EVALUATION OF WATER HYACINTH CO-COMPOSTS FOR NUTRIENT RETENTION IN LATERITIC SOIL

by

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(2018-11-177)

THESIS

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DECLARATION

I, Anisha V.A. (2018-11-177) hereby declare that this thesis entitled **"Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil"** is a bonafide record of research work done by me during the course of research and that the thesis has not been previously formed for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil"** is a record of research work done independently by **Mrs. Anisha V.A.** (2018-11-177) under my guidance and supervision and that it has not been previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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Dedicated to my beloved Unniettan, Achan, Amma, Malu and Devu

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Introduction

1.INTRODUCTION

Water hyacinth (*Eichhornia crassipes*) is one of the most noxious aquatic weeds in the world. It is a native of Brazil and has spread to more than 50 countries due to its rapid multiplication rate (double the population within 12 days). In 1890s water hyacinth was introduced to India as an ornamental plant and eventually spread throughout the country. Approximately 20-25 per cent of the water resources of the country is severely infested by this alien weed (Varshney *et al.*, 2008). It adds to aesthetic value of the habitats by its lilac flowers and bright leaves and popularly known as 'lilac devil', but the euryhaline and prolific nature has adversely affected water transportation (freshwater and backwater canals), aquatic biodiversity, fishing and serve as microhabitats for vectors like mosquitoes. The invasion of the weed reduces the flow of water by 40-95 per cent. Water hyacinth is a serious menace in the low land ecosystems of the state particularly in Kuttanad. It has been reported that almost 95 per cent area of water bodies in Kuttanad is infested by water hyacinth.

Invasive nature of the weed called for serious efforts to control its spread through various strategies *viz.*, chemical, physical, biological and integrated approaches. But various physical, chemical and biological methods employed to control the weed has shown unsatisfactory results due to several reasons. It seems impossible to eradicate the weed for reasons of environmental sustainability and economic viability and hence its utilization paved a way for its management. Sustainable management through potential utilization of the most productive weed, water hyacinth is highly promising and found attractive. It can be utilized in agriculture, industries and many other fields. Nowadays exploitation of nonconventional organic sources like weeds proved as an effective way of improving soil health and productivity. As the weed accumulates N, P, K and other essential nutrients, compost made from water hyacinth can be utilized for improving crop production. Moreover, water hyacinth is well known phytoextractor of heavy metals *viz.,* Fe, Al, Mn, Zn, Cu Cd and Pb *etc*. However, composting of this weed has faced challenges due to its high moisture content (>92%), loss of nitrogen through leaching and denitrification (Prasad *et al*., 2013).

Nutrient leaching from compost amended soils is a major problem as it threatens the health of coastal and freshwater ecosystems through eutrophication process

(Howarth and Marino, 2006). Co-composting is a controlled aerobic degradation of organics using more than one feed stock, the benefits of both can be used to optimize the process and the products. Results of several studies indicated that composting of water hyacinth with co-substrates such as poultry manure, rice straw, sawdust, biochar etc., hastened the composting process and reduced the nutrient losses particularly in lateritic soils (Beesigamukama *et al.*, 2018). Most of the cultivated lands have negative nutrient balances due to leaching, denitrification and soil erosion. Furthermore, farms solely depend on chemical fertilizers have low nutrient use efficiencies attributed to low organic matter content of the soils. As tropical soils are highly weathered and leached with low CEC, low pH and low organic matter content, its nutrient reserves and retention can be enhanced by combined application of good quality organic manure with mineral fertilizers. The use of water hyacinth co-composts can be an alternative to addition of conventional organic matter sources. However, much research work is needed to find out the suitable combination of substrates and to estimate the efficacy of water hyacinth co-composts for nutrient retention in laterite soils.

In view of the above, the present study was programmed with the following objectives:

- To find out the suitable combination of co-substrates for enhancing the quality of water hyacinth composts
- To assess the nutrient retention capacity of different water hyacinth co-composts in lateritic soil

Review of literature

2. REVIEW OF LITERATURE

The literature pertaining to the present investigation entitled "Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil" are reviewed in detail and presented under different subheadings.

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms, is one of the world's most prevalent invasive aquatic weed. It is seen in tropical and sub-tropical areas where water nutrient concentrations are often high due to agricultural runoff, deforestation and insufficient waste water treatment. Water hyacinth is a serious menace in low land ecosystems of Kerala, which make large areas of rice fields uncultivable, lakes and streams non-navigable and inaccessible (Jayan and Sathyanathan, 2012).

Its spread has threatened water quality and aquatic life and the various biological, chemical and physical methods that have been employed to control the weed has yielded minimal results (Kateregga and Sterner, 2007). The occurrence of water hyacinth in water bodies has led to major problems like reduction in fish population, blockage of irrigation canals, blockage interference with hydel power projects and destruction of rice fields (Gupta *et al*., 2007). Higher sedimentation rates within the plant's complex root structure and higher evapotranspiration rates from water hyacinth leaves were revealed in a study conducted by Gopal (1987). It has been reported that water hyacinth mats decrease dissolved oxygen concentrations beneath it by preventing the transfer of oxygen from the air to the water's surface (Hunt & Christiansen, 2000). According to Giraldo and Garzon (2002), water hyacinth was found to stabilise pH levels and temperature within the systems, increasing mixing within the water column and prevent stratification. Rommens *et al.* (2003) observed lower phytoplankton productivity and dissolved oxygen concentrations beneath the water hyacinth mats.

Mitigation efforts of water hyacinth by chemical, mechanical and biological means on long term basis was a failure (Bindu and Ramaswamy, 2005). These methods demand enormous recurring costs for keeping the weed infestations in check (Gajalakshmi *et al*., 2001). Present scenario of sustainable agriculture necessitated the management of highly productive weeds like water hyacinth through its utilisation to benefit agricultural production.

2.1 UTILIZATION OF WATER HYACINTH IN AGRICULTURE

2.1.1. Water hyacinth as mulch

Water hyacinth can be effectively utilised in many ways to support crop production. Many aquatic weeds serve as excellent mulching material for crop production. Mulching regulates soil temperature, improve soil moisture status, enhance nutrient uptake, suppress weeds, control diseases and increases the growth and yield of crops.

