Zn, Co and Pb was higher in 100 per cent effluent concentration than 50 per cent effluent concentration. (Momtaz *et al.*, 2013).

The trend of sorption of heavy metals by water hyacinth from tannery waste water contaminated East Calcutta wetlands was Cr>Mn>Fe>Cu>Zn>Pb and the plant accumulated 9.93 mg/kg Pb, 67.06 mg/kg Cu, 24.83 mg/kg Zn, 76.99 mg/kg Mn, 6457.03 mg/kg Mg, 72.03mg/kg Fe and 144.06 mg/kg Cr. Narang *et al.* (2011) observed that water hyacinth roots absorbed 92.21 μg/g mercury, when treated with 1000 μg/L of mercuric acetate. Maximum accumulation of Hg occurred at lower concentration (1μg/L) of the medium. Mishra *et al.* (2008) stated that *Eichhornia crassipes* accumulated more Hg and As than *Lemna minor* and *Spirodela polyrrhiza* and translocation of metals from root to leaves were low. Hg and As accumulation by the plant led to deterioration of chlorophyll, N, P, K and protein content in the plants.

Odjegba and Fasidi (2007) revealed that water hyacinth had high tolerance for Zn and low tolerance for Hg and elements like Ag, Cd, Cr, Cu, Hg, Ni, Pb and Zn were more in roots than shoots. Kularatne *et al.* (2009) reported that constructed wetlands consisting of water hyacinth could remove Mn from synthetic waste water and phytoremediation was primarily due to phytoextraction. Baquerizo and Salazar (2015) reported that Cu uptake ability of water lettuce and water hyacinth were 98.87% and 98.34% respectively and the plant growth reduced when copper concentration of the growth medium was increased beyond 10 mg/L.

Bais *et al.* (2015) observed that Cd, Fe and Ni from domestic sewage were removed by water hyacinth in slum areas of Allahabad. The order of accumulation by the plant was Cd followed by Ni and Fe and the highest accumulation occurred in rainy season compared to winter and summer season. Aurangzeb *et al.* (2014) reported that water lettuce absorbed Pb and Cu with 70.7 per cent and 66.5 per cent efficiency and water hyacinth had greater efficiency for Cd (82.8%), Cu (78.6%), As (74%), Al (73%) and Pb (73%) respectively. *Polygonum senegalensis, Amaranthus hybridus, Eichhornia crassipes* were used to remove heavy metals such as Cu, Zn, and Cd from Nairobi river by Orwa *et al.* (2014) and found that all the plant parts could remove Cu, Zn and Cd from water. Roots accumulated more heavy metals followed by shoots and then leaves.

Uptake of heavy metals such as Cu, Pb, Cd and Zn by water hyacinth at pH 8 and 6 was estimated by Smolyakov (2012). Concentration of heavy metals relative to their initial concentration at pH 8 and 6 were 8 per cent and 24 per cent for Cu, 11 per cent and 26 per cent for Pb, 24 per cent and 50 per cent for Cd and 18 per cent and 57 per cent for Zn respectively. Bioconcentration factor was more than 2000 for all metals except Zn and Cd at pH 6. Constructed wetland using water hyacinth. cattail (*Typha domingensis*) and elephant panic grass (*Panicum*

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elephantipes) removed Cr and Ni by 86 per cent and 7 per cent respectively. Zn concentration reduced considerably and 70 per cent and 60 per cent of nitrate and nitrite were removed. Hua *et al.* (2007) observed that water hyacinth could accumulate Cu at medium concentration (0.5 mg/L) without any damages to chlorophyll but when the concentration increased to 5 or 10 mg/L degradation of photosynthetic pigments happened. Water hyacinth accumulated 314 mg/kg Cu under 5 mg/l Cu^{2+} exposure.

Water hyacinth removed heavy metals such as Cd, Cr, Co, Ni and Pb from coal mine effluent efficiently than *Lemna minor* and *Azolla pinnata*. Metal accumulation by roots was higher than shoot and translocation from root to leaves was very low (Upadhyay and Tripathi, 2007). Giri and Patel (2011) reported that water hyacinth grown in 4 mg/L Cr accumulated the highest metal concentration than plants grown in 0, 0.75, 1.50, 2.50 mg Cr/L. The metal accumulation in roots and shoots of the plant was 1.22 mg/g and 0.24 mg/g respectively. Absorption of arsenic by water hyacinth increased with increase in duration of exposure to the metal, and water hyacinth roots accumulated 7.2 mg/kg As and shoots accumulated 32.1 mg/kg As, when the plants were cultured in 0.10 mg/L As solution.

Wang *et al.* (2002) stated that water hyacinth was a good accumulator of Cd with a bioconcentration factor of 1225. Accumulations of heavy metals from flowing textile effluent by different plants were analyzed by Yasar *et al.* (2013) and found that *Pistia stratiotes* accumulated Cu and Ni (BCF 140.72 and 377.36 respectively) and water hyacinth absorbed more Cr (BCF 176.63).

Agunbiade *et al.* (2009) reported that water hyacinth accumulated heavy metals such as Cr, Cd, Pb, and As in roots and shoot at higher concentration and hence the plant can be used for phytoremediation of metals from contaminated water. When *Centella asiatica* and water hyacinth were used to remove Cu from different concentration of copper solution, Moktar *et al.* (2011) observed 99.6% Cu accumulation by *Centella asiatica* and 97.3% by *Eichhornia crassipes*. Copper

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accumulation by *Centella asiatica* was 1353.0 mg/kg, while *Eichhornia crassipes* absorbed 1147.5 mg/kg and accumulation was higher in roots than in shoots.

Removal of Cr and Cd by water hyacinth from municipal waste water was 80.26 per cent for Cr and 71.28 per cent for Cd and the mean removal rate were 0.10µg/day and 0.12µg/day respectively (Narain *et al.*, 2011). Wei and Lian (2004) noted that water hyacinth had higher BCF for Cd, Pb, Cu, Zn and Ni and the concentration of metals were more in root (3-15 fold) than in shoots. The trend of accumulation of heavy metals in roots were Cu>Zn>Ni>Pb>Cd. Alvarado *et al.* (2008) commented that *Lemna minor* accumulated As (140 mg/ha) with a removal recovery of 5 per cent and water hyacinth removed 600 mg As/ha with a removal recovery of 18 per cent and As removal was higher in water hyacinth because of its higher biomass production.

Water hyacinth accumulated more Cu and Ni, whereas *Marsilea minuta* and *Hydrilla verticillata* accumulated more Cr and Pb from tannery effluent (Kumar *et al.*, 2012). Kamel (2013) studied removal of heavy metals by various aquatic macrophytes present in El-Temsah lake, Egypt and reported that the pattern of accumulation was Zn> Pb> Cd> Cu> Ni> Co. The bioconcentration factor for water hyacinth was 1172.8. Shah *et al.* (2015) compared phytoremediation potential of native macrophytes present in polluted Gomti river and observed that the macrophytes absorbed heavy metals such as Fe, Cd, Cu, Cr, and Pb. *Eichhornia crassipes* had high removal ability for Fe, Cd and Pb, *Jussiaea repens* for Cr, *Pistia stratiotes* for Cd and *Typha latifolia* for Cu.

In an experiment to assess the response of water hyacinth to combined exposure to KNO_3 and Hg Caldelas *et al.* (2009) reported that Hg accumulation by the plants within 2 months of treatment was 4 mg/kg and it caused reduction of P, K and S accumulation by different plant parts and increased Ca and Mg content of submerged plant parts. Junior *et al.* (2009) reported that dry biomass of water hyacinth could be used for removing heavy metals such as Cd, Pb, Cr, Cu and Zn from polluted water bodies. Fawzy *et al.* (2012) studied phytoremediation

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potential of six aquatic macrophytes such as *Ceratophyllum demersum, Echinochloa pyramidalis*, *Eichhornia crassipes, Myriophyllum spicatum, Phragmites australis and Typha domingensis* and found that the plants contained heavy metals in the manner Zn> Cu> Pb> Cd. Roots of all plants had higher Cu and Zn content than shoots while leaves contained maximum concentration of Pb and variation in Cd accumulation by different plant parts were not significant.

The ability of water hyacinth to uptake Ag, Ba, Cd, Mo, and Pb from waters in gold mine tailing area were studied by Romanova *et al.* (2016) and reported that water hyacinth accumulated high concentration of Mo, Pb and Ba with BCF values 24360±3600, 18800±2800, 10040±7400 respectively. Accumulation of metals by the plant was directly related to concentration of heavy metal in the medium. Moleon *et al.* (2010) studied Mn removal by water hyacinth from solution containing 10, 50 and 100 mg/L Mn and found that water hyacinth reduced Mn concentration considerably. Mn accumulation increased with increased Mn concentration of solution. Singh and Sinha (2011) reported that water hyacinth accumulated 88 per cent Cr (VI) from synthetic waste water within 48 hours of treatment. Within 20 days, Cr content decreased below 97 per cent of initial concentration.

Aisien *et al.* (2010) grew water hyacinth in bore well water containing 5 mg/L Zn, Pb and 1mg/L Cd at pH 4.5, 6.8, and 8.5. Accumulation of metals by roots was more at higher pH. Water hyacinth accumulated 4870mg/kg Zn, 4150 mg/kg Pb and 710 mg/kg Cd respectively and BCF for Zn, Pb and Cd were 1674, 1531, 1479 respectively. Water hyacinth, water lettuce, and alligator weed were used to accumulate Mn from solutions having 0, 50, 200, and 400 mg Mn/L by Hua *et al.* (2012). Manganese accumulation by the plants increased with increased Mn concentration of solution and the highest Mn accumulation was reported in water lettuce. Hazra *et al.* (2015) from experiment to study heavy metal pollution in water bodies of Ranchi, Jharkhand used aquatic plants such as *Typha latifolia, Eichhornia crassipes* and *Monochoria hastata* and reported that *Eichhornia crassipes* had maximum BCF for Mn, Fe and the accumulation by roots and shoots differed. Bio concentration factor for Mn by root was 278.6 and by shoot was 142 and BCF of Fe for root was 151 and for shoot was 36.13 respectively.

Water hyacinth plants were cultured in Hoagland solution containing 3, 5, 7, 10, and 20 mg/L Cr by Woldemichael *et al.* (2011) and found sustained Cr removal up to 10 mg/L and higher concentration caused toxic symptoms in plants. Maximum efficiency of Cr removal was 91 per cent and roots accumulated more Cr than the shoot. Potassium and lead uptake by water hyacinth from solutions having 100 ppm element concentration were 13.52 ppm and 0.01 ppm respectively (Okunowo and Ogunkanmi, 2010).

Singh and Rai (2016) studied the effect of culturing aquatic macrophytes such as *Eichhornia crassipes, Lemna minor, Pistia stratiotes* and *Salvinia cucullata* collected from Loktak lake, North Eastern India in 1, 3 and 5 mg/L Fe concentration. The highest accumulation was by *Eichhornia crassipes* and the lowest by *Lemna minor. Eichhornia crassipes* removed 89 per cent Fe from 1 mg/L, 81.3 from 3 mg/L and 73.2 per cent from 5 mg/L solution. *Lemna minor, Pistia stratiotes and Eichhornia crassipes* removed Cu, Pb, Ni, Fe Zn, Cr and Cd and *Hydrilla verticillata* and *Valisnaria spiralis* removed Cr and Cd from contaminated water of waste land fill site, Sibiu county (Malschi *et al.*, 2015).

Eichhornia crassipes and *Myriophyllum aquaticum* had high tolerance for heavy metals such as Cu, Hg, Pb and Zn and uptake of Cu, Pb, Hg and Zn by *Eichhornia crassipes* were 99.80 per cent, 97.88 per cent, 99.53 per cent and 94.37 per cent respectively (Hernandez *et al.*, 2017). Water hyacinth accumulated heavy metals even when their concentration in water was low and content of heavy metals in plants were 3-28 times more than that present in water (Ndimele and Jimoh, 2011). Mahmood *et al.* (2010) reported that water hyacinth accumulated Ni (1.954µg/g) when the plants were grown in Hoagland solution supplied with Ni. Dried water hyacinth roots (DHR) were used to absorb As using batch and continuous column at United States Environmental Protection (USEPA) Test and Evaluation (T & E) facility, Ohio by Govindasamy *et al.* (2011). Addition of

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20g/L DHR to water led to removal of 90 per cent As from batch and continuous system and As content was reduced from 300μg/L to below 20μg/L.

Romanova *et al.* (2015) reported that water hyacinth accumulated 74-92 per cent Cd and 88-91 per cent Cu from water and most of the Cd (97%) was accumulated in roots than shoot and leaves. Cu absorption was not affected by Cd but Cu negatively interfered with the absorption of Cd in case of sequential addition and BCF for Cd was 2600±150 and that of Cu was 3500±200. Olutona *et al.* (2011) from his study on accumulation of Mn by water hyacinth found that it could accumulate Mn moderately and the BCF for roots and leaves of water hyacinth were 644.8 and 97.9 respectively. Pandey (2016) reported that water hyacinth accumulated trace elements like Cr, Cu, Cd in roots and stem from fly ash pond.

Mohanty *et al.* (2012) stated that removal of Cr from mine water at Kaliapani chromite mine, Orissa was 24-54 per cent by water hyacinth and 18-33 per cent by para grass (*Brachiaria mutica*). Water hyacinth had a BCF of 2.865 and translocation factor of 3.214 for Zn (Kamari *et al.*, 2017). Hassan *et al.* (2012) studied trace element removal by water hyacinth and reported that the highest removal was for Mn (87.88%) followed by Cd (81.69%), Fe (81.09), Cu (77,56%), Al (66.28%), Zn (56.11%), Cr (46.51%), and Ni (41%). When water bodies polluted with As were treated with water hyacinth, COD reduced by 50-60 per cent within 15 days and water hyacinth survived in water having 4 mg/L but it could remove only 20% As from the water (Jasrotia, 2017). Laniyan *et al.* (2015) studied As removal by water hyacinth at three growth stages (sprouting, flowering and mature) and found that maximum accumulation of As occurred at 100 mg/l by mature plants.

Bioconcentration factor of Cu, Zn and Hg for water hyacinth exceeded 1000 indicating that the plants could be selected for hyper-accumulation of these metals from water and over 80 per cent of total quantity of metals removed was accumulated in the roots of which 30-52 per cent was adsorbed on to root surfaces

(Newete *et al.*, 2016). Water hyacinth was used to remediate problems of chromium from waste water at Sukinda chromite mine area of Orissa by Saha *et al.* (2017) and observed that the plant could remove 99.5 per cent Cr in just 15 days. Removal of Copper and cadmium by water hyacinth roots was accompanied with the release of protons and cations such as Ca^{2+} and Mg^{2+}. Ionic exchange was identified as a predominant mechanism of the metal sorption by water hyacinth roots and the amine and oxygen containing groups were the major binding locations for metal sorption through chelation and co-ordination (Zheng *et al.*, 2016).

The metal removal efficiency of water hyacinth from ceramic waste water was studied by evaluating the translocation of metals in roots, leaves and shoot of water hyacinth by Elias *et al.* (2014) and reported that heavy metal removal efficiency was in the order Fe>Zn>Cd>Cu>Cr>B during the process and the concentration of metals in roots were 10 fold higher than that in the leaves. Ndimele *et al.* (2014) conducted an experiment to investigate the ability of water hyacinth to absorb and translocate Fe and Cu and reported that Fe had the highest accumulation in the root (11.22±6.69 mg/kg), while Cu was accumulated mostly in the leaf (3.80±0.12 mg/kg).

According to Hammad (2011) Cu, Ni and Zn accumulated largely in water hyacinth roots, *i.e.,*their accumulation was 2-17 times higher than in shoots. Trace metal accumulation in the root was found to be in the order of Zn> Cu> Ni. Maximum bioconcentration factor for Cu, Ni and Zn were 1344.6, 1250.0, and 22758.6 respectively. Phytoremediation efficiencies of water hyacinth grown under different nutrient conditions of Fe rich waste waters in batch type constructed wetlands was studied by Jayaweera *et al.* (2008). They further reported that Fe removal was largely due to rhizofiltration and phytoremediation efficiency of 47 per cent at the end of 6^{th} week was found with the highest accumulation of 6707 mg/kg dry weight.

According to Das *et al.* (2016) Cd uptake by water hyacinth increased up to 15 mg/L, when the plants were cultured in 5, 10, 15, 20 mg/L $CdCl_2$ solution for 21 days. Shoot tissues accumulated more Cd than root and leaf tissues and the higher accumulation by the plant was 1927.83μg/g Cd at 15 mg/L Cd concentration.

2.5 Utilization of water hyacinth as livestock feed by ensiling with additives

Many aquatic weeds are used as feed for both ruminants and non-ruminants. Those weeds, which contain high fibre content such as water hyacinth, water cabbage, cattail, and duck weed, can be used as feed for ruminants and poultry. Water hyacinth contains high protein content and therefore, silages are made out of it with some additives. Livestock are reluctant to eat water hyacinth in fresh form. Additives are the different kinds of substances which are added to silages to enhance both the quality and palatability. Tham (2012) reported that improved silage could be made from water hyacinth by the use of additives such as molasses and rice bran. Molasses is a universal additive to silage but not so easily available to common people. Lowilai *et al.* (1993) reported the use of cassava flour instead of molasses.

As stated by NAS (1976) ensiling water hyacinth could be a better option in humid tropical regions where complete drying into hay is difficult. The water hyacinth silage alone was said to be having an undesirable fish smell (Li *et al.*, 2007). Little (1979) reported that water hyacinth contained 1.3-3.7 per cent nitrogen and 8.2-23.1 per cent crude protein. Preservation and cattle acceptability of water hyacinth ensiled with dried citrus pulp, sugarcane molasses and yellow dent corn were studied by Baldwin *et al.* (1975) and reported that there was positive correlation between preservative level, pH and the acceptability of silage to cattle.

In an experiment to investigate potential of water hyacinth for ruminant nutrition, Lowilai *et al.* (1994) observed improved quality of water hyacinth silage when additives like rice bran or wheat bran was used. Silage with more than 15

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per cent of the additive was of high quality with both rice bran and wheat bran addition; wheat bran was slightly better than rice bran. Aboud *et al.* (2005) reported that addition of 10 or 20 per cent molasses to the water hyacinth silage significantly improved the organic matter digestibility and the crude protein (CP) content was significantly lower for 10 and 20 per cent molasses-treated silages compared to untreated silage.

The quality of water hyacinth silage prepared with or without rice straw was evaluated by Li *et al.* (2007) and reported that silage prepared from water hyacinth alone was of poor quality, with undesirable odour and colour, while addition of 10 per cent rice straw increased dry matter content, and reduced the proportion of ammonia-N relative to the total N content, pH value and crude protein concentration. Tham (2012) from experiments to study ensilability and feeding value of water hyacinth to cattle reported that application of sugars in the form of molasses or rice bran as a water absorbent resulted in a rapid decrease of pH and the best fermentation quality was achieved in the silages with added molasses, absorbent or with a combination of the two.

El-Serafy *et al.* (1989) from a study conducted in Egypt reported that chopped corn stalks, chopped rice straw, wheat bran, ground corn and urea could be used as additives for water hyacinth silage preparation and sugarcane molasses was necessary for starting fermentation. According to Bagnall *et al.* (1974), acceptable silage could be prepared from water hyacinth by mechanically removing water and adding free carbohydrate like dried citrus pulp or cracked yellow dent corn (2-4%).

According to Gurjar and Taparia (1998) dried and ground water hyacinth could be incorporated up to 20 per cent in concentrate mixtures without any adverse effect on digestibility, feed intake and nitrogen balance in heifers receiving sorghum stover as basal roughage. Physical characteristics and chemical composition of water hyacinth silage prepared with rice straw 0, 5, 10, 15 parts by weight (pbw) and urea 0, 0.5, 1 pbw were studied by Kibria *et al.* (1989) and reported that higher rice straw levels decreased the total moisture content of silage and good quality water hyacinth could be made with the addition of rice straw 10 pbw and urea 0.5 pbw.

Thanh and Thu (2010) reported that silage made from water hyacinth treated with molasses level of 11.5 and 15.3 per cent was good in terms of colour and smell and easily accepted by the cattle. Crude protein content of water hyacinth silage was significantly higher than that of ground maize at the same levels of treating. Silage produced from water hyacinth, 5 per cent molasses and 0.5 per cent urea was not suitable as sole ratio, but when mixed with para grass in equal parts resulted in acceptable milk production by cattle (Chakraborty *et al.*, 1991). Woomer *et al.* (2000) reported that without additives, the pH of water hyacinth silage alone was 7.33 suggesting poor quality, while addition of 15 per cent maize bran or molasses resulted in silage of pH 4.1 and 4.2 respectively and was readily accepted by goats and young steers. Silage prepared with 15 per cent maize bran contained 20 per cent dry weight with 13 per cent crude protein and 20 per cent acid detergent fibre.

Samanta and Mitra (1992) reported that water hyacinth silage had 13.1 per cent crude protein, 17.9 per cent crude fibre, 3.2 per cent ether extract, 51.1 per cent nitrogen free extract, 14.7 per cent total ash, 2.6 per cent calcium and 0.7 per cent phosphorus. The average daily weight gain of black Bengal goats fed with concentrate at 150 g/head daily plus water hyacinth silage and para grass at 1 kg/head was 39.14, 39.19 and 37.69 g respectively. According to Poddar *et al.* (1990), water hyacinth silage with paddy straw was more palatable to growing calves than fresh or wilted water hyacinth, and molasses addition increased the palatability of silage. Silage was superior to para grass or paddy straw or a combination of both, when given to appetite with concentrates in promoting growth of the calves.

Mson and Sangodoyin (1995) ensiled water hyacinth and guinea grass using caged layer excreta (CLE) and observed low dry matter losses and increased

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crude protein content with CLE addition. Crude protein recoveries with 10, 30, and 50 per cent CLE additions were 113, 107 and 111 per cent respectively and in all silages, acetic acid rather than lactic acid was the main preservative. Viswanathan and Thomas (1985) reported that the recovery of unspoiled silages from fresh water hyacinth wilted to 15 or 30 per cent DM and ensiled with 10 per cent molasses, water hyacinth wilted to 15 per cent DM ensiled with chopped paddy straw 10 per cent and molasses 15 per cent, water hyacinth wilted to 30 per cent DM and ensiled with 5 per cent jaggery were 69, 82, 85 and 62 per cent respectively and dry matter content was 22, 29, 30.5 and 25.5 per cent respectively.

Water hyacinth silage fed with concentrates were more palatable to Murrah buffalo calves than fresh plant material and the addition of molasses further increased the palatability of the ration. The water hyacinth silage with concentrate was superior to para grass hay in promoting growth in buffalo calves (Mitra *et al.*, 1997). High quality silage was prepared from water hyacinth by the addition of 15 deoiled rice bran or rice bran and the digestible crude protein was 9.5 and 8.9 respectively (Lowilai *et al.*, 1995).

XinZhu *et al.* (2011) studied the effect of additives such as fermented green juice, cellulose and fermented green juice + cellulose on the quality of water hyacinth and maize stalk mixture at four mixture ratio (8:2, 7:3, 6:4, and 5:5) and reported that the additives significantly improved the fermentation quality of silages and with the increase of corn straw mixture ratio the quality of silage was improved. The effect of addition of urea and beet pulp on silage quality and rumen fermentation characteristics were investigated by MiaoMiao *et al.* (2011). They reported that dry matter of water hyacinth silage increased and crude protein content decreased by the addition of beet pulp. However, addition of urea increased crude protein, but the apparent characteristics were poor. The dietary value and apparent silage characteristics of water hyacinth stem and leaf with beet pulp at lower level (4%) was superior to higher level (8%).

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Kiflewahid (1976) stated that crude fibre digestibility of rations containing 20 per cent water hyacinth silage was significantly higher than that with cotton seed hulls. Chopping and pressing significantly decreased crude protein and increased organic matter. Concentration of neutral detergent fibre, acid detergent fibre, hemicellulose, cellulose and lignin were significantly higher in water hyacinth parts after processing. Gupta *et al.* (1982) reported that wilted water hyacinth + 2 per cent salt + 5 per cent molasses improved percentage recovery of good silage and overall quality. Addition of 1 per cent urea also enhanced the quality. Salt and molasses improved recovery and reduced non-protein nitrogen. Added urea was degraded to ammonia, while checking degradation of the protein.

Byron *et al.* (1975) evaluated acetic acid, formic acid and a commercial product containing 80 per cent propionic and 20 per cent acetic acid at high (0.5 per cent) and low, (0.25 per cent) levels as additives and revealed that ensiled water hyacinth were preserved to the acceptable level. Voluntary intake of silage improved as lactic acid concentration increased and pH decreased. Treatments with high and low levels of commercial product and high formic acid were more acceptable to cattle than low formic acid, high acetic acid and low acetic acid silages. Chhibbar and Singh (1971) commented that silage made by mixing fresh water hyacinth and rice straw in 4:1 ratio contained 14.7 per cent crude fibre, 55.1 per cent nitrogen free extract, 20.6 per cent ash and there was no loss in weight of cows fed with this silage. Malek *et al.* (2008) stated that ensiling straw with supplementation of 25 per cent water hyacinth, azolla or duck weeds resulted in an increase in CP content from 12.2 per cent to 18.7 per cent, organic matter 88.3 per cent to 89.5 per cent, ether extract 3.1 per cent to 4.1 per cent, nitrogen free extract 38.2 to 44.3 per cent ash 10.5 to 11.7 per cent and decreased crude fibre from 29.7 to 27.4 per cent.

Uriyapongson and Taoprayoon (1994) from experiments to compare water hyacinth ensiled with yeast culture (*Candida utilis*) to dried water hyacinth reported that ensiled water hyacinth had higher dry matter and CP than dried water hyacinth. Water hyacinth silage when used as roughage for lambs showed

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higher digestibility of CP than dried water hyacinth. Cruz *et al.* (2011) stated that bacteria inoculants (*Lactobacillus plantarum*) and molasses (150 g/kg) addition resulted in good water hyacinth silage quality. Chakraborty (1991) observed that diet containing 50% ensiled or fresh water hyacinth and 50 per cent para grass hay gave best growth performance in Jersey X Haryana calves without any adverse effect on blood and urine composition.

Kabata *et al.* (1985) observed that water hyacinth pressed cake containing 85 per cent moisture prepared by squeezing out excess moisture by the roller press machine, when used as raw silage material along with molasses or formic acid ranked excellent in terms of quality of silage. The pH values ranged from 3.98 to 4.01 and concentration of ammonium-N was low. Combs *et al.* (1975) found highest voluntary intake of water hyacinth by sheep and cattle with treatments containing 4 kg dried citrus pulp and 1 kg sugarcane molasses/100 kg water hyacinth press residue. Preservation of water hyacinth silage was satisfactory with formic, propionic and acetic acid mixtures as measured by acidity, temperature and spoilage.

2.6. Preparation of compost from water hyacinth

Composting is a microbiological method for disposal and recycling of organic wastes by bioconversion to manure. As the aquatic weeds produce large quantities of biomass, it would be a viable technology for the production of good organic manure and the problem of disposal of these weeds can be solved largely. Parra and Hortestine (1974) commented that water hyacinth could be used as a green manure as the release of nutrients from it was easier than from the other plant residues.

Water hyacinth based compost used as an organic fertilizer has appropriate macronutrients, micronutrients and microorganisms that will support plant growth (Viveka and Grace, 2009). Compost was prepared from water hyacinth using three different pit methods, namely, Indore method, Bangalore method and phospho-compost method. All the three composts had recorded higher macro and

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micronutrients, especially in Bangalore compost from initial to final stage. Girija *et al.* (2005) compared vermi- compost from water hyacinth and salvinia using *Eisenia foetida*, which was ready for use within 40-45 days. According to them, the quality of compost from water hyacinth was much better than that from *Salvinia* in terms of both nutritive value and the recovery percentage.

An experiment conducted by Sannigrahi (2009) showed that aquatic weeds like *Typha angustifolia, Eichhornia crassipes,* and *Pistia stratiotes* could be managed by converting into vermicompost within 2-3 months using earthworm, *Perionyx excavatus*. Nutritive value of compost prepared from *Eichhornia crassipes* was significantly higher (1.36% N, 0.75% P and 1.44% K) compared to other aquatic plants, but it needed more time for composting because the roots took more time to decompose. Trials were conducted at RARS Kumarakom for quick composting of salvinia using different additives, like urea, cowdung, and *Pleurotus*. Higher nitrogen content content was noticed in samples using *Pleurotus* as additive followed by urea. P and K did not vary much with additives (Geetha, 2009).

Rajkowa (2008) evaluated the possibility of utilizing the biomass of weeds viz., *Ipomoea carnea* and *Eichhornia crassipes* either as fresh or as vermicompost prepared from such weed biomass for substituting fertilizer N in rice-rice system under puddled soil conditions. Results revealed that vermicompost prepared from either *I. carnea* or *E. crassipes* was at par or superior to fresh biomass incorporation and FYM in increasing crop yield, nitrogen uptake and improvement in soil nutrient status. Prameela *et al.* (2012) attempted to make vermicompost from alligator weed (*Alternanthera philoxeroides*) as a means to develop sustainable use of the noxious weed and the compost contained appreciable amount of macronutrients (N -1.7%, P – 0.6%, K – 0.85%) on dry weight basis. Viveka and Grace (2011) observed higher N, P, K and organic carbon values when water hyacinth was used as a substrate for vermicomposting. Decreased bulk density and increased porosity and water holding capacity of compost were also reported.

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Umsakul *et al.* (2010) studied physical, chemical and biological changes during composting of water hyacinth. The compost had black colour with no smell and a pH of 7 after 11 weeks of composting and C/N ratio of the compost was 18.12. Ali (2012) reported that vermicompost could be prepared from water hyacinth using earth worm *Eisenia foetida* within 24 days and the compost had a pH of 6.8, EC (3.1), organic C (17.10%), total N (0.50%), total P (0.58%), total K (0.38%), Zn (485.32 ppm), Cu (34 ppm), Mn (719.17 ppm) and Fe (2851.33 ppm). According to Balasubramanian *et al.* (2013), C/N ratio of fresh water hyacinth reduced while composting indicating higher nitrogen release and the quality of compost was good as the C/N ratio was less than 25 compared to compost made out of *Hydrilla* spp., *Najas* spp., *Ottelia* spp. and *Pistia stratiotes*.

Chatterjee *et al.* (2005) compared heap, pit and vermicomposting systems for water hyacinth composting and found that in all the systems, maximum temperature of 64-70°C was achieved within 7 days. Initial pH decreased to near neutrality while composting for 105 days in all the methods. Specific carbon concentration was observed more in pit method. Vermicompost had the highest organic C mineralization, lowest concentration of mineralizable carbon and heap method had less mineralizable carbon than pit. Five types of phosphocompost were prepared from water hyacinth using aerobic composting method along with cow manure, mud, bean rhizosphere, urea or KCl and rock phosphate by Marcano *et al.* (1999). All the treatments had higher soluble P content than control without rock phosphate and maximum concentration was reported from water hyacinth+ mud+ rock phosphate (472.66 mg/kg) and water hyacinth+ cow manure+ rock phosphate (459.56mg/kg) but mature compost+ rock phosphate and water hyacinth+ mineral fertilizers+ rock phosphate had lower phosphorus content (321.6 and 321.94 respectively).

Tiwari (2016) prepared vermicompost from water hyacinth using cowdung and earthworm which had high organic C (12.5%), organic matter (21.55%), N (2.155%), Mg (80.16 ppm), and Zn (22.14 ppm). Varma *et al.* (2016) used earthworm species such as *Esienia foetida*, *Eudrillus eugeniae* and *Perionyx*

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excavates for preparing vermicompost from water hyacinth and found that nutrient content such as total N, available P, K, Ca, Mg, and Na increased and *Eisenia foetida* was the best for vermicomposting. In another study water hyacinth was composted along with saw dust and cattle manure in different proportions such as 10:0:0, 8:1:1, 7:2:1,6:3:1 and 5:4:1 using rotary drum composter by Sarika *et al.* (2014). The lignin and cellulose reduction in all the five trials ranged from 10- 40 per cent and 4 – 55 per cent respectively and maximum reduction was observed when the ingredients were mixed in 6:3:1 ratio. The nutrient contents (N, P, Na, K, Ca and Mg) were increased significantly during the process.

Vermicompost was prepared from water hyacinth, soil and cowdung in 1:2:1, 2:1:1 and 1:1:2 ratios by using two earthworm species such as *Eudrillus euginiae* and *Eisenia foetida.* Nutrient contents increased while heavy metal content decreased during composting. Total nitrogen contents in earth worm treated water hyacinth and control were 1.68 per cent and 0.18 per cent and phosphate contents 1.64 per cent and 0.63 per cent. The corresponding values of Zn were 2.58 ppm and 7.66 ppm and Cu 1.15 ppm and 6.68 ppm respectively. Ankaram *et al.* (2012) prepared vermicompost from water hyacinth using *Eudrillus euginiae* and observed that N, P and K contents increased whereas C/N ratio, EC and pH reduced. Microbial count also increased during composting.

Ansari and Rajpersaud (2012) prepared vermicompost from grass, water hyacinth and water hyacinth+ grass separately and reported that temperature during composting was 28.26±2.19°C, 27.31±0.80°C and 26.94±0.68°C respectively. The pH of all the compost was near neutral (6.81±0.18) and C/N ratio reduced (12.41±3.71). All the composts showed high nutrient contents and vermicomposting of water hyacinth and grass mixture had high productivity than that from water hyacinth and grass alone. Pramanik (2012) prepared traditional and vermicompost using water hyacinth mixed with 200 mg rock phosphate per kilogram of waste and control without rock phosphate. Compared to traditional composting, vermicomposting was faster and nutritionally superior and addition of rock phosphate enhanced total P content of the compost.

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Mahanta and Jha (2009) prepared vermicompost from water hyacinth using *Eisenia foetida* and *Eudrillus euginiae* and reported that earthworm activity reduced the C/N ratio and enhanced the nutrient content of the compost and both species took 50-70 days for composting and N, P, K and organic carbon content of the compost were 1.50 per cent, 0.72 per cent, 2.20 per cent and 48.20 per cent respectively. Blessy *et al.* (2014) used *Eudrillus euginiae* for vermicomposting water hyacinth and found that N, P and K content of the compost were 0.56 per cent, 1 per cent and 1.26 per cent respectively. Singh and Kalamdhad (2015) evaluated nutrients and stability parameters during 30 days of agitated pile composting of water hyacinth mixed with cowdung and found that nutrients like N, P, K, Ca and Na increased during composting and total coliform reduced significantly and the pH changed from slightly acidic to neutral at the end of composting process.

Water hyacinth was used to prepare aerobic compost and vermicompost by Sasidharan *et al.* (2013) and observed that the composts were comparable to farm yard waste compost having pH of 6.8, EC (0.02 dS/m), organic carbon (37.6-41.4%), C/N ratio (13.2-14.2), nitrogen (2.8-2.9%), total phosphates (2.7%), and potash (1.4-1.6%) but the water hyacinth composts had higher Fe, Mn and Cd content than farm yard waste compost.

2.7. Water hyacinth as mulch

Application of mulches on the soil surface is a very common practice in high-value crops. Mulching not only increases the growth and yield of crops but also improves soil moisture status, nutrient utilization, weed suppression, disease control and temperature regulation of upper layers of the soil. Many aquatic weeds form excellent mulch material.

Lakshmi and John (2015) conducted a pot culture study to assess the allelopathic compatibility of leaves of certain homestead trees, viz. coconut (*Cocos nucifera* L.), cashew (*Anacardium occidentale* L.), jack (*Artocarpus heterophyllus* Lamk.), mango (*Mangifera indica* L.), tamarind (*Tamarindus indica*

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L.) and teak (*Tectona grandis* L.f.), commonly planted in the home gardens of Kerala, when applied as mulch in turmeric (cv. Sobha). They reported that at 6 months after planting (MAP), the number of leaves was significantly less in plants mulched with leaves of coconut, mango and teak, but rhizome yield was significantly higher when mulched with cashew (660 g/plant), jack (557 g/plant) and teak (565 g/plant) leaves.

Yong *et al.* (2017) conducted an experiment to evaluate the effects of water hyacinth residues as mulch on soil water content and grain yield of maize and reported higher moisture content in the 0-90 cm soil layer of the mulched plots compared to non-mulched plots. The maize grown in soil mulched with water hyacinth produced higher grain yield than the non-mulched plots. Effect of mulching, N and K nutrition on the growth and yield of carrot was studied by Islam *et al.* (2014) and reported that water hyacinth mulch along with the application of 200 kg N/ha and 200 kg K/ha can be recommended for carrot cultivation in areas where irrigation facilities are not available.

Singh *et al.* (2014) observed higher growth and yield attributes of mustard *viz.,* plant height, number of leaves per plant, number of primary and secondary branches per plant, dry matter accumulation per plant, siliqua length, number of siliqua per plant, 1000 grain weight, seed and stover yield and harvest index with reduced tillage and water hyacinth mulch compared to other treatments. Kabir *et al.* (2013) conducted a trial to study the effects of different thickness of water hyacinth mulch (0, 6, 8, 10 and 12 cm) and tillage (conventional and zero) on the storage life of garlic and reported that garlic production under zero tillage with 12 cm mulch could be used for better storability. Kabir *et al.* (2016) observed better growth parameters and bulb yield with water hyacinth mulch, which was on a par with paddy straw mulch.

Mulching with water hyacinth showed significant effect on growth, yield components and yield of tomato (Kayum *et al.*, 2008). Islam *et al.* (2002) reported that mulching and irrigation significantly affected the growth and yield of

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cabbage. The highest marketable yield was obtained due to water hyacinth mulch (90.99 t/ha) followed by irrigation at 15 days interval, whereas non-mulching and non-irrigated plots exhibited the lowest marketable yield (38.8 t/ha). Maurya *et al.* (2015) studied the effect of organic manuring and mulching on growth and yield of pearl millet and reported higher values for growth and yield parameters with legume straw mulching+ FYM+ vermicompost followed by water hyacinth mulch+ FYM+ vermicompost.