Islam *et al.* (2014) opined that mulching and irrigation significantly influenced the growth and yield of cabbage. Highest marketable yield was from water hyacinth mulched plots followed by irrigated plots (irrigation at 15 days interval) as compared to no-mulched and non-irrigated plots. Jalil *et al.* (2004) claimed that Cardinal and Lalpakri varieties of potato had highest yield with water hyacinth mulch. Mostarin *et al.* (2005) observed that water hyacinth mulch along with 120 kg N/ha produced highest green pod yield (17.9 t/ha) in french bean. According to Zaman *et al.* (2009) higher tuber yield of potato was obtained under irrigation at IW/CPE of 0.6 and water hyacinth mulch under minimum tillage coupled with various irrigation scheduling and mulching in rice -potato system. Balasubramanian *et al.* (2013) found water hyacinth as a potential organic substrate for soil respiration and microbial population.

Rahman *et al.* (2013) evaluated the effectiveness of mulches like water hyacinth and paddy straw and concluded that water hyacinth mulch recorded higher yield in onion compared to paddy straw.

Yong *et al.* (2017) revealed the effect of water hyacinth residues as mulch on soil moisture content and yield of maize. He concluded that maize grown in soil mulched with water hyacinth recorded high yield and moisture content (0-90 cm soil layer) than non-mulched plots. The influence of different mulches on growth and yield of onion as indicated by plant height, number of leaves per plant, bulb length, bulb weight and bulb yield were studied by Singh *et al.* (2017). He concluded that highest yield was observed with water hyacinth mulch. Indulekha (2018) compared three mulching materials *viz.*, water hyacinth, jack tree leaves and coconut leaves with non-mulch control in turmeric and found that water hyacinth mulched turmeric recorded higher plant height, number of leaves, leaf area index, leaf area ratio and dry matter production.

2.1.2. Water hyacinth as animal feed

Aquatic weeds are most commonly used as animal feed. Being a weed with high fibre and protein content, good quality silages can be prepared from water hyacinth with some additives. It has been reported that improved silage could be made from water hyacinth by adding molasses and rice bran (Tham, 2012).

Samanta and Mitra (1992) concluded that water hyacinth silage had 17.9 per cent crude fibre, 13.1 per cent crude protein, 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. Thanh Van and Van Thu (2010) opined that silage made from water hyacinth possessed good attributes like colour and odour and was readily accepted by the cattle. Cruz *et al.* (2011) claimed that addition of bacterial inoculants (*Lactobacillus plantarum*) and molasses @150g/kg resulted in good quality water hyacinth silage.

Poddar *et al.* (1990) mentioned that water hyacinth ensiled with paddy straw showed more palatability when fed to growing calves compared to fresh or wilted water hyacinth. According to Mitra *et al.* (1997) water hyacinth silage with concentrate was superior to para grass hay in promoting growth of buffalo calves.

2.1.3. Water hyacinth as phytoremediant

Heavy metal contamination posed serious threats to environment and have adverse effect on human and animal health. They are non-biodegradable and accumulate in the environment.

Phytoremediation is defined as the use of plants and associated soil microbes to reduce the concentrations or toxic effects of contaminants in the environments (Greipsson, 2011). Water hyacinth is an excellent extractor of nutrients and heavy metals from contaminated water. Its phytoextraction capacity can be best utilized to treat effluents and contaminated water throughout the world. Phytoremediation ability is attributed to its higher root biomass, root surface area, root activity and net photosynthetic rate.

Madan and Verma (2011) evaluated water hyacinth for waste water treatment using 50 per cent and 100 per cent waste water and found that BOD (Biological Oxygen Demand), COD (Chemical oxygen demand), turbidity, hardness and total dissolved solids of the waste water reduced significantly while total nitrogen decreased 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 .It has been reported that ammoniacal nitrogen, total dissolved solids, BOD and COD of water decreased and the quality of domestic waste water improved after treatment with water hyacinth for two weeks (Rezania *et al.*, 2016).

Water hyacinth can be effectively utilized for treating industrial effluents. Mahmood *et al.* (2005) highlighted the use of water hyacinth for textile effluent treatment and concluded that pH, BOD, COD and total suspended solids reduced to 7, 40-70 per cent and 50 per cent, respectively.

2.1.4. Water hyacinth as organic manure

For reasons of cost effectiveness and environment friendliness, farmers are moving towards replacing inorganic fertilizers with organic manures for agricultural production. Eventhough water hyacinth has proved as a menace to aquatic ecosystems, it accumulates nutrients like nitrogen, phosphorus, potassium and micronutrients. It accumulates 99.2 kg N/ ha, 7.7 kg P/ ha and 182.3 kg K/ ha within a week which can be effectively utilized to improve crop production (Amoding *et al*., 1999). It has been reported that water hyacinth could be effectively used as an organic manure as it releases nutrients faster compared to other plant residues (Parra and Hortestine, 1974). Rommens *et al.* (2003) investigated the capacity of water hyacinth to absorb nitrate, ammonium and phosphate from the water column and noted that on an average, plant absorbed 2.36 mg of ammonium, 1.13 mg of nitrate and 0.39 mg of phosphate per kilogram of water hyacinth (wet weight) each hour.

Lata and Veenapani (2011) noticed the positive effect of water hyacinth manure application on growth and yield of *Coriandrum sativum* compared to control. The results revealed significant response with 100 per cent water hyacinth manure, 50 per cent water hyacinth manure and water hyacinth manure combined with farm yard manure on the growth behaviour of seedlings compared with that of the seedlings grown in control.

The effect of water hyacinth manure on growth and yield of *Celosia argentea* was investigated and results revealed that application of water hyacinth manure significantly improved the growth and yield of *C. argentea*. Among the treatments water hyacinth manure applied at the rate of 2.64 kg/plot (60g/plant) performed best in all the estimated parameters (Sanni and Adesina, 2012).