Jalil *et al.* (2004) reported that yield of potato varieties Cardinal and Lalpakri was the highest with water hyacinth mulching. Sannigrahi and Borah (2002) conducted an experiment to evaluate the effectiveness of organic mulches on tomato and okra production and reported that mulching increased the number of tomato fruits per plant. Water hyacinth mulch gave the highest increase in tomato yield (by 91 %) and maximum okra yield was obtained under black polythene mulch (12.12 t/ha) followed by water hyacinth (10.71t/ha). The highest yield (59.41t/ha) of tomato was observed under rice straw mulch followed by water hyacinth mulch (52.5 t/ha) and the benefit: cost ratio was the highest in rice straw mulch followed by water hyacinth mulch.

According to Hoque *et al.* (2004) potato variety Dheera and Diamant produced the highest yield under water hyacinth mulch followed by rice straw mulch. An experiment was conducted by Rahman and Yabata (2007) to study the effect of mulches and irrigation regimes on leaf water status and pod yield of common bean. They reported significantly higher yield with irrigation at IW/CPE 1.0 and water hyacinth mulch. According to Azad *et al.* (2014) water hyacinth mulching and K nutrition had significant influence on plant height, spread of plant, length of root per plant, fresh weight of stem, fresh weight of head, diameter of head and gross yield of cabbage.

Islam *et al.* (2007) commented that mulching with black polyethylene, water hyacinth and straw resulted in yields of 5.80, 5.70 and 5.48 t/ha in garlic, which was 39, 36.6 and 31.4 per cent higher than the yields of the control and the

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effect of black polyethylene and water hyacinth on growth and yield of garlic was almost similar. According to Mostarin *et al.* (2005), water hyacinth mulch along with 120 kg N/ha produced the highest yield of green pod (17.9 t/ha) of French bean. Zaman *et al.* (2009) studied the response of potato under minimum tillage with various irrigation scheduling and mulching in rice-potato system and reported higher tuber yield under irrigation at IW/CPE of 0.6 and water hyacinth mulch.

According to Rahman *et al.* (2013), mulching of soil with straw and water hyacinth increased length and diameter of bulb, fresh weight, dry weight of bulb, and bulb yield of onion, but mulching with water hyacinth gave the highest yield (10.46 t/ha) than mulching with rice straw (9.78 t/ha). According to Sarkar *et al.* (2007), adoption of zero tillage and organic mulching in a lowland rainfed ecosystem would utilize the residual soil moisture following rice, resulting in rice-yellow sarson as a viable profitable cropping system. Seed yield of yellow sarson was 37 per cent more with water hyacinth mulch compared to no mulch treatment. Balasubramanian *et al.* (2013) indicated that water hyacinth as a potential organic substrate that stimulated the growth and diversity of microbial population in agricultural soil. Soil respiration and microbial population were significantly greater in mulched plots compared to control.

Singh *et al.* (2017) from an experiment conducted to assess the influence of different mulches on the growth and yield of onion reported that plant height, number of leaves per plant, bulb length, bulb diameter, bulb weight and bulb yield increased significantly with mulching and mulching with pipal leaf and water hyacinth gave the highest yield 38.8 t/ha and 38.4 t/ha respectively. Sarkar *et al.* (2016) observed the highest yield of chickpea under black polythene mulch, which was about 2.94 per cent, 6.99 per cent and 9.35 per cent higher than the treatments receiving straw @ 5 t/ha, water hyacinth @5t/ha and no mulch respectively. Kotoky and Bhattacharyya (1996) reported the highest fruit TSS, reducing sugars and ascorbic acid content when banana plants were mulched with

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10 t paddy husk per hectare and the lowest titratable acidity was observed with water hyacinth mulch (10 t/ha).

Khan and Parvej (2010) reported nearly double grain yield (8.73 t/ha) with water hyacinth mulching than the unmulched treatment (4.93 t/ha) for quality protein maize cv. Pozarica. The indigenous mulches like water hyacinth and rice straw suppressed weed growth greatly producing less than one third of the total biomass compared to that of control. Under non-tilth condition, water hyacinth and rice straw mulches reduced the maximum soil temperature at 5 cm depth by 3.5-4.2°C and 1.2-1.4°C at 6.00 hrs. and the water retentive capacity of the mulched soil under zero tillage condition was higher at all the stages of plant growth and ranked in the order of water hyacinth> rice straw> rice husk> ash> control.

Rubel *et al.* (2014) studied the effect of mulching on seed production of onion by using three types of mulches *viz.*, water hyacinth, black polythene and no mulch and observed significantly greater plant height, number of leaves per plant, weight of leaves per plant, number of flowers per umbel, number of fruits per umbel, yield of seeds per plant, 1000 seed weight and seed yield with black polythene mulch and water hyacinth mulch compared to no mulch treatment. Assam lemon plants when mulched with water hyacinth (50 t/ha) increased leaf chlorophyll content and relative water content (1.025mg/g and 79.08 % respectively) compared to no mulch treatment (0.686 mg/g and 71.17% respectively) (Nath and Sarma, 1993).

Rautaray (2010) from an experiment conducted at Regional Rainfed Lowland Rice Research Station, Kamrup, Assam reported that water hyacinth improved tuber yield of potato by 3.02t/ha from 11.36 t/ha under no mulching and the proportion of larger sized tuber was higher (60%) under mulching as compared to no mulching control (51%). According to Borthakur and Bhattacharyya (1992), when 10 cm of rice husk, paddy straw and water hyacinth mulch were applied to guava cv. Allahabad Safeda the highest soil organic matter

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content (1.47%) was obtained with rice straw mulch, while the highest soil pH (5.56) was obtained with rice husk and water hyacinth mulches. Singh (2010) reported that water hyacinth mulch along with the application of oxadiazon (0.75 kg/ha) at seven days after planting gave the most efficient weed control (94-95%), produced maximum tuber yield, gave the highest net returns and maximum benefit: cost ratio compared to no mulch control.

Ghosh (2008) from experiments to study the efficacy of different organic mulches in ginger (*Zingiber officinale* L) as intercrop in a 21 year old coconut garden observed significant improvement on growth and yield parameters under paddy straw followed by water hyacinth. Chakravarti *et al.* (2010) reported that mulching with water hyacinth greatly altered the thermal environment by reducing air temperature and canopy temperature in groundnut and improved drymatter production and yield. Mulching with water hyacinth significantly increased soil organic C, total N, available P and K as compared to the non-mulched plots of lowland rainfed rice farming system in north-east India (Balasubramanian *et al.*, 2013).

Khatun and Farooque (2005) reported that plastic mulch gave the highest yield (22.9 t/ha) of carrot followed by water hyacinth (21.6 t/ha) and natural mulch (2.02 t/ha), respectively while the non-mulched control produced the lowest yield (15.6 t/ha). Mondai *et al.* (2009) stated that residual nutrient status of soil increased with mulching of potato leading to higher tuber yield and benefit: cost ratio. Razzaque and Ali (2007) from an experiment to find out suitable mulching materials for potato under no tillage condition reported that the variety Heera produced higher yield under both rice straw mulch (19.45 t/ha) and water hyacinth mulch (23.15 t/ha).

Rahman and Khan (2002) observed that water hyacinth mulch reduced the maximum soil temperature at 5 cm depth by 4-9°C at 14.00 h and raised the minimum temperature by 1.7- 2.5°C at 6.00 h compared to control. It also conserved more soil water during the entire growing period and gave higher

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seedling emergence (90.6 and 88.2%) and grain yield (6.67 and 5.54 t/ha) of quality protein maize compared to control (75% and 2.96 t/ha). Water hyacinth applied as surface mulch to field acted as an organic input to soil because of relatively rich nutrient contents and rapid decay pattern (Amoding *et al.*, 1999)

Islam *et al.* (2005) reported that grain yield increase over no mulch in wheat crop were 23, 18 and 11 per cent with rice straw mulch, water hyacinth mulch, and polythene mulch, and tillage and mulching markedly influenced the physical properties of soil such as bulk density and soil strength. Lamid and Wahab (1996) from experiments to study the effect of water hyacinth as fresh mulch for weed control on the growth of soybean cv. Willis reported that increased rates of fresh mulch suppressed the weed population up to 63-73 per cent and improved the growth. When a fresh mulch of water hyacinth was applied at the rate of 25 t/ha soybean yield increased 171 per cent due to low weed population besides greater pod formation and size of seeds. Plant growth and yield of *Colocasia esculenta* cv. Bilashi was the highest with water hyacinth mulch yielding 5.76 and 13.27 t/ha of primary corm and cormels respectively and improved the time to 50 per cent emergence by $\geq$ 8 days.

According to Baten *et al.* (1995), bulb length, bulb diameter, clove length, clove diameter, clove number per bulb, 100-clove weight and yield of late planted garlic were significantly higher with water hyacinth mulch. It also provided efficient weed control and compensated for reductions in garlic yield due to late planting. Different mulches such as guatemala (*Tripsacum laxum*), siam weed (*Eupatorium odoratum*) and Indian rhododendron (*Melastoma malabathricum*), water hyacinth (*Eichhornia crassipes*) and paddy straw reduced the diurnal variation in soil temperature by reducing soil heating during the warmer part of the day (10 am to 6pm) and increased the soil water content, soil pH, organic C content, available N and K (Sarma and Baruah, 1997).

Tripathi *et al.* (1991) reported that mulching with water hyacinth increased total cured leaf and first grade leaf yield of tobacco cv. DD 437 intercropped with

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potato cv. Kufri Jyoti and the net income was higher with intercropping, along with mulching with water hyacinth and topping at 8 leaves per plant. Seven year old Assam lemon plants grown on sandy soil when mulched to a depth of 8 to 10 cm with litchi leaves, paddy straw, paddy husk, water hyacinth saw dust and banana leaves resulted in increased growth and yield compared to control. Mulching also improved the conservation of soil moisture, maintenance of soil temperature, and organic matter content of the soil (Nath and Sarma, 1992). Kotoky and Bhattacharyya (1991) reported that banana cultivars Jahaji, Chenichampa and Manohar when mulched with rice husk (10 t/ha), water hyacinth (10 t/ha) and rice straw (36 t/ha) to 8-10 cm soil depth significantly increased the bunch weight and yield in all the cultivars.

Borthakur and Bhattacharya (1988) observed that the relative water content of guava cultivar Banarasi Safeda was the highest in plots mulched with water hyacinth. Mohankumar and Sadanandan (1988) reported that mulching with green leaves or water hyacinth produced corm yields of 3.05-3.10 t/ha compared to 2.57 t/ha without mulch and 2.91 t/ha with black polythene mulch. Gogoi *et al.* (1991) conducted field with water hyacinth mulch and manual weed control at the tuber formation stage by comparing with pre-emergence herbicides for the control of weeds in potato cv. Kufri Jyoti and reported that all the weed control treatments significantly reduced weed population compared to the control.

Rashid *et al.* (1981) reported that tuber yield of potato cv. Cardinal was the highest (17.6 t/ha) when the plants were cultivated on ridges and mulched with water hyacinth. Emergence of potato was significantly high on mulched plots compared to control plots. Rahman *et al.* (2004) opined that potato could be cultivated in saline soil by minimizing salinity with the application of mulches like rice straw and water hyacinth and potato tuber yield was the highest (23.02 t/ha) under rice straw mulch followed by water hyacinth (22.23 t/ha). Maurya (1985) observed increased emergence, vine growth, protein and starch content of lesser yam tubers with mulching. Moreover mulching with 15 t water hyacinth, mango leaves, sugarcane leaves or paddy straw per hectare resulted in tuber yields of 16.65, 15.03, 14.02 and 13.55 t/ha respectively compared with 10.5 t/ha without mulch.

Ahammed *et al.* (1988) reported that mulching with water hyacinth increased cormel yield of *Colocasia esculenta* cv. MK 065. Paul *et al.* (1993) observed potato tuber yield of 7.04 and 8.09 t/ha from earthing up and mulching with dry water hyacinth respectively compared to control (5.9 t/ha), in cv. Lalpakri. Potato cv. Kufri Jyoti produced tuber yields of 7.47, 7.24 and 6.32 t/ha respectively. According to Rabbani and Siddique (1987) sweet potato cv. Kamalasundari planted in furrows and mulched with water hyacinth increased the tuber yield from 9.35 to 11.48 kg/plot (5.4 m^2). Azad and Nabi (1984) reported that mulching of potato with water hyacinth increased yields significantly than mulching by earthing up. Water hyacinth conserved soil moisture efficiently when used as mulch (Hafeez, 1975).

Tomato varieties Bari tomato-4 and Bari tomato-6 produced significantly higher yields with mulching using water hyacinth, straw and black polythene compared to no mulch treatment (Hasan *et al.*, 2005). De *et al.* (2005) from experiments to study the efficacy of some mulching materials (water hyacinth, rice straw, banana leaves, jute sticks, white polythene sheet) on moisture conservation and yield of groundnut reported that water hyacinth mulch in comparison to other mulches conserved more soil moisture, reduced soil temperature at root zone depth and gave highest kernel yield (0.67 t/ha).

A field investigation at Central Research Farm, BCKV, at Gayaspur on elephant-foot yam (*Amorphophallus paeoniifolius*) was carried out with various mulch materials, viz., black polythene, wheat straw, paddy straw, banana leaf, water hyacinth. Black polythene, paddy straw and water hyacinth produced significantly higher yields (50.2–52.8 t/ha), which was 7.1-28.8 per cent more than that of no-mulch control (Goswamy and Saha, 2006). Verma and Sarnaik (2006) reported that paddy straw mulch resulted in maximum plant height (84.40 cm), number of leaves (10.32) and yield (16.93 t/ha) of turmeric in comparison to mulching with dry grass, palash leaves and plastic mulch. Kaur *et al.* (2008) reported that straw mulching @ 9 t/ha significantly reduced weed dry matter and produced 29.2 per cent higher yield of turmeric than straw mulching @ 6 t/ha.

Abraham *et al.* (2016) from a pot culture study to investigate the allelopathic effect of mulching with fresh leaves on the growth and yield of ginger reported that rhizome yield reduced significantly when mulched with mango and tamarind leaves. However, mulching with matty (*Ailanthus triphysa*), wild jack(*Artocarpus hirsuta*), teak (*Tectona grandis*), rubber (*Heavea braziliensis*) and panal (*Glycosmis pentaphylla*) gave significantly higher rhizome yield. Thankamani *et al.* (2016) compared different mulches such as paddy straw, coir pith compost, dried coconut leaves, *Glycosmis pentaphylla* leaves, *Lantana camara* leaves, cowpea plants and plastic mulch and reported that application of paddy straw @ 6 t/ha along with green leaf mulch @ 7.5 t/ha at 45 and 90 days after planting and application of dried coconut leaves at the time of planting had higher weed control efficiency and higher economic returns from ginger crop, compared to the application of *Glycosmis pentaphylla* leaf mulch (farmers practice).

Vanlalhluna *et al.* (2010) from a study to compare relative efficiency of different mulch materials (rice straw, weeds and subabul) applied at 6, 8, and 10 t/ha observed that application of mulches at 10 t/ha conserved more moisture as well as increased yield of turmeric. Soil moisture relation was in the order of rice straw> subabul leaves> weeds, and application of subabul gave maximum yield over other mulches. Application of paddy straw mulch (6.25 t/ha) significantly increased the plant height, number of leaves, rhizome weight and yield of turmeric compared to no mulch control (Kumar *et al.*, 2017). From an experiment to study the water use and productivity of turmeric as a function of straw mulching and irrigation scheduling, Kaur and Brar (2016) reported that turmeric yield was 125.2 per cent higher with mulching than no mulch with 50 per cent saving in irrigation water.

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MATERIALS AND METHODS

3. Materials and Methods

The present investigation on "Management and utilization of water hyacinth (*Eichhornia crassipes* (Mart.) Solms)" was carried out at the Department of Agronomy, College of Horticulture, Vellanikkara during the period 2015 to 2017. The objectives of the study were to assess the phytoremediation capacity of water hyacinth and to manage it by eco-friendly means such as silage making, composting, and mulching. In order to achieve the objectives, four separate experiments were carried out. The materials used and the methodology adopted for the studies are presented in this chapter.

3.1. Details of the study area

3.1.1. Location

The experiments were conducted at the Agronomy Research Farm of College of Horticulture, Kerala Agricultural University, Vellanikkara. Geographically, the area is located at 10° 31' N latitude, 76° 13' E longitude and at an altitude of 40.3 m above mean sea level.

3.1.2. Climate and weather

The area enjoys humid tropical climate. The mean monthly averages of important meteorological parameters observed during the experimental period are presented in Appendix I.

3.2. Experimental details

Four experiments were conducted during the course of the study. The details of each experiment are given below:

3.2.1. Experiment I: Phytoextraction capacity of water hyacinth

Purposive sampling was carried out to collect water hyacinth samples from 20 sites from Central Kerala representing ponds, fallow paddy fields, and canals. Five water and plant samples each from four districts (Kottayam, Ernakulam, Thrissur, and Palakkad) were collected.

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Water sampling

Water samples from each site were collected in clean plastic bottles, labelled carefully and brought to laboratory. The samples were preserved in non-reactive plastic bottles and kept under refrigeration till analysis. The samples were characterized for various macro and micro nutrients. Analysis was also done for the presence of heavy metals such as Cd, Cr, As, Hg, and Pb. Total nutrient content of water samples were estimated by evaporating the water samples in water bath to complete dryness followed by digestion using di-acid (nitric acid and perchloric acid in the ratio 9:4). The procedures followed for analysis of water samples are given below (Table 2).

Table. 2. Standard procedures followed in water analysis

Parameter	Method	References
pH	pH meter	Gupta,1999
EC	Conductivity meter	Gupta,1999
NH_4-N and NO_3-N	Micro Kjeldahl digestion and distillation	AOAC,1950
Phosphates	Spectrophotometry	Murphy and Riley, 1962
Potassium	Flame photometry	American Public Health Association (APHA), 1989
Sulphates	Turbidimetric method	Chesnin and Yien, 1951
Fe, Mn, Zn, Cu, Pb, Cd, Cr, Hg	Nitric-perchloric acid (9:4) digestion (Hesse,1971) and estimation using ICP-OES (Model: Optima® 8x00 series)	

Plant sampling

Actively growing water hyacinth samples from 0.25 m^2 of the water body were collected in plastic bags, labelled carefully, and brought to the laboratory. The samples were washed with clean water, air dried and then oven dried at $80 \pm 5°C$ until constant weight was achieved. Then the samples were powdered well and stored in butter paper covers. The samples were analysed for various macro, micro nutrients and heavy

Plate 1. Collection of samples from different sites

metals. Plant samples were digested using di-acid (nitric acid and perchloric acid in the ratio 9:4) for the estimation of different elements. The methods followed for plant analysis are described below (Table 3).

Table 3. Standard procedures followed in plant analysis

Parameters	Methods	References
Nitrogen	Micro Kjeldahl digestion and distillation	Piper (1966)
Phosphorus	Vanadomolybdophosphoric yellow colour method using Spectronic-20 spectrophotometer	
Potassium	Flame photometry	
Calcium and Magnesium	Nitric- perchloric acid (9:4) digestion and estimation using ICP-OES (Model: Optima 8x00 series)	
Sulphur	Nitric- perchloric acid (9:4) digestion and turbidimetric method and estimation using spectronic-20 spectrophotometer	Chesnin and Yien (1951)
Fe, Mn, Zn, Cu, Pb, Cd, Cr, As, Hg, Al, and Ni	Nitric- perchloric acid (9:4) digestion (Hesse, 1971) and estimation using ICP-OES (Model: Optima 8x00 series)	

3.2.2. Experiment II: Utilization of water hyacinth as livestock feed by silage making

The experiment involved four levels of water hyacinth materials and three levels of additives. Water hyacinth from a site which showed less accumulation of heavy metals was utilized for silage preparation. Treatments included combinations of two factors viz; Factor A (four levels of water hyacinth materials) and Factor B (three levels of additives). Details of treatments are given below (Table 4).

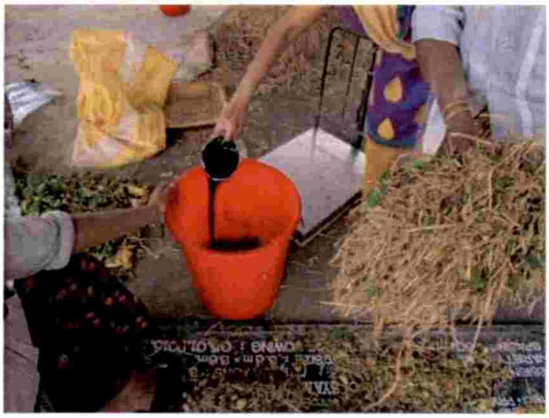
Table.4. Treatment details of experiment II

Treatments	
Factor A: Water hyacinth materials (4)	
1	Wilted water hyacinth alone
2.	Fresh water hyacinth + 10 % rice straw
3.	Wilted water hyacinth + 10 % rice straw
4.	Wilted water hyacinth + 10 % guinea grass
Factor B: Additives (3)	
1.	Molasses (5 % by wet weight)
2.	Cassava flour (10 % by wet weight)
3.	Rice bran (10 % by wet weight)

Method

The experiment was carried out at the Agronomy Research Farm, College of Horticulture, Kerala Agricultural University Vellanikkara, Thrissur during August to October, 2016. The experimental design adopted was completely randomized design (CRD) with twelve treatment combinations and three replications. The treatments included wilted water hyacinth alone, wilted water hyacinth with 10 per cent rice straw or 10 per cent grass and fresh water hyacinth with 10 per cent rice straw and three additives (molasses, cassava flour and rice bran). Both petiole and leaves were cut in to 4-5 cm pieces, spread on plastic sheets and wilted in shade for two days. Depending on treatments, additives were added and thoroughly mixed. Then it was filled in little bags (polyethylene covers) @ 5 kg/cover. The mixtures were compressed by hand to remove as much air as possible. Covers were tightly tied and stored indoors. Observations on pH, dry matter content, and proximate analysis after 60 days of ensiling were done.

Chopping of water hyacinth and straw



Addition of molasses

Addition of cassava flour

Addition of rice bran

Tying the bags

Plate 2. Various stages of silage preparation

Observations

pH

For pH determination, 10 g silage was taken in a beaker to which 100 ml hot distilled water was added and stirred intermittently for 30 minutes and the pH of the suspension was recorded using pH meter (AOAC, 1990).

Crude protein

The nitrogen content was estimated by Micro Kjeldahl digestion and distillation method (Jackson, 1958). The nitrogen content thus obtained was multiplied by 6.25 to get the crude protein content in the plant samples.

Crude fibre

The crude fibre content was estimated using acid- alkali digestion method (Sadasivam and Manickam, 1992).

Ether extract

The ether extract content, which represents the crude fat fraction of the sample, was estimated by extracting the plant fat using the organic solvent, petroleum benzene (AOAC, 1990).

Ash

The ash content was determined by igniting a known quantity of plant sample at 600°C for three hours (AOAC, 1990).

Nitrogen free extract

Nitrogen free extract was estimated by subtracting the crude protein, crude fibre, ether extract and ash content from 100.

Silica content

Acid-insoluble ash which consist of indigestible mineral components mainly silica was determined by digesting ash in dilute HCl to dissolve the soluble fraction, which is then separated from insoluble residue by filtration. The filter paper containing the insoluble residue was incinerated and the weight of the residue was recorded (AOAC, 1990).

Heavy metals

The silage samples were digested using nitric acid in microwave digestion system and heavy metal content of the samples were estimated using ICP OES (Model: Optima® 8x00 series).

Observation on animal feeding

Palatability

The term palatability designates those characteristics of a feed that invoke a sensory response in the animal (Greenhalgh and Reid, 1971). The sensory response invoked by a feed is expressed by the intake rate when no choice is offered to the animal and by the feed preferences in the choice situation. Feeds that can be ingested fast and that are rapidly digestible are very palatable provided they do not contain toxic compounds.

Method

Palatability studies were carried out at the cattle farm of University Livestock Farm and Fodder Research Station, Kerala Veterinary and Animal Sciences University (KVASU), Mannuthy. A total of 12 test animals (heifers) were used for the study. Silage was fed as the first meal and feed intake was noted. The intake measurement consisted of two days for adaptation to the diets and three days for feed intake measurements. The animals were allowed to feed on a given weight of silage (W_1) and after 15 minutes the weight of left over feed (W_2) was noted. Afterwards, the percentage left over was worked out by the formula,

$$\text{Percentage of left over feed} = \frac{W_2}{W_1} \times 100$$

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Silage after 45 days

Silages ready for feeding

Plate 3. Palatability test

3.2.3. Experiment III: Conversion of water hyacinth (*Eichhornia crassipes*) into nutrient rich compost

Water hyacinth plants were collected from nearby site and were brought to Agronomy Farm, Vellanikkara. The plants were allowed to wilt for two days to remove excess moisture before composting. The experiment was done to find out the most efficient composting method.

Treatments

T1 – Bangalore method

T2 – Indore method

T3- Phospho-compost

T4- Vermi compost

Design: CRD

Replications: 4

Bangalore method

The Bangalore method of composting or the 'hot fermentation method' is predominantly anaerobic in nature. Bangalore composting was carried out in ferro-cement tanks of 60 cm height and 60 cm diameter. Cowdung and water hyacinth were added in alternate layers of about 15 cm thickness. About 5 kg of cowdung was added as inoculum with 40 kg water hyacinth substrate. After filling, the tanks were covered with 15 cm thick layer of water hyacinth and sealed with mud plaster. No turning in was given.

Indore method

Howard and Wad (1931) developed Indore method of composting. In the Indore method, composting is accelerated by frequent turnings, whereby aeration, mixing of compost material and moistening is done. Composting was done in tanks provided with sufficient holes for air circulation. About 5 kg of cowdung was added as

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inoculum in alternate layers with 40 kg water hyacinth substrate. Watering and turning was given at every two weeks interval.

Phospho-compost

Compost generally contains less phosphorus and hence phosphorous is added to enrich the compost. Phospho-compost is prepared by mixing phosphorous fertilizers at the rate of 5% P_2O_5 with the composting mass. About 5 kg of cowdung was added as inoculum in alternate layer with 40 kg water hyacinth substrate. Rock phosphate (5 kg) was sprinkled over each layer. Watering and turning was done at every two weeks interval.

Vermicompost

Vermicomposting is a process by which organic wastes are converted to rich organic manure using earthworms. Tanks with sufficient holes for ventillation were used for composting. Coconut husks were used to line the bottom of tank. Turmeric powder was sprinkled over the ground to ward off pests. Water hyacinth was spread after mixing with cowdung in the ratio 8:1 up to a height of 30 cm. The worms were introduced after 30 days of pre-digestion of biomass. Jute sacks were used to cover the tanks. Moisture status of the compost was monitored and water was sprinkled as and when necessary. Turning was given at two weeks interval for the entire period.

Observations

Compost samples were collected after three and six months for analysis. Nutrient content of compost and other physical parameters were analyzed as per standard procedures (Table 5).

Table.5. Standard procedures followed for compost analysis

Parametres	Methods	References
Bulk density	Using measuring cylinder	GOI,1985
Porosity	Using measuring cylinder	
pH	pH meter (1:12 compost: water suspension)	
Total salt concentration	Conductivity meter	
Organic carbon	Loss on ignition	
Total Nitrogen	Micro-Kjeldahl digestion and distillation (Piper,1966)	
Total Phosphorus	Ashing- 25% HCl extract- colourimetry	
Total Potassium	Ashing-25% HCl extract- flame photometry	
Total Calcium and total Magnesium	Ashing-25% HCl extract (GOI,1985)- estimation (using ICP-OES (Model: Optima® 8x00 series)	
Total Sulphur	Ashing-25% HCl extract- turbidimetric method (GOI,1985) and estimation using spectronic-20 spectrophotometer	
Total micronutrients Fe, Mn, Zn and Cu	Ashing-25% HCl extract (GOI,1985)- estimation using ICP-OES (Model: Optima® 8x00 series)	
Heavy metals As, Cd, Cr, Ni and Pb	Ashing-25% HCl extract (GOI,1985)- estimation using ICP-OES (Model: Optima® 8x00 series)	
Hg	Ashing-25% HCl extract (GOI,1985)- estimation using AAS (Furnace method)	

Treatment application in ferro-cement tanks

Bangalore composting

Plate 4. Compost making

3.2.4. Experiment IV: Evaluation of water hyacinth as a mulch in turmeric

Field experiments were conducted during the period May 2014 –January 2015 and May 2015-January 2016 at Agronomy Farm of College of Horticulture, Kerala Agricultural University. The layout of the field is given in Fig.1. The experiment was laid out in randomized block design (RBD) with five replications. The treatment details are the following

Treatments

T1 – Water hyacinth mulch

T2 – Jackfruit leaves

T3 – Coconut fronds

T4 – No mulch

The mulches were applied at the rate of 15 tonnes per hectare (green) at the time of planting and 50 days after planting. All the cultural operations were carried out as per the Package of Practices Recommendations (KAU, 2011).

Cropping history of the experimental site

The experiment site had been under cassava cultivation during the past season before which it was under turmeric crop for one year. Before the turmeric cultivation, the field was fallowed for two years.

The Cultivar

The turmeric cultivar 'Sona' released from the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University was used for the experiment. It was developed through clonal selection of local germplasm and is best suited for cultivation in the central zone of Kerala. It has 240-270 days duration with 21.3 t/ha mean rhizome yield (fresh). Dry recovery is 18.9 per cent, with 7.1 per cent curcumin, 10.3 per cent oleoresin and 4.4 per cent volatile oil contents. The rhizomes are orange yellow in colour, medium bold with no tertiary fingers. The scales on the rhizomes are prominent and dark brown.

Land preparation and planting

On the receipt of summer showers, the area was ploughed, stubbles removed, levelled and laid out into plots as per the layout plan. Four raised beds of 2m length and 1m width were prepared in plots of 8 m^2. Planting was done during the month of May with the receipt of four to five pre-monsoon showers. Small pits were taken in beds at spacing of 25 X 25 cm. Rhizome bits were planted with a viable healthy bud facing upwards at a depth of 4 to 5 cm along with farmyard manure and then covered with soil.

Fertilizer application

The fertilizer recommendation adopted was N, P_2O_5 and K_2O 30:30:60 kg per hectare. N, P_2O_5 and K_2O were applied as urea (46% N), Mussorie rock phosphate (20% P_2O_5) and Muriate of Potash (60% K_2O). Farmyard manure at the rate of 40 t/ha was applied as basal dose along with full dose of P_2O_5 (30kg/ha) and half dose of K_2O (30 kg/ha). Two-third dose of nitrogen (20 kg/ha) was applied at 30 days after planting. The remaining quantity of N (10 kg/ha) and K_2O (30 kg/ha) were applied 60 days after planting.

Intercultural operations

Manual weeding was done thrice at 45, 90 and 150 days after planting. Earthing up was done at 60 days after planting. The crop was entirely dependent on rainfall.

Harvesting

The crop was harvested during the first week of January 2015 and 2016 when the plants completely dried in the field. Harvesting was done, avoiding one border row from all the sides. After harvest, the fibrous roots as well as the soil particles that adhered to the rhizomes were removed, and the rhizomes were stored in the field laboratory.

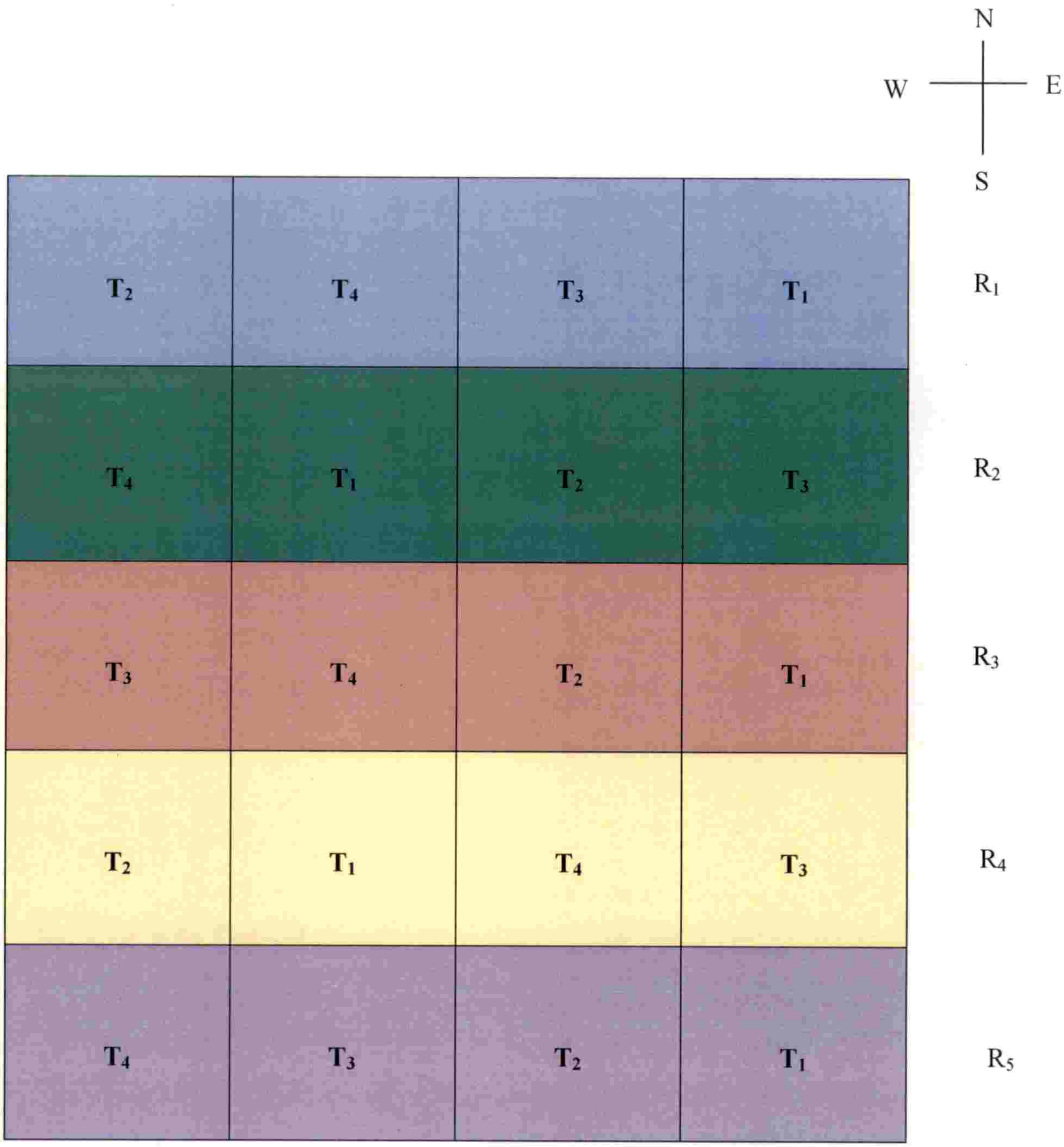

Fig. 1. Layout plan of the experimental field

T1 – Water hyacinth mulch

T2 – Jackfruit leaves

T3 – Coconut fronds

T4 – no mulch

Plate 5.Layout of field

Plate 6. Mulch application

Biometric observations

For recording various biometric observations, five plants were selected at random as observation plants. Pre-harvest observations were recorded at monthly intervals starting from 90 days after planting.

Plant height

Plant height in cm was measured from the ground level to the tip of topmost leaf. It was recorded at monthly intervals from the third month onwards from five sample plants and the average was computed.

Number of tillers

Total number of tillers produced per clump of each sample plant was recorded and the average number of tillers was worked out.

Number of leaves per plant

Number of leaves was recorded from the five sample plants and their average was worked out.

Dry matter production

Five plants from each plot were uprooted at 90, 120 DAP and at harvest. The plants were cleaned, air dried and oven dried in a hot air oven set at 80±5°C for a period of 48 hours till constant weight was achieved and dry weight was recorded in grams and then expressed as kg/ha.

Physiological parameters

Leaf area index

Leaf area index was expressed as the ratio of leaf area to unit land area.

$$\text{Leaf area index (LAI)} = \frac{\text{Leaf area}}{\text{Land area}}$$

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Leaf area was calculated by multiplying the leaf length, width, and number of leaves with conversion factor 0.72. The conversion factor was worked out by dividing the actual leaf area recorded by computed leaf area as outlined by Rao and Swamy (1984). Leaf area index was measured at 90 and 120 DAP.

Leaf area ratio

Leaf area ratio, a measure of relative leafiness of the plant, is the ratio between area of leaf lamina or the photosynthesizing tissues to the total respiring plant tissues or total plant biomass. For practical purpose LAR is defined as the ratio of total leaf area to whole plant dry weight and expressed in cm^2/g.

$$\text{Leaf area ratio (LAR)} = \frac{\text{Leaf area per plant}}{\text{Plant dry weight}}$$

Plant analysis

Nitrogen, P and K uptake by the crop were analyzed after the field experiment. The samples of crop collected at the time of harvest were dried, powdered and analyzed for total N, P and K by following standard procedures (Jackson, 1958). Total N content of the plant sample was determined by micro-Kjeldahl digestion and distillation method. Diacid mixture (nitric and perchloric acid in the ratio 9:4) was used to digest the plant samples. Total P content was determined by vanadomolybdophosphoric yellow colour method. Intensity of colour was read using Spectronic 20 spectrophotometer at 420 nm. Potassium content in the diacid digest was estimated using flame photometer. The nutrient content (%) was multiplied with respective dry weight and expressed as nutrient uptake in kg/ha.