Vidya and Girish (2014) revealed the effectiveness of water hyacinth as green manure on wheat crop. They estimated physico-chemical parameters of crop *viz.* percentage germination, length of shoot, length of root, root: shoot ratio, biomass, chlorophyll, protein and reducing sugar. All parameters had higher values as compared to control. The results signified the use of water hyacinth as an alternative to conventional organic manures.

Rahman *et al.* (2017) evaluated the green manure potentials of water hyacinth on production of healthy forest tree seedlings like *Albizia saman*. Seed germination and seedling growth were observed against different permutations of water hyacinth and sewage sludge. A ratio of 1:1 of water hyacinth and sewage sludge showed the best results in seed germination and subsequent seedling growth. This mixture resulted in the highest germination rate (90%), the longest root length (54 cm), highest collar diameter (7.87 mm), and the highest number of nodes (57) and leaves (13).

Mohamed and Rashad (2020) opined that water hyacinth and faba bean straw were promising as sandy soil amendments compared to the conventional compost. Water holding capacity of soil increased significantly by 20 per cent using water hyacinth. Physical and chemical properties of water hyacinth provided optimum N, P, and K availability, better textural and moisture state and more stable supporting matrix for sandy soil. Besides, presence of biologically active phyto-chemicals in water hyacinth regulates microbial activity and hence keeps its N content available for plant.

2.1.4.1. ***Composting and compost quality of water hyacinth***

Composting has been proved as an effective technique for safe and quick disposal of the weed. As the weed accumulates N, P, K and other essential nutrients, compost made from water hyacinth can be utilized for improving crop production.

Chatterjee *et al.* (2005) evaluated different systems for water hyacinth composting and noticed that vermicompost had the highest organic carbon mineralisation. The maximum temperature of 70^{0}C was reached within 7 days and pH was turned to near neutrality within 105 days of composting in all methods. According to Girija *et al.* (2005), vermi compost of water hyacinth was superior to that of salvinia in terms of nutritive value, compost maturity time and recovery percentage.

Water hyacinth-based compost showed good content of macronutrients and micronutrients as well as beneficial microorganisms that would support crop production (Viveka and Grace, 2009).

Water hyacinth was composted by Bangalore, Indore and Pit methods. Mahanta and Jha (2009) prepared vermicompost from water hyacinth using *Eisenia foetida* and *Eudrillus euginiae* and showed that earthworm activity reduced the C/N ratio and improved the nutrient content of compost. The results revealed that both the species took 50-70 days for composting and organic carbon, nitrogen, phosphorus and potassium content were 48.20 per cent, 1.50 per cent, 0.72 per cent and 2.20 per cent respectively.

Sannigrahi (2005) suggested that aquatic weeds *viz., Eichhornia crassipes, Typha augustifoila* and *Pistia stratiotes* could be effectively managed by converting in to vermicompost using earth worm, *Perionyx excavates*. The compost prepared from water hyacinth was nutrient rich with 1.36 per cent nitrogen, 0.75 per cent phosphorous and 1.44 per cent potassium. In wet land rice ecosystems, fertilizer nitrogen can be substituted by incorporating the weeds like fresh water hyacinth or vermi composted water hyacinth (Rajkowa, 2008). Results suggested that vermicompost was superior in improving crop production compared to fresh biomass addition. Umsakul *et al*. (2010) investigated the kinetics of physical, chemical and biological properties during composting of water hyacinth. The compost had no odour with black colour and a pH of 7 after 11 weeks of composting and the C/N ratio was 18.12. It was reported that vermicompost could be prepared from water hyacinth within a period of 24 days using the earth worm *Eisenia foetida* and the compost had a pH of 6.8, EC (3.1), organic carbon (17.10 %), total N (0.50 %), total P (0.58 %), total K (0.38%), Zn (485.32 ppm), Fe (2851.33 ppm) and Cu (34 ppm).

Viveka and Grace (2011) noticed higher organic carbon, nitrogen, phosphorus ang potassium content in vermicompost prepared out of water hyacinth. Compost also showed decreased bulk density, increased porosity and water holding capacity. Vermicompost prepared out of water hyacinth using earth worm recorded high organic C (12.5 %), organic matter (21.55%), nitrogen (2.15%), magnesium (80.16 ppm), and zinc (22.14 ppm).

Ankaram *et al.* (2012) evaluated vermicompost prepared from water hyacinth using the earth worm *Eudrillus euginiae* and noticed that N, P, K contents as well as microbial counts were increased whereas pH, EC and C/N ratio were decreased during composting.

In another experiment vermicompost prepared from grass, water hyacinth along with grass separately and noticed that temperature during composting was 28.26±2.19^{0}C, 27.31±0.80^{0}Cand 26.94±0.68^{0}C respectively (Ansari and Rajpersaud, 2012). All the composts showed near neutral pH, high nutrient status and high productivity than that from water hyacinth and grass alone. Pramanik (2012) compared traditional and vermicompost prepared from water hyacinth in combination with 200 mg rock phosphate per kilogram of biomass. Results revealed that vermicomposting was faster and superior compared to traditional composting and rock phosphate enhanced total P content of compost.

Sasidharan *et al.* (2013) explored the feasibility of producing aerobic and vermicompost from water hyacinth and observed that these composts were comparable to farm yard manure with a pH of 6.8 and EC of .02 dS/m. The C/N ratio was 13.2-14.2 with organic carbon, total nitrogen, total phosphorous and potash contents 37.6-41.4, 2.8-2.9, 2.7 and 1.4-1.6 per cent, respectively.

Blessy and Prabha (2014) prepared vermicompost from water hyacinth using *Eudrillus euginiae* and found that organic carbon, nitrogen, P and K contents of the compost were 48.20, 1.5, 0.72 and 2.20 per cent, respectively. Nutrient contents and stability parameters during the first month of agitated pile composting was investigated by Singh and Kalamdhad (2013) and noted that nutrients viz. N, P, K, Na and Ca increased during composting. Total coliform count was reduced and pH was turned to neutral at the end of composting.

Vermi compost prepared from water hyacinth with cow dung using the earthworm recorded high organic carbon (12.5 %), organic matter (21.55%), N (2.15%), Mg(80.16ppm) and Zn (22.14 ppm) (Tiwari, 2016). Varma *et al.* (2016) utilized earthworm species viz. *Esienia foetida, Eudrillus euginae* and *Perionyx excavates* for preparing vermicomposted water hyacinth. The results revealed that *Esisenia foetida* was best for composting and nutrients *viz.*, total N, available, Ca, Mg and Na were also increased.

Indulekha (2018) found that vermi compost prepared from water hyacinth recorded high porosity and nutrient content (N, K, Mg, Ca, S and C:N ratio) compared to compost derived through Bangalore and Indore methods.

2.1.4.2. *Co-composting of water hyacinth*

Nutrient losses from water hyacinth compost through leaching was reported by Gao *et al.* (2012). High moisture content of water hyacinth resulted in leaching losses of nitrogen when composted (Prasad *et al.,* 2013). Hence there is a need to improve the composting process of water hyacinth by adding co-substrates which act as bulking agents to minimize the nutrient losses while reducing the compost maturity period. In view of this co-composting can be proposed as a good and effective technology for composting water hyacinth.

Co-composting is the controlled aerobic degradation of organics, using more than one feed stock, the benefits of each can be used to optimize the process and the product. Adding co-substrate to water hyacinth during composting enhance nitrogen conservation and agronomic value of water hyacinth compost. Epstein (1997) found that improving the composting process of water hyacinth could include addition of materials that can act as bulking agents as well as a source of carbon and nutrients.

It has been reported that co-composting with water hyacinth, sewage sludges and cattle manure improved the C/N ratio of the low moisture and high nitrogen containing rubber factory waste (Kaosol and Wandee, 2009). They opined that the final compost obtained from rubber factory waste, sewage sludge and water hyacinth can be promoted to fertilizer for agriculture due to the high N, P, K and Ca content.

Poultry manure and cattle manure absorb moisture from water hyacinth in addition to acting as nutrient sources for composting microorganisms as well as enriching the compost (Sylvia *et al*., 2005). It has been reported that optimal degradation of water hyacinth can be possible in the presence of carbonaceous materials like cattle manure, saw dust, and rice straw. Higher degradation was achieved with rice straw as a bulking agent compared to saw dust (Dhal *et al.*, 2012).

Manish *et al.* (2014) investigated the nutrient status of time efficient co-composts prepared out of water hyacinth and distillery wastes in various ratios with *Trichoderma viride*, *Phanerochaete chrysosporium*, *Bacillus cereus* using earthworms. They observed a decrease in moisture content, total organic carbon and C:N ratio and an increase in temperature, pH, total potassium and total phosphorus. Out of the five treatments, 60% distillery sludge and 80% distillery sludge treatments were stable and matured with C:N ratio of 18.68±1.1 and 14.73±1.12, respectively. In another study vermicompost prepared from water hyacinth, soil and cow dung in 1:2:1, 2:1:1 and 1:1:2 ratios using the earth worms *Eisenia foetida* and *Eudrillus euginiae* recorded high nutrient status as well as low heavy metal content (Ankaram *et al*., 2012).

Sarika *et al.* (2014) explored the feasibility of producing water hyacinth co-composts in combination 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 in rotary drum composter. The results revealed that there was a reduction in lignin and cellulose in all five trials ranging from 10-40 per cent and 4-55 per cent, respectively and maximum reduction was noticed when the substrates mixed in 6:3:1 ratio. In addition, a significant hike in nutrient contents *viz.*, N, P, K, Ca and Mg was also observed.

2.1.4.3. *Role of bulking agents/co-substrates in composting water hyacinth*

Adhikari *et al.* (2008) revealed the role of bulking agents *viz.*, sawdust, rice husk, maize straw in controlling the moisture content while composting. They also found that straw, saw dust and cow dung are fed as co-substrates to provide specific bulk density for compost.

pH is a determining factor in the biodegradation of wastes during vermi composting. Chang and Chen (2010) reported that co-substrates like cow dung, saw dust, rice husk etc. could control the pH value during composting. They suggested that different co-substrates *viz.* poultry manure, saw dust, rice husk, rice bran and cow dung are effective in controlling and maintaining C/N ratio in the compost. In composting, the bulking agents are used to control pH, moisture content, bulk density, carbon to nitrogen ratio and aeration (Batham *et al*., 2014). Bulking agents like cow dung and saw dust are very useful to control the moisture content while composting water hyacinth. Varadharasu *et al.* (2017) reported that co-composting of water hyacinth with crop residues and cow dung in the ratio of 1:1:1 with the supplementation of *P.djamor* and *E.eugeniae* could yield a manure of higher nutrient status.

Table 2.1. Various types of bulking agents and their function

Sl. No	Bulking Agent	Function	References
1.	Poultry waste	Control carbon content and bulk density	Goyal *et al.* 2005
2.	Saw dust	Control moisture, pH, aeration, bulk density, temperature	Adhikari *et al.* 2008
3.	Cow dung	Control carbon content, bulk density, pH	Singh and Kalamdhad, 2013
4.	Glyricidia	Improve nutrient content	Tennakoon and Bandara, 2003
5.	Paddy straw	Improve nutrient content and pH	Shukla *et al.* 2016
6.	Biochar	Improve bulk density, water and nutrient holding capacity	Swiatek *et al.* 2019

Table 2.2. Different types of wastes and co-substrates in composting

Sl.No	Waste	Bulking agent used	References
1.	Water hyacinth	Cattle manure, saw dust and cow dung slurry	Gajalakshmi *et al.* 2001
2.	Water hyacinth	Cow manure	Pramanik, 2012

2.1.4.4. ***Agronomic efficiency of water hyacinth co-composts***

Adesina (2011) reported that combined application of 30 kg N/ha through mineral fertilizer and 30 kg N/ha through water hyacinth compost resulted in the largest vine length, vine girth, leaf area, number of leaves, as well as fruit yield per plant in cucumber.