Soil analysis

The soil of the experimental site was sandy clay loam in texture belonging to the order Ultisol. Soil samples were collected during land preparation, before the application of manures and fertilizers. Soil samples after the complete harvest of the crop was also collected. The samples were air dried, sieved through a 0.5 mm sieve

Plate 7. Field view at different stages

and analyzed for available N, available P and exchangeable K. The samples sieved through 0.5 mm sieve were used for the estimation of organicC. Analysis was done by following standard procedures as shown in Table 6.

Table.6. Standard procedures followed for the soil analysis

Particulars	Method used
Organic carbon (%)	Wet digestion (Walkely and Black,1934)
Available N (kg/ha)	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P_2O_5 (kg/ha)	Bray-1 extractant colourimetry (Bray and Curtz, 1945)
Available K_2O (kg/ha)	Neutral normal ammonium acetate extractant flame photometry (Hesse,1994)

Observations on weeds

Number of weeds

Weed count was taken using 50 x 50 cm (0.25 m^2) quadrat. The quadrat was placed at random and observations were recorded from each plot at 45, 90 and 150 days after planting and were reported as number per square metre.

Dry matter of weeds

The weeds uprooted from the quadrat were cleaned, air dried and then oven dried at 80±5°C for 48 hours till constant weight was obtained. Then dry weight was recorded in grams and expressed as kg/ha.

3.3. Statistical analysis

The data collected were analysed and treatment effects were detected using the statistical package WASP (Web Based Agricultural Statistics Software Package) and SPSS (Statistical Packages for the Social Sciences).

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RESULTS

4. RESULTS

4.1 Experiment I: Phytoextraction capacity of water hyacinth

A comprehensive survey covering the whole of central Kerala was carried out for collecting water hyacinth and the respective habitat water samples. In toto 20 samples each were collected. The samples were analysed to assess the nutrient content and the heavy metal content. The results are presented below.

4.1.1 Electro-chemical properties of water samples

Water samples were analysed for pH, electrical conductivity (EC) and total salt concentration (TSC). Statistical analysis was done to assess the variation within and between district and the data are presented in Tables 7 and 8.

In Palakkad district water sample from Pattikkara had significantly higher pH (7053) and those from Kalpathy (6.38) and Mannathumkavu (6.47) had lower pH. In Thrissur district, water samples from Chettupuzha had the highest value for pH while the lowest pH was recorded from Kanimangalam. Almost all samples of Ernakulam district were slightly alkaline in nature and the highest pH was observed from Irumbanam and Manjummal, whereas the lowest was observed at Kalamassery. In Kottayam district, the highest pH was reported from Vaikkom, while the lowest pH was from Kumarakam. An overall district wise analysis revealed the descending ordering as Ernakulam, Thrissur, Kottayam and Palakkad.

Electrical conductivity denotes the ability of water to conduct electric current. Dissolved salts like sodium and potassium chloride determine the electrical conductivity of water. The values of electrical conductivity ranged from 0.09 to 24.55 dS/m. Electrical conductivity values of water samples were low to very high saline. All samples from Palakkad district had low EC and the highest was recorded from Pattikkara (0.38 dS/m). In Thrissur district, samples from Enamavu (1.21 dS/m) had the highest and Karivannur (0.09 dS/m) the lowest EC.

Water sample from Eloor (24.55 dS/m) had significantly higher EC and that from Kalamassery (0.12 dS/m) had the lowest EC.

Table 7. Electro-chemical properties of water samples from various locations in Central Kerala

Sites	pH	EC (dS/m)	TSC (mg/L)
Palakkad			
Mannathumkavu	6.47	0.16	100.78
Kannannur	6.89	0.17	107.39
Pattikkara	7.53	0.38	244.91
Kalpathy	6.38	0.18	114.26
Thenur	6.79	0.16	103.94
CD (5%)	0.25	0.02	13.36
Thrissur			
Enamavu	7.15	1.21	773.12
Aramkallu	7.07	0.59	377.39
Chettupuzha	7.43	0.29	183.47
Kanimangalam	6.56	0.37	235.52
Karivannur	6.79	0.09	58.71
CD (5%)	0.10	0.02	12.52
Ernakulam			
Angamaly	7.67	0.16	101.25
Kalamassery	7.59	0.12	77.01
Manjummal	7.79	12.84	8217.60
Irumbanam	7.82	5.71	3652.27
Eloor	7.73	24.55	15712.00
CD (5%)	0.06	0.20	125.76
Kottayam			
Vaikkom	7.34	6.74	4313.60
Vechur	6.65	2.09	1335.89
Kumarakam	6.11	11.92	7628.80
Nattakam	6.97	1.39	888.32
Changanassery	7.12	0.30	189.87
CD (5%)	0.09	0.10	66.14

Table 8. Electro-chemical properties of water samples from different districts of Central Kerala

District	pH	EC (dS/m)	TSC (mg/L)
Palakkad	6.81	0.21	134.26
Thrissur	7.00	0.51	325.64
Ernakulam	7.72	8.68	5552.03
Kottayam	6.84	4.49	2871.30
CD (5%)	0.10	0.01	5.82

In Kottayam, the highest EC was recorded from Kumarakam (11.92 dS/m) and that from Changanassey (0.30 dS/m) had the lowest EC. The overall analysis revealed steep difference and the ascending rank was Palakkad, Thrissur, Kottayam and Ernakulam.

Total salt concentration of water indicates the total quantity of salts dissolved in water and the approximate relationship between EC and TSC in water is total salt concentration (mg/L) = electrical conductivity (dS/m) X 640. Thus the same trend as that of electrical conductivity was observed for total salt concentration of water samples of the different districts.

4.2 Chemical properties of water and water hyacinth samples

4.2.1 Nitrogen

Ammoniacal nitrogen (NH_4-N) content of water samples ranged from 1.4 to 8.4 mg/L and the nitrate nitrogen (NO_3-N) content ranged from 1.4 to 22.4 mg/L (Table 9). The lowest N content was recorded from water samples collected from Palakkad district. The highest N content was recorded from Kottayam district (Table 10). In Palakkad district, Pattikkara and Kalpathy had significantly higher nitrogen content. In Thrissur district, water samples from Aramkallu and Enamavu had the highest and lowest N content respectively. Water sample from Eloor had the highest N content and that from Manjummal had the lowest N

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content in Ernakulam district. In Kottayam district, water sample from Vaikkom had the highest N content and that from Kumarakam had the lowest N content.

Water hyacinth samples collected from Palakkad district had the highest N content and the N content of samples from Ernakulam and Kottayam districts was on par with that of Palakkad. Plant samples from Thrissur district had the lowest N content (Table 11). Plant samples from Pattikkara had the highest N content in Palakkad district (Table 12). In Thrissur district, plant samples from Chettupuzha had the highest N content and was on par with N content of plant sample from Enamavu. The N content of plant samples collected from Eloor and Irumbanam of Ernakulam district was significantly higher. Plant samples from Vaikkom and Kumarakam recorded higher N content in Kottayam district.

Table 9. Nutrient content (mg/L) of water samples collected from different sites of central Kerala

Sites	N			P	K	Ca	Mg	S
	NH_4-N	NO_3-N	TN					
Palakkad								
Mannathumkavu	2.8	2.80	5.60	0.270	1.15	22.14	10.50	7.83
Kannannur	1.4	3.08	4.48	0.477	2.73	12.00	3.90	4.00
Pattikkara	4.2	2.80	7.00	0.400	7.77	41.80	27.67	12.50
Kalpathy	4.2	2.80	7.00	0.837	3.76	28.14	17.07	11.00
Thenur	2.8	1.40	4.20	0.250	6.48	33.00	18.33	9.00
CD (5%)	*	*	0.69	0.101	0.80	3.35	3.49	3.81
Thrissur								
Enamavu	1.4	1.82	3.22	0.063	7.30	16.33	17.33	7.65
Aramkallu	1.4	12.60	14.00	0.203	6.92	28.83	8.33	0.46
Chettupuzha	2.8	5.60	8.40	0.153	6.14	8.07	1.10	0.94
Kanimangalam	2.8	2.80	5.60	0.200	3.26	17.60	2.87	9.72

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Karivannur	1.4	2.38	3.78	0.200	1.23	5.60	3.87	0.33
CD (5%)	*	*	0.31	0.026	1.20	3.91	1.83	0.95
Ernakulam								
Angamaly	4.2	2.66	6.86	0.493	1.62	4.07	2.40	1.73
Kalamassery	2.8	1.40	4.20	0.637	59.21	4.00	3.47	1.19
Manjummal	1.4	1.40	2.80	0.233	55.77	71.67	167.33	110.25
Irumbanam	2.8	3.92	6.72	0.537	25.68	35.67	75.33	65.40
Eloor	8.4	2.80	11.20	0.350	63.55	184.00	371.67	114.07
CD (5%)			0.18	0.056	1.34	6.48	3.01	1.21
Kottayam								
Vaikkom	2.8	22.40	25.20	0.450	49.40	106.00	52.67	10.87
Vechur	1.4	17.50	18.90	0.087	14.27	247.67	18.83	0.40
Kumarakam	2.8	1.82	4.62	0.247	47.87	104.33	131.83	87.33
Nattakam	1.4	3.78	5.18	0.180	7.63	24.67	20.50	20.30
Changanassery	1.4	3.92	5.32	0.287	1.49	8.50	7.83	3.14
CD (5%)			0.18	0.022	1.42	4.34	2.65	3.01

* Not analysed statistically as total nitrogen only is reckoned.

Table 10. Total nutrient content (mg/L) of water samples collected from different districts of central Kerala

District	N	P	K	Ca	Mg	S
Palakkad	5.66	0.447	4.38	27.42	15.49	8.87
Thrissur	7.00	0.164	4.97	15.29	6.70	3.82
Ernakulam	6.36	0.450	41.17	59.88	124.04	58.53
Kottayam	11.84	0.250	24.13	98.23	46.33	24.41
CD (5%)	0.33	0.022	0.82	1.31	1.43	0.73

Table 11. Nutrient content (mg/kg) of water hyacinth samples collected from different water bodies of central Kerala

Sites	N	P	K	Ca	Mg	S
Palakkad						
Mannathumkavu	12833.33	2149.12	41166.67	13465.00	8023.33	1513.44
Kannannur	13416.67	4561.40	41875.00	11965.00	6649.17	1916.67
Pattikkara	26250.00	3728.07	52325.00	15739.17	4779.17	1432.80
Kalpathy	21583.33	7631.58	38950.00	8730.00	6189.17	2521.51
Thenur	15166.67	1907.90	43437.50	11944.17	7717.50	1150.54
CD (5%)	3330.62	1112.46	2348.33	2781.84	251.48	282.73
Thrissur						
Enamavu	10500.00	657.90	13733.33	11264.17	7649.17	814.52
Aramkallu	9333.33	1754.39	20965.00	15369.17	4134.17	1029.57
Chettupuzha	14000.00	1228.07	20818.33	10144.17	5671.67	1072.58
Kanimangalam	9333.33	1798.25	19992.50	14283.33	4242.00	3053.76
Karivannur	5833.33	1798.25	15535.83	9760.00	4259.17	1330.65
CD (5%)	4783.24	856.12	1264.37	1226.70	816.61	255.22
Ernakulam						
Angamaly	12833.33	4605.26	44000.00	14560.00	8689.17	1142.47
Kalamassery	14583.33	5175.44	43133.33	15416.67	12165.00	2206.99
Manjummal	13416.67	2149.12	22103.33	11320.83	8171.67	888.00
Irumbanam	18666.67	7017.54	16083.33	8808.33	11169.17	1118.28
Eloor	21000.00	3114.04	43050.00	11820.00	12189.17	876.34
CD (5%)	3002.18	1484.16	1736.77	1876.97	1020.69	205.31
Kottayam						
Vaikkom	21000.00	4166.67	16602.50	12954.17	13239.17	2715.05
Vechur	15750.00	921.05	15577.50	11954.17	9229.17	3166.67
Kumarakam	18666.67	2236.84	13997.50	8368.33	12725.00	3717.74
Nattakam	14583.33	1535.09	19122.50	11521.67	8778.33	2537.64
Changanassery	15166.67	2675.44	21794.17	9348.33	9089.17	2577.96
CD (5%)	4326.60	900.74	1565.08	768.25	598.37	331.99

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Table 12. Nutrient content (mg/kg) of water hyacinth samples collected from water bodies of different districts of central Kerala

District	N	P	K	Ca	Mg	S
Palakkad	17850.00	3995.61	43550.83	12368.67	6671.67	1706.99
Thrissur	9800.00	1447.37	18209.00	12164.17	5191.33	1460.22
Ernakulam	16100.00	4412.28	33674.00	12385.17	10476.83	1246.23
Kottayam	17033.33	2307.02	17418.83	10829.33	10612.17	2943.01
CD (5%)	1873.01	600.52	928.24	802.09	157.84	95.96

4.2.2 Phosphorus

The total phosphorus content of water samples ranged from 0.063-0.837 mg/L. Water samples from Ernakulam district had significantly higher P content, which was on par with water samples collected from Palakkad district (Table 10). Samples from Thrissur district had lower P content. Water sample from Kalpathy in Palakkad district contained significantly more P (Table 9). In Thrissur district, water samples from Aramkallu, Kanimangalam, and Karivannur had more P and the lowest P was recorded from Enamavu. In Ernakulam district, the highest total P content was recorded from Kalamassery, whereas, the lowest was from Manjummal. Water sample from Vaikkom had more P and that from Vechur had the least P content in Kottayam district.

Phosphorus content in water hyacinth samples collected from Ernakulam and Palakkad was significantly higher and the lowest P content was observed in plant samples collected from Thrissur district (Table 12). Similar trend as that of total P in water samples was observed in the case of P content of plant samples.

4.2.3 Potassium

The total K content of water samples ranged between 1.15 and 63.55 mg/L. The significantly highest total K was recorded from water samples of Ernakulam district whereas the lowest total K was observed in K was recorded

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from Pattikkara and the lowest was from Mannathumkavu. Water samples from Enamavu and Karivannur had the highest and lowest total K content respectively in Thrissur district. In Ernakulam district, water samples from Eloor contained significantly higher total K content while samples from Angamaly recorded the lowest total K. Water samples collected from Vaikkom and Changanassery had the highest and lowest total K content in Kottayam district.

The K content of water hyacinth samples collected from Palakkad district was significantly the highest, whereas the plant samples from Kottayam district had the lowest K content. In Palakkad district, plant samples collected from Pattikkara had the highest K content while those from Kalpathy and Mannathumkavu had lower K content. Plant samples from Aramkallu, Chettupuzha and Kanimangalam had the higher K content and the lowest was observed from Enamavu in Thrissur district. Plant samples from Irumbanam had the lowest K content in Ernakulam district and the higher K content was observed from Angamaly, Kalamassery and Eloor. In Kottayam district, plant samples collected from Changanassery recorded the highest K content and the lowest K content was observed from Kumarakam.

4.2.4 Calcium

Calcium content of water samples ranged from 4.00-247.67 mg/L. Significantly higher Ca content was observed from water samples of Kottayam district, whereas those from Thrissur district had the lowest content of Ca. In Palakkad district, water samples from Pattikkara had the highest Ca content, while that from Kannannur has the lowest Ca. Water samples from Aramkallu had significantly the highest Ca content in Thrissur district, whereas those from Karivannur and Chettupuzha had the lowest content. The highest Ca content was observed in water samples from Eloor of Ernakulam district and the lowest was recorded from Angamaly, which was on par with that of Kalamassery. In Kottayam district, water samples of Vechur showed the highest and Changanassery lowest Ca content.

Water hyacinth samples collected from Palakkad, Thrissur, and Ernakulam district had significantly higher Ca content than those from Kottayam district. Water hyacinth samples collected from Pattikkara in Palakkad district had the highest Ca content, whereas the lowest was observed from Kalpathy. In Thrissur district, plant samples from Aramkallu and Kanimangalam had higher Ca content and those from Karivannur had the least content of Ca. Plant samples from Kalamassery and Angamaly had higher Ca content in Ernakulam district, whereas those from Irumbanam had the lowest Ca content. In Kottayam district, plant samples from Vaikkom and Kumarakam had the highest and the lowest Ca content respectively.

4.2.5. Magnesium

Magnesium content of water samples ranged from 1.10 to 371.67 mg/L. Water samples from Ernakulam district had the highest Mg content, whereas those from Thrissur had the lowest Mg content. In Palakkad district, water samples from Pattikkara and Kannannur had the highest and the lowest Mg content respectively. Of the water samples collected from Thrissur district, those from Enamavu had the highest Mg, whereas those from Chettupuzha and Kanimangalam had the lowest Mg. In Ernakulam district, water samples from Eloor had significantly higher Mg and those from Angamaly and Kalamassery had the least Mg content. In Kottayam district, water samples from Kumarakam had the highest Mg, and the lowest was observed from Changanassery.

Water hyacinth samples from Kottayam district had the highest Mg content, whereas those from Thrissur had the lowest Mg. In Palakkad district, plant samples collected from Mannathumkavu had the highest Mg content and the lowest was recorded from Pattikkara. Plant samples collected from Enamavu in Thrissur had the highest Mg content. In Ernakulam district, plant samples from Eloor and Kalamassery had the highest Mg content, whereas the lowest Mg content was observed in plant samples from Manjummal and Angamaly. The

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highest and lowest Mg content was recorded in plant samples from Vaikkom and Nattakam respectively in Kottayam district.

4.2.6 Sulphur

Sulphur content of water ranged between 0.33 and 114.07 mg/L. Water samples collected from Ernakulam district contained more sulphur and those from Thrissur district. From Palakkad district, water samples from Pattikkara had significantly the highest S and those from Kannannur had the lowest sulphur content. In Thrissur district, water samples from Kanimangalam had the highest S content. In Ernakulam district, water samples from Eloor showed the highest S content, whereas those from Angamaly and Kalamassery had the least S contents in Ernakulam district. The highest and lowest S content of water samples were observed from Kumarakam and Vechur respectively in Kottayam district.

Water hyacinth samples collected from Kottayam showed the highest sulphur content whereas, those from Ernakulam district had the lowest S content. In Palakkad district, plant samples collected from Kalpathy river had the highest S content and the lowest was observed from Thenur. Plant sample from Kanimangalam had the highest S content in Thrissur district. In Ernakulam district, plant samples from Kalamassery had the highest S content, whereas those from Eloor and Manjummal had the least content of sulphur. In Kottayam district, the highest S content was recorded from Kumarakam.

4.2.7 Iron

Iron content of water samples ranged between 0.64-5.42 mg/L. Among the districts surveyed, significantly the highest Fe content was observed in water samples of Thrissur district, while those from Palakkad had the lowest Fe content (Table 14). In Palakkad district, water samples from Kannanur had the highest Fe content, whereas those from Kalpathy had the least content (Table 13). Water samples from Aramkallu and Chettupuzha in Thrissur district had the highest and the lowest Fe contents respectively. In Ernakulam district, water samples from Angamaly had the highest Fe content and the lowest was observed from Eloor and

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Kalamassery. In Kottayam district, the highest Fe content of water samples was recorded from Vechur in Kottayam district, whereas the lowest content was observed from Nattakam.

Plant samples from Kottayam district had significantly higher Fe content and the lowest was from Ernakulam district (Table 16). In Palakkad district, plant samples collected from Kalpathy had the highest Fe content and those from Thenur had the lowest Fe content (Table 15). Iron content of plant samples collected from Karivannur was the highest in Thrissur district and the lowest was observed from Enamavu. In Ernakulam district, plant samples from Angamaly had the highest Fe content and the lowest Fe content was recorded from Irumbanam. Plant samples from Nattakam and Changanassery had the highest and the lowest Fe content respectively in Kottayam district.

4.2.8. Manganese

Manganese content of water samples ranged from 0.134-0.450 mg/L. Water samples from Palakkad district had the highest Mn content, whereas those from Kottayam and Ernakulam had the lowest Mn content. In Palakkad district, water samples from Pattikkara had the highest Mn content and the lowest was observed from Mannathukavu. Water samples of Enamavu in Thrissur district had the highest Mn content, whereas those from Chettupuzha and Karivannur had the lowest Mn content. In Ernakulam district, water samples of Angamaly had the highest Mn content and the lowest was recorded from Manjummal and Eloor. Significantly the highest and the lowest Mn content in Kottayam district was recorded from Vechur and Nattakam respectively.

Table 13. Micronutrient content (mg/L) of water samples collected from different water bodies of central Kerala

Sites	Fe	Mn	Zn	Cu	Co	Ni	Al
Palakkad							
Mannathumkavu	1.17	0.134	1.43	0.063	0.000	0.010	1.87
Kannannur	3.58	0.214	0.00	0.131	0.000	0.228	6.63
Pattikkara	2.00	0.769	0.15	0.074	0.000	0.015	2.41
Kalpathy	0.64	0.159	0.05	0.067	0.000	0.010	1.59
Thenur	0.97	0.211	0.22	0.089	0.000	0.013	1.86
CD (5%)	0.28	0.040	0.04	0.020		0.007	0.22
Thrissur							
Enamavu	3.79	0.384	0.00	0.139	0.005	0.147	3.03
Aramkallu	5.42	0.276	0.00	0.109	0.000	0.122	1.83
Chettupuzha	2.35	0.136	0.00	0.134	0.003	0.168	1.82
Kanimangalam	3.64	0.277	0.20	0.133	0.003	0.183	4.88
Karivannur	3.65	0.159	0.00	0.109	0.006	0.161	1.90
CD (5%)	0.18	0.043	0.01	0.009	0.002	0.035	0.73
Ernakulam							
Angamaly	3.09	0.374	0.00	0.094	0.000	0.138	6.72
Kalamassery	1.60	0.184	0.00	0.130	0.003	0.181	3.69
Manjummal	1.64	0.157	0.00	0.113	0.005	0.161	3.14
Irumbanam	2.11	0.286	0.00	0.124	0.005	0.180	5.00
Eloor	1.54	0.169	0.00	0.114	0.003	0.154	8.72
CD (5%)	0.06	0.014		0.004	0.002	0.016	0.79
Kottayam							
Vaikkom	3.15	0.450	0.00	0.115	0.002	0.132	5.00
Vechur	4.19	0.168	0.00	0.119	0.003	0.122	5.80
Kumarakam	3.25	0.179	0.22	0.444	0.003	0.207	4.48
Nattakam	2.82	0.147	0.00	0.094	0.002	0.159	6.05
Changanassery	3.24	0.159	0.00	0.085	0.000	0.164	5.55
CD (5%)	0.30	0.024	0.01	0.023	0.001	0.019	0.45

Among the districts, water hyacinth samples of Palakkad district had the highest Mn content and the lowest was recorded from Ernakulam district. In Palakkad district, the highest Mn content was observed in plant samples from Thenur and the lowest was recorded from Pattikkara. Plant samples of Enamavu and Karivannur had the highest and the lowest Mn content in Thrissur district respectively. Manganese content in plant samples of Angalamy was the highest in Ernakulam district, whereas those from Irumbanam had the lowest Mn content. In Kottayam district, plant samples from Nattakam had the highest content of Mn.

Table 14. Micronutrient content (mg/L) of water samples collected from different districts of central Kerala

District	Fe	Mn	Zn	Cu	Co	Ni	Al
Palakkad	1.67	0.298	0.370	0.085	0.000	0.055	2.87
Thrissur	3.77	0.247	0.040	0.125	0.003	0.156	2.69
Ernakulam	1.99	0.234	0.000	0.115	0.003	0.163	5.45
Kottayam	3.33	0.220	0.045	0.171	0.002	0.125	5.38
CD (5%)	0.09	0.019	0.008	0.007	0.001	0.014	0.27

4.2.9 Zinc

Zinc content of water samples ranged from 0.00-1.43 mg/L. The Zn content was significantly higher in samples collected from Kottayam and Thrissur and no trace of the same was observed in Ernakulam district (Table 13). In Palakkad district, water samples from Mannathumkavu had the highest Zn content but it was zero in Kannannur. Only water samples from Kanimangalam had detectable trace of Zn in Thrissur district. In Kottayam district, Zn was present only in water samples collected from Kumarakam.

Water hyacinth samples collected from Ernakulam district had the highest Zn content and the lowest was observed from Thrissur (Table 16). Plant samples of Kalpathy and Thenur had the highest and the lowest Zn content in Palakkad district respectively. In Thrissur district, plant samples from Kanimangalam had the highest Zn content and the lowest was recorded from Aramkallu and Karivannur. Zinc content in plant samples collected from Kalamassery and Angamaly was the highest and the lowest respectively in Ernakulam district. Of the samples collected from Kottayam district, plant samples from Nattakam had the highest and those from Vechur had the lowest Zn content.

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Table 15. Micronutrient content (mg/kg) of water hyacinth samples collected from different water bodies of central Kerala

Samples	Fe	Mn	Zn	Cu	Co	Ni	Al
Palakkad							
Mannathumkavu	15573.33	1812.50	170.88	13.00	15.25	17.00	8951.67
Kannannur	13585.83	2441.58	193.75	67.63	10.75	22.25	32725.00
Pattikkara	5151.67	1217.67	142.88	38.25	2.00	8.88	2219.17
Kalpathy	23764.17	3398.75	307.50	71.50	14.13	23.25	32700.00
Thenur	3850.00	5592.50	57.75	11.50	1.38	8.88	6044.17
CD (5%)	1456.82	241.74	13.04	9.89	1.66	2.21	1534.78
Thrissur							
Enamavu	4870.00	2565.42	32.50	7.50	3.25	8.00	4485.83
Aramkallu	14857.50	787.92	20.75	3.63	0.00	6.38	1776.33
Chettupuzha	10083.33	1158.50	43.75	16.38	7.50	18.38	22657.50
Kanimangalam	20076.67	1061.25	71.63	11.88	4.13	6.75	6433.33
Karivannur	27114.17	597.50	27.75	12.50	3.38	13.88	23661.67
CD (5%)	2238.72	251.57	8.91	1.33	0.44	0.71	1374.49
Ernakulam							
Angamaly	3585.00	1725.00	70.13	13.25	1.88	5.50	3002.25
Kalamassery	2614.75	529.17	385.50	14.50	0.00	5.63	3088.33
Manjummal	2556.67	862.25	158.63	11.25	0.00	3.63	1573.92
Irumbanam	1344.25	374.17	92.38	14.50	0.00	3.50	2343.00
Eloor	2549.92	1661.75	341.75	21.38	0.00	6.13	3394.17
CD (5%)	648.03	198.18	7.51	1.92	0.10	1.03	248.85
Kottayam							
Vaikkom	20397.50	425.25	51.88	8.88	0.38	7.25	11915.83
Vechur	23885.83	436.50	9.75	4.50	0.00	6.25	5622.50
Kumarakam	21271.67	393.50	32.13	12.75	0.50	9.50	11152.50
Nattakam	25787.50	5816.67	225.13	26.50	17.63	17.88	41029.17
Changanassery	15087.50	2832.75	111.13	19.50	0.00	15.88	23908.33
CD (5%)	2343.66	242.26	9.64	1.69	1.16	1.81	1255.35

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Table 16. Micronutrient content (mg/kg) of water hyacinth samples collected from water bodies of different districts of central Kerala

District	Fe	Mn	Zn	Cu	Co	Ni	Al
Palakkad	12385.00	2892.60	174.55	40.38	8.70	16.05	16528.00
Thrissur	15400.33	1234.12	39.28	10.38	3.65	10.68	11802.93
Ernakulam	2530.12	1030.47	209.68	14.98	0.38	4.88	2680.33
Kottayam	21286.00	1980.93	86.00	14.43	3.70	11.35	18725.67
CD (5%)	466.00	81.97	1.92	3.08	0.43	1.16	622.90

4.2.10 Copper

The water samples collected contained Cu in the range of 0.063-0.444 mg/l (Table 13). Among the districts, Cu content of water samples was the highest from Kottayam district and the least content was observed from Palakkad district. Water samples collected from Kannannur in Palakkad district had the highest Cu content and the lowest was observed from Mannathumkavu and Kalpathy. Water samples from Enamavu, Chettupuzha and Kanimangalam had higher Cu contents in Thrissur district, whereas those from Aramkallu and Karivannur had less Cu. In Ernakulam district, the highest and the lowest Cu content in water samples was observed from Kalamassry and Angamaly respectively. Water samples from Kumarakam had the highest Cu content in Kottayam district, whereas those from Changanassery and Nattakam had the lowest Cu.

Copper content of plant samples collected from Palakkad district was significantly higher and those from Thrissur had the lowest Cu content. In Palakkad district, plant samples from Kalpathy and Kannannur showed higher Cu content and lower values were observed from Thenur and Mannathumkavu. In Thrissur district, plant samples from Chettupuzha had significantly the highest Cu content and those from Aramkallu had the lowest Cu content. The highest and the lowest Cu content of plant samples of Ernakulam district was observed from

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Eloor and Manjummal respectively. In Kottayam district, plant samples from Nattakam had the highest Cu content and the lowest was from Vechur.

4.2.11 Cobalt

The cobalt content of water samples ranged from 0.000-0.006 mg/L (Table 13). No trace of Co could be observed from water samples of Palakkad district. In Thrissur district, Co was more in Karivannur, whereas Co was not detected at all from Aramkallu. Water samples from Manjummal and Irumbanam had higher Co, while it was absent in Angamaly. Water samples of Vechur and Kumarakam had more Co content, whereas in Changanassery, Co was not detected.

Cobalt content of water hyacinth samples was significantly higher in Palakkad district and lower in Ernakulam district. Plant samples collected from Mannathumkavu and Kalpathy had higher Co content whereas those from Thenur and Pattikkara had the lowest Co content. Of the plant samples collected from Thrissur district, significantly higher Co content was recorded from Chettupuzha, whereas Co was absent in plant samples from Aramkallu. In Ernakulam district, detectable traces of Co were recorded only from Angamaly. In Kottayam district, the highest Co content was observed from Nattakam, whereas in Vechur and Changanassery the Co content was zero.

4.2.12 Nickel

The water samples contained nickel in the range of 0.010-0.228 mg/L (Table 13). Nickel content was more in water samples collected from Ernakulam and Thrissur district, whereas it was less in samples collected from Palakkad. Nickel content of Kannannur was significantly the highest in Palakkad district and the lowest Ni was recorded from Kalpathy and Mannathumkavu. In Thrissur district, water samples from Kanimangalam and Aramkallu had the highest and the lowest Ni content respectively. Water samples of Kalamassery and Irumbanam had higher Ni content and the lowest was observed from Angamaly. In Kottayam district, the highest Ni content was observed in water samples

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collected from Kumarakam and the lowest was observed from Vechur and Vaikkom.

Water hyacinth samples from Palakkad district had significantly the highest Ni content and the lowest Ni content was observed from Ernakulam district. In Palakkad district, the highest Ni was recorded from Kalpathy and Kannannur and the lowest Ni content was from Pattikkara and Thenur. Plant samples of Chettupuzha had the highest Ni content in Thrissur district, whereas it was less in samples from Aramkallu and Kanimangalam. In Ernakulam district, the highest Ni content was found in Eloor and the lowest Ni content was from Irumbanam and Manjummal. Nickel content of plant samples was the highest in Nattakam in Kottayam district, whereas it was lowest in Vechur and Vaikkom.

4.2.13 Aluminium

The Al content of water samples ranged from 1.59-8.72 mg/L. Water samples of Kannannur had the highest Al content in Palakkad district, whereas the lowest was from Mannathumkavu and Thenur. In Thrissur district, water samples from Kanimangalam had the highest Al content. Aluminium content of water samples of Ernakulam district was the highest in Eloor and the lowest in Kalamassery and Manjummal. In Kottayam district, the highest Al content was observed from Nattakam and the lowest was recorded from Kumarakam and Vaikkom.

Plant samples collected from Kannannur and Kalpathy had the highest Al in Palakkad district whereas the lowest was from Thenur. In Thrissur district, the highest Al content was observed from Karivannur and Chettupuzha and the lowest Al was recorded from Aramkallu. Plant samples from Eloor had the highest Al content in Ernakulam district and the lowest Al content was recorded from Manjummal. In Kottayam distrct the samples from Changanassery had the highest Al content and the lowest was from Vechur.

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4.2.14 Arsenic

Arsenic content was not present in any of the water samples (Table 18) whereas in plant samples As content ranged between 0.000-0.153 mg/L (Table 17). In Palakkad district, As was detected only in plant samples collected from Kannannur. In Thrissur district, water hyacinth samples of Enamavu and Chettupuzha had higher arsenic content, whereas As content was zero in samples from Kanimangalam. In Ernakulam district, the highest arsenic content was recorded from Kalamassery, whereas, the lowest was from Angamaly. Arsenic was present only in plant samples collected from Kumarakam and Vechur of Kottayam district.

4.2.15 Lead

Lead was not present in any of the water samples. In water hyacinth plant samples Pb content ranged between 0.008 and 0.430 mg/kg (Table 17). The samples from Kottayam and Palakkad had the highest and the lowest Pb contents respectively (Table 18). Plant samples collected from Kannannur had the highest Pb content in Palakkad district, whereas the lowest Pb content was recorded from Kalpathy. In Thrissur district, plant samples from Chettupuzha and Kanimangalam had the highest and the lowest Pb contents respectively. Lead content in plant samples collected from Irumbanam and Eloor was significantly higher and the lowest Pb was from Angamaly. The highest Pb content was observed from Kumarakam in Kottayam district and the lowest was noted from Nattakam.

4.2.16 Cadmium

Cadmium was not detected in any of the water or plant samples.

4.2.17 Chromium

The chromium content of water samples ranged from 0.006-0.347 mg/L. Water samples of Kottayam district and Thrissur had significantly higher Cr content. In Palakkad district, the highest Cr content was observed from

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Kannannur and the lowest was noted from Mannathumkavu. Water samples of Enamavu and Kanimangalam had the highest and the lowest Cr content in Thrissur district. Chromium content in water samples was the highest in Manjummal and the lowest was from Eloor in Ernakulam district. In Kottayam district, higher Cr content was observed from Nattakam and Vechur and the lowest Cr was noted from Kumarakam.

Water hyacinth samples from Palakkad had the highest Cr content, whereas the lowest Cr content was recorded from Ernakulam district. In Palakkad district, the highest Cr content was observed from Kannannur and the lowest was recorded from Pattikkara. Chromium content of plant samples of Karivannur and Kanimangalam were the highest and lowest respectively in Thrissur district. Plant samples of Eloor had the highest Cr in Ernakulam district and the lowest was from Irumbanam. In Kottayam district, plant samples from Changanassery and Nattakam had higher Cr content and the lowest Cr content was noted from Vaikkom and Vechur.

4.2.18 Mercury

Mercury content of water samples ranged between 0.002 to 0.008 mg/L. There was no significant difference in Hg content of water samples from the four districts. In Palakkad district no significant difference in Hg content was observed among different sites. In Thrissur distict the higher Hg content was observed from water samples of Chettupuzha, Kanimangalam and Karivannur. The lowest Hg content was observed in water samples of Enamavu and Aramkallu in Thrissur district. Water samples of Eloor, Kalamassery and Irumbanam had higher Hg content and the lowest content was observed from Angamaly and Manjummal. In Kottayam district, water samples collected from Vaikkom had the highest Hg content, whereas those from Nattakam and Changanassery had the lowest Hg content.

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Table 17. Heavy metal content (mg/L) of water samples collected from different water bodies of central Kerala

sites	As	Pb	Cd	Cr	Hg
Palakkad	BDL*	BDL	BDL		
Mannathumkavu				0.006	0.004
Kannannur				0.347	0.005
Pattikkara				0.014	0.005
Kalpathy				0.009	0.005
Thenur				0.014	0.005
CD (5%)				0.004	0.0001
Thrissur	BDL	BDL	BDL		
Enamavu				0.277	0.002
Aramkallu				0.227	0.003
Chettupuzha				0.255	0.005
Kanimangalam				0.218	0.004
Karivannur				0.269	0.004
CD (5%)				0.020	0.001
Ernakulam	BDL	BDL	BDL		
Angamaly				0.264	0.003
Kalamassery				0.269	0.005
Manjummal				0.294	0.003
Irumbanam				0.277	0.005
Eloor				0.247	0.006
CD (5%)				0.017	0.001
Kottayam	BDL	BDL	BDL		
Vaikkom				0.274	0.008
Vechur				0.297	0.005
Kumarakam				0.239	0.006
Nattakam				0.317	0.004
Changanassery				0.267	0.004
CD (5%)				0.024	0.001

*BDL: Below the detectable level in all the samples

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Table 18. Heavy metal content (mg/L) of water samples collected from water bodies of different districts of central Kerala

District	Cr	Hg
Palakkad	0.274	0.005
Thrissur	0.297	0.004
Ernakulam	0.239	0.004
Kottayam	0.317	0.005
CD (5%)	0.027	0.000

The mercury content in water hyacinth plant samples ranged from 0.484-0.540 mg/L. In Palakkad and Thrissur districts, no significant difference in Hg content was observed among the different sites. In Ernakulam district, the highest Hg content was observed from Kalamassery. In Kottayam district, plant samples from Vaikkom and Kumarakam had the highest Hg content in Kottayam district and the lowest was in Changanassery.