Seoudi (2013) evaluated the agronomic efficiency of water hyacinth and banana waste composts at various rates in cow pea and found that there was a marked increase in pod characters, yield and its components. Highest yield and nutrient elements were noticed when compost applied at the higher rates (20 t/fed.) followed by 15 and 10 t/fed as compared with the control.

Singh and Kalamdhad (2013) proved that vermicomposting of water hyacinth by *E. fetida* was very effective for reduction of bioavailability and leachability of selected heavy metals *viz*., Zn, Cu, Mn, Fe, Ni, Pb, Cd, and Cr.

Mashavira *et al.* (2015) explored the potential of different water hyacinth compost application rates in influencing growth attributes, yield and heavy metal accumulation of lead (Pb), copper (Cu), nickel (Ni) and zinc (Zn) in tomato fruits. Results showed that water hyacinth compost application rates significantly influenced plant height, days to maturity and yield. The heavy metal concentrations were lower than the Codex Alimentarious Commission permissible levels for Pb, Cu and Zn.

Water hyacinth compost rate of 25 Mg ha-1enhanced shoot dry weight by 50.10 per cent, 45.30 per cent and 216.89 per cent in sweet corn for Andepts, Udepts and Udults, respectively in comparison to that control (Muktamar *et al.*, 2016). The results indicated the positive response of sweet corn to water hyacinth compost when grown in Udults.

Water hyacinth co-compost prepared using water hyacinth, crop residues and cow dung in the ratio1:1:1 supplemented with *Pencillium djamor* and *Eudrillus euginiae* showed higher mean values of total N (0.93 %), total P (1.00 %) and total K (1.10 %) and a germination of 100 per cent with vigour index of 13.90 and 12.85, respectively for cluster bean and tomato (Varadharasu *et al*., 2017).

Beesigamukama *et al.* (2018) evaluated the agronomic performance of water hyacinth co-composts with maize as a test crop. Among the different co-composts prepared, the highest harvest index and agronomic nitrogen efficiency were obtained at 3.0t/ha water hyacinth + poultry manure and water hyacinth+ molasses respectively.

Naluyange *et al.* (2014) concluded that the commercial *Rhizobium* inoculant is predominantly compatible with water hyacinth compost formulations containing effective microbes and cattle manure culture, which could enhance tolerance of bean plants to anthracnose disease and aphids.

Atere and Olayinka (2019) concluded that soil nutrient status, maize agronomic yield and nutrient uptake status were improved by the application of water hyacinth compost with and without inorganic nitrogen and phosphorus. The rate of 5.0 t ha^{-1} of the sole compost and its organo-mineral form proved superior in enhancing maize growth and soil nutrient status. Hence the noxious weed water hyacinth could be used as an alternative to organic manures, if composted.

2.1.4.5. ***Nutrient retention capacity of water hyacinth co-composts***

When fertilizers are applied to the soil, a significant amount of nutrients is lost through leaching, which might hamper the crop production and pollutes the environment. Leaching loss varied from soil to soil and the rate of loss differed from nutrient to nutrient. In well-drained sandy soils, much of the nitrate can be lost by leaching as water moves nitrate down through the soil profile. The magnitude of fertilizer-N leaching varies depending on soil condition and the method. Nutrient leaching from soils is a major concern as it leads to eutrophication process which threaten the health of coastal and fresh water ecosystems (Howarth and Marino, 2006). Camberato *et al*. (2008) reported that N fertilizers are completely water soluble and a significant portion is lost through leaching.

Hepperly *et al*. (2009) studied the long-term effect of composts and vermi composts on soil N dynamics, and revealed that vermicompost showed increased N retention capacity in soil. Soil having low organic matter status cause more leaching loss of nitrogen than soil rich in organic matter.

According to Islam *et al*. (2014) leaching losses of essential plant nutrients like N, P, and K from lateritic and the sandy soil of old Brahmaputra floodplain under continuous standing water were quite significant. Application of chemical fertilizer at higher rates resulted in greater loss of nutrients. Integrated approach of fertilizer management with application of organic manures and compost along with chemical fertilizers proved to minimize such losses to a great extent.

In order to increase the ability of soil to retain nutrients, the best thing is to add organic matter such as vermi compost. Compost releases nutrients at a slow rate by microbially mediated mineralization process and make it less susceptible to large nutrient losses during a single rain event (Guster *et al*., 2005). However soluble nutrients present in the compost are prone to leaching during rains. It has been reported that nitrate leached at decreasing rates over the same time period from different composts *viz.*, thermophilic compost, vermi compost and compost mixed soils.

Jouquet *et al.* (2011) concluded that vermicompost improve macronutrient retention and plant growth in degraded tropical soils in northern Vietnam.

Masaka and Ndhlovu (2007) reported N and K losses of 73.0 and 83.0 per cent, respectively after composting of water hyacinth. The nutrient losses from compost seems to be aggravated by the long compost maturity period. Lata and Veenapati (2011) noticed a compost maturity period of 100 days, whereas Seoudi, (2013) reported a period of 126 days. Later Osoro *et al.* (2014) found that the water hyacinth compost was ready within 63 days. By shortening the period of compost maturity, nutrient losses from compost can be minimized.

Hagemann *et al.* (2017) reported that biochar promoted plant growth, especially when combined with nutrient-rich organic matter, *e.g.*, co-composted biochar. It has been reported that a complex, nutrient-rich organic coating on co-composted biochar that covers the outer and inner (pore) surfaces of biochar particles using high-resolution spectro microscopy and mass spectrometry. This coating adds hydrophilicity, redox-active moieties, and additional mesoporosity, which strengthens biochar water interactions and thus enhances nutrient retention. Amending soil with biochar accepted as a globally applicable approach to address climate change and soil degradation by carbon sequestration, reducing soil-borne greenhouse-gas emissions and increasing soil nutrient retention.

Effects of biochar addition on vermicomposting of sewage sludge from food industry was studied by Swiatek *et al.* (2019). When vermi-composted with biochar, the weight and volume of product decreased, at the same time the nutrients such as N, P, and K become concentrated and made more accessible for plant roots. Instead of typical bulking agents powdered biochar exhibits beneficial effects on the process and improved the value of the final compost.

Studies have also shown that under reduced N applications, the beneficial effects of biochar and vermicompost on physical and chemical properties of the plant rhizosphere are enhanced (Van Zwieten *et al*., 2010). Altland and Locke (2013) explored the effect of biochar type on macronutrient retention and release from soil less substrate by conducting leaching experiments. They found that biochar was effective in retaining all the macro nutrients especially potassium.

Cao *et al.* (2019) also observed the positive effects of biochar in combination with reduced N fertilizer rates on the biomass of *M. hupehensis*. Messiga *et al*. (2020) observed high NUE at 50 per cent N inputs across all amended growing media like (a) coir, (b) coir + biochar, (c) coir + vermicompost, (d) peat, (e) peat + vermicompost, (f) peat + biochar combined with three nitrogen (N) rates zero per cent (0 g $N \cdot pot^{-1}$), 50 per cent (0.5 g $N \cdot pot^{-1}$), and 100 per cent (1.0 g N pot^{-1}) commercial recommendation during cabbage production cycle.

Nutrient retention, availability and greenhouse gas emissions from biochar-fertilized Chernozems were explored by Romero *et al. (*2021). They revealed that applying biochar along with NP fertilizer provided a benefit to available phosphorous and available nitrogen without increasing soil pH, implying that soil-aged biochar particles favoured plant-available P and N pools.

Materials & Methods

3.MATERIALS AND METHODS

The materials utilized and methodology adopted for fulfilling the objectives of the study entitled "Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil" are detailed in this chapter.

The present research work was conducted in the year 2020 with the objective to evaluate the nutrient retention capacity of different water-hyacinth co-composts. The research work involved two experiments namely1. Evaluation of compost quality of different water-hyacinth co-composts and 2. Evaluation of nutrient retention capacity of different water-hyacinth co-composts in lateritic soil. The first experiment was laid out in CRD in vermi compost unit of the Dept. of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikkara. The water hyacinth co-composts from the first experiment were used to carry out the incubation study to test their efficacy for nutrient retention in lateritic soil (Ultisol) from Instructional farm, Vellanikkara. The second experiment was conducted in the Soil Science Research Laboratory housed at RTL (Radio Tracer Laboratory), Vellanikkara. The details of experiments conducted *viz.* methods of procurement of water hyacinth and co-substrates, characterization of water hyacinth and co-substrates, preparation of composts, methods of analysis of compost and soil samples and statistical techniques followed are detailed in this chapter under the following headings

3.1. EXPERIMENT I

EVALUATION OF COMPOST QUALITY OF DIFFERENT WATER HYACINTH CO-COMPOSTS

The experiment comprised of preparation of water-hyacinth based vermi-composts with co-substrates *viz.*, poultry manure, paddy straw, saw dust, glyricidia, biochar, dried leaves and cattle manure.

3.1.1. Procurement of water hyacinth and co-substrates

Details of water hyacinth and co-substrates collected and utilized for composting are listed in Table 3.1.

Table.3.1. Details of water hyacinth and co-substrates used for composting

Sl.No	Name of substrate/co-substrates	Place of procurement/ Method of preparation
1.	Water-hyacinth	Kole lands, Thrissur
2.	Poultry manure	Poultry farm, AICRP on poultry, Kerala Veterinary and Animal Sciences University, Mannuthy
3.	Cattle manure	Local suppliers
4.	Saw dust	Saw mill, Paravattany
5.	Glyricidia	Local suppliers
6.	Dried leaves	Local suppliers
7.	Paddy straw	Local suppliers
8.	Biochar	Prepared in kiln at Coconut Development Farm, Vellanikkara using coconut shell and husk as raw materials.

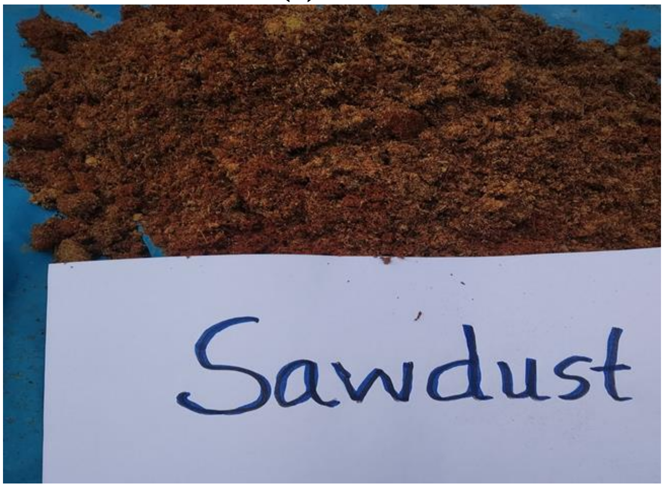
3.1.1.1. Preparation of biochar

The production of biochar was carried out in specially designed kiln fabricated exclusively for the purpose. It consists of two chambers (90 cm^3) with strong metallic doors. Air entry into the kiln was regulated by the special design.

The biomass selected for the purpose were coconut shells and husks and were collected from local suppliers. Dried coconut husks and shells were packed in the kiln according to the capacity and burned the biomass. Once the burning was evidenced by less intensity of the smoke, the metal doors were closed to prevent the entry of air into the chamber. The closure of doors slowed down the entry of air and thereby facilitated the formation of biochar. After 2-5 hrs, the kiln was allowed to cool and the final product ‘biochar’ was collected. The process was repeated for a week until 120 kg of biochar was obtained. The biochar obtained was crushed to powder using a wooden mallet and sieved through a 2mm sieve.