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Table 19. Heavy metal content (mg/kg) of plant samples collected from different water bodies of central Kerala

sites	As	Pb	Cd	Cr	Hg
Palakkad			BDL*		
Mannathumkavu	0.000	0.013		35.917	0.508
Kannannur	0.072	0.118		91.333	0.495
Pattikkara	0.000	0.015		19.500	0.504
Kalpathy	0.000	0.008		56.833	0.494
Thenur	0.000	0.015		22.583	0.502
CD (5%)	0.004	0.014		4.387	NS
Thrissur			BDL		
Enamavu	0.148	0.120		23.333	0.487
Aramkallu	0.065	0.121		19.833	0.502
Chettupuzha	0.132	0.133		34.167	0.486
Kanimangalam	0.000	0.103		15.417	0.485
Karivannur	0.115	0.113		43.083	0.484
CD (5%)	0.026	0.018		1.591	NS
Ernakulam			BDL		
Angamaly	0.013	0.107		11.917	0.499
Kalamassery	0.153	0.118		19.500	0.540
Manjummal	0.093	0.112		10.500	0.493
Irumbanam	0.121	0.142		9.750	0.494
Eloor	0.080	0.135		33.083	0.498
CD (5%)	0.024	0.020		2.088	0.032
Kottayam			BDL		
Vaikkom	0.000	0.123		22.667	0.506
Vechur	0.027	0.166		22.333	0.497
Kumarakam	0.064	0.430		31.667	0.503
Nattakam	0.000	0.098		44.167	0.499
Changanassery	0.000	0.106		45.167	0.489
CD (5%)	0.012	0.049		2.562	0.007

*BDL: Below the detectable level in all the samples

Table 20. Heavy metal content (mg/kg) of plant samples collected from water bodies of different districts of central Kerala

District	As	Pb	Cr	Hg
Palakkad	0.015	0.034	45.233	0.501
Thrissur	0.092	0.118	27.167	0.488
Ernakulam	0.092	0.123	16.950	0.505
Kottayam	0.018	0.185	33.200	0.499
CD (5%)	0.011	0.008	1.986	NS

4.2 Experiment II: Utilization of water hyacinth as livestock feed by silage making

4.2.1 Quality of silage

The prepared silage was assessed for pH, colour and odour.

pH

Influence of various additives on the pH of water hyacinth silage is presented in Table 21. Rice bran addition generally increased the pH of water hyacinth silage. Wilted water hyacinth + rice straw (10%) + rice bran (10%) had the significantly highest pH (8.30) followed by wilted water hyacinth+ guinea grass (10%) + rice bran (10%) (7.24). Cassava flour addition decreased the pH of the silage. The lowest pH (4.19) was noticed in the treatment wilted water hyacinth + cassava flour (10%). The results revealed that wilted water hyacinth plus cassava flour (10%), wilted water hyacinth plus rice straw (10%) plus cassava flour (10%), and wilted water hyacinth plus guinea grass (10%) plus cassava flour (10%) were almost equal in quality with respect to pH.

Colour and odour of silage

The colour and smell of the silages were noted immediately after the little bags were opened by employing volunteers and the results are tabulated in Table

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21. The colour of silages varied based on the ingredients used, and were mostly brownish green or grey. Odour of the treatments such as wilted water hyacinth + cassava flour (10%), fresh water hyacinth + rice straw (10%) + molasses (5%), and wilted water hyacinth + guinea grass (10%) + cassava flour (10%) were rated as 'very good'. Rice bran added silages had bad smell and treatments like wilted water hyacinth + rice bran (10%), fresh water hyacinth + rice straw (10%) + rice bran (10%), wilted water hyacinth + rice straw (10%) + molasses (5%), and wilted water hyacinth + guinea grass (10%) + rice bran (10%) were rated as 'bad'.

Table 21. Effect of additives on quality of water hyacinth silage

	Treatments	pH	Colour	Odour
T1	Wilted water hyacinth + molasses (5%)	4.53^{d}	Dark brown	Good
T2	Wilted water hyacinth + cassava flour (10%)	4.19^{d}	Brownish green	Very good
T3	Wilted water hyacinth + rice bran (10%)	6.36^{b}	Greenish brown	Bad
T4	Fresh water hyacinth + rice straw (10%) + molasses (5%)	5.44^{c}	Golden yellow	Very good
T5	Fresh water hyacinth + rice straw (10%) + cassava flour (10%)	4.37^{d}	Grey	Good
T6	Fresh water hyacinth + rice straw (10%) + rice bran (10%)	6.58^{b}	Brown	Bad
T7	Wilted water hyacinth + rice straw (10%) + molasses (5%)	7.15^{b}	Dark brown	Bad
T8	Wilted water hyacinth + rice straw (10%) + cassava flour (10%)	4.38^{d}	grey	Good
T9	Wilted water hyacinth + rice straw (10%) + rice bran (10%)	8.30^{a}	brown	Good
T10	Wilted water hyacinth + guinea grass (10%) + molasses (5%)	6.36^{b}	Brownish green	Good
T11	Wilted water hyacinth + guinea grass (10%) + cassava flour (10%)	4.24^{d}	Grey	Very good
T12	Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	7.24^{b}	Greenish brown	Bad

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4.2.2 Chemical composition

Crude protein

The data on crude protein content of the silage are presented in Table 22. Additives influenced the crude protein content of water hyacinth silage. Among the treatments, wilted water hyacinth+ guinea grass (10%) + rice bran (10%) had the highest crude protein content (10.45%). It was followed by fresh water hyacinth + rice straw (10%) + rice bran (10%) and wilted water hyacinth+ rice straw (10%) + rice bran (10%). Rice bran addition increased the crude protein content of the silage, whereas cassava flour added silages had low crude protein content. The lowest crude protein content is recorded in the treatments, fresh water hyacinth + rice straw (10%) + cassava powder (10%) (4.86%) which was on par with fresh water hyacinth + rice straw (10%) + molasses (5%) (5.43%).

Crude fibre

The data related to the crude fibre content of the silage is presented in Table 22. Crude fibre content was the highest in silages added with adsorbents such as rice straw and guinea grass. Rice bran addition also enhanced the crude fibre content. The highest crude protein content was recorded in the treatment *viz.*, fresh water hyacinth + rice straw (10%) + rice bran (10%), which was on par with wilted water hyacinth + rice straw (10%) + rice bran (10%). The lowest crude fibre content was observed in the treatment wilted water hyacinth + molasses (5%).

Ether extract

The data pertaining to ether extract are shown in Table 22. Rice bran addition positively influenced the crude fat content of the silage. Wilted water hyacinth + rice bran (10%) had the highest crude fat content (1.81%) followed by wilted water hyacinth + guinea grass (10%) + rice bran (10%) and fresh water hyacinth + rice straw (10%) + rice bran (10%). Treatments such as wilted water hyacinth+ molasses (5%) and wilted water hyacinth + rice straw (10%) + molasses (5%) had the lowest ether extract content.

Nitrogen free extract

The influence of various additives on the nitrogen free extract of silage is presented in Table 23. Nitrogen free extract represents the digestible carbohydrate content. Cassava flour addition enhanced the carbohydrate content. The highest NFE of 58.94 per cent was noted in the treatment wilted water hyacinth + cassava powder (10%). It was followed by wilted water hyacinth + rice straw (10%) + cassava flour (10%), wilted water hyacinth + molasses (5%), fresh water hyacinth + rice straw (10%) + cassava flour (10%) and wilted water hyacinth + guinea grass (10%) + cassava flour (10%). The lowest NFE content was observed in treatments such as wilted water hyacinth + rice straw (10%) + rice bran (10%) and wilted water hyacinth + guinea grass (10%) + rice bran (10%).

Total ash content

The data pertaining to total ash content of the silage are presented in Table 23. The highest ash content was noted in the treatment fresh water hyacinth + rice straw (10%) + rice bran (10%). It was followed by the treatments, wilted water hyacinth + rice straw (10%) + rice bran (10%), wilted water hyacinth + rice bran (10%), fresh water hyacinth + rice straw (10%) + molasses (5%) and wilted water hyacinth + guinea grass (10%) + rice bran (10%). The lowest ash content was observed in the treatments wilted water hyacinth + guinea grass (10%) + cassava flour (10%), wilted water hyacinth + cassava flour (10%) and wilted water hyacinth+ rice straw (10%) + cassava flour (10%).

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Table 22. Effect of additives on the crude protein, crude fibre and ether extract (DW basis) of water hyacinth silage

	Treatments	Crude protein (%)	Crude fibre (%)	Ether extract (%)
T1	Wilted water hyacinth + molasses (5%)	8.06^{d}	16.81^{f}	0.53^{f}
T2	Wilted water hyacinth + cassava flour (10%)	7.15^{e}	17.90^{e}	1.39^{c}
T3	Wilted water hyacinth + rice bran (10%)	8.14^{d}	22.04^{bc}	1.81^{a}
T4	Fresh water hyacinth + rice straw (10%) + molasses (5%)	5.43^{g}	20.86^{d}	0.72^{e}
T5	Fresh water hyacinth + rice straw (10%) + cassava flour (10%)	4.86^{g}	22.25^{b}	1.08^{d}
T6	Fresh water hyacinth + rice straw (10%) + rice bran (10%)	9.72^{b}	25.35^{a}	1.62^{b}
T7	Wilted water hyacinth + rice straw (10%) + molasses (5%)	6.56^{f}	20.98^{d}	0.55^{f}
T8	Wilted water hyacinth + rice straw (10%) + cassava flour (10%)	7.85^{d}	22.07^{bc}	1.04^{d}
T9	Wilted water hyacinth + rice straw (10%) + rice bran (10%)	9.34^{bc}	24.62^{a}	1.54^{bc}
T10	Wilted water hyacinth + guinea grass (10%) + molasses (5%)	9.14^{c}	20.61^{d}	0.58^{ef}
T11	Wilted water hyacinth + guinea grass (10%) + cassava flour (10%)	8.88^{c}	21.23^{cd}	1.09^{d}
T12	Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	10.45^{a}	22.87^{b}	1.65^{b}

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Table 23. Effect of additives on the contents of nitrogen free extract, ash, and silica of water hyacinth silage

	Treatments	Nitrogen free extract (%)	Ash (%)	Silica content (%)
T1	Wilted water hyacinth + molasses (5%)	54.77[b]	19.84[b]	4.05[ef]
T2	Wilted water hyacinth + cassava flour (10%)	58.94[a]	14.63[e]	3.69[f]
T3	Wilted water hyacinth + rice bran (10%)	47.33[e]	20.68[b]	6.66[a]
T4	Fresh water hyacinth + rice straw (10%) + molasses (5%)	52.53[cd]	20.46[b]	5.06[c]
T5	Fresh water hyacinth + rice straw (10%) + cassava flour (10%)	54.31[b]	16.97[d]	4.40[de]
T6	Fresh water hyacinth + rice straw (10%) + rice bran (10%)	41.06[g]	22.79[a]	5.96[b]
T7	Wilted water hyacinth + rice straw (10%) + molasses (5%)	53.56[bc]	18.35[c]	4.79[cd]
T8	Wilted water hyacinth + rice straw (10%) + cassava flour (10%)	54.84[b]	14.20[e]	4.03[ef]
T9	Wilted water hyacinth + rice straw (10%) + rice bran (10%)	43.62[f]	20.89[b]	5.10[c]
T10	Wilted water hyacinth + guinea grass (10%) + molasses (5%)	51.58[d]	18.09[cd]	4.54[d]
T11	Wilted water hyacinth + guinea grass (10%) + cassava flour (10%)	54.20[b]	14.60[e]	3.19[g]
T12	Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	44.64[f]	20.39[b]	5.91[b]

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Silica content

The highest silica content (6.66%) was found in silage made of wilted water hyacinth + rice bran (10%). It was followed by fresh water hyacinth + rice straw (10%) + rice bran (10%) and wilted water hyacinth+ guinea grass (10%) + rice bran (10%). The lowest silica content was recorded in the treatment wilted water hyacinth+ guinea grass (10%) + cassava powder (10%).

4.2.3 Heavy metal content of the silage

Heavy metal content of the silage is given in Table 24. Heavy metals like As and Cd were below detectable limit. But heavy metals like Pb, Cr and Hg were detected in the silage samples. However, their presence was within the permissible limits set by the EU directive on animal feed. The treatments did not vary significantly in heavy metal content of the silage. Lead content of the samples varied from 2.83-3.5 mg/kg. The chromium content of the samples varied from 1.292-1.917 mg/kg and mercury content of the samples ranged from 0.202-0.212 mg/kg.

4.2.4. Palatability of the silage

The data on palatability of the silage are presented in Table 25. On the first day of trial, there was only one treatment *viz.*, wilted water hyacinth+ rice straw (10%) + cassava flour (10%) with zero per cent feed left over. From the second day onwards the palatability of the silage treatments improved. On the second day, treatments with zero per cent feed left over were wilted water hyacinth+ molasses (5%), wilted water hyacinth+ cassava flour (10%), wilted water hyacinth+ rice straw (10%) + cassava flour (10%), and wilted water hyacinth+ guinea grass (10%) + cassava flour (10%). The treatment which was least preferred by the animals by the third day was fresh water hyacinth+ rice straw (10%) + rice bran (10%).

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Table 24. Effect of additives on the heavy metal content of water hyacinth silage

	Treatments	Pb (mg/kg)	Cr (mg/kg)	Hg (mg/kg)
T1	Wilted water hyacinth + molasses (5%)	3.000	1.292	0.206
T2	Wilted water hyacinth + cassava flour (10%)	2.667	1.625	0.205
T3	Wilted water hyacinth + rice bran (10%)	3.333	1.750	0.202
T4	Fresh water hyacinth + rice straw (10%) + molasses (5%)	3.500	1.875	0.204
T5	Fresh water hyacinth + rice straw (10%) + cassava flour (10%)	3.000	1.833	0.208
T6	Fresh water hyacinth + rice straw (10%) + rice bran (10%)	3.333	1.917	0.209
T7	Wilted water hyacinth + rice straw (10%) + molasses (5%)	3.000	1.708	0.212
T8	Wilted water hyacinth + rice straw (10%) + cassava flour (10%)	3.000	1.917	0.204
T9	Wilted water hyacinth + rice straw (10%) + rice bran (10%)	3.167	1.792	0.207
T10	Wilted water hyacinth + guinea grass (10%) + molasses (5%)	3.000	1.625	0.202
T11	Wilted water hyacinth + guinea grass (10%) + cassava flour (10%)	2.833	1.750	0.202
T12	Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	3.167	1.792	0.203
	CD (5%)	NS	NS	NS

Table 25. Palatability of silage

	Treatments	Percentage of feed left over		
		1st day	2nd day	3rd day
T1	Wilted water hyacinth + molasses (5%)	55.24	0	0
T2	Wilted water hyacinth + cassava flour (10%)	49.81	0	0
T3	Wilted water hyacinth + rice bran (10%)	99.62	46.61	0
T4	Fresh water hyacinth + rice straw (10%) + molasses (5%)	56.20	25.76	0
T5	Fresh water hyacinth + rice straw (10%) + cassava flour (10%)	89.39	72.98	76.77
T6	Fresh water hyacinth + rice straw (10%) + rice bran (10%)	96.71	95.02	87.35
T7	Wilted water hyacinth + rice straw (10%) + molasses (5%)	85.66	78.95	61.89
T8	Wilted water hyacinth + rice straw (10%) + cassava flour (10%)	0	0	0
T9	Wilted water hyacinth + rice straw (10%) + rice bran (10%)	88.45	79.86	72.30
T10	Wilted water hyacinth + guinea grass (10%) + molasses (5%)	87.35	54.75	0
T11	Wilted water hyacinth + guinea grass (10%) + cassava flour (10%)	96.97	0	0
T12	Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	99.62	38.64	29.28

4.3 Experiment III: Conversion of water hyacinth into nutrient-rich compost

4.1. Influence of different composting methods on compost quality

4.1.1 pH

The data on pH of prepared composts are presented in Table 25. Vermicompost had significantly higher pH (7.57) compared to the other composts. All other composts had similar pH values.

4.1.2 Electrical Conductivity (EC)

The data pertaining to EC of composts are presented in Table 26. Significantly higher EC was recorded for Bangalore compost (0.91 dS/m), which was on par with that of vermicompost (0.83).

4.1.3. Total Salt Concentration (TSC)

Total salt concentration was the highest in Bangalore compost, which was on par with that of vermicompost.

Table 26. Effect of composting methods on pH, EC and TSC of compost

Treatment	pH	EC (dS/m)	TSC (mg/kg)
Bangalore compost	7.39	0.91	582.40
Indore compost	7.35	0.63	401.76
Phospho-compost	7.40	0.58	373.12
Vermicompost	7.57	0.83	530.88
CD (5%)	0.14	0.14	86.96

4.1.4 Bulk density

The data on bulk density of composts are presented in Table 27. The lowest bulk density was recorded with vermicompost (0.89 g/cm^3). Bulk density of the other compost did not showed significant variation.

4.1.5. Porosity

The data on porosity of composts are presented in Table 27. Porosity was the highest in vermicompost (61.18%) and the lowest porosity was recorded with Bangalore compost (53.68 %).

4.1.6. C: N ratio of the compost

The data on C: N ratio of the composts are presented in Table 27. The lowest C: N ratio was recorded with vermicompost (11.58). Other methods of composting showed no significant variation in C: N ratio.

Table 27. Effect of composting methods on bulk density, porosity and C: N ratio of the compost

Treatment	Bulk density (g/cm^3)	Porosity (%)	C:N ratio
Bangalore compost	1.09	53.68	12.68
Indore compost	1.07	58.31	13.17
Phospho-compost	1.08	57.38	13.19
Vermi compost	0.89	61.18	11.58
CD (5%)	0.12	2.66	0.99

4.2 Macro and micronutrients in compost

4.2.1. Nitrogen

The data on N content at 3 MAC (months after composting) and 6 MAC are presented in Table 28. At 3 MAC, the N content was significantly higher in vermicompost (1.23 %) which was on a par with that of Bangalore compost (1.19%). Nitrogen content at 6 MAC was the highest in vermicompost (1.75%) and other methods of composting showed no significant variation in N content.

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4.2.2. Phosphorus

The data pertaining to P content of compost at 3 and 6 MAC are presented in Table 28. Phosphorus content of compost varied with the method of composting. At 3 MAC, significantly highest P content was recorded in phospho-compost (0.47 mg/kg) and the lowest P content was recorded in Indore compost (0.32 mg/kg). Phosphorus content at 6 MAC was the highest in phospho-compost (0.61 mg/kg) and the lowest P content was observed in Indore compost, which was on par with that of Bangalore compost.

4.2.3. Potassium

The data on potassium content at 3 and 6 MAC are presented in Table 28. At 3 MAC different methods of composting did not vary significantly in K content. Potassium content at 6 MAC was the highest in vermicompost (1.53%) and the lowest in phospho-compost (1.22%) which was on par with that of Indore compost (1.26%).

Table 28. Effect of different composting methods on N, P and K content of compost at 3 and 6 months after composting

Treatments	N (%)		P (%)		K (%)	
	3 MAC	6 MAC	3 MAC	6 MAC	3 MAC	6 MAC
Bangalore compost	1.19	1.58	0.35	0.43	1.07	1.36
Indore compost	1.14	1.51	0.32	0.41	1.01	1.26
Phospho-compost	1.09	1.49	0.47	0.61	0.98	1.22
Vermi compost	1.23	1.75	0.37	0.47	1.09	1.53
CD (5%)	0.07	0.13	0.02	0.03	NS	0.05

4.2.4. Calcium

The data on calcium content at 3 and 6 MAC are presented in Table 28. Calcium content at 3 MAC (0.55%) and 6 MAC (0.86%) were the highest in vermicompost. Other composting methods showed no significant variation in Ca content at 6 MAC.

Table 29. Effect of different composting methods on Ca, Mg, and S content of compost at 3 and 6 months after composting

Treatments	Ca (%)		Mg (%)		S (%)	
	3 MAC	6 MAC	3 MAC	6 MAC	3 MAC	6 MAC
Bangalore compost	0.41	0.75	0.25	0.45	0.07	0.14
Indore compost	0.39	0.72	0.23	0.43	0.06	0.12
Phospho-compost	0.50	0.81	0.22	0.40	0.07	0.13
Vermi compost	0.55	0.86	0.26	0.47	0.08	0.17
CD (5%)	0.041	0.038	0.014	0.024	0.003	0.023

4.2.5 Magnesium

The data on Mg content of composts at 3 and 6 MAC are presented in Table 29. Magnesium content at 3 MAC was the highest in vermicompost (0.26%), which was on par with that of Bangalore compost (0.25%). At 6 MAC, the highest Mg content was recorded in vermicompost (0.47%,) which was on par with that of Bangalore compost (0.45%). The lowest Mg content was in phospho-compost (0.40%).

4.2.6. Sulphur

The data on S content of composts at 3 and 6 MAC are presented in Table 29. At 3 MAC, the highest S content was recorded in vermicompost and the lowest S content was in Indore compost. At 6 MAC, the highest S content was observed in vermicompost (0.17%), but the other composting methods showed no significant variation in S content.

4.2.7. Micronutrients

The data on micronutrient content of composts at 3 and 6 MAC are presented in Tables 30 and Table 31. Different composting methods showed no significant variation for Fe and Mn content of the compost. Zinc content at 3 MAC showed no significant difference among various composting methods. However, at 6 MAC the highest Zn content was recorded in Bangalore composting (170.25 mg/kg), which was on par with that of Indore compost (165.00 mg/kg), and the lowest Zn content was observed in phospho-compost (157.50 mg/kg), which was on par with that of vermicompost (161.00 mg/kg).

Copper content at 3 MAC did not vary significantly among treatments. At 6 MAC, the highest Cu content was recorded in Bangalore compost (41.94 mg/kg) and the lowest Cu content was recorded in phospho-compost (35.26 mg/kg). Cobalt content at 3 MAC was the lowest in phospho-composting (5.75 mg/kg) and the other methods of composting showed no significant variation in Co content. At 6 MAC, the highest Co content was recorded in Bangalore compost (12.59 mg/kg) and Co content of other compost did not vary significantly. Nickel content at 3 MAC was significantly higher in Bangalore compost, which was on par with that of Indore compost. At 6 MAC, the highest Ni content was recorded in Bangalore compost (27.30 mg/kg) and the lowest Ni content was observed in phospho-compost, which was on par with that of vermicompost.

Table 30. Effect of different composting methods on Fe, Mn and Zn content (mg/kg) at 3 and 6 months after composting

Treatments	Fe		Mn		Zn	
	3 MAC	6 MAC	3 MAC	6 MAC	3 MAC	6 MAC
Bangalore compost	6668.75	9184.13	567.50	933.75	68.85	170.25
Indore compost	6656.25	9073.75	562.00	928.38	67.25	165.00
Phospho-compost	6612.50	8901.25	545.00	909.38	64.50	157.50
Vermi compost	6594.00	8581.25	558.00	916.25	66.38	161.00
CD (5%)	NS	NS	NS	NS	NS	6.37

Table 31. Effect of different composting methods on Cu, Co and Ni content (mg/kg) at 3 months and 6 months after composting

Treatments	Cu		Co		Ni	
	3 MAC	6 MAC	3 MAC	6 MAC	3 MAC	6 MAC
Bangalore compost	21.81	41.94	6.79	12.59	17.44	27.30
Indore compost	20.91	39.31	6.55	11.38	16.81	26.08
Phospho-compost	19.80	35.26	5.75	11.16	15.99	25.56
Vermi compost	20.86	39.14	6.36	11.23	16.43	25.74
CD (5%)	NS	2.39	0.59	0.75	0.98	0.69

4.3 Heavy metal content

Data on heavy metal content of composts at 3 and 6 MAC are presented in Table 32. Heavy metals such as As, Cd and Pb were below detectable level in the compost, whereas the compost contained Cr and Hg. Chromium content at 3 MAC was the highest in Bangalore compost (20.35 mg/kg) and the other composting methods showed no significant variation in Cr content. At 6 MAC, Cr content did not differ significantly among the treatments. Mercury content at 3 and 6 MAC did not vary significantly among different composting methods.

Table 32. Effect of different composting methods on heavy metal content (mg/kg) at 3 and 6 months after composting

Treatments	Cr		Hg	
	3 MAC	6 MAC	3 MAC	6 MAC
Bangalore compost	20.35	36.88	0.006	0.011
Indore compost	19.65	35.48	0.005	0.009
Phospho-compost	19.18	33.25	0.004	0.009
Vermi compost	19.38	34.06	0.004	0.008
CD (5%)	0.68	NS	NS	NS

4.4 Experiment IV: Evaluation of water hyacinth as a mulch in turmeric

Biometric observations

Plant height

The data pertaining to plant height at 90, 120, 150, 180 and 210 days after planting are given in Table 33. In general, throughout the period of observation, there was a steady increase in plant height. However, height increase was slow from 180 to 210 DAP (days after planting). During 2014-2015, plant height at 90 DAP was the highest with mulching with jack leaves (108.20 cm) which was on par with mulching with water hyacinth (103.60 cm) and mulching with coconut leaves (98.20 cm). The lowest plant height was recorded in plot without mulching

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(81.40 cm). This trend continued until 210 DAP. In 2015-2016 too, the same trend as for the previous year continued.

Table 33. Effect of various mulches on plant height (cm) at different stages

Treatments	90 DAP		120 DAP		150 DAP		180 DAP		210 DAP	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	103.60	74.00	119.00	93.26	128.60	106.68	138.98	114.52	142.78	123.8
Mulching with jack leaves	108.20	78.25	114.60	91.76	130.70	109.02	140.44	115.60	144.64	123.2
Mulching with coconut leaves	98.20	75.25	112.20	90.66	123.00	104.44	130.80	113.74	135.20	121.1
No mulch	81.40	55.10	96.80	76.28	109.38	83.96	118.98	92.64	123.98	99.38
CD (5%)	15.27	8.17	15.11	7.51	14.80	6.69	15.79	10.81	15.31	11.42

Number of tillers per plant

The data pertaining to the number of tillers per plant are presented in Table 34. There was an increasing trend in tiller production from 90 to 210 days after planting. Number of tillers per plant did not differ significantly among the treatments in 2014-2015 and 2015-2016.

Table 34.Effect of various mulches on number of tillers per plant at different stages

Treatments	90 DAP		120 DAP		150 DAP		180 DAP		210 DAP	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	1.56	1.44	1.76	1.64	1.88	1.80	2.08	1.92	2.20	2.00
Mulching with jack leaves	1.60	1.52	1.84	1.72	2.04	1.88	2.12	2.00	2.24	2.04
Mulching with coconut leaves	1.52	1.40	1.72	1.60	1.88	1.76	2.00	1.84	2.12	1.92
No mulch	1.48	1.20	1.64	1.40	1.76	1.60	1.88	1.72	1.96	1.76
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Number of functional leaves per plant

The data regarding the number of standing/ functional leaves per plant are presented in Table 35. Number of functional leaves increased from 90 DAP to 180 DAP, after which a decreasing trend was noticed in both years. The number of leaves per plant of mulched plots was significantly higher than non-mulched plots. The number of leaves did not differ significantly among different type of mulches at any of the stage in both the years. The lowest number of leaves at all stages in both years was recorded in non-mulched plots.

Table 35. Effect of various mulches on number of functional leaves per plant

Treatments	90 DAP		120 DAP		150 DAP		180 DAP		210 DAP	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	9.48	9.28	11.84	11.40	13.64	13.56	14.48	13.64	10.92	10.34
Mulching with jack leaves	10.52	10.40	12.84	12.32	14.92	14.04	15.04	14.52	11.40	11.00
Mulching with coconut leaves	9.24	9.12	11.78	11.26	13.52	13.36	14.20	13.56	10.80	10.28
No mulch	7.60	7.00	9.92	9.12	11.68	10.68	12.04	10.72	8.08	7.72
CD (5%)	1.29	1.72	1.80	2.04	2.00	2.44	1.64	2.75	1.17	0.76

Leaf area index

Leaf area index (LAI) was estimated at 90 DAP and 120 DAP and the data are presented in Table 36. Leaf area index at 90 DAP and 120 DAP in both years was the highest in plots mulched with jack leaves, which was on par with mulching by water hyacinth and mulching by coconut leaves. The lowest LAI was recorded in non-mulched plots in both the years.

Table 36. Effect of various mulches on leaf area index

Treatments	90 DAP		120 DAP	
	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	3.87	3.69	5.84	4.97
Mulching with jack leaves	4.00	3.71	5.91	5.10
Mulching with coconut leaves	3.43	3.36	5.53	4.70
No mulch	2.53	2.40	3.97	3.50
CD (5%)	0.63	0.38	0.53	0.94

Leaf area ratio

The data on leaf area ratio at 90 DAP and 120 DAP are presented in Table 37. Leaf area ratio (LAR) at 90 DAP in both the years was the highest in plots mulched with jack leaves. However, no significant difference was noted in LAR of plants mulched with water hyacinth or coconut leaves. LAR at 90 DAP was the lowest in non-mulched plants in both the years. LAR of plants mulched with jack leaf was significantly higher at 120 DAP in 2014-15, followed by water hyacinth mulch and coconut leaves. Non-mulched plants showed the lowest value. In 2015-16 too, LAR was the highest in plants mulched with jack leaves. However, there was no significant difference between plants mulched with water hyacinth or coconut leaves. The lowest LAR was recorded in non-mulched plots.

Dry matter production

Dry matter production was calculated at 90 DAP, 120 DAP, and 210 DAP and the data are presented in Table 38. In 2014-2015, dry matter production at 90 DAP was higher in plants mulched with jack leaves (1550.40 kg/ha), which was on par with plants mulched with water hyacinth (1510 kg/ha) and plants mulched with coconut leaves (1460.20 kg/ha). The lowest dry matter accumulation of

1028.20 kg/ha was noticed in non-mulched plots. The same trend was observed in 2015-2016 also.

Dry matter production at 120 DAP was higher in plots mulched with jack leaves in 2014-2015 (4070.80 kg/ha), which was on par with mulching by water hyacinth or coconut leaves. In 2015-2016, the highest dry matter production at 120 DAP was observed in plots mulched with jack leaves (3437.60 kg/ha), which was on par with mulching by water hyacinth (3211.20 kg/ha). The lowest dry matter accumulation was noted in non-mulched plots in both the years (3079.40 kg/ha and 2336.40 kg/ha respectively).

Dry matter production at 210 DAP was significantly higher in plots mulched with jack leaves, which was on par with mulching by water hyacinth and coconut leaves. The lowest dry matter production in both the years was recorded in non-mulched plots.

Table 37. Effect of various mulches on leaf area ratio (cm^2/g)

Treatments	90 DAP		120 DAP	
	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	36.54	33.00	49.02	45.00
Mulching with jack leaves	41.02	36.80	54.20	52.60
Mulching with coconut leaves	35.60	31.80	47.62	43.80
No mulch	29.80	27.80	40.20	37.60
CD (5%)	1.41	1.87	1.38	2.57

Table 38. Effect of various mulches on dry matter production (kg/ha)

Treatments	90 DAP		120 DAP		210 DAP	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	1510.00	1396.00	3959.00	3211.20	8260.00	7440.00
Mulching with jack leaves	1550.40	1420.00	4070.80	3437.60	8491.20	7645.60
Mulching with coconut leaves	1460.20	1339.20	3889.60	2912.80	8017.80	7382.00
No mulch	1028.20	1058.80	3079.40	2336.40	7089.00	6122.00
CD (5%)	91.95	95.76	595.11	413.47	524.75	420.76

Rhizome yield

The data on rhizome yield are presented in Table 39. In 2014-2015, rhizome yield was higher in plots mulched with jack leaves (22.45 t/ha), which was on par with mulching by water hyacinth (20.52 t/ha) and mulching by coconut leaves (20.12 t/ha). The lowest rhizome yield was noted in non-mulched plots (15.91 t/ha). In 2015-2016, also no significant difference in rhizome yield was observed between different mulches and the lowest rhizome yield was observed in non-mulched plots (13.71 t/ha).

Table 39. Effect of various mulches on rhizome yield (t/ha)

Treatments	2014-15	2015-16
Mulching with water hyacinth	20.52	17.00
Mulching with jack leaves	22.45	18.65
Mulching with coconut leaves	20.12	16.91
No mulch	15.91	13.71
CD (5%)	3.63	2.89

Weed population

In both the years, weed population was recorded at 45 DAP, 90 DAP and 150 DAP and the data are presented in Table 40. In 2014-2015 the number of weeds at 45 DAP was higher in non-mulched plots (35.20/m^2). There was no significant difference in weed count among different mulches. In 2015-2016, the highest weed count was observed in non-mulched plots (34.80/m^2) followed by mulching by water hyacinth (14/m^2). The lowest weed count was observed in plots mulched with jack leaves (7.20/m^2), which was on par with mulching by coconut leaves (8.80/m^2).

In 2014-2015, weed count at 90 DAP was the highest in non-mulched plots (21.20/ m^2) followed by mulching by water hyacinth (11.60/m^2). The lowest weed count was observed in plots mulched with jack leaves (6.80/m^2), which was on par with mulching by coconut leaves (8.40/m^2). The same trend was observed in 2015-2016 also.

In 2014-2015, weed count at 150 DAP was the highest in non-mulched plots (32.80/m^2) followed by mulching with water hyacinth. The lowest weed count was observed in plots mulched with jack leaves, which were on par with mulching by coconut leaves. In 2015-2016 the highest weed count was recorded in non-mulched plots (25.20/m^2) and there was no significant difference in weed count among different mulches.

Weed dry weight

Dry matter production of weeds at various stages was affected by mulching and the results are presented in Table 41. Dry matter production of weeds at 45 DAP in both the years were higher in non-mulched plots (535.20 kg/ha and 289.56 kg/ha respectively). There was no significant difference in weed dry weight among different mulching treatments. The same trend was observed at 90 DAP and 150 DAP in both the years.

Table 40. Effect of various mulches on total weed population (No./m^2) in turmeric

Treatments	45 DAP		90 DAP		150 DAP	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	4.33 (18.00)	3.84 (14.00)	3.51 (11.60)	3.36 (10.60)	4.26 (17.60)	3.66 (12.80)
Mulching with jack leaves	3.35 (10.80)	2.78 (7.20)	2.77 (6.80)	2.58 (5.80)	2.97 (8.40)	3.06 (9.60)
Mulching with coconut leaves	3.89 (14.80)	3.03 (8.80)	3.04 (8.40)	2.87 (7.40)	3.77 (13.60)	3.02 (8.40)
No mulch	5.99 (35.20)	5.95 (34.80)	4.65 (21.20)	4.25 (17.40)	5.78 (32.80)	5.06 (25.20)
CD (5%)	1.11	1.02	0.68	0.52	1.23	0.97

$\sqrt{x+1}$ transformed values. Original values are given in parentheses.

Table 41. Effect of various mulches on weed dry weight (kg/ha)

Treatments	45 DAP		90 DAP		150 DAP	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	15.77 (263.04)	12.42 (155.04)	12.06 (146.16)	11.87 (141.90)	13.94 (196.66)	12.43 (158.92)
Mulching with jack leaves	10.90 (132.96)	9.54 (95.04)	10.52 (112.14)	10.63 (116.96)	10.70 (126.77)	10.01 (106.43)
Mulching with coconut leaves	14.03 (214.56)	11.20 (129.83)	11.21 (126.42)	10.85 (119.11)	13.15 (192.80)	11.52 (169.12)
No mulch	25.58 (535.20)	17.25 (289.56)	17.42 (313.74)	16.33 (273.05)	20.70 (434.76)	17.41 (271.82)
CD (5%)	5.68	3.24	3.38	3.44	5.66	4.02

$\sqrt{x+1}$ transformed values. Original values are given in parentheses.

Uptake of nutrients by turmeric crop

Uptake of major nutrients was estimated and the data are presented in Table 42. In 2014-2015, the N uptake by the crop was higher in plots mulched with jack leaves (109.56 kg/ha), which was on par with mulching by water hyacinth or coconut leaves. The lowest N uptake was recorded in non-mulched plots (74.19 kg/ha). The same trend was observed in 2015-2016 also.

In 2014-2015, the P uptake by the crop was higher in plots mulched with jack leaves (17.18 kg/ha), which was on par with mulching by water hyacinth or coconut leaves. The lowest P uptake was recorded from non-mulched plots. In 2015-2016, maximum P uptake was observed in plots mulched with jack leaves (16.62 kg/ha), which was on par with mulching by water hyacinth (15.55 kg/ha). P uptake was the lowest in non-mulched plots (10.56 kg/ha).

In both the years, K uptake was the lowest in non-mulched plots (108.20 and 98.20 kg/ha) respectively. There was no significant difference in K uptake among different mulched plots.

Table 42. Effect of various mulches on N, P and K uptake (kg/ha) by turmeric

Treatments	N		P		K	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	107.35	97.59	16.24	15.55	137.61	125.60
Mulching with jack leaves	109.65	102.63	17.18	16.62	138.83	126.54
Mulching with coconut leaves	103.75	91.70	15.83	14.29	129.70	119.44
No mulch	74.19	72.90	12.72	10.56	108.20	98.20
CD (5%)	18.95	11.79	3.46	2.22	22.95	21.87

Nutrient content of the soil

Nutrient content before and after the experiment are presented in Table 43 and Table 44 respectively. The organic C content in both years varied significantly among the different treatments. Soil organic C was significantly increased due to mulching. The N, P and K content of the soil decreased after the experiment. In 2014-15, the highest available N content was observed in plots mulched with water hyacinth and the lowest N content was observed in non-mulched plots. In 2015-16, N content of the soil was the highest in plots mulched with water hyacinth, which was on par with that of jack leaves. The lowest N content was observed in non-mulched plots.

Available P content of soil did not differ significantly among the treatments in both years. Exchangeable K content of soil was the highest in plots mulched with water hyacinth in 2014-15 and the lowest K content was recorded in non-mulched plots. In 2015-16 also, K content of soil was the highest in plots mulched with water hyacinth. However, no significant difference was observed in K content of soils mulched with jack leaves or coconut leaves.

Table 43.Nutrient content of the soil before the experiment

Particulars	Value
Organic carbon (%)	1.24
Nitrogen (kg/ha)	468.43
Phosphorus (kg/ha)	20.25
Potassium (kg/ha)	373.27

Table 44. Effect of various mulches on nutrient content in the soil after the experiment

Treatments	Organic carbon (%)		N (kg/ha)		P (kg/ha)		K (kg/ha)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Mulching with water hyacinth	1.31	1.32	455.58	468.07	18.82	20.03	370.40	373.19
Mulching with jack leaves	1.27	1.29	440.53	458.34	18.62	18.67	364.52	368.70
Mulching with coconut leaves	1.25	1.26	435.51	449.10	18.60	18.80	363.89	368.06
No mulch	1.14	1.15	427.98	427.47	17.42	17.00	351.86	349.20
CD (5%)	0.09	0.10	14.85	14.93	NS	NS	4.32	4.43

DISCUSSION

5. DISCUSSION

The results of the various experiments conducted on "Management and utilization of water hyacinth (*Eichhornia crassipes* (Mart.) Solms)" were presented in chapter 4. The discussion pertaining to the findings are detailed below.

5.1 Experiment I: Phytoextraction capacity of water hyacinth

Water samples and water hyacinth plant samples from 20 representative sites from central Kerala were collected and analysed for various macro and micro nutrients and heavy metals. The results of the study were presented in Chapter 4. Section 4.1. The results are discussed below.

5.1.1 Electro-chemical properties of water samples

The electro-chemical properties of most water bodies indicated heavy pollution due to anthropogenic activities. Prolific growth of water hyacinth in these water bodies are due to pollution of aquatic system by nitrates and phosphates. The pH, EC and TSC are important electrochemical properties influencing water quality. The pH of water samples from the 20 sites ranged from 6.11-7.82 (Table 6). The pH of a water body is a very important quality parameter since it affects other chemical reactions such as solubility and metal toxicity (Fakayode, 2005). According to Indian standards, the maximum permissible pH for drinking water is 8.5 and minimum is 6.5 (BIS, 1986). The pH of water depends upon carbon-dioxide and carbonate to bi-carbonate equilibrium. Sujitha *et al.* (2012) reported that pH affects the solubility and biological availability (amount that can be utilized by aquatic life) of nutrients like C, N and P as well as heavy metals such as Pb, Cu and Cd.) Beegum (2016) reported that pH of water bodies of six acid sulphate soil series of Kuttanad were slightly acidic with pH ranging from 5.4-6.6.

The EC of water samples ranged from 0.09 to 24.55 dS/m (Table 6). Electrical conductivity in lake water provides rather sufficient information about

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the quantity of dissolved materials found in water. Water bodies that have an EC value of 50- 200 μS/cm, 200-500 μS/cm, 500-2000 μS/cm are classified as very soft, soft and hard respectively (Hutter, 1992). According to Indian standards for irrigation water, EC below 1.5 dS/m is classified as low salinity water, EC within 1.5-3 dS/m is classified as medium salinity water, EC between 3-6 dS/m is classified as high salinity water, and EC above 6 dS/m is classified as very high salinity water (BIS, 1986). Accordingly, water samples from Palakkad and Thrissur district could be regarded as low saline water. In Ernakulam district, samples from Angamaly and Kalamassery could be regarded as low saline water, those from Manjummal and Irumbanam as high saline, and those from Eloor could be classified as very high saline water. In Kottayam district, water samples from Nattakam and Changanassery could be regarded as low salinity water, those from Vechur could be classified as medium salinity water, and those from Vaikkom and Kumarakam could be classified as very high saline water.

5.1.2 Nutrient content in water samples

Nitrogen

Total N content of water samples of Palakkad, Thrissur, Ernakulam and Kottayam was in the range of 4.2-7.0 mg/L, 3.22-14.00 mg/L, 2.80-11.20 mg/L and 4.62-25.20 mg/L respectively (Table 9). The N content in plants ranged from 12833.33 to 26250 mg/kg. Nitrate and ammonia are the forms of nitrogen found in water. Excess accumulation of nitrate leads to eutrophication of water bodies. Any form of N can be toxic to aquatic organisms when its concentration is above maximum permissible limit (Lindau *et al.*, 1988). Permissible limit of NH4-N in water is 16 mg/L and concentration greater than this is lethal to aquatic organism (Sebastian, 1994). According to WHO (1984), the nitrate concentration above 50 ppm in drinking water could affect the health of infants, a condition known as methemoglobinemia. Nitrate content of all the water samples are below 50 ppm. The highest nitrate content (22.40 mg/L) was observed at Vaikkom in Kottayam district.

Phosphorus and potassium content

Total P content of water samples of Palakkad, Thrissur, Ernakulam, and Kottayam district was in the range of 0.250-0.837 mg/L, 0.0603-0.200 mg/L, 0.233-0.637 mg/L and 0.180-0.450 mg/L respectively (Table 9). Excess P in water causes eutrophication. Water collected from different sites showed very low P content. According to Beegum (2016) low P content of water bodies was caused by the absorption of P by macrophytes or by the slow release of P by sediments. Total K content of water samples of Palakkad, Thrissur, Ernakulam, and Kottayam was in the range of 1.15-7.77 mg/L, 1.23-7.30 mg/L, 1.62-63.55 mg/L and 1.49-49.40 mg/L respectively (Table 9).

Calcium, Mg and S content in water samples

Total Ca content of water samples of Palakkad, Thrissur, Ernakulam, and Kottayam district was in the range of 12.00-41.80 mg/L, 5.60-28.83 mg/L, 4.00-184 mg/L and 8.50-247.67 mg/L respectively (Table 9). According to BIS (2003) maximum permissible limit of Ca is 200 mg/L and only the water sample from Vechur exceeded this limit. Total Mg content of water samples of Palakkad, Thrissur, Ernakulam, and Kottayam districts ranged respectively from 3.90-27.67 mg/L, 1.10-17.33 mg/L, 2.40-371.67 mg/L, 7.83-131.83 mg/L. The maximum permissible limit of Mg in water is 100 mg/L. Samples from Manjummal, Eloor and Kumarakam exceeded the permissible limit. Total S content of water samples of Palakkad, Thrissur, Ernakulam, and Kottayam districts was in the range of 4.00-12.50 mg/L, 0.33-7.65 mg/L, 1.19-110.25 mg/L, and 0.40-87.33 mg/L respectively. The permissible limit of sulphate in water is 400 mg/L (BIS, 2003), indicating that S content was within the permissible limits in all the samples.

Micronutrients and heavy metals

Water samples collected from different districts showed the presence of micronutrients such as Fe, Mn, Zn, Cu, Co, and Ni. Among the micronutrients, Fe was the dominating element; content ranging from 0.97-5.42 mg/L (Table 13). The maximum permissible limit of Fe in water is 1.0 mg/L (WHO, 1971). All the samples, except those from Kalpathy and Thenur showed Fe content above permissible limit. The highest value was reported in water samples collected from Aramkallu in Thrissur district. This might be due to the Fe rich 'Kole' soils with high levels of soluble Fe in the submerged soil and subsequent leaching to water bodies.

The Mn content of water samples ranged from 0.134 mg/L to 0.769 mg/L. The highest Mn content was present in samples collected from Pattikkara. According to Indian Standard for Drinking Water as per BIS specifications (IS 10500-1991), the permissible limit of Mn in water is 0.3 mg/L. Water samples from Pattikkara, Enamavu, Angamaly, and Vaikkom had Mn content above the permissible limit. Zn was absent in water samples of Ernakulam district. Zn content could be detected from Kanimangalam and Kumarakam of Thrissur and Kottayam districts respectively. In Palakkad district, all samples except those from Kannannur, contained Zn. The maximum permissible limit by WHO is 5 mg/L. All the samples had Zn content below the permissible limit. Zinc concentration in surface water is generally low due to its restricted mobility from its sources or from rock weathering sites (Beegum, 2016).

The Cu content of water samples was in the range of 0.063-0.444 mg/L. The permissible limit of Cu in water according to BIS specification is 1.5 mg/L and all the water samples had Cu content below the permissible limit. Co content was very low in all the water samples and Co could not be detected in water samples of Palakkad district. Nickel content of water samples ranged from 0.010 to 0.228 mg/L. Aluminium content of water samples ranged from 1.59 to 8.72 mg/L. According to WHO standards, maximum permissible limit of Al in drinking water is 0.2 mg/L. All the water samples had Al content above the permissible limit. Kuttanad soils contained more soluble Al due to continuous submergence (Beegum, 2016). Draining the water from submerged area into canals led to increased concentration of Al in water (Nair and Pillai, 1990).

Chromium content in water samples ranged from 0.006-0.317 mg/L (Table 17). The maximum permissible limit of Cr in drinking water as per WHO standards is 0.1 mg/L. All the samples, except those from Mannathumkavu, Pattikkara, and Kalpathy had Cr content above the permissible limit. Beegum (2016) reported that water samples collected from acid sulphate soils of Kuttanad region contained Cr above the permissible limit, which might be due to higher content of Cr in soils. Mercury content ranged from 0.003 to 0.008mg/L. The maximum permissible limit of Hg in water is 0.001 mg/L (BIS, 2003). The present study revealed that concentration of Hg is in all tested water samples were above the maximum limit and thus unfit for use as drinking water.

5.1.3 Phytoremediation potential of water hyacinth

Kerala's wetlands and water bodies are facing severe pollution problems due to anthropogenic activities. Heavy metal contamination adversely affects soil ecology, agricultural production, and quality of water. Prolific growth of water hyacinth in the water bodies are due to pollution of aquatic system by nitrates and phosphates. Indiscriminate application of fertilizers and disposal of urban and industrial wastes cause heavy metal pollution. Many aquatic weeds have been found to extract heavy metals from polluted water. Phytoremediation by aquatic plants is a low cost technology for the control of water pollution. Water hyacinth's capacity to absorb nutrients makes it a potential biological alternative to secondary and tertiary treatment for waste water. Nutrient and heavy metal removal by water hyacinth present in water bodies of Central Kerala is discussed below based on the studies conducted.

Total N content of water hyacinth samples of Palakkad, Thrissur, Ernakulam, and Kottayam ranged from 12833 to 26250 mg/kg, 5833 to 14000 mg/kg, 12833 to 21000 mg/kg, and 14583 to 21000 mg/kg respectively. Water hyacinth has been studied previously by many scientists for its phytoremediation potential. Nitrogen content of water hyacinth plant samples of acid sulphate soil series such as Ambalappuzha, Kallara, Thakazhi, Purakkad, Thottapally, and

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Thuravur series of Kuttanad ecosystem ranged from 1.21 to 2.38 percent (Beegum, 2016), which is equivalent to 12100 mg/kg to 23800 mg/kg. In the present study, maximum value was 26250 mg/kg from Pattikkara in Palakkad. Hyper accumulators are defined as those plants capable of accumulating metals at levels 100 fold greater than those typically measured in common non-accumulator plants. Bioconcentration factor was highest (10000) for water hyacinth for N in Vellayani lake and plants with such high BCF values could be used for phytoremediation of N and for waste water treatment (Kamal, 2011). Water hyacinth is better than water lettuce for removal of nitrogen from water because of its higher root surface area, root biomass, root activity and net photosynthetic rate (Qin *et al.*, 2016).

Total P content of water hyacinth samples of Palakkad, Thrissur, Ernakulam, and Kottayam ranged from 1909 to 7631 mg/kg, 657 to 1798 mg/kg, 2149 to 7017 mg/kg, and 921 to 4166 mg/kg respectively (Table 11). Yong *et al.* (2011), Hua *et al.* (2014), Gao *et al.* (2015), and Victor *et al.* (2016), also reported P accumulation by water hyacinth plants.

The K content in water hyacinth samples of Palakkad, Thrissur, Ernakulam, and Kottayam ranged from 38950 to 52325 mg/kg, 13733 to 20965 mg/kg, 16083 to 44000 mg/kg, and 13997 to 21794.17 mg/kg respectively (Table 11). Beegum *et al* (2016) reported that water hyacinth samples from Kuttanad accumulated K in the range of 0.88-1.21 percent. Bio-concentration factor for K by water hyacinth of Vellayani lake was 26 (Kamal, 2011). In the present study, K accumulation was above this range in all the samples showing greater leaching of K from fertilizers and other sources to water bodies and consequent luxury consumption.

The respective values of Ca content in water hyacinth samples was in the range of 8730-15739 mg/kg, 9760-15369 mg/kg, 8808-15416 mg/kg, 8368-12954 mg/kg in Palakkad, Thrissur, Ernakulam, and Kottayam respectively (Table 11). Magnesium content in water hyacinth samples was in the range of 4779-8023

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mg/kg, 4134-7649 mg/kg, 8171-12189 mg/kg, and 8778-13239 mg/kg in Palakkad, Thrissur, Ernakulam and Kottayam districts respectively. Water hyacinth could be used for the phytoremediation of K, Ca and Mg from waste water (Okunowo and Ogunkanmi, 2010). Ajibade *et al.* (2013) suggested that water hyacinth could be used to reduce the Ca and Mg hardness of domestic sewage. Sulphur content of plant samples collected from these districts ranged from 1150 to 2521 mg/kg, 814 to 3053 mg/kg, 876 to 2206 mg/kg, and 2537 to 3717 mg/kg. Hyper accumulation of S from acid sulphate soils of Kuttanad (KAU, 2009) and Vellayani lake (Kamal, 2011) by water hyacinth has been reported. Evidence of sulphate reduction has been presented in studies carried out by Ndimele (2012) and Moyo *et al.* (2013).

5.1.4 Micronutrient and heavy metal accumulation by water hyacinth

The order of accumulation of heavy metals in water hyacinth based on the study conducted was Fe> Al> Mn> Zn> Cr> Ni> Co> Hg> Pb> As. Higher content of Fe in plant samples might be due to its high content in habitat water. Higher content of Fe in water hyacinth plants due to the higher availability of Fe in the sediments and water of Vembanad wetlands was reported by Sasidharan *et al.* (2013). Even though the content of Al in water was higher than Fe, its content in plants was lower than Fe content. Zn and Co were not present in many of the water samples but were detected in the corresponding plant samples. Although heavy metals like As and Pb were absent in all the water samples, it could be detected in the plant samples. Among the heavy metals, Pb content in plant samples was within the permissible limit but content of Fe, Cu, Cr, Zn and Ni were beyond the safe limits prescribed by WHO (1996). This reveals the potential of water hyacinth to accumulate huge quantities of these heavy metals.

Beegum (2016) reported that *Eichhornia crassipes* could be effectively used for phytoremediation of acid sulphate soils of Kuttanad ecosystem. Heavy metal content in tested plants were in the order of Fe>Mn>Al>Zn>Cr>Cu>Pb. Thampatti *et al.* (2007) found that plants like *Hydrilla verticillata, Eichhornia* *crassipes*, and *Cyperus pangora* possess hyper accumulation capacity for Fe, Mn, Zn, Cu, and Al in the wetlands of Kuttanad. A study on phytoremedial capability of water hyacinth was done by Sasidharan *et al.* (2013) at the Regional Agricultural Research Station, Kumarakom. Concentration of heavy metals was higher in the plant tissue compared to their concentration in sediment and lake water. While Cd, Pb and Ni concentration in the lake water was higher than Cu and Zn, their content in *E. crassipes* was less than Cu, Cr and Zn. The present study confirms earlier reports of phytoremediation potential of water hyacinth.

5.1.5. Dependency of nutrients and heavy metals in water hyacinth on concentration of nutrients and heavy metals in water

In order to study the association of plant nutrients with water nutrients, cross tabulation was done and dependence of plant nutrient factor on water nutrient was measured through Chi-square. The association between the levels of the same in water and plant were measured through correlation.

The nitrogen content in water hyacinth was not dependant on the nitrogen content of water; however, a positive correlation was noticed and was significant only at 10% level. This means that there is a possibility of increased N content in plant when the N content in water is relatively higher. An exact proportionate increase in N content of plant in relation to increased N content in water is evasive at this stage of observation. There is every possibility of such an outcome when the observations are continued in a spatially distributed manner.

The Chi-square statistic was significant for P, Mg and Ni. Thus the level of nutrients in water could be brought to a minimum through water hyacinth. Therefore it is recommended that water hyacinth may be allowed to grow in patches, but not obstructing the stream flow. Chi-square statistic was not significant for K. Association of plant K with water K was not readable at all. Similar inferences can be drawn for Ca, S, Fe, Mn, Zn, Cu, Co, Al and heavy metals such as Cr and Hg.

P / W	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Co	Ni	Al	Cr	Hg
N	↑														
P		↑													
K			↔												
Ca				↔											
Mg					↑										
S						↔									
Fe							↔								
Mn								↔							
Zn									↔						
Cu										↔					
Co											↔				
Ni												↑			
Al													↔		
Cr														↔	
Hg															↔

Chart 4.1. Dependency chart of the nutrients and heavy metals in plant with its corresponding level in water

W- Water

P- Plant

↑ - Total association

↔ - Undulating

The sensitivity and host specificity are very evident from the presence of heavy metals such as As and Pb in traces in plant samples but no detectable trace of the same could be detected in water samples. This means heavy metals such as As and Pb are present in water but in a totally unsaturated form. This is a reassertion of the fact that water hyacinth has a phytoremediation action that encompasses all other aquatic macrophytes.

5.2 Experiment II: Utilization of water hyacinth as livestock feed by silage making

Little bag silages were prepared from water hyacinth leaves and petioles using molasses, cassava flour, and rice bran as additives during August to October 2016 at the College of Horticulture, Vellanikkara, Thrissur and the prepared silages were tested for palatability at the University Livestock Farm and Fodder Research Station, KVASU, Mannuthy. The results of the experiment presented in Chapter 4 are discussed as follows.

5.2.1 Physical quality parameters

In all the treatments, the silage was ready for use after 45 days. A main quality criteria of silage is pH, and based on pH, silage is generally classified as very good (pH 3.8 to 4.2), good (pH 4.2 to 4.5), and fair silage (pH >4.5) (Thomas, 2008). In this experiment, wilted water hyacinth along with cassava powder (10%) seems to have good quality as it showed pH of 4.19 (Table 21 and Fig.2). The odour of this silage was rated 'very good'. All the treatments with 10 per cent cassava powder showed low pH values. Quality wise, rice bran added silages were poor in terms of pH values, which were above 6.36. The results revealed that wilted water hyacinth plus cassava powder (10%), wilted water hyacinth plus rice straw (10%) plus cassava powder (10%), and wilted water hyacinth plus guinea grass (10%) plus cassava powder (10%) are almost equal in quality with respect to pH. The odour of these combinations was rated either 'good' or 'very good'. Rice bran added silages, in general, had bad odour. According to Li *et al.* (2007), water hyacinth silage without additives had an undesirable fishy smell. Among the fresh water hyacinth combinations, only those with rice straw (10%) and cassava powder (10%) proved good in terms of pH. The colour varied based on the ingredients used, mostly brownish green or grey.

Silage fermentation is affected mostly by water soluble carbohydrate content (Liu *et al.*, 2011). Rice bran had 53 g water soluble carbohydrate per kilogram drymatter whereas molasses contain 700 g water soluble carbohydrate per kilogram drymatter (Lowilai *et al.*, 1994; McDonald *et al.*, 2011). Ngoan *et al.* (2000) stated that fermentation will be enhanced more by molasses than rice bran. As pH is a good indicator of fermentation, high pH of rice bran added silages may be due to the slower fermentation. Zanine *et al.* (2010) obtained low pH silage with cassava scrapings. Cassava scrapings (a by-product from the flour milling industry) at 7 per cent level improved the fermentation of elephant grass silage due to the high level of soluble carbohydrates and dry matter concentration and the pH of the silage was within the ideal range (3.8±0.12). In experiments to study ensilability and feeding value of water hyacinth to cattle, Tham (2012) reported that application of sugars in the form of molasses or rice bran as a water absorbent resulted in a rapid decrease of pH and the best fermentation quality was achieved in the silages with added molasses, absorbent or with a combination of the two

Good quality silage has a characteristic yellowish green to brownish green colour (Gallaher and Pitman, 2000) depending upon silage material and has pleasant, sour and sweet smell (Thomas, 2008). Thanh and Thu (2010) reported that silage made from water hyacinth treated with molasses level of 11.5 and 15.3 per cent was good in terms of colour and smell and easily accepted by cattle.

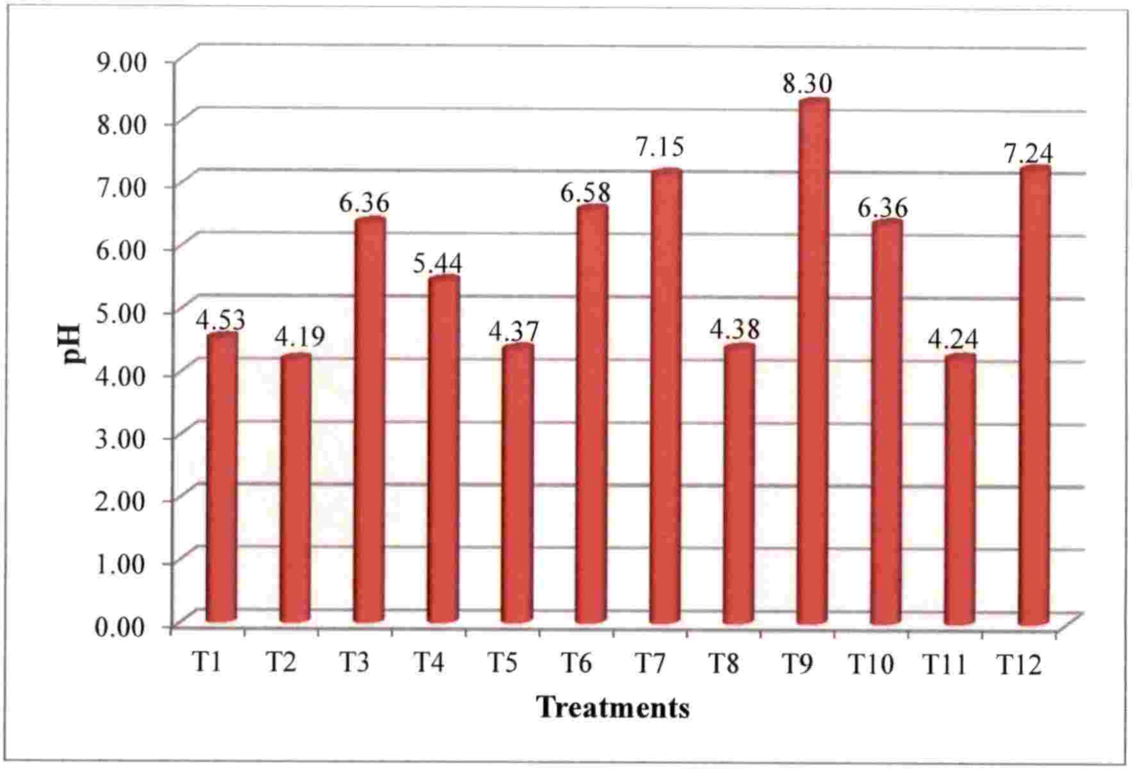

Fig. 2. The pH of water hyacinth silage as influenced by additives

5.2.2 Chemical composition of the silage

The additives used influenced the chemical composition of water hyacinth silage (Table 22 to 24 and Fig.3 to 9). Crude protein content gives an approximate value of protein content in forages. Among the treatments, wilted water hyacinth+ guinea grass (10%) + rice bran (10%) had the highest crude protein content (10.45%) followed by fresh water hyacinth+ rice straw (10%) + rice bran (10%), and wilted water hyacinth+ rice straw (10%) + rice bran (10%). Jones and Jones (1996) reported that absorbents rich in fibre such as straw reduce the nutritive quality during the ensiling process. Among the absorbents used, rice bran enhanced the crude protein significantly. As cassava contains low protein, those treatments with cassava powder showed the lowest crude protein content. Low crude protein and crude fibre content with the addition of cassava scrapings were reported by Zanine *et al.* (2010).

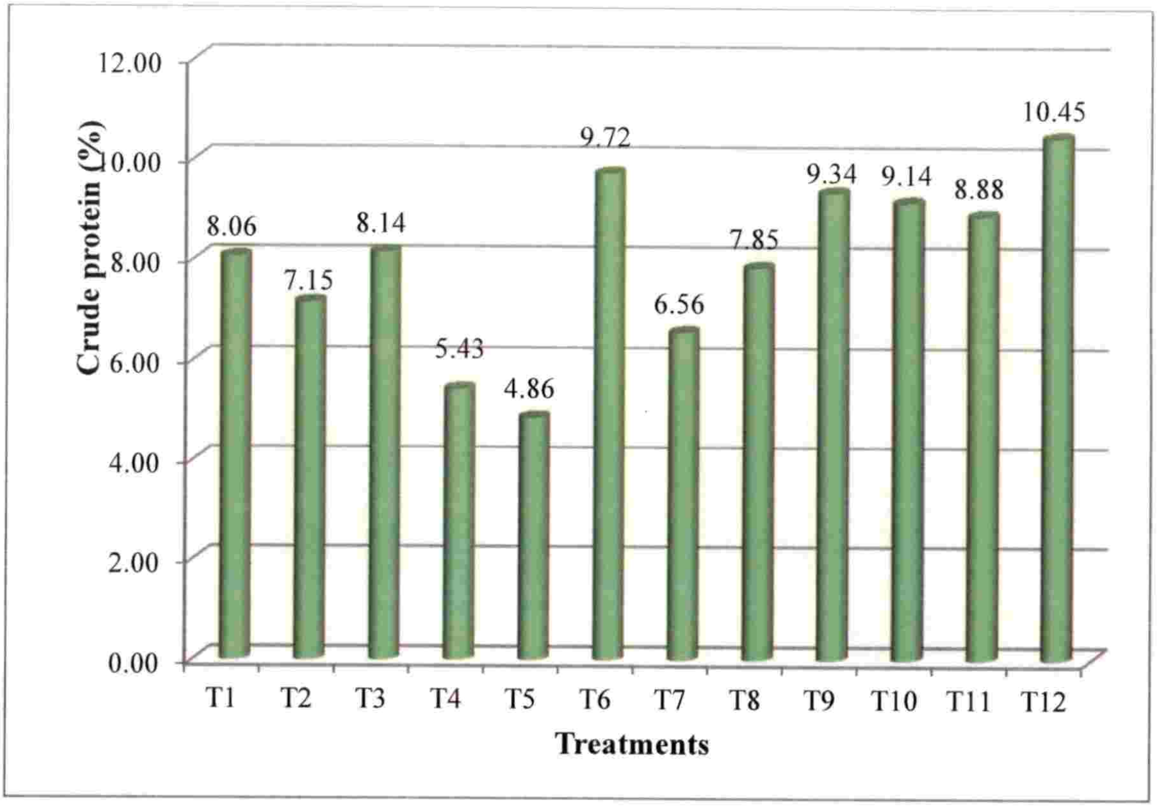

Fig. 3. Crude protein content of water hyacinth silage as influenced by additives

Crude fibre content was the highest in silages added with rice straw and guinea grass. Rice bran addition also enhanced the crude fibre content. The highest crude protein content of 25.35 per cent was recorded in the treatment fresh water hyacinth+ rice straw (10%) + rice bran (10%), which was on par with wilted water hyacinth+ rice straw (10%) + rice bran (10%) with a crude fibre content of 24.62 per cent. The lowest crude fibre content was observed in the treatment wilted water hyacinth+ molasses (5%). Rice bran addition positively influenced the ether extract content of the silage. Wilted water hyacinth+ rice bran (10%) had the highest ether extract content (1.81%) followed by wilted water hyacinth+ guinea grass (10%) + rice bran (10%) and fresh water hyacinth+ rice straw (10%) + rice bran (10%). Li *et al.* (2007) reported higher crude protein and crude fat by the addition of wheat bran.

Nitrogen free extract represents the digestible carbohydrate content. As cassava tubers are rich in carbohydrate content, it gave significantly high nitrogen free extract. Maximum NFE of 58.94 per cent was noted in the treatment wilted water hyacinth+ cassava powder (10%). Ash content represents the mineral content of the silage. Rice bran addition significantly increased the ash content of the silage. Samanta and Mitra (1992) reported that water hyacinth silage had 13.1 per cent crude protein, 17.9 per cent crude fibre, 3.2 per cent ether extract, 51.1 per cent nitrogen free extract, 14.7 per cent total ash, 2.6 per cent calcium and 0.7 per cent phosphorus.

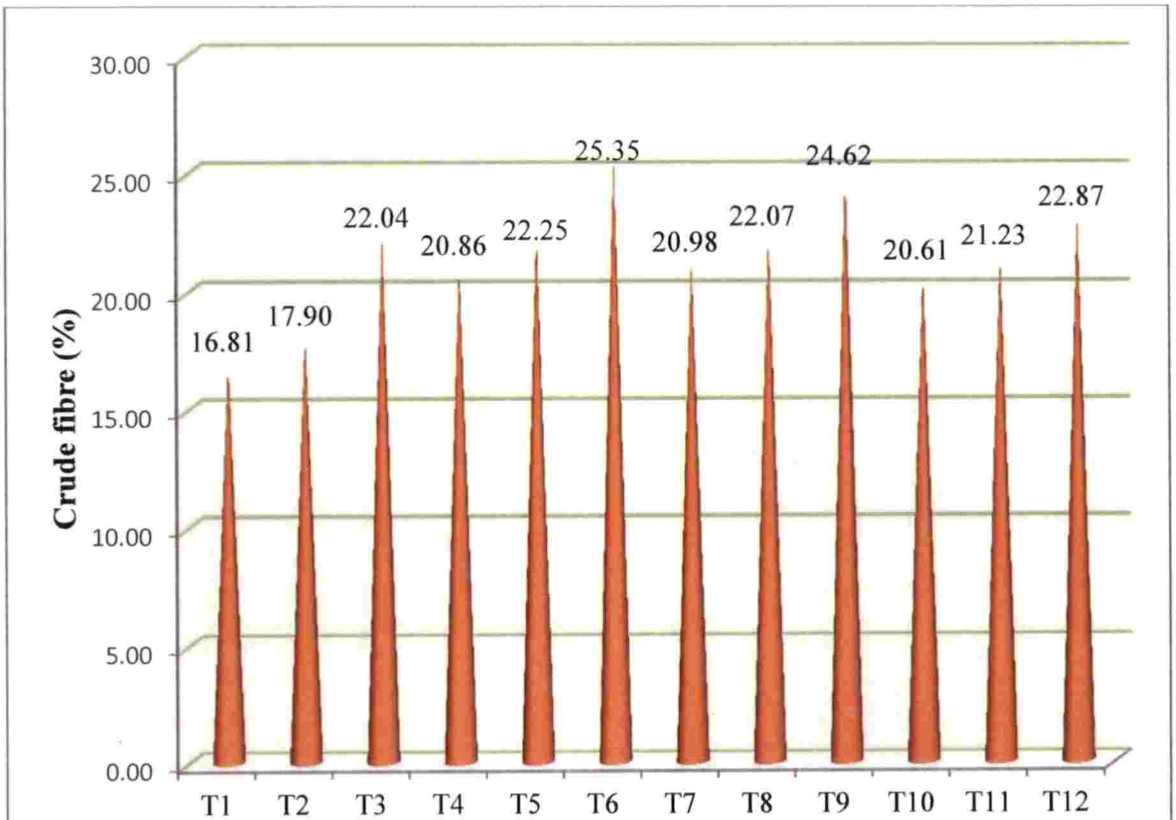

Fig. 4. Crude fibre content of water hyacinth silage as influenced by additives

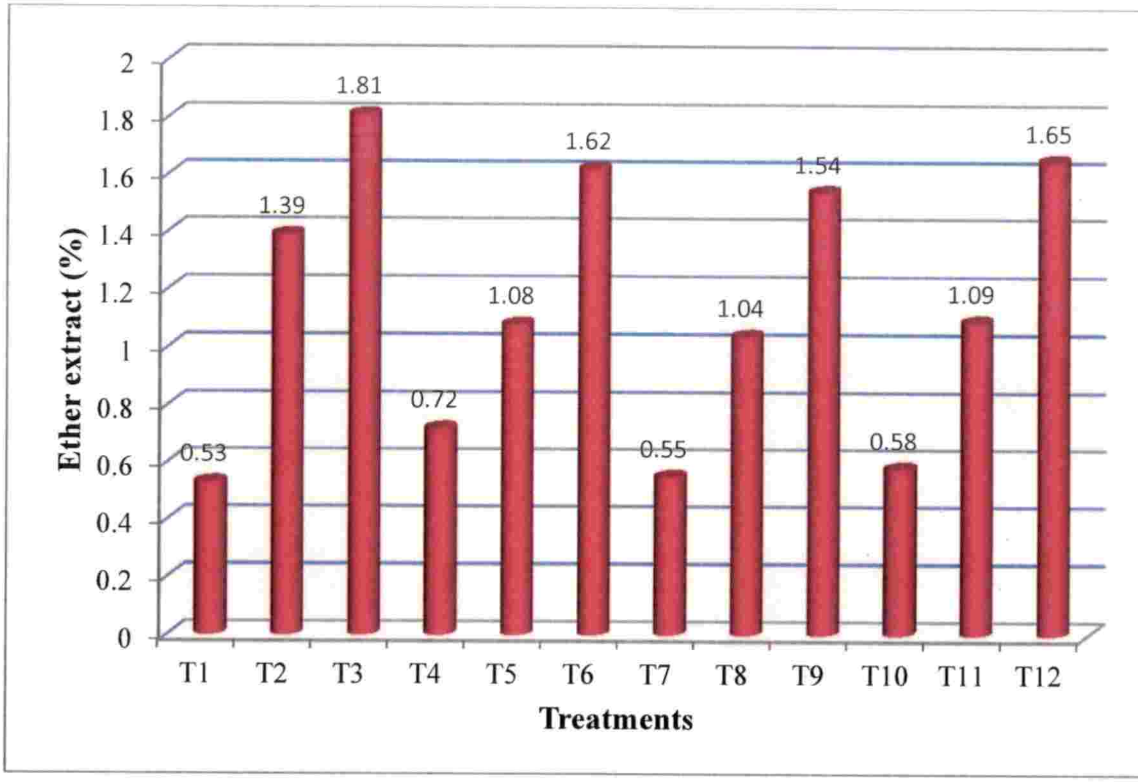

Fig. 5. Ether extract content of water hyacinth silage as influenced by additives