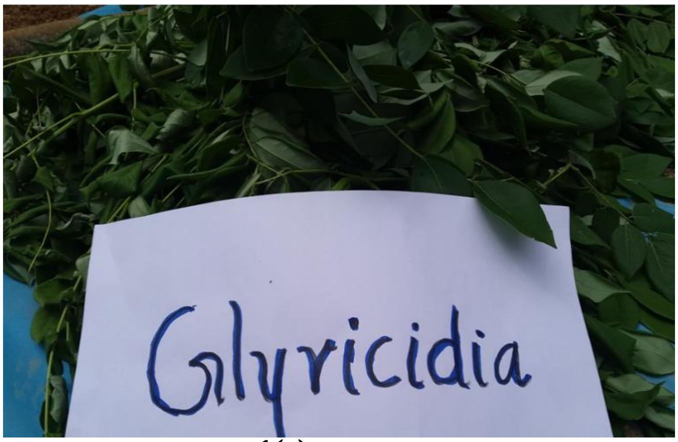
1(a)

1(b)

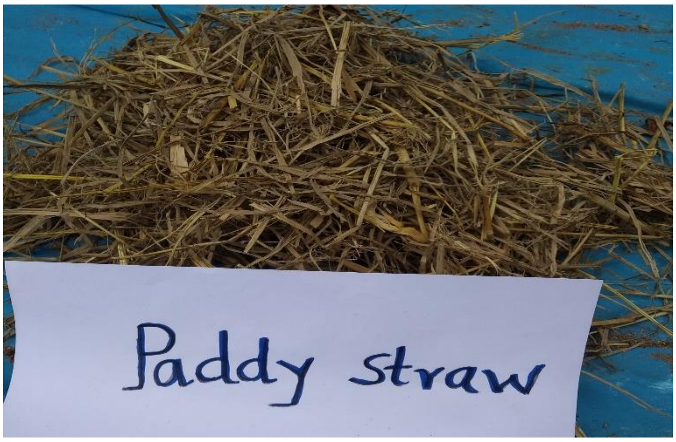


1(d)

1(c)



1(e)



1(f)

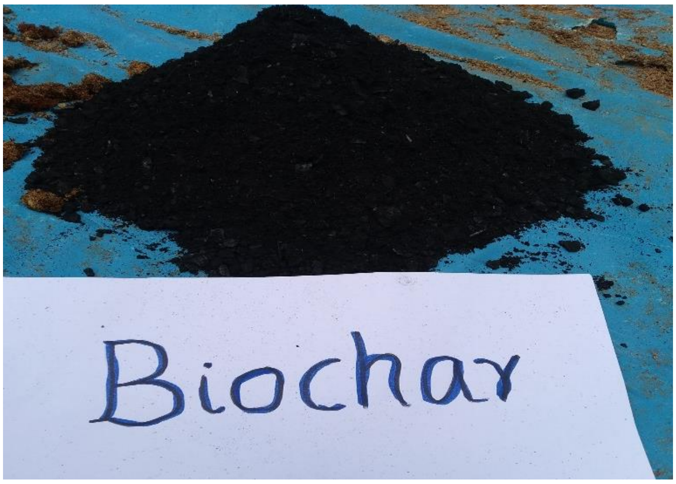


Plate1. Water hyacinth and co-substrates (a)water hyacinth, (b)dried leaves, (c)sawdust, (d)cattle manure, (e)gliricidia, (f)paddy straw, (g) poultry manure, (h) biochar

2(a)

2(b)

2(c)

2(d)

2(e)

Plate 2. Preparation of biochar (a) brick kiln, (b) Igniting coconut husk in kiln (c)Start of pyrolysis (d) Collection of charred biomass, (e) Powdered biochar

3.1.2. Preparation of water-hyacinth co-composts

Water-hyacinth used for composting was collected from the Kole lands of Thrissur district and was kept for a week to reduce the bulkiness in order to facilitate the composting process.

Composting was carried out in ferrocement tanks of dimension 1m X 0.5m with a capacity of 150 kg. Altogether 21 tanks were used to carry out the experiment with 7 treatments and 3 replications. The tanks were properly labelled and treatments were laid out randomly as per the design. Water-hyacinth, co-substrates and cattle manure were mixed to maintain a ratio of 4:4:1 on weight basis as per the treatments. Initially, a layer of coconut husks was spread at the bottom of the tank in such a way that the concave surfaces of the husks face upwards. The water-hyacinth and co-substrate were weighed separately to get 40 kg of each in a mechanical weighing balance. They were thoroughly mixed and layered over the coconut husks. Then a layer of cattle manure was also spread uniformly. This process was continued until the mixture was completely layered and finally cow dung slurry was sprinkled over it. Then the tanks were covered using shade nets to facilitate better aeration. After a week, earth worms were introduced in the tanks @1500 worms per tank. A moisture content of 40-50 per cent was maintained throughout the period and the compost was ready by 100 days. When the compost maturity was indicated by appearance, odour and colour it was transferred from the tank with worms and heaped under shade. As the worms moved down to the bottom of the heap, compost was removed from the top after one or two days, sieved, packed and stored. Then the compost samples were analyzed following the standard procedures.

3.1.3. Experimental details

Water hyacinth co-composts were prepared using different feed stocks as per the treatments detailed below. The experiment was conducted in completely randomized design with three replications.

Table.3.2. Treatment details of composting experiment

Treatment	Substrate composition (weight basis)	Notation
T_1	water hyacinth + poultry manure + cattle manure (4:4:1)	(W+P+M)
T_2	water hyacinth + saw dust + cattle manure (4:4:1)	(W+S+M)
T_3	water hyacinth + biochar + cattle manure (4:4:1)	(W+B+M)
T_4	water hyacinth + glyricidia + cattle manure (4:4:1)	(W+G+M)
T_5	water hyacinth + paddy straw + cattle manure (4:4:1)	(W+PS+M)
T_6	water hyacinth + dried leaves + cattle manure (4:4:1)	(W+D+M)
T_7	water hyacinth + cattle manure –control (8:1)	(W+M)

3.1.4. Characterization of water-hyacinth and co-substrates before experiment

The chemical characterization of water-hyacinth and co-substrates was carried out following the standard procedures as detailed in Table 3.3.