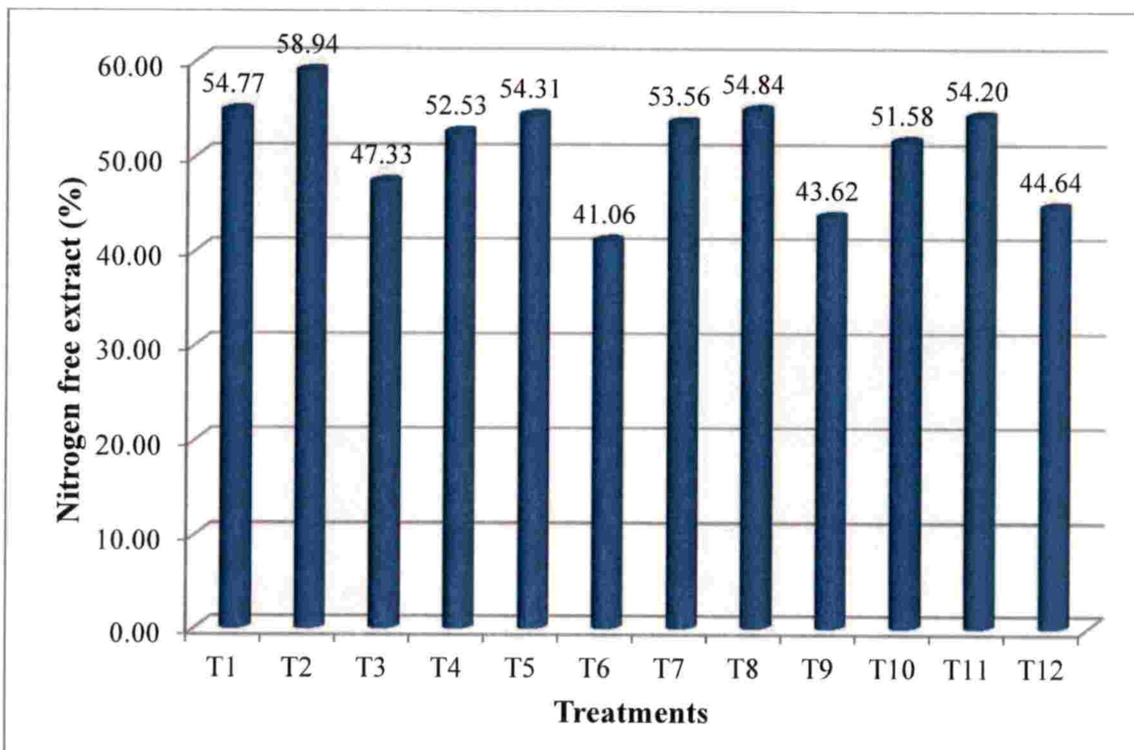

Fig. 6. NFE content of water hyacinth silage as influenced by additives

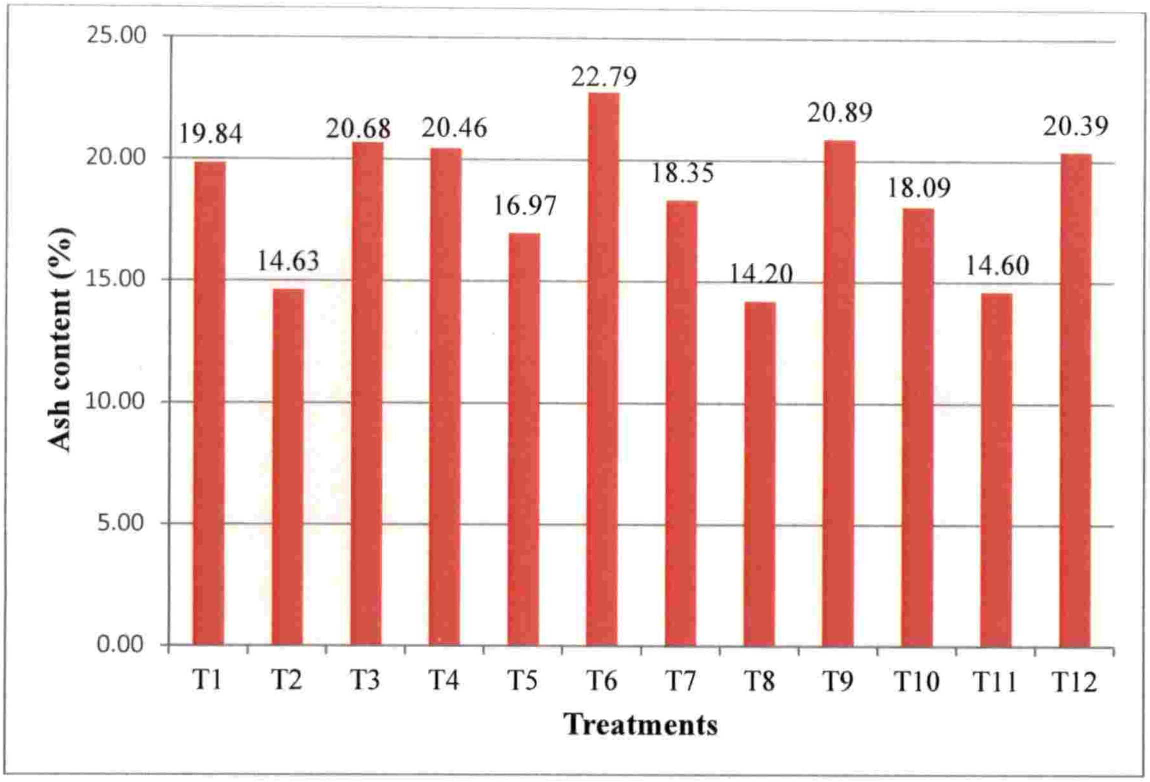

Fig. 7. Ash content of water hyacinth silage as influenced by additives

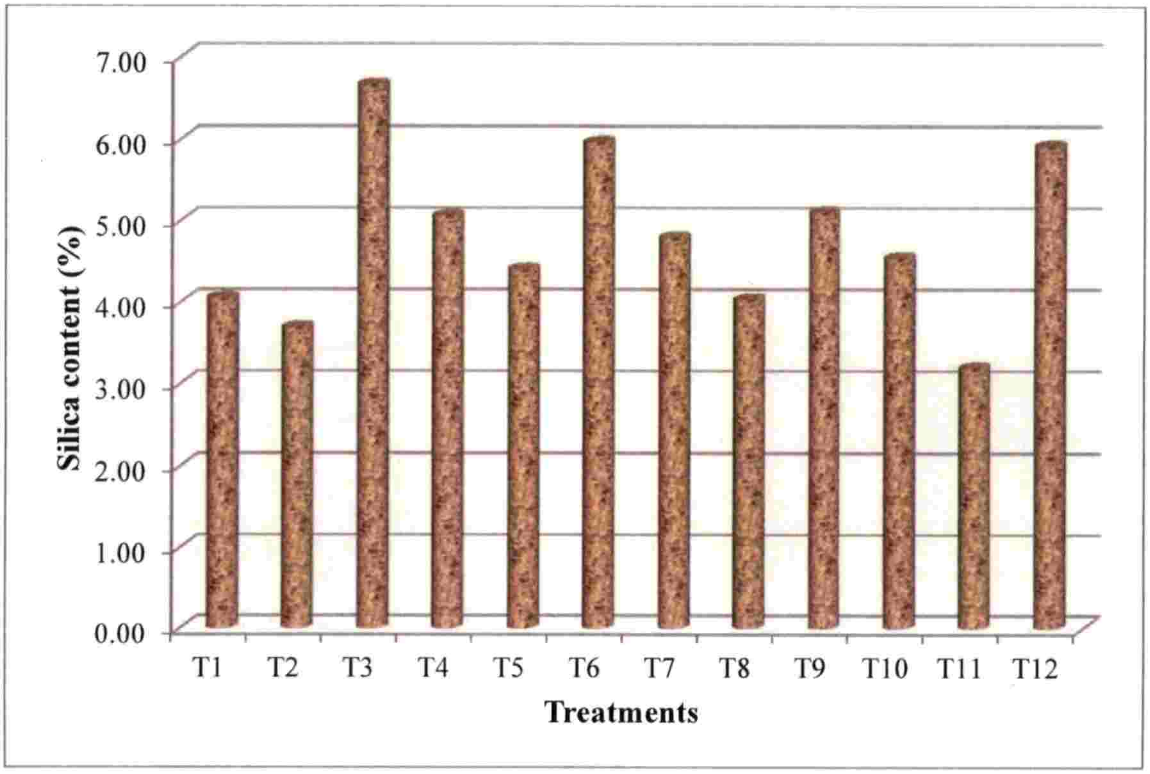

Fig.8. Silica content of water hyacinth silage as influenced by additives

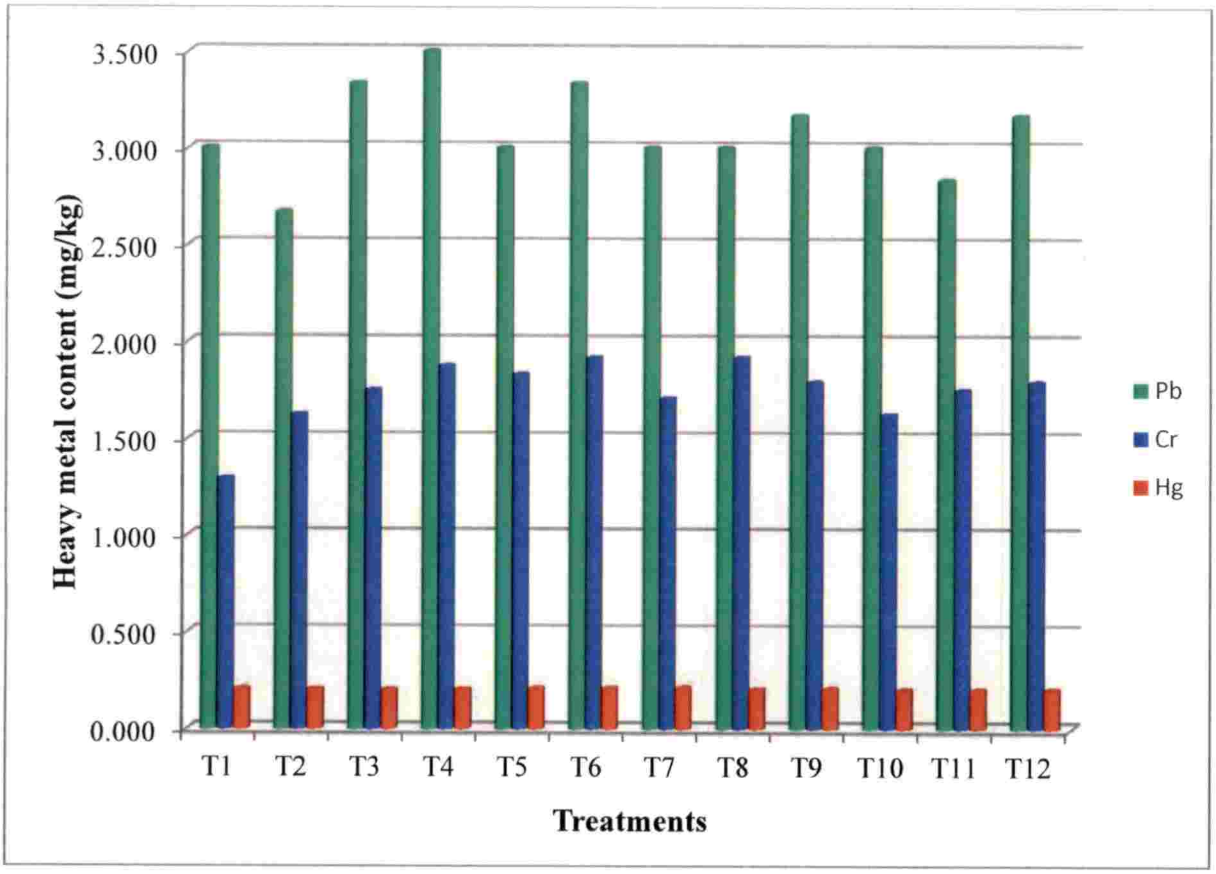

Fig. 9. Heavy metal content of water hyacinth as influenced by additives

5.2.3. Palatability of silage

When considering the quality of silage, palatability of the product is an important criterion. Estimated palatability of silage as percentage of left over feed is given in Table 25. The silage combinations with low pH values were preserved well and had high palatability values. Rice bran addition reduced the palatability although its nutritional content was high. Cassava powder added silages have shown high palatability. On the first day of trial, there was only one treatment, viz., wilted water hyacinth+ rice straw (10%) + cassava powder (10%) with zero per cent feed left over. From the second day onwards, the palatability of the silage treatments improved. On the second day, treatments with zero per cent left over feed were wilted water hyacinth+ molasses (5%), wilted water hyacinth+ cassava powder (10%), wilted water hyacinth+ rice straw (10%) + cassava powder (10%), and wilted water hyacinth+ guinea grass (10%) + cassava powder (10%). The treatment with the least preference by the animals was fresh water hyacinth+ rice straw (10%) + rice bran (10%). On the third day too, the least preferred silage treatment was fresh water hyacinth+ rice straw (10%) + rice bran (10%). Baldwin *et al.* (1975) reported that there is positive correlation between preservative level, pH, and the acceptability of silage to cattle. Woomer *et al.* (2000) reported that without additives, the pH of water hyacinth silage alone was 7.33 suggesting poor quality, while addition of 15 per cent maize bran or molasses resulted in silage of pH 4.1 and 4.2 respectively, and was readily accepted by goats and young steers. According to Poddar *et al.* (1990), water hyacinth silage with paddy straw was more palatable to growing calves than fresh or wilted water hyacinth, and molasses addition increased the palatability of silage.

From the results, it can be concluded that palatable silage could be made from wilted water hyacinth along with additives such as molasses and cassava powder. Both molasses and cassava powder ensured the quality of silage by lowering pH and enhancing animal intake. The quality of rice bran added silages were low in terms of pH, odour, and palatability; although its nutritional quality was high. Taking into account the quality parameters, wilted water hyacinth along with molasses (5%) or cassava flour (10%) and wilted water hyacinth along with cassava powder (10%) plus rice straw (10%) or guinea grass (10%) are the best options for utilizing water hyacinth as silage for feeding animals.

5.3 Experiment III: Conversion of water hyacinth into nutrient rich compost

Composting is the biological conversion of heterogeneous organic substrate, under controlled conditions, into a humus rich, stable product. During this process, a diverse group of microorganisms transforms decomposable materials into nutrient rich compost. The beneficial effect of compost on crop production and soil quality are influenced by physical, chemical and biological properties of the compost (He *et al.*, 1995). Composts were prepared from water hyacinth using cowdung by employing different methods such as Bangalore composting, Indore composting, Phospho composting, and vermicomposting. Results of the experiment presented in chapter 4 can be discussed as follows

5.3.1. Influence of composting methods on physical characteristics of compost

Colour change of compost is an indication of maturity of compost. In all the methods of composting, colour of the composts changed to dark brown indicating that decomposition had taken place in all the methods. According to Sughara *et al.* (1981), while advancing maturity, the colour of composting material will change from dark or greyish black. None of the composts had foul odour, but an earthy smell which is an indication of humification of organic matter. Compost with an obnoxious smell indicates instability (Henry and Harrison, 1996).

The data on the bulk density of composts as affected by method of composting are presented in Table 27 and Fig.10. Lowest bulk density was observed in vermicompost. All other methods of composting did not influence bulk density significantly. Porosity of compost is another important physical parameter that determines quality of compost. Porosity denotes volume of pore space in compost. It measures the proportion of a given volume of compost occupied by pores containing air and water. The pore space between compost particles should be such that there should be retention of water and air. Porosity was maximum in vermicompost (Table 27 and Fig.11). The porosity depends on bulk density and moisture content of compost. The porosity decreased with increasing bulk density and moisture content (Ahn *et al.*, 2008).

5.3.2. Influence of composting methods on chemical characteristics of compost

The pH, EC, C: N ratio, nutrient content and heavy metal content are the important chemical attributes monitored. The pH of composts prepared by different methods varied from neutral to slightly alkaline range (7.35-7.57). According to Bisen *et al.* (2011), during the final stages of composting, pH becomes neutral by the combined action of ammonium ion and acidic humate ion released by decomposition of substrates by microorganism. The highest pH was observed in vermicompost (Table 26 and Fig 12). Narayanan (2015) reported that higher pH of vermicompost might be due to the excretion of calcium by calciferous glands of earthworms.

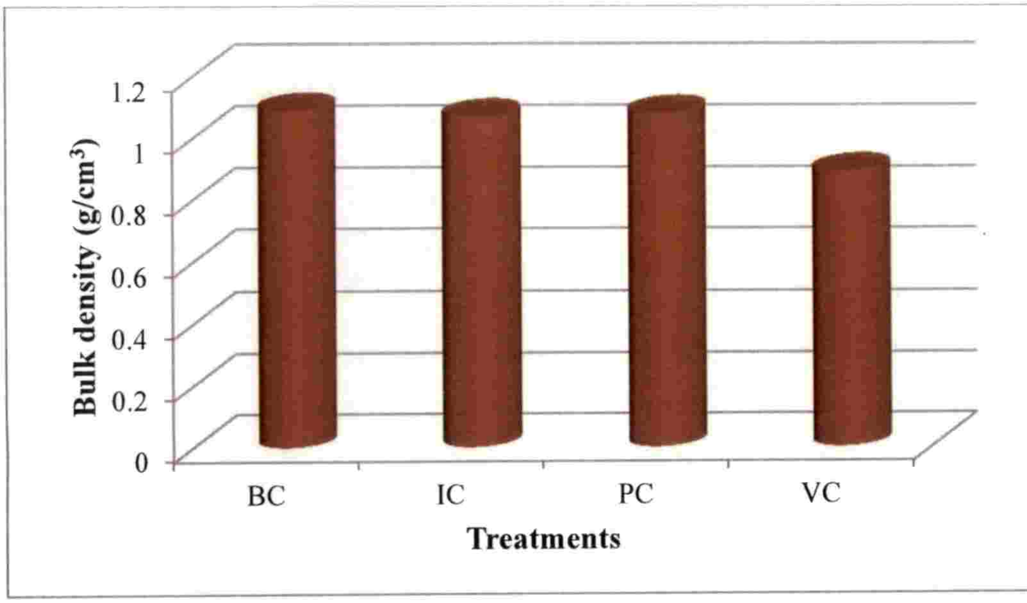

Fig. 10. Influence of composting methods on bulk density

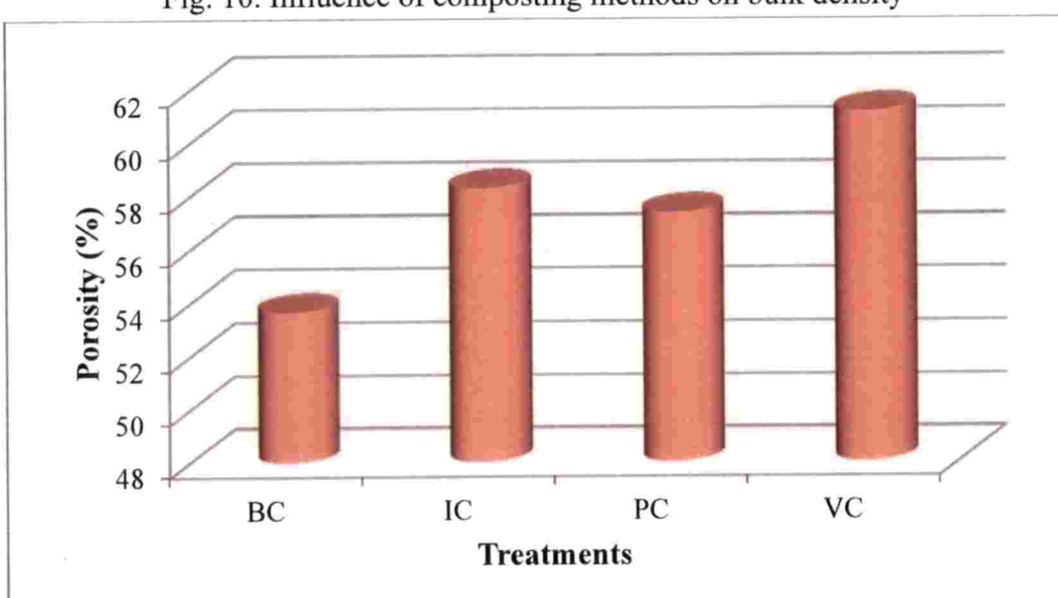

Fig. 11. Influence of composting methods on porosity

The variation in EC among the different composts is shown in Table 26 and Fig.13. Electrical conductivity gives a measure of concentration of soluble salts in compost at a particular temperature. Higher EC indicated the higher salt content. Electrical conductivity of Bangalore compost was the highest, and was on par with that of vermicompost. However, none of the composts exceeded the

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threshold value of 3 dS/m (Lazcano *et al.*, 2008). According to Mayadevi (2016) decomposition of substrates and subsequent release of exchangeable bases might have increased EC of compost under *ex-situ* composting and leaching of bases in *in-situ* pits dilutes the soluble salt concentration. Vermicompost had high electrical conductivity due to high concentration of base forming cations like Ca, N, P, and K.

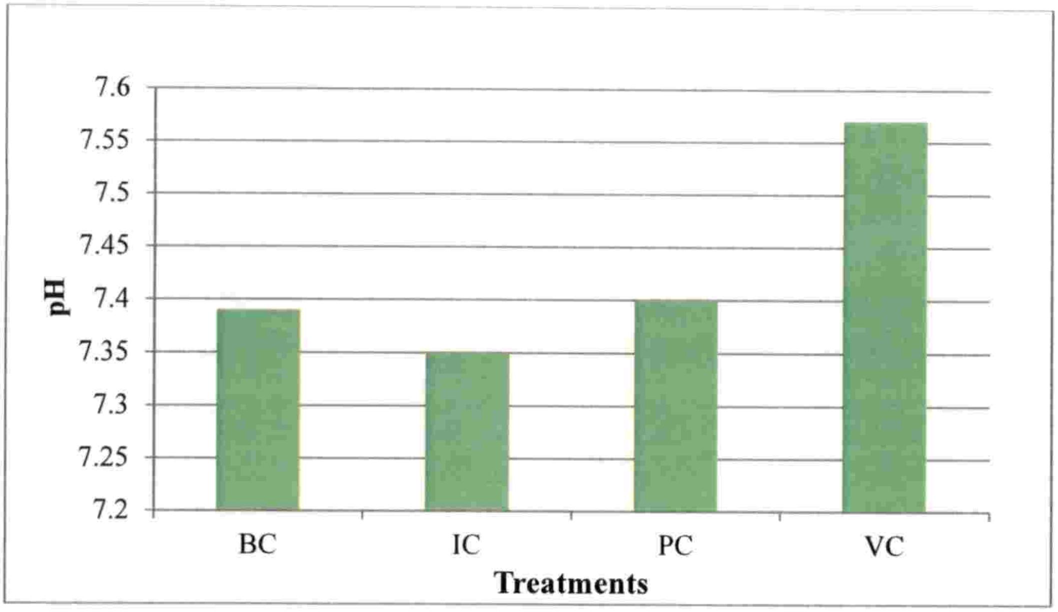

Fig. 12. Influence of composting methods on pH of composts

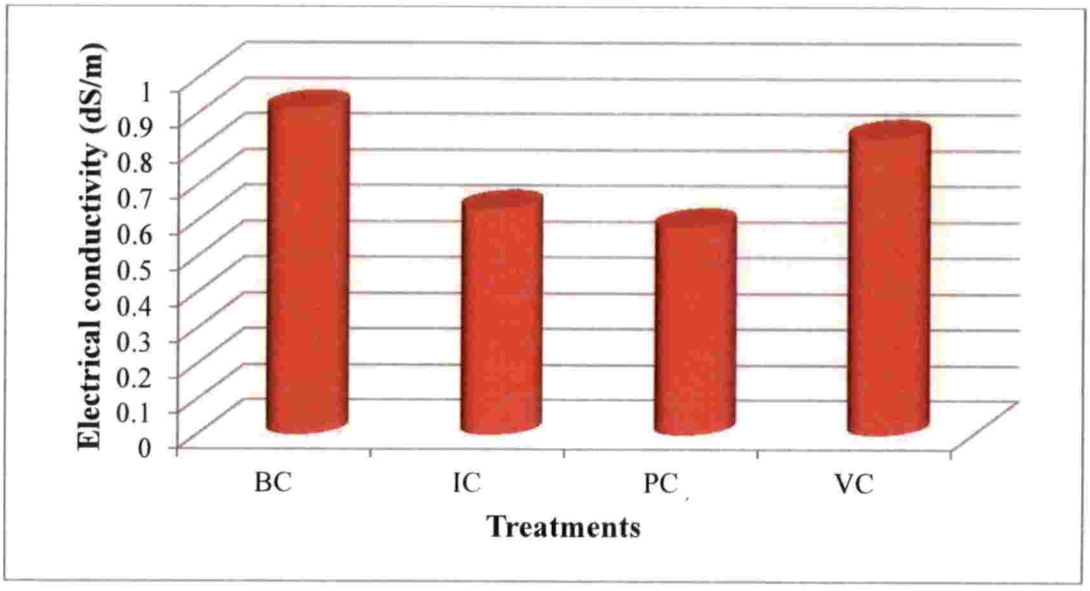

Fig. 13. Influence of composting methods on EC of composts

C: N ratio is an important index of compost maturity that decides the manurial value of compost (Golueke, 1977). It reflects organic matter decomposition and stabilization during composting. As composting proceeds the microorganisms use the substrate carbon as energy source and carbonaceous materials are converted to microbial biomass, CO_2, water and humus. C: N ratio of <20 is established as a maturity index for composts of all origins (Bernal *et al.*, 2009). In the present study all the treatments had C: N ratio below 20 (Fig.14) and the lowest C: N ratio was observed in vermicompost.

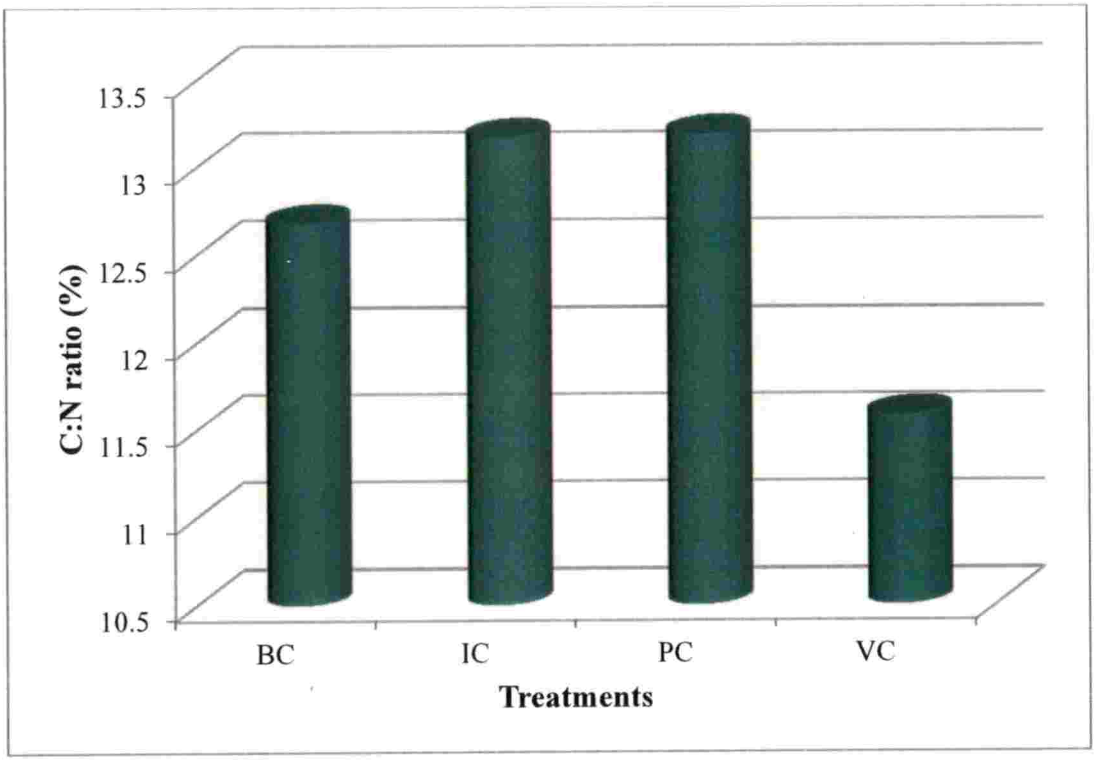

Fig. 14. Influence of composting methods on C: N ratio of composts

Composting methods showed significant variation in N content (Table 28 and Fig. 15. Nitrogen content was the highest in vermicompost (1.75%) after 6 MAC. Sannigrahi (2009) reported a N content of 1.36 per cent in vermicompost prepared from water hyacinth. Phosphorus content was the highest in phospho-compost at 3 MAC and 6 MAC. This might be due to addition of rock phosphate. Higher P content in phospho-compost compared to Bangalore and Indore compost was reported by Viveka and Grace (2009). Among the different methods of

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composting, vermicomposting had the highest K content at 6 MAC. Sasidharan *et al.* (2013) reported higher K content (1.6%) of *Eichhornia* vermicompost compared to *Eichhornia* compost and farmyard waste compost. According to Rao *et al.* (1996), increased K content in vermicompost compared to ordinary compost was probably due to physical decomposition of organic waste due to biological grinding during passage through the gut coupled with enzymatic activity in worm's gut.

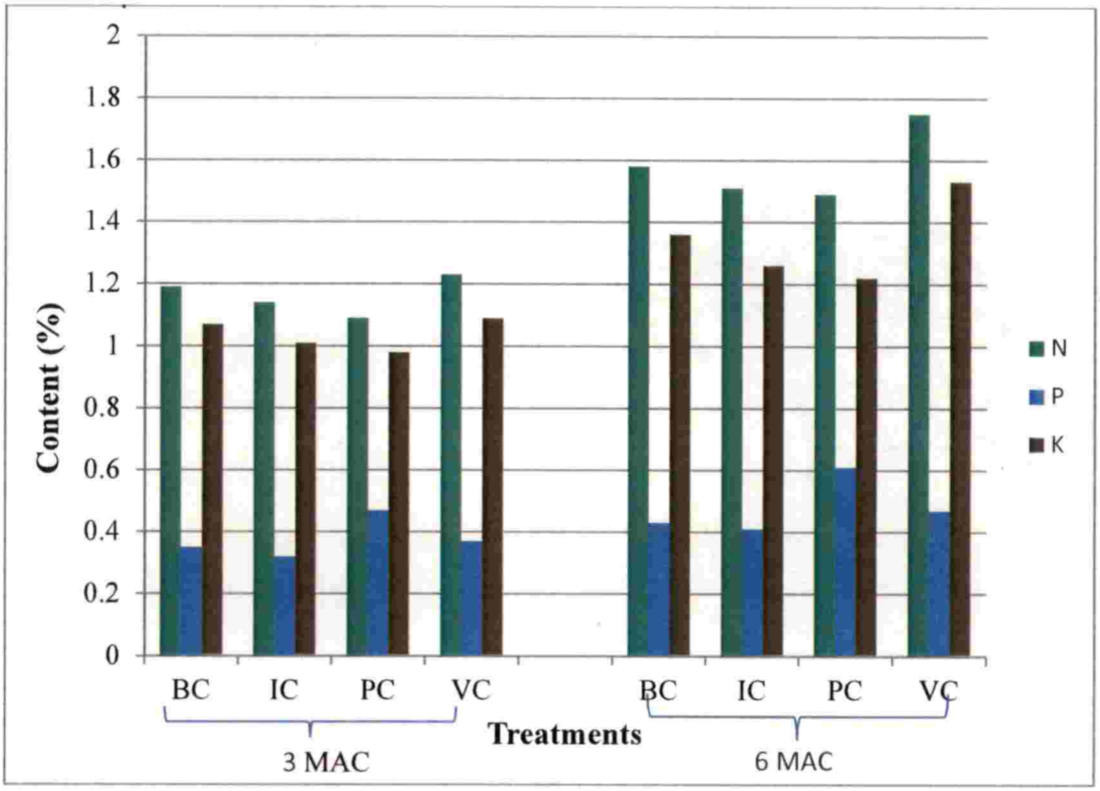

Fig. 15. Influence of composting methods on N, P, K content of compost

Different composting methods influenced Ca content of composts (Table 29 and Fig. 16). Calcium content was significantly higher in vermicompost at 3 MAC and 6 MAC. Padmavathiamma *et al.* (2008) reported that earthworms absorb Ca in excess from their food and transfer it to calciferous glands, which contain carbonic anhydrase enzyme, which catalyse the fixation of CO_2 as $CaCO_3$ concretions before being excreted through digestive tracts. Higher magnesium

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content was observed in vermicompost and Bangalore compost. Sulphur content was maximum in vermicompost.

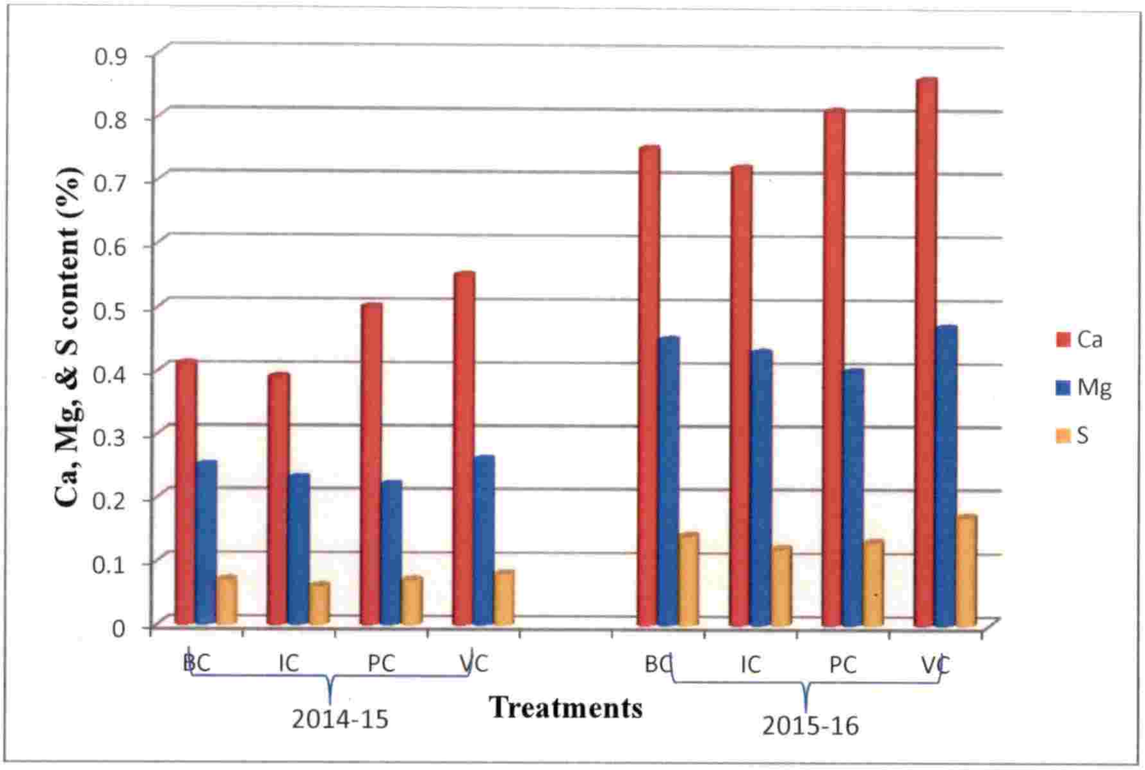

Fig. 16. Influence of composting methods on Ca, Mg, S content of compost

Among the micronutrients, Fe and Mn contents were not affected significantly by method of composting (Fig 17 and 18). High Fe content (12576.5 mg/kg) of vermicompost prepared from water hyacinth was reported by Sasidharan *et al.* (2013). Zn content at 6 MAC was the highest in Bangalore compost, which was identical to that of Indore compost (Fig.18). However, none of the composts contained Zn beyond the threshold limit of 1000 mg/kg (DOA, 2013). Cu content at 6 MAC was the highest in Bangalore compost (Fig 19.). Increase of Zn and Cu content from initial to final stage of composting in Bangalore composting was reported by Viveka and Grace (2009). Cu content in all the compost was within the safe limit of 300 mg/kg. Cobalt and nickel content was the highest in Bangalore compost. Heavy metals like Cr and Hg at 6 MAC were not significantly influenced by the treatments and none of the composts

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contained these heavy metals beyond the safe limit (50 mg/kg and 0.15 mg/kg respectively.)

In general, there was increase in concentration of most nutrients from 3 months to 6 months after composting. As Thilagavathi (1992) and Viveka and Grace (2009) suggested the increase in the concentration of these nutrients can be attributed to the mineralization of native carbon of compost materials accompanied by a reduction in the total volume of compost under typical conditions of decomposition.

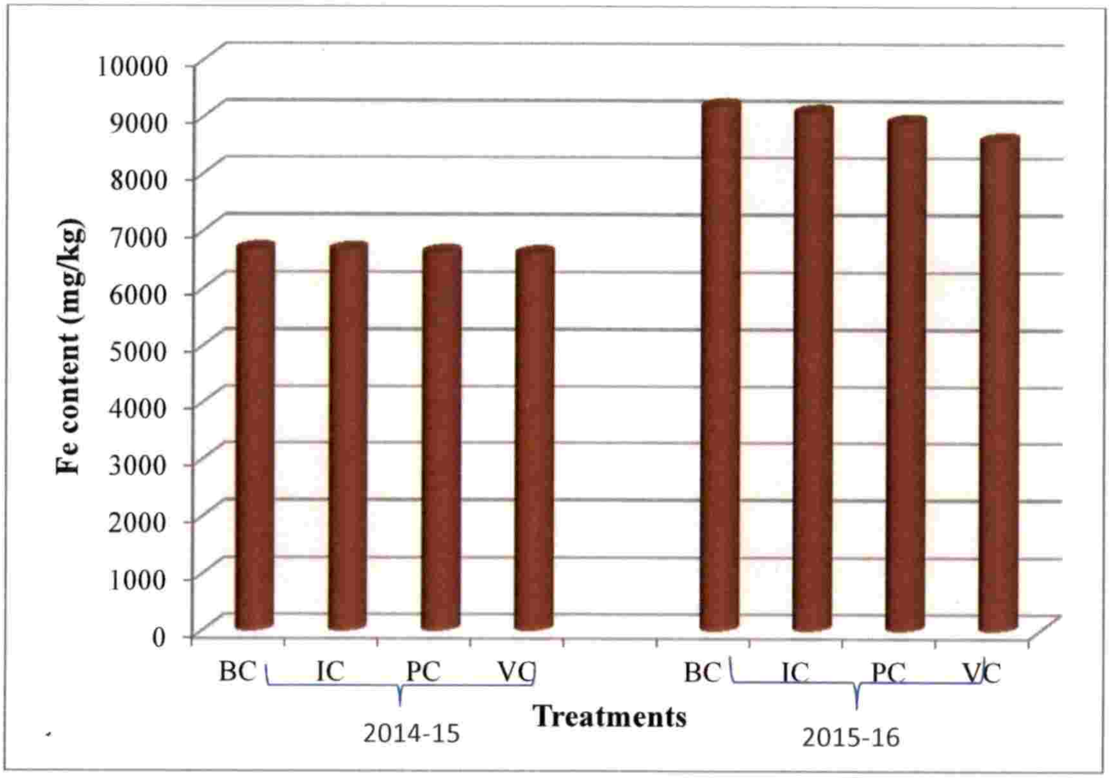

Fig. 17. Influence of composting methods on Fe content of compost

For the safe and quick disposal of aquatic weeds, composting is a good technique. As water hyacinth produce large quantities of biomass, it would be a viable technology for the production of good organic manure and the problem of disposal of these weeds can be solved largely.

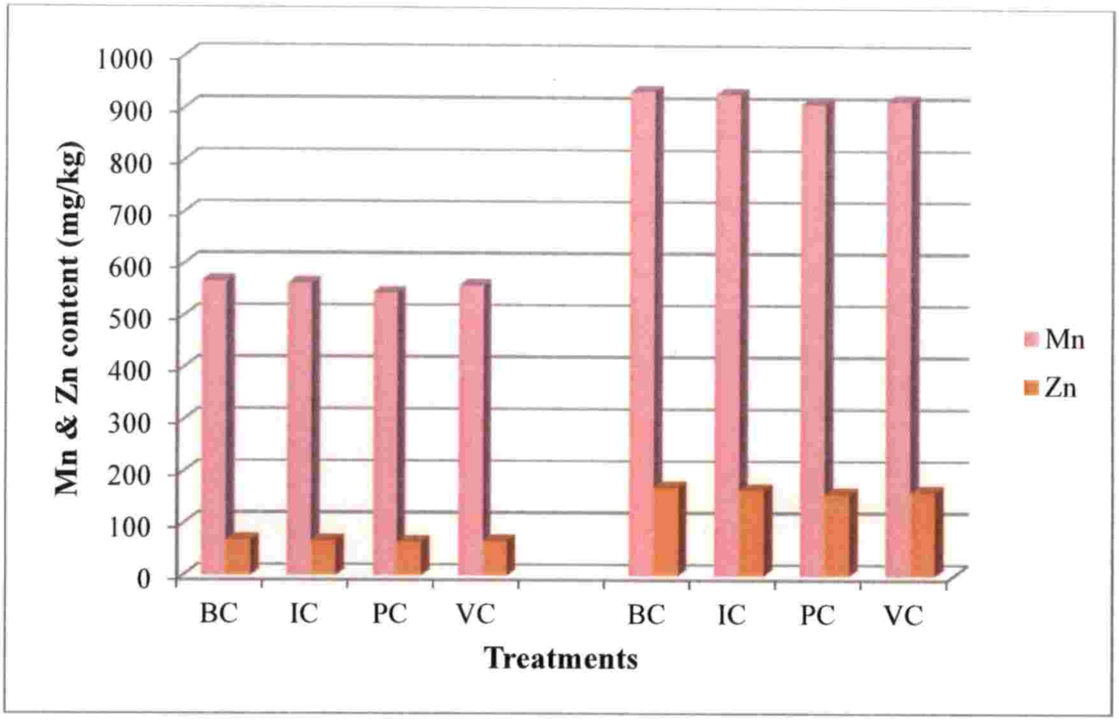

Fig. 18. Influence of composting methods on Mn and Zn content of compost

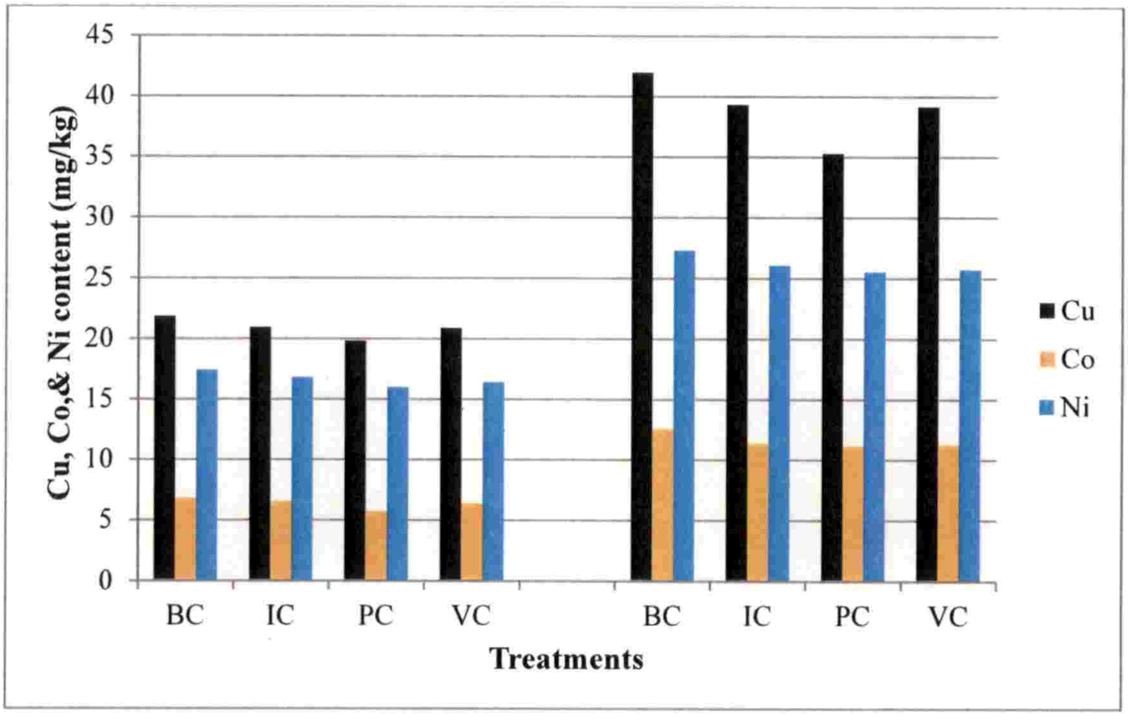

Fig. 19. Influence of composting methods on Cu, Co and Ni content of compost

5.4 Experiment IV: Evaluation of water hyacinth as a mulch in turmeric

The experiment entitled 'evaluation of water hyacinth as a mulch in turmeric' was conducted at the Department of Agronomy, College of Horticulture, Vellanikkara during May 2015 to January 2016 and May 2016 to January 2017. The results obtained from the experiment presented in the previous chapter are discussed below.

Turmeric is a herbaceous long duration spice crop grown as rainfed in Kerala. As its planting and early growth period coincides with the south-west monsoon season, weeds also flourish and compete with the crop for different resources limiting its productivity. The magnitude of yield loss varies from 30 to 75 per cent, depending upon the growth and persistence of weeds in the standing turmeric crop (Krishnamurthy and Ayyaswamy, 2000). Babu *et al.* (2015) reported that mulching in turmeric with green leaves is critical to improve germination of seed rhizomes. It also adds organic content to the soil and conserves moisture during the later part of the crop growth period.

5.4.1 Efficacy of various mulches for weed management

The results of the weed population and dry matter production are given in Table 40 and 41. It was found that, weed count was the highest in non-mulched plots at all stages of observation. At 45 DAP, during the first year, weed count in different mulched plots did not vary much, however, during the second year, jack leaves and coconut leaves were much better compared to water hyacinth mulch to control weeds. But weed dry matter production did not vary significantly among different mulches. At 90 DAP, during both years, jack leaves and coconut leaves mulched plots showed less weed count compared to plots mulched by water hyacinth. The same trend continued at 150 DAP also during the year 2014-15 but there was no significant difference among mulches at this stage in the subsequent year. Weed population and weed dry weight at all stages were higher in non-mulched plots (Fig 20).

Jack leaves and coconut leaves decomposed slowly compared to water hyacinth and smothered the weeds more efficiently. Water hyacinth, which is rich in nutrients, released more nutrients, which favoured weed growth. According to Liebman and Mohler (2001), coconut leaves as organic mulch act as a physical barrier because it decreases light penetration and soil temperature, resulting in inhibition of weed shoot emergence. Thankamani *et al.* (2016) compared different mulch materials such as paddy straw, coir pith compost, dried coconut leaves, *Glycosmis pentaphylla* leaves, *Lantana camara* leaves, cowpea plants and plastic mulch and reported that application of paddy straw @ 6 t/ha along with green leaf mulch @ 7.5 t/ha at 45 and 90 days after planting and application of dried coconut leaves @ 5.4t/ha at the time of planting showed higher weed control efficiency and higher economic returns from ginger crop. The beneficial effect of mulching in controlling weeds was due to delayed emergence of weeds and smothering effect on weed seedlings. Similar results were reported by Phihar et al. (1975) and Mahey *et al.* (1986).

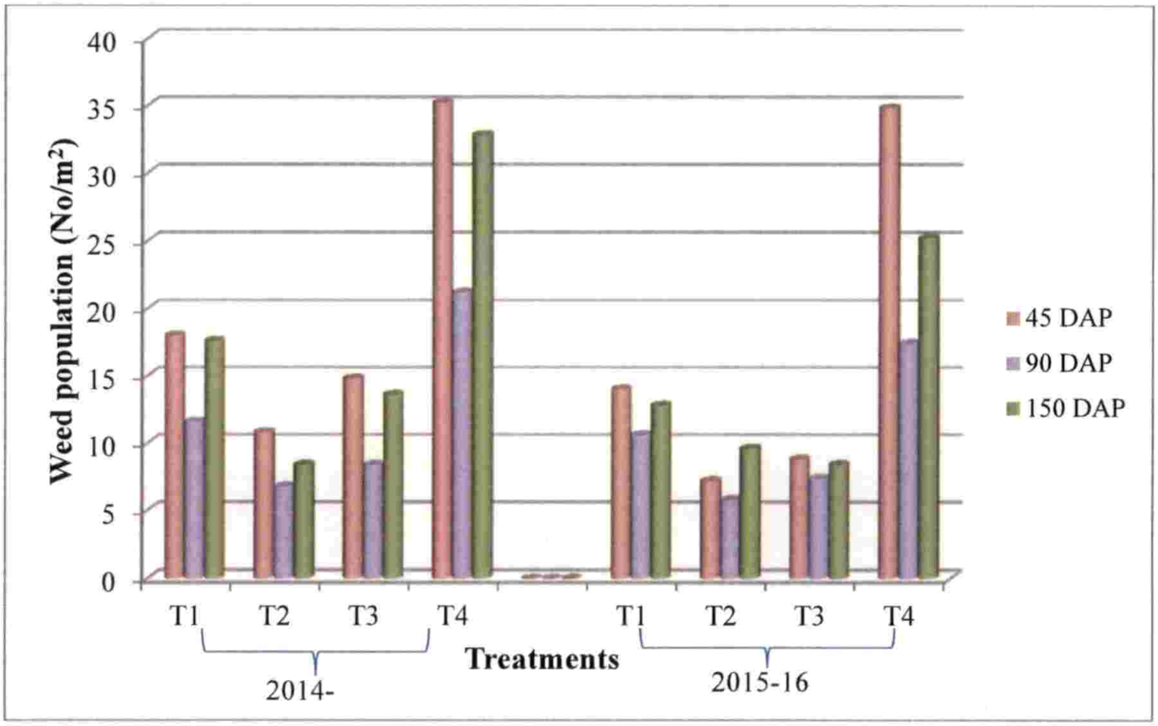

Fig 20. Effect of various mulches on weed population

5.4.2 Effect of mulches on plant growth

In turmeric, mulching is an important cultural practice, and mulching with green leaves immediately after planting and subsequently after 50 days is recommended (KAU, 2011). Initial growth of turmeric is slow, and if weeds are not controlled properly, it may cause considerable yield reduction. Mulching is, therefore, an essential operation in turmeric cultivation.

Different mulches significantly increased the plant height of turmeric throughout the crop growth period compared to no mulch control. In all treatments, plant height increased progressively with time reaching 123.98 cm to 144.64 cm during 2014-15 and 99.38 cm to 123.80 cm during 2015-16 by 210 days after planting (Table 33 and Fig. 21 and 22). Mulching with jack leaves produced taller plants throughout the crop period in both the years. However, there was no significant difference in plant height between mulching with water hyacinth, jack leaves, and coconut leaves. The lowest plant height at all stages was recorded in no mulch control. Mulching enhances plant height by influencing soil environment by maintaining favourable temperature, soil moisture status and increased nutrient availability. Mohanty *et al.* (1991), Gill *et al.* (1999), Swain *et al.* (2007), Manhas (2009), and Sidhu *et al.* (2016) reported favourable effects of mulching in enhancing plant height of turmeric.

Number of tillers per plant did not show any significant variation due to treatments at any stage of the crop in both years (Table 34). Turmeric, being a low tillering plant, compensates its tillers with enhanced number of leaves (Sanghamithre, 2014). Mulching, however, affected the number of leaves produced per clump of turmeric. All treatments were on par, except for no mulch control, which recorded consistently lower values (Table 35 and Fig.23 and 24). Significantly lower leaf number in turmeric in non-mulch control was reported earlier by Verma and Sarnaik (2006) and Manhas *et al.* (2011).

Leaf area index indicates the proportion of land area covered by the foliage and leaf area ratio denotes a measure of relative leafiness of the plant. The variation in leaf number and leaf area ratio was reflected in leaf area index, indicating better coverage of the crop canopy due to mulching. Leaf area index in both years was higher in plots mulched with jack leaves, which were on par with mulching by water hyacinth and mulching by coconut leaves (Table 35 and Fig. 25). Leaf area index values were lower in non-mulched plots in both years. Leaf area ratio was the highest in plants mulched with jack leaves and the lowest in non-mulched plants (Table 36 and Fig.26). Competition by the weeds for different factors might have reduced the vegetative growth of plants. Early and greater sprouting of rhizomes in the mulched plots gave dominance of the crop over weeds, and as a result, the crop utilized higher amount of nutrients from the soil and produced more leaf area compared to non- mulch plots. A similar result was reported in turmeric grown under rainfed condition in Orissa by Mohanty *et al.* (1991).

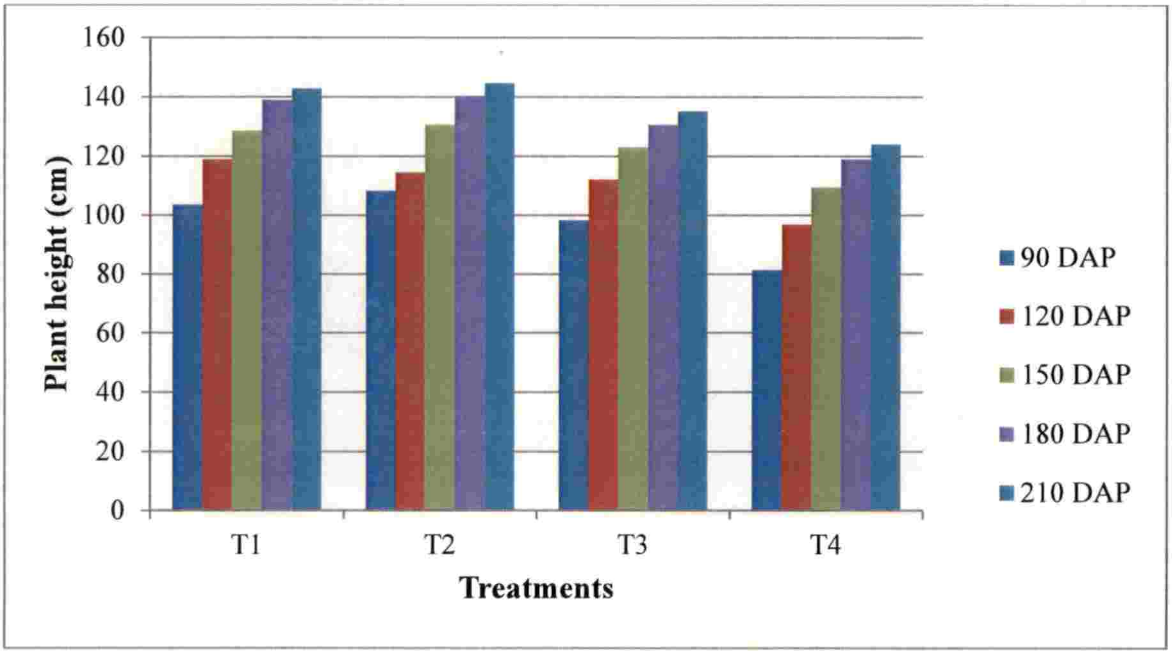

Fig. 21. Effect of various mulches on height of turmeric plants (2014-15)

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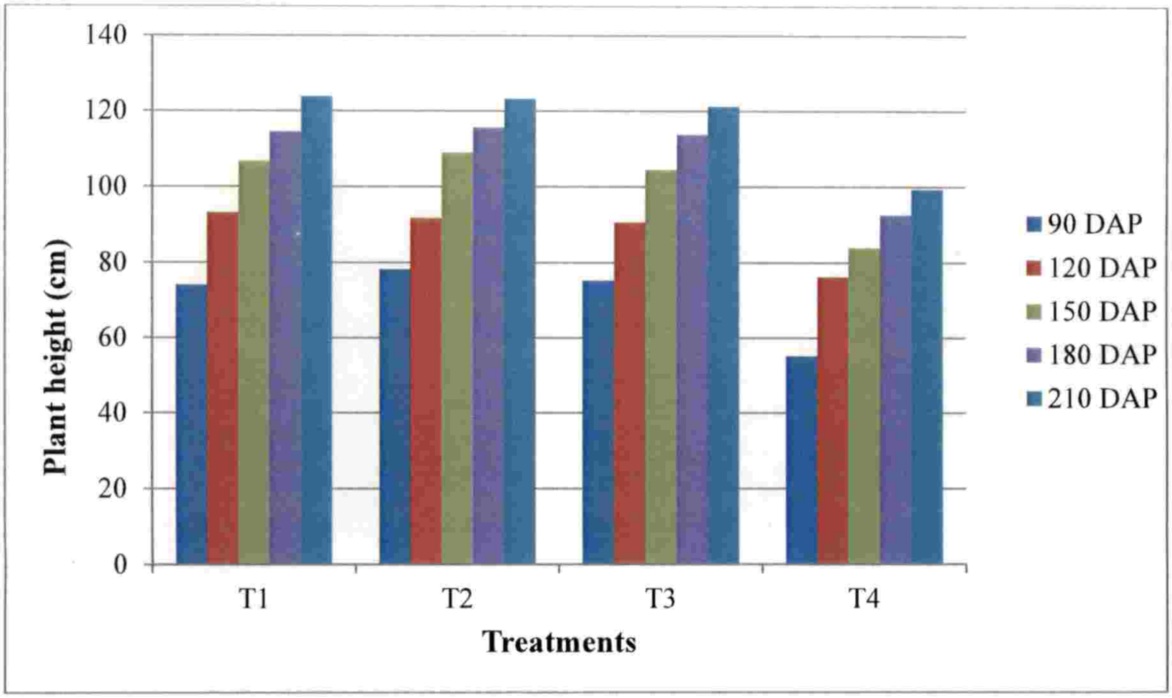

Fig. 22. Effect of various mulches on height of turmeric plants (2015-16)

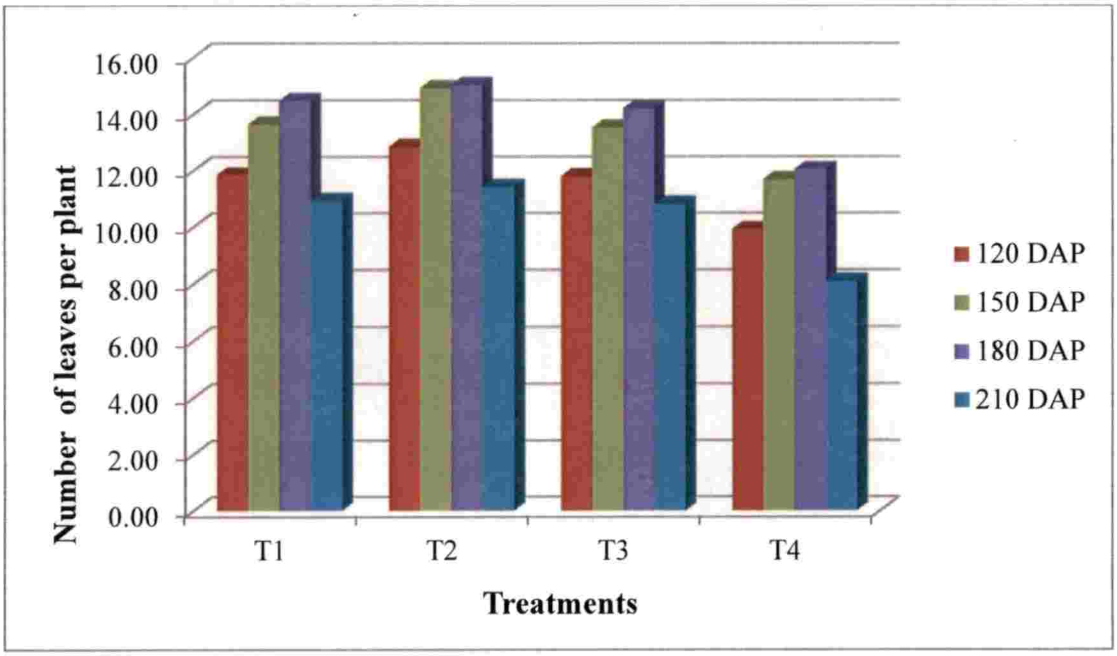

Fig. 23. Effect of various mulches on number of leaves per plant (2014-15)

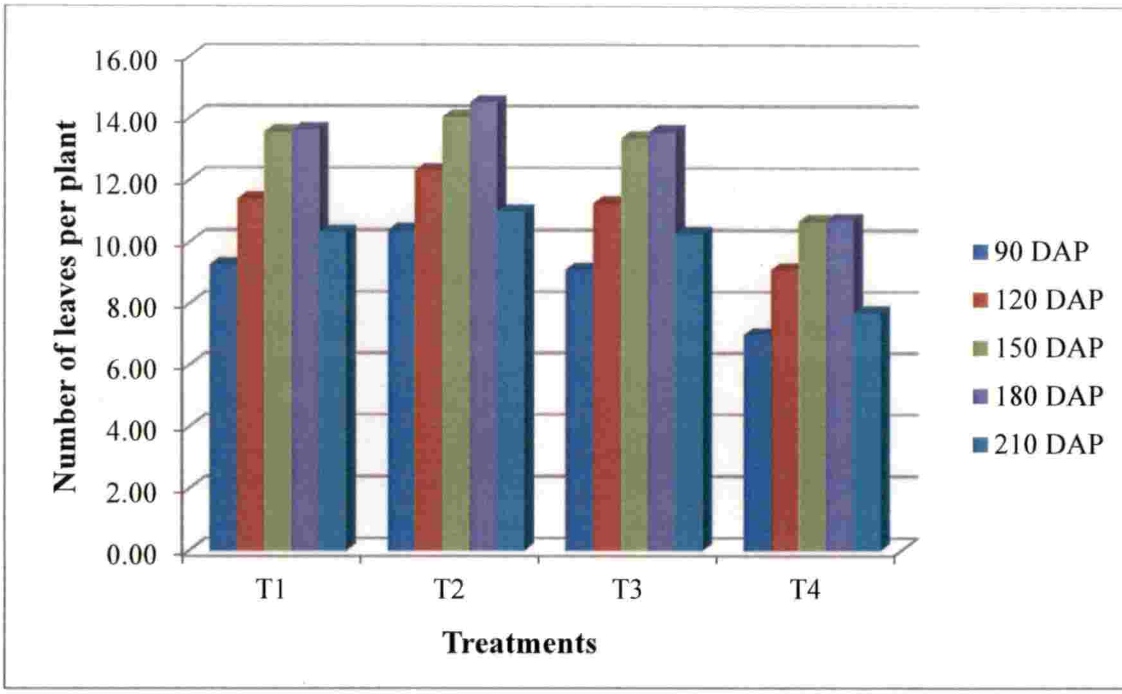

Fig. 24. Effect of various mulches on number of leaves per plant (2015-16)

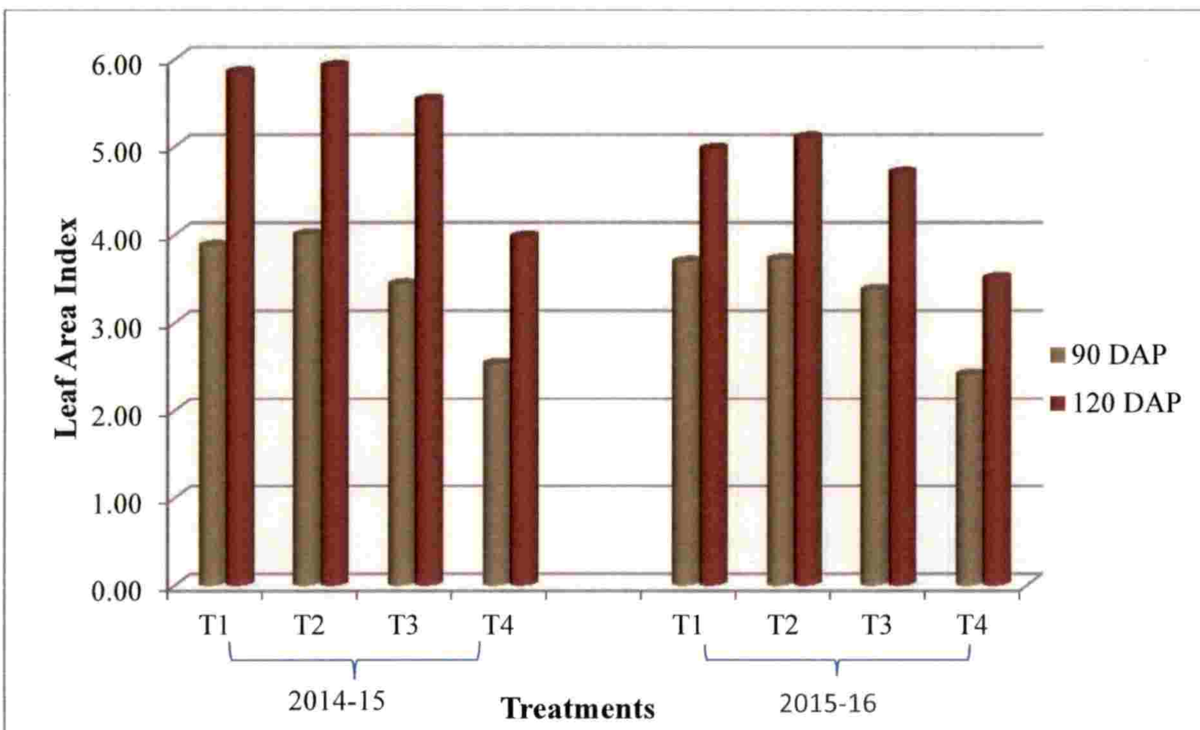

Fig. 25. Effect of various mulches on leaf area index of turmeric crop

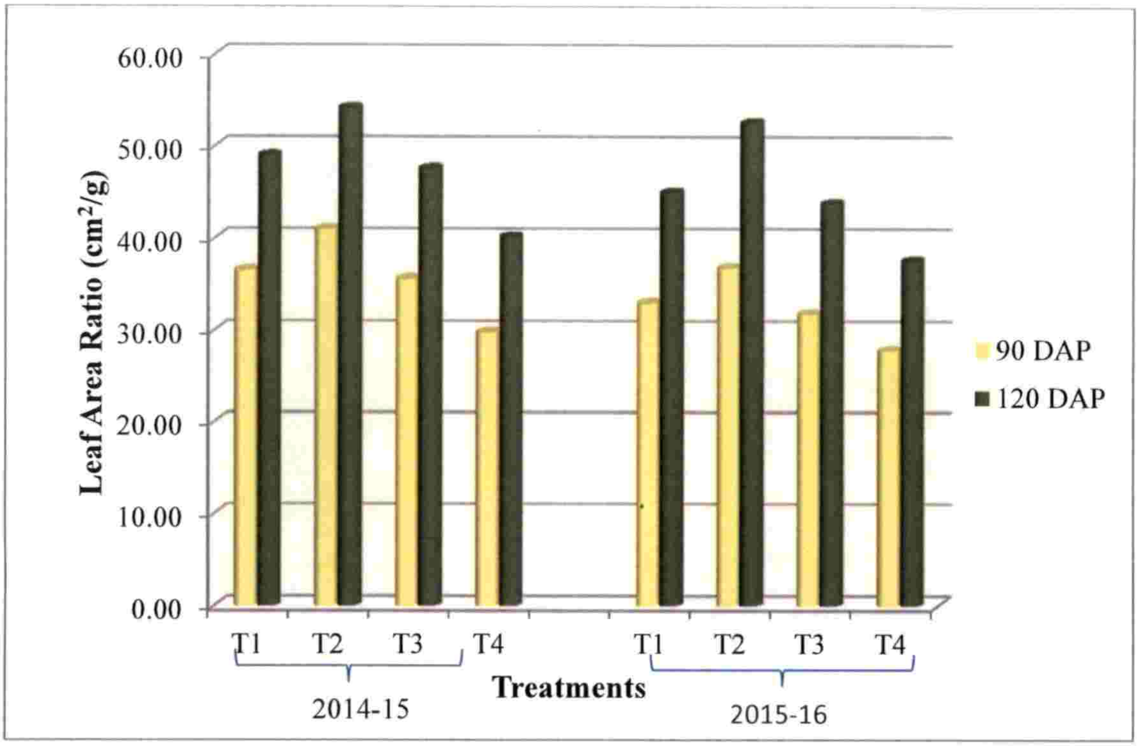

Fig. 26. Effect of various mulches on leaf area ratio of turmeric

5.4.3 Effect of various mulches on dry matter production and yield of turmeric

Higher leaf number, leaf area, and nutrient uptake by the crop resulted in higher dry matter production in mulched plants (Table 38 and Fig.27). Chakravarti *et al.* (2010) reported that mulching by water hyacinth improved dry matter production and yield of groundnut by altering the thermal environment through reduction of air and canopy temperatures.

Rhizome yield was significantly higher in mulched plots compared to non-mulched plots (Table 39 and Fig.28). In this case, water hyacinth maintained its lead on par with other mulched materials. Higher weed growth in non-mulched plots may have influenced crop growth and finally yield. According to Lakshmi and John (2015), cashew, jack, and teak leaves are relatively larger and also thicker, and hence, are likely to reduce soil temperature and conserve soil moisture better than the other tree leaves. They attributed higher yield obtained by mulching with cashew, jack, and teak leaves due to the favourable influence on soil moisture. In general, rhizome yield was less during the second year which can be attributed to lower rainfall during the crop growth period (appendix).

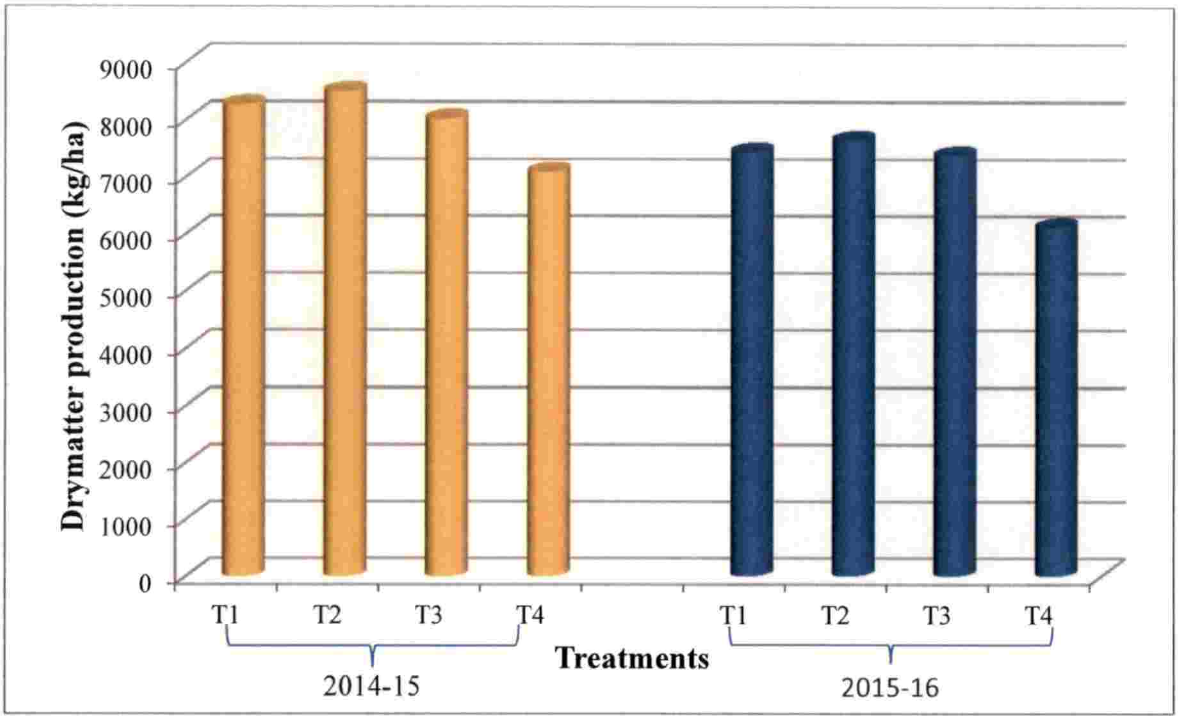

Fig.27. Effect of various mulches on dry matter production at harvest

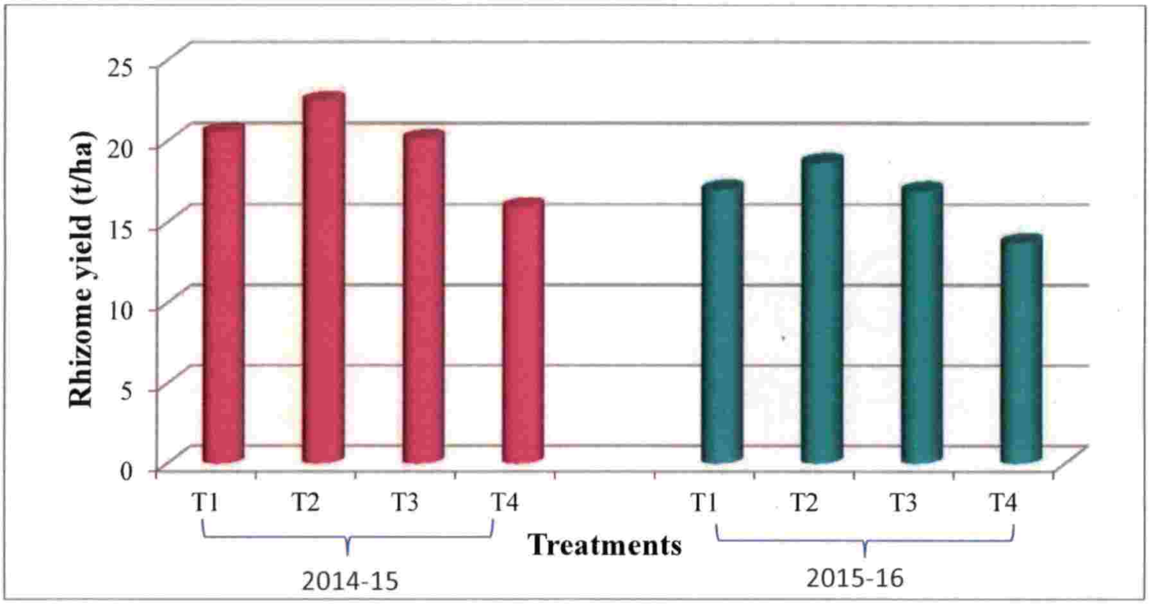

Fig.28. Effect of various mulches on rhizome yield

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5.4.4 Effect of mulches on nutrient uptake by the crop

The nutrient uptake by turmeric as influenced by mulching is presented in Table 42 and Fig.29 to 31. During both years of crop cultivation, N, P, and K uptake were the highest in the mulched plots compared to non-mulch control. There was no significant difference in N uptake among different mulches in both the years. This may be due to higher dry matter production under mulching. Less weed competition in mulched plots may have resulted in higher dry matter accumulation by the plant.

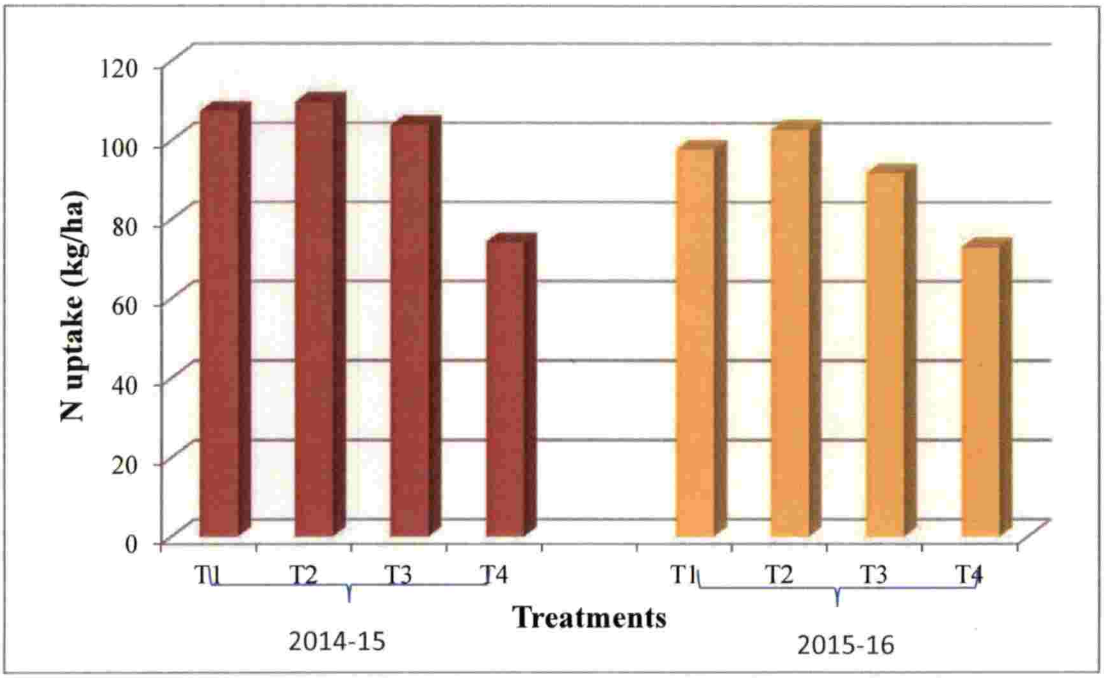

Fig.29.Effect of various mulches on N uptake by turmeric

5.4.5 Effect of mulching on nutrient status of the soil

The results of nutrient status of soil as influenced by mulching are presented in Table 44 and Fig.32 to 35. The organic C content in both years varied significantly among different treatments. Soil organic C significantly increased because of mulching. According to Sarora and Lal (2003), continuous addition of plant residues like water hyacinth increases soil organic carbon.

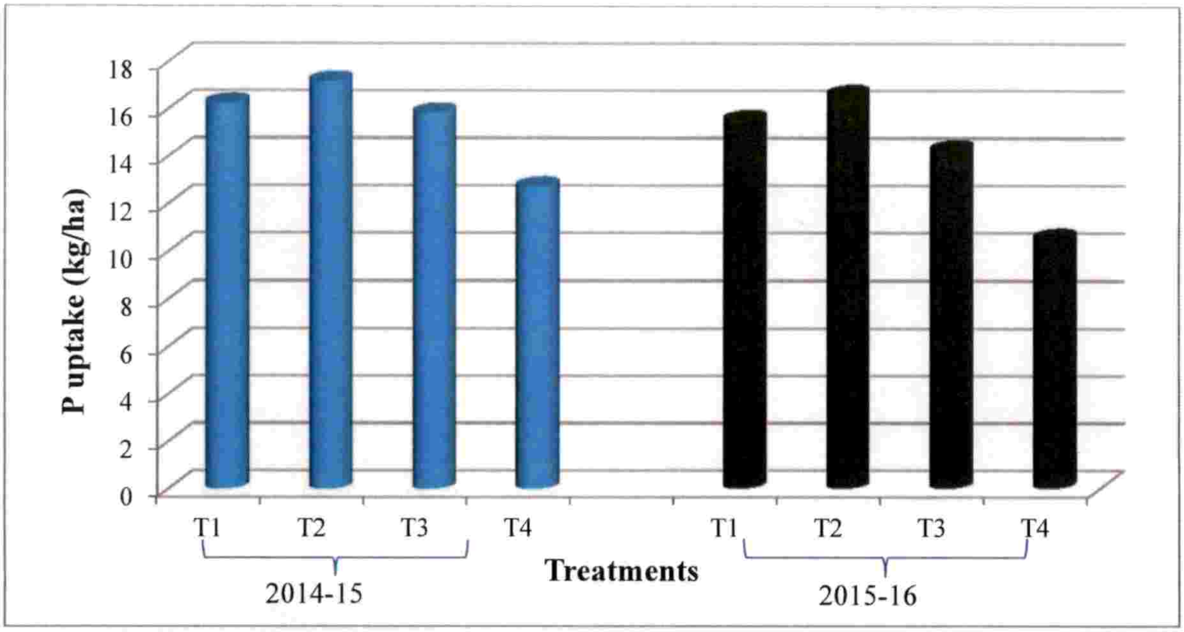

Fig.30.Effect of various mulches on P uptake by turmeric

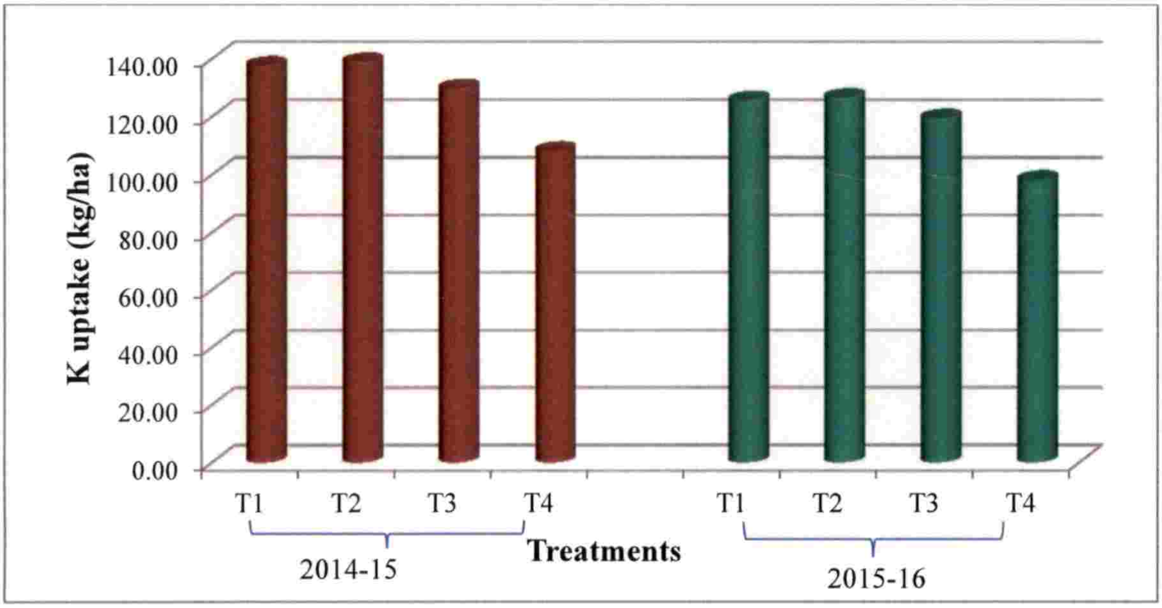

Fig.31. Effect of various mulches on K uptake by turmeric

In 2014-15, the highest available N content was observed in plots mulched with water hyacinth and the lowest N content was observed in non-mulched plots. In 2015-16, N content of the soil was the highest in plots mulched with water hyacinth which was on par with that of jack leaves. The lowest N content was

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observed in non-mulched plots. Increase in soil N content with water hyacinth mulching due to lower C/N ratio of green water hyacinth was reported earlier by Balasubramanian *et al*. (2013).

Available P content of soil did not differ significantly among the treatments in both years. Exchangeable K content of soil was the highest in plots mulched with water hyacinth in 2014-15 and the lowest K content was recorded in non-mulched plots. In 2015-16 also, K content of soil was the highest in plots mulched with water hyacinth. However, no significant difference was observed in K content of soils mulched with jack leaves or coconut leaves.

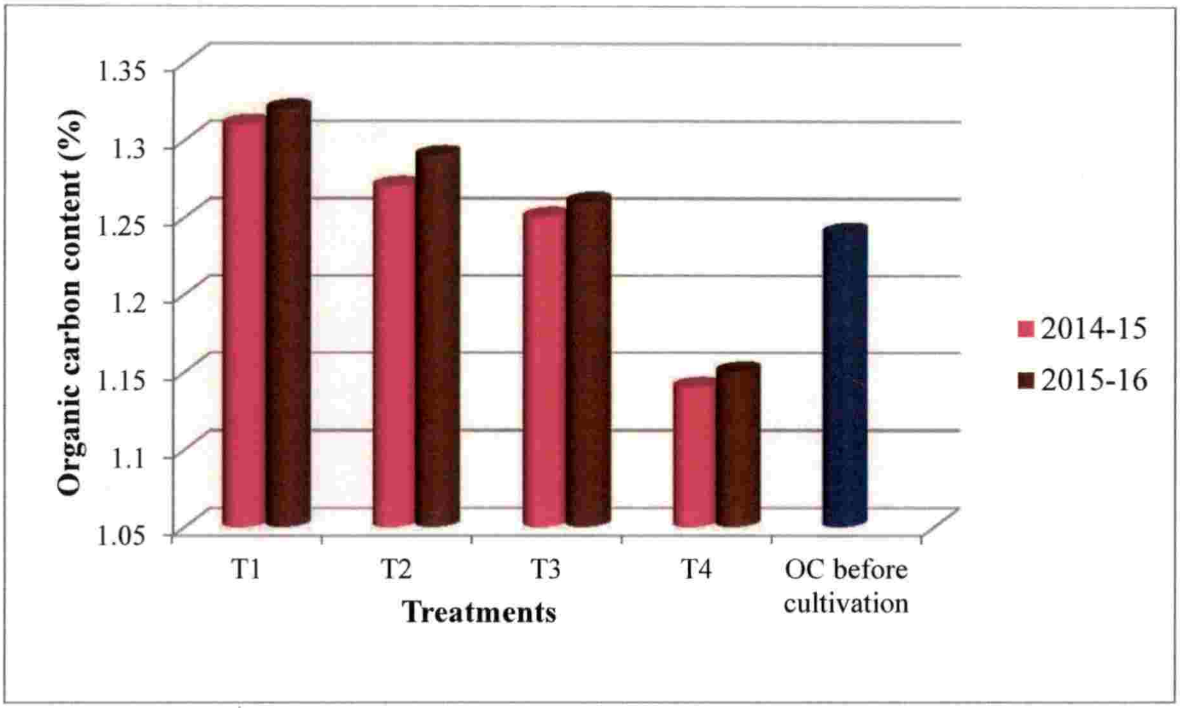

Fig.32. Effect of various mulches on organic carbon content of the soil

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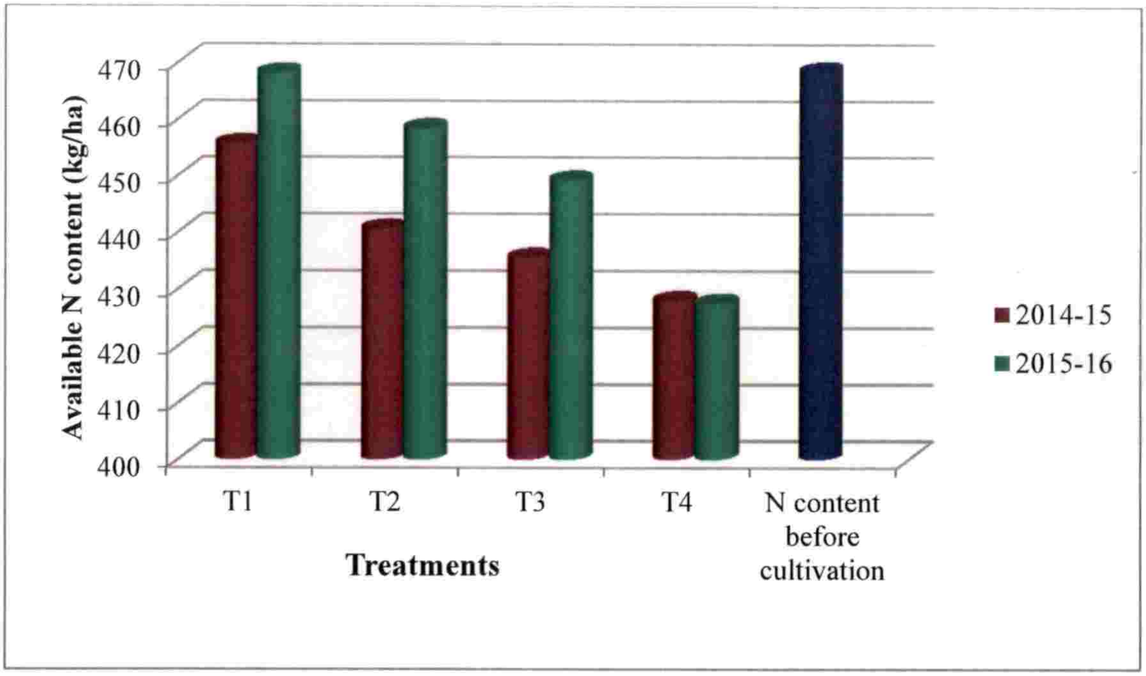

Fig. 33.Effect of various mulches on available N content of the soil

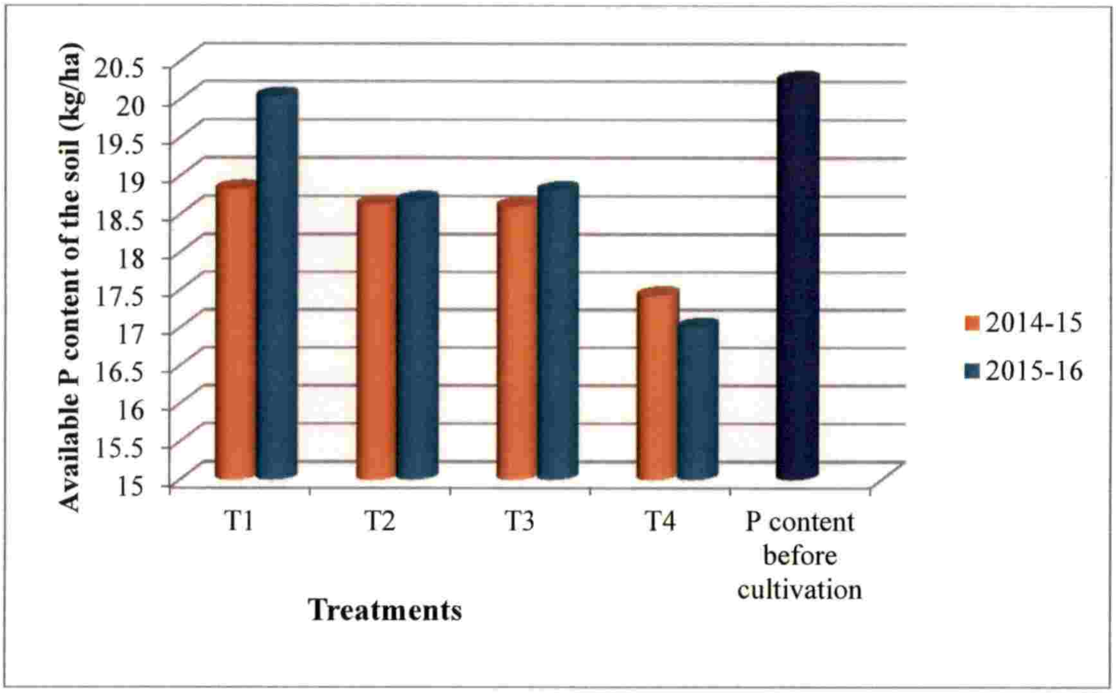

Fig. 34.Effect of various mulches on available P content of the soil

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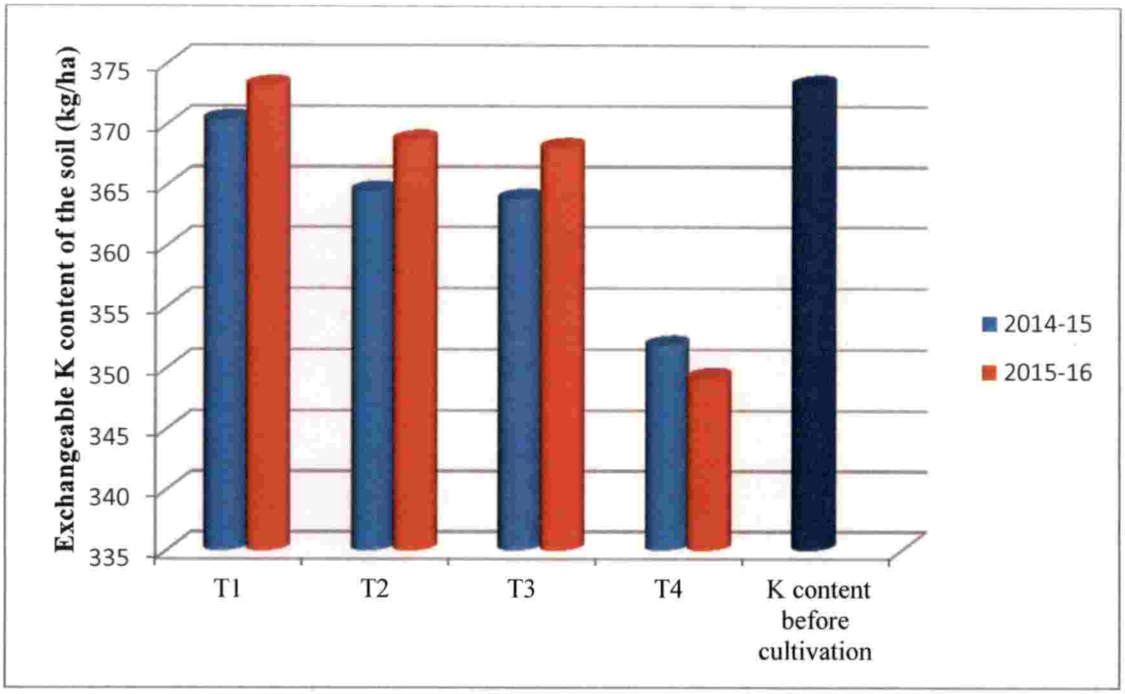

Fig.35.Effect of various mulches on available K content of the soil

From the results reported, it can be concluded that mulching turmeric crop with plant materials including water hyacinth significantly improves its growth and yield attributes. Water hyacinth can be recommended as a mulch in turmeric as it is comparable to common mulches like coconut leaves and jack leaves. Mulching reduces weed population and weed dry weight at different stages of crop. When applied as mulch, jack leaves, coconut leaves, and water hyacinth also enriches the soil nutrient status.

SUMMARY

6. SUMMARY

A study titled 'Management and utilization of water hyacinth (*Eichhornia crassipes* (Mart.) Solms)' was carried out at the Department of Agronomy, College of Horticulture, Vellanikkara during 2013-2016 with the objectives of studying the phytoremediation capacity of water hyacinth and managing it by ecofriendly means such as silage making, composting, and mulching. In order to achieve the objectives, four separate experiments were undertaken, the results of which are summarized below.

Phytoextraction capacity of water hyacinth

A purposive sampling was carried out to collect water and water hyacinth plant samples from 20 sites in central Kerala. Water and plant samples were analyzed for various macro and micronutrients as well as heavy metals. Salient findings were:

- The pH of water samples ranged from 6.11 to 7.82. The highest pH was observed from Irumbanam and the lowest was observed from Kumarakam.
- The EC of water samples ranged from 0.09 dS/m to 24.55 dS/m. The highest EC was observed in water samples collected from Eloor and the lowest from Karivannur.
- The ammoniacal N content of water samples ranged from 1.4 mg/L to 8.4 mg/L and the nitrate N content ranged from 1.4 mg/L to 22.4 mg/L.
- The N content of water hyacinth samples varied from 5833.33 mg/L to 26250 mg/L. Water hyacinth samples collected from Palakkad district had the highest N content and the N content of samples from Ernakulam and Kottayam districts was on par with that of Palakkad.
- The total P content of water samples ranged from 0.063 mg/L to 0.837 mg/L. Water samples from Ernakulam district had significantly higher P content which was on par with water samples collected from Palakkad district.

- The P content in the water hyacinth samples ranged from 657.90 mg/L to 7631.58 mg/L. Phosphorus content in water hyacinth samples collected from Ernakulam and Palakkad was significantly higher and the lowest P content was observed in plant samples collected from Thrissur district
- The total K content of water samples ranged from 1.15 mg/L to 63.55 mg/L. The highest total K was recorded from water samples of Ernakulam district, whereas the lowest total potassium was observed in water samples collected from Palakkad and Thrissur.
- The K content of plant samples ranged from 13733.33 mg/kg to 44000 mg/kg. The K content of water hyacinth samples collected from Palakkad district was significantly the highest, whereas the plant samples from Kottayam district had the lowest K content.
- The Ca content of water samples ranged from 4.00 mg/L to 247.67 mg/L. Significantly higher Ca content was observed from water samples of Kottayam district, whereas those from Thrissur district had the lowest content of Ca.
- The Ca content of plant samples ranged from 8368.33 mg/kg to 15739.17 mg/kg.
- The Mg content of water samples ranged from 1.10 to 371.67 mg/L. Water samples from Ernakulam district had the highest magnesium content, whereas those from Thrissur had the lowest Mg content.
- The Mg content of the plant samples ranged from 4242.00 mg/kg - 13239.17 mg/kg. Water hyacinth samples from Kottayam district had the highest Mg content whereas those from Thrissur had the lowest Mg.
- The S content of water ranged from 0.33 mg/L to 114.01 mg/L. Water samples collected from Ernakulam district contained more S than those from Thrissur district had less S content.
- The S content of water hyacinth samples ranged from 814.52 mg/kg to 3717.74 mg/kg. Water hyacinth samples collected from Kottayam showed the highest sulphur content whereas, those from Ernakulam district had the lowest S content.

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- The Fe content of water samples ranged from 0.64 mg/L to 5.42 mg/L. The highest Fe content was observed in water samples of Thrissur district, while those from Palakkad had the lowest Fe content.
- The water hyacinth samples contained Fe in the range of 1344.25 mg/kg to 23885.83 mg/kg. Plant samples from Kottayam district had significantly higher Fe content and the lowest was from Ernakulam district.
- The Mn content of water samples ranged from 0.134 mg/L to 0.450 mg/L. Water samples from Palakkad district had the highest Mn content, whereas those from Kottayam and Ernakulam had the lowest Mn content.
- The Mn content of water hyacinth samples ranged from 374.17 mg/kg to 5816.67 mg/kg. Water hyacinth samples of Palakkad district had the highest Mn content and the lowest was recorded from Ernakulam district.
- The Zn content of water samples ranged from nil to 1.43 mg/L. Zinc content was higher in samples collected from Kottayam and Thrissur and no trace of the same was observed in Ernakulam district.
- The Zn content of plant samples ranged from 9.75 mg/kg to 385.50 mg/kg. Water hyacinth samples collected from Ernakulam district had the highest Zn content and the lowest was observed from Thrissur.
- The water samples collected contained Cu in the range of 0.063 mg/L to 0.444 mg/L. Among the districts, copper content of water samples was the highest from Kottayam district and the least content was observed from Palakkad district. Water samples collected from Kannannur in Palakkad district had the highest Cu content and the lowest was observed from Mannathumkavu and Kalpathy.
- Copper content of water hyacinth samples ranged from 3.63 mg/kg to 67.63 mg/kg. Copper content of plant samples collected from Palakkad district was significantly higher and those from Thrissur had the lowest Cu content.
- Cobalt content of water samples ranged from 0 to 0.006 mg/L. There was no significant difference in Co concentration of water samples collected

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from the four districts. No traces of Co could be observed from water samples of Palakkad district.

- Water hyacinth plants contained Co in the range of 0 to 17.63 mg/kg. Cobalt content of water hyacinth samples was significantly higher in Palakkad district and lower in Ernakulam district.
- The water samples contained Ni in the range of 0.010-0.228 mg/L. Nickel content was more in water samples collected from Ernakulam and Thrissur district, whereas it was less in samples collected from Palakkad.
- The Ni content of water hyacinth samples ranged from 3.50 mg/kg to 23.25 mg/kg. Water hyacinth samples from Palakkad district had significantly higher Ni content and the lowest Ni content was observed from Ernakulam district.
- The Al content of water samples ranged from 1.59 mg/L to 8.72 mg/L. The Al content of plant samples ranged from 1573.92 mg/kg to 41029.17 mg/kg.
- The As content was below the detectable limit in water samples, whereas in plant samples arsenic content ranged between 0 and 0.153 mg/L.
- The Pb was not present in any of the water samples, whereas in plant samples Pb content ranged between 0.008 mg/L and 0.430 mg/L.
- Cadmium was not detected in any of the water or plant samples.
- The Cr content of water samples ranged from 0.006 mg/L to 0.347 mg/L. Water samples of Kottayam district had significantly higher Cr content.
- The Cr content of plant samples ranged from 9.57 mg/kg - 91.33 mg/kg. Water hyacinth samples from Palakkad had the highest Cr content, whereas the lowest Cr content was recorded from Ernakulam district.
- The mercury content of water samples ranged between 0.002 mg/L and 0.008 mg/L. There was no significant difference in Hg content of water samples from the four districts. The mercury content in water hyacinth plant samples ranged from 0.484 mg/L to 0.540 mg/L.
- The order of accumulation of heavy metals in the water hyacinth samples was Fe> Al> Mn> Zn> Cr> Ni> Co> Hg> Pb> As.

Utilization of water hyacinth as livestock feed by silage making

The experiment was done adopting completely randomized design (CRD) with 12 treatment combinations and 3 replications. The treatments included combination of wilted and fresh water hyacinth with or without rice straw or guinea grass and using any of the additives such as molasses, cassava flour and rice bran. In all the treatments, the silage was ready for use after 45 days. Salient results were:

- Rice bran addition increased the pH of water hyacinth silage. Wilted water hyacinth + rice straw (10%) + rice bran (10%) had the highest pH (8.30).
- Cassava flour addition decreased the pH of the silage.
- The lowest pH (4.19) was noticed in the treatment wilted water hyacinth + cassava flour (10%).
- The colour of silages varied based on the ingredients used, mostly brownish green or grey.
- The odour of the treatments such as wilted water hyacinth+ cassava powder (10%), fresh water hyacinth + rice straw (10%) + molasses (5%), and wilted water hyacinth+ guinea grass (10%) + cassava flour (10%) were rated as 'very good'.
- Rice bran added silages in general had bad odour.
- Among the additives used, rice bran enhanced the crude protein significantly.
- As cassava contains low protein, those treatments with cassava powder showed lower crude protein content.
- The highest crude protein content was observed in the treatment wilted water hyacinth + guinea grass (10%) + rice bran (10%)
- The crude fibre content was the highest in silages added with adsorbents such as rice straw and guinea grass. Rice bran addition also enhanced the crude fibre content.
- The highest crude fibre content of 25.35 per cent was recorded in the treatment *viz.*, fresh water hyacinth + rice straw (10%) + rice bran (10%)

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which was on par with wilted water hyacinth + rice straw (10%) + rice bran (10%) with a crude fibre content of 24.62 per cent.

- Rice bran addition increased the crude fat content.Wilted water hyacinth+ rice bran (10%) had the highest crude fat content (1.81%).
- As cassava tubers are rich in carbohydrate content, it gave significantly high nitrogen free extract. Maximum NFE of 58.94% was noted in the treatment wilted water hyacinth+ cassava flour (10%).
- The highest ash content was noted in the treatment wilted water hyacinth + rice straw (10%) + rice bran (10%).
- The maximum silica content was found in the treatment wilted water hyacinth + rice bran (10%).
- Heavy metals like As and Cd were below detectable limit in all the treatments.
- Although heavy metals like Pb, Cr and Hg were detected in the silage samples, they were within the permissible limits set by the EU directive on animal feed.
- The silage combinations with low pH values preserved well and had high palatability values.
- Rice bran addition reduced the palatability although its nutritional content was high. Cassava powder added silages had high palatability.

Conversion of water hyacinth (*Eichhornia crassipes*) into nutrient rich compost

The experiment consisted of four composting methods *viz*., Bangalore compost, Indore compost, phospho-compost, and vermicompost and was conducted in CRD with 4 replications. Salient results were:

- All the composts had neutral to slightly alkaline pH. Vermicompost had significantly high pH (7.57) compared to other composts.
- Bangalore compost had the highest EC (0.91 dS/m), which was on par with vermicompost (0.83 dS/m).
- Total salt concentration was the highest in Bangalore compost, which was on par with that of vermicompost.

- The maximum porosity was observed in vermicompost (61.18%) followed by Indore compost (58.31%).
- The lowest C: N ratio was recorded with vermicompost (11.58).
- Nitrogen content at 3 months after composting (MAC) was the highest in vermicompst, which was on par with that of Bangalore compost. The highest nitrogen content (1.75%) at 6 MAC was observed in vermicompost.
- Phosphorus content was the highest in phospho-compost at 3MAC and 6 MAC.
- There was no significant difference in K content of different composts. Among different composts, K content was the highest in vermicompost (1.53%) followed by Bangalore compost (1.36%) at 6 MAC.
- Calcium content was the highest in vermicompost at 3 MAC and 6 MAC. Other composting methods showed no variation in Ca content.
- Magnesium content at 3 MAC and 6 MAC was the highest in vermicompost, which was on par with that of Bangalore compost.
- The highest S content was observed in vermicompost at 3 MAC and 6 MAC.
- The different composting methods showed no significant difference in Fe and Mn content.
- Micro nutrients such as Zn, Cu, Co, and Ni were the highest in Bangalore composting.
- Heavy metals such as As, Cd and Pb were not detected in any of the composts.
- Chromium content was the highest in Bangalore compost at 3 MAC. There was no significant difference in Cr content among different treatments at 6 MAC.
- There were no significant differences in Hg content among the different composts.

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Evaluation of water hyacinth as a mulch in turmeric

Field experiments were conducted during May 2014 to January 2015 and May 2015 to January 2016 at the Agronomy Farm, College of Horticulture, so as to study the mulch value of water hyacinth in turmeric. The experiment was laid out in Randomized Block Design (RBD) with 4 treatments and 5 replications. Important results were:

- In all the treatments, plant height increased progressively with time, reaching 123.98 cm to 144.64 cm during 2014-15 and 99.38 cm to 123.80 cm during 2015-16 by 210 days after planting. However, there was no significant difference in plant height among mulching materials (water hyacinth, jack leaves, and coconut leaves).
- Number of tillers per plant did not show any significant variation due to treatment at any stage of the crop in both years.
- The lowest number of leaves at all stages in both years was recorded in non-mulched plots and mulching improved the number of leaves per plant in both years.
- The leaf area index values in both years were higher in plots mulched with jack leaves, which were on par with mulching by water hyacinth and mulching by coconut leaves. Leaf area index values were lower in non-mulched plots in both years.
- Leaf area ratio (LAR) at 90 DAP in both years was the highest in plots mulched with jack leaves. The lowest LAR was recorded in non-mulched plots.
- Total dry matter production of turmeric at all the stages was significantly higher in plots mulched with jack leaves, water hyacinth, and coconut leaves than non-mulched plots.
- In 2014-2015, rhizome yield was higher in plots mulched with jack leaves (22.45 t/ha), which was on par with mulching by water hyacinth (20.52 t/ha) and mulching by coconut leaves (20.12 t/ha). The lowest rhizome yield was noted in non-mulched plots (15.91 t/ha).

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- In 2015-2016 also, no significant difference in rhizome yield was observed among the different mulches, but the yield was lower in non-mulched plots (13.71 t/ha).
- Nitrogen uptake by the crop was higher in plots mulched with jack leaves (109.56 kg/ha), which was on par with mulching by water hyacinth or coconut leaves in both the years.
- In both the years, P uptake by the crop was higher in plots mulched with jack leaves (17.18 kg/ha), which was on par with mulching by water hyacinth or coconut leaves. Phosphorus uptake was lower in non-mulched plots.
- In both years, K uptake was the lowest in non-mulched plots (108.20 and 98.20 kg/ha). There were no significant differences in K uptake among different mulched plots.
- The weed count and the weed dry weight at all the stages were higher in non-mulched plots.
- In the case of number of weeds germinated, jack leaves and coconut leaves had a slight edge over water hyacinth probably because of their slow decaying rate.
- Soil organic C was significantly increased because of mulching.
- In 2014-15, the highest available N content was observed in plots mulched with water hyacinth and the lowest N content was observed in non-mulched plots. In 2015-16, N content of the soil was the highest in plots mulched with water hyacinth, which was on par with that of jack leaves. The lowest N content was observed in non-mulched plots.
- Available P content of soil did not differ significantly among the treatments in both years.
- Exchangeable K content of soil was the highest in plots mulched with water hyacinth in both the years and the lowest potassium content was recorded in non-mulched plots.

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Conclusion

Evaluation of the phytoextraction capacity of water hyacinth indicated that the level of nutrients such as N, P, Mg, and Ni in water bodies could be brought to minimum level through water hyacinth. The accumulation of heavy metals in water hyacinth was in the decreasing order of Fe, Al, Mn, Zn, Cr, Ni, Co, Hg, Pb, and As. Water hyacinth can be utilized as palatable silage with additives such as molasses and cassava flour. Wilted water hyacinth with molasses (5%) or cassava flour (10%) and wilted water hyacinth with cassava flour (10%) plus rice straw (10%) or guinea grass (10%) are the best options for utilizing water hyacinth for animal feeding. All the composting methods studied (Bangalore composting, Indore composting, phosphocomposting, and vermicomposting) were effective for the disposal of harvested water hyacinth and production of good organic manure. Among the composting methods, the lowest C: N ratio was with vermicompost (11.58) followed by Bangalore compost (12.68). As a mulch material in turmeric, water hyacinth performed equally well with that of jack and coconut leaves.

Future line of work

- As most aquatic weeds accumulate toxic substances, chances of bio-magnification in water hyacinth have to be monitored on a regular basis.
- Financial viability of the recommendations must be studied in actual field situations before giving them as recommendations.
- Ensiling with additives such as urea and sodium chloride shall also be explored
- Monitoring growth of water hyacinth in stagnant and flowing water bodies
- Monitoing growth and phytoextraction capacity in various seasons
- Influence of water hyacinth mulch on soil temperature
- Survey of water bodies for studying the extent of mercury pollution

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APPENDIX

Appendix

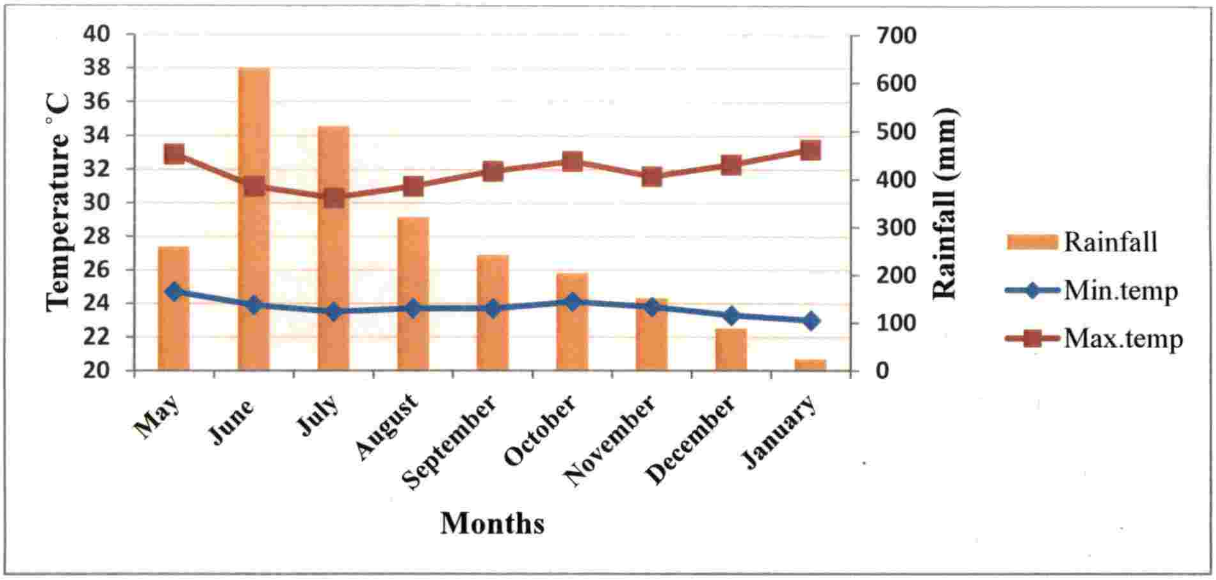

Fig. 36. Weather data during 2014-15

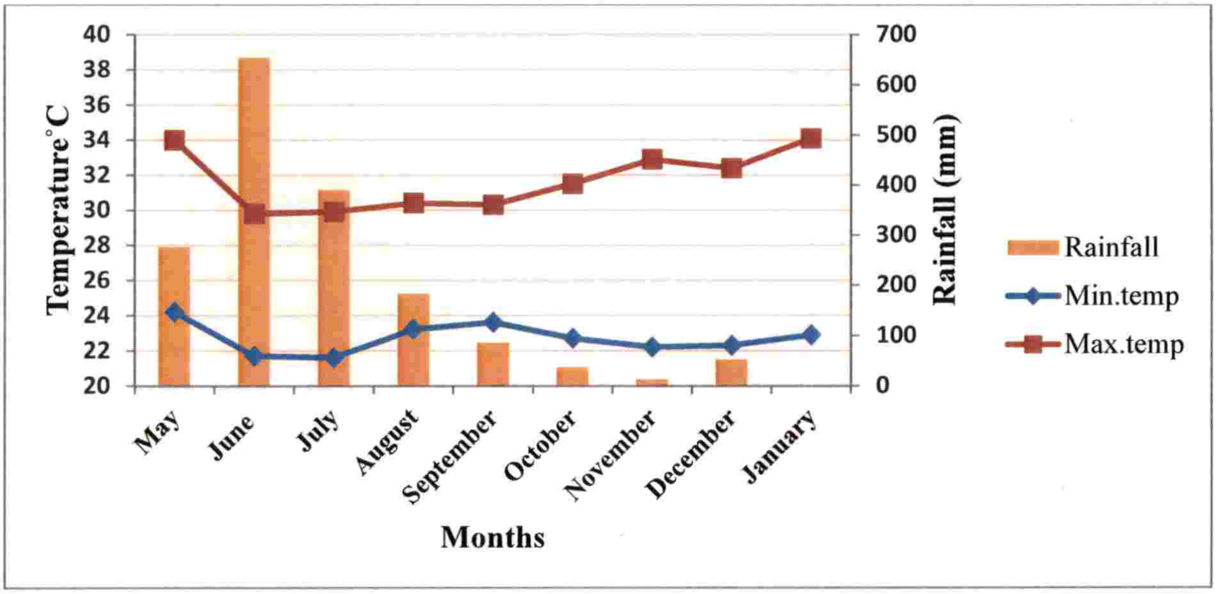

Fig. 37. Weather data during 2015-16

MANAGEMENT AND UTILIZATION OF WATER HYACINTH (*Eichhornia crassipes* (Mart.) Solms)

By
INDULEKHA V. P.
(2013-21-117)

ABSTRACT OF A THESIS

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COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 656

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ABSTRACT

Water hyacinth is one of the most productive plants on earth, but it is also considered as the world's worst aquatic weed. The phytoremediation capacity of water hyacinth and its management through ecofriendly means like silage making, composting, and mulching were studied at the College of Horticulture, Vellanikkara.

The phytoextraction capacity of water hyacinth was evaluated through a purposive sampling by collecting plant and water samples from 20 sites in central Kerala. These samples were analysed for various nutrients including heavy metals. To study the association of plant nutrients with water nutrients, cross tabulation was done and dependence of plant nutrient factor on water nutrient was measured through Chi-square. The Chi-square statistic was significant for N, P, Mg, and Ni indicating that the level of nutrients could be brought to a minimum through water hyacinth. The accumulation of heavy metals in water hyacinth was in the order Fe> Al> Mn> Zn> Cr> Ni> Co> Hg> Pb> As. Among them, Pb content in plant samples was within the permissible limit, but contents of Fe, Cu, Cr, Zn and Ni were beyond the safe limits.

The quality and palatability of silage prepared with fresh and wilted water hyacinth with or without rice straw or guinea grass and using molasses, cassava flour, or rice bran as additives was investigated. Considering the quality parameters such as pH, odour, and palatability, wilted water hyacinth with molasses (5%) or cassava flour (10%) and wilted water hyacinth with cassava flour (10%) and rice straw (10%) or guinea grass (10%) are the best options for utilizing water hyacinth as silage.

The composting experiment consisted of four methods *viz.*, Bangalore method, Indore method, phospho-composting, and vermicomposting. All the prepared composts had neutral to slightly alkaline pH. The lowest C: N ratio was recorded with vermicompost (11.58) followed by Bangalore compost (12.68). Nitrogen content at 3 months after composting (MAC) was higher in

vermicompost and Bangalore compost. The highest N content at 6 MAC was observed in vermicompost (1.75%). Phosphorus content was higher in phospho-compost at 3MAC and 6 MAC. There was no significant difference in K content of different composts at 3 MAC. Calcium, Mg and S contents were high in vermicompost. Micronutrients such as Zn, Cu, Co, and Ni were higher with Bangalore composting. Heavy metals such as As, Cd, and Pb were not detected in any of the composts. None of the composts contained heavy metals beyond safe limits.

A field experiment involving three mulch materials–jack tree leaves, green water hyacinth, and coconut leaves–were compared with no mulching in turmeric for two years. All the mulch materials including water hyacinth had positive effects on most morphological and physiological parameters of turmeric such as plant height, number of leaves, leaf area index, leaf area ratio, and dry matter production. In both years, rhizome yield was also higher in plots mulched with organic debris compared to non-mulch control. Nutrient uptake by the crop was also higher with mulching compared to non-mulched plots. All the mulch materials substantially affected weed density and weed dry weight and reduced turmeric-weed competition for different growth factors.