3(a)

3(b)

Plate 3. General view of the composting experiment

(a) Compost tanks before filling (b) Compost tanks after filling

4(a)

4(b)

4(c)

4(d)

Plate 4. Steps in compost preparation (a) Mixing of water hyacinth and co-substrate (b) Filling composting mixture in the tank(c) Application of cow dung slurry (d) Introduction of earthworms in compost tank

5(a)

5(b)

Plate 5. Periodical operations (a) Turning of composting mixture (b) measurement of temperature in compost tank

6(a)

6(b)

Plate 6. Difference between initial substrate and finished product (co-compost)
(a) water hyacinth- paddy straw composting mixture- water hyacinth -paddy straw co-compost
(b) water hyacinth- dried leaves composting mixture- water hyacinth -dried leaves co-compost

Table.3.3. Analytical procedures adopted for water hyacinth, co-substrates and compost samples

Sl.No.	Parameter	Methodology		Reference
		Extraction	Estimation	
1.	Bulk density (for compost)	Measuring cylinder		GOI, 1985
2.	Porosity (for compost)	Measuring cylinder		
3.	Moisture content	Gravimetric method		
4.	pH	1:10(organic manure: water) extract	Potentiometry	
5.	EC	1:5(organic manure: water) extract	Conductometry	
6.	Total C	Loss on ignition		Heiri *et al*., 2001
7.	Total N	Micro-Kjeldhal digestion and distillation		Piper, 1966
8.	Total P	Microwave digestion system (HNO_3)	Colorimetry	Jackson, 1958
9.	Total K		Flame photometry	Jackson, 1958
10.	Total Ca		ICP-OES (Model: Optima® 8x00 series)	
11.	Total Mg			
12.	Total Fe, Mn, Zn, Cu,B			
13.				
14.	Total S		Turbidimetry	Chesnin and Yein, 1951
15.	CEC	Saturation and displacement method		Harada and Inoko, 1980

3.1.5. Characterization of composting mixtures during composting period

The physical properties of co-composts *viz.*, temperature, moisture content and chemical properties like pH, EC and total nitrogen (at 20 days, 60 days and 100 days of composting) were analyzed at soil science analytical laboratory housed at Radio Tracer Laboratory, KAU, Vellanikkara. The methods of analysis are given in Table 3.2.

3.1.6. Characterization of water hyacinth co-composts

Physical and chemical parameters *viz.*, bulk density, porosity, pH, EC, organic carbon, CEC, C:N ratio, total nutrients (N, P, K, Ca, Mg, Fe, Zn, Cu, Mn, S and B) were analyzed. The methods of analysis are detailed in Table 3.3.

3.2. EXPERIMENT II

INCUBATION STUDY TO EVALUATE THE NUTRIENT RETENTION CAPACITY OF DIFFERENT WATER-HYACINTH CO-COMPOSTS IN LATERITIC SOIL

Incubation study was undertaken in the net house attached to RTL, Vellanikkara. The compost amended soils were incubated for a period of 28 days and periodical observations were taken to evaluate the nutrient retention capacity of the same in lateritic soil. One kilogram of soil collected from Instructional Farm was mixed with compost @25 t/ha and incubated in plastic pots. Soils in the pots were maintained at field capacity throughout the experiment. Initially soil samples were drawn from the pots and digested with diacid mixture for estimation of total nutrients. About 20 g of soil samples were drawn at 7, 14, 21 and 28 days of incubation and 200 ml of distilled water was added, shaken for 30 minutes in a mechanical shaker and filtered through Whatman No.42 filter paper. The filtrates were made up to 250 ml and subjected to chemical analysis to estimate water soluble nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, boron and zinc. The nutrient retention capacity of the compost was estimated by subtracting the water soluble nutrients from the total nutrients initially present in the compost amended soil.

3.2.1. Experimental details of incubation experiment

The experiment was conducted in completely randomized design with eight treatments and three replications as given in Table.3.4.

Table.3.4. Treatment details of incubation study

Treatment	Description
T_1	Soil + compost 1 (water hyacinth + poultry manure + cattle manure)
T_2	Soil + compost 2 (water hyacinth + saw dust + cattle manure)
T_3	Soil + compost 3(water hyacinth + biochar + cattle manure)
T_4	Soil + compost 4(water hyacinth + glyricidia + cattle manure)
T_5	Soil + compost 5(water hyacinth + paddy straw + cattle manure)
T_6	Soil + compost 6(water hyacinth + dried leaves + cattle manure)
T_7	Soil + compost 7(water hyacinth + cattle manure)
T_8	Soil alone - control

3.2.2. Collection and processing of soil samples

Soil samples for incubation experiment were collected from 10 different locations of Instructional Farm, Vellanikkara. At each location, a 'V' shaped cut was taken using a spade and sample was collected from 0-15 cm depth following standard procedure. Then the samples were pooled, dried in shade and processed to get 25 kg of 2 mm sized samples for incubation.

3.2.3. Estimation of physical and chemical properties of soil before experimentation

The analytical techniques followed for the estimation of physical and chemical properties of soil selected for the study are presented in Table 3.5.

Table 3.5. Methodology followed for chemical characterization of soil

<table>
<tr><th rowspan="2">Sl.No</th><th rowspan="2">Parameter</th><th colspan="2">Method</th><th rowspan="2">Reference</th></tr>
<tr><th>Extraction</th><th>Estimation</th></tr>
<tr><td>1.</td><td>pH</td><td rowspan="2">1:2.5 soil water suspension</td><td>Potentiometry</td><td rowspan="2">Jackson, 1958</td></tr>
<tr><td>2.</td><td>EC</td><td>Conductometry</td></tr>
<tr><td>3.</td><td>Organic carbon</td><td colspan="2">Chromic acid wet digestion</td><td>Walkley and Black, 1934</td></tr>
<tr><td>4.</td><td>Total nitrogen</td><td colspan="2">Micro-Kjeldhal digestion and distillation</td><td>Piper, 1966</td></tr>
<tr><td>5.</td><td>Total phosphorus</td><td rowspan="5">Nitric-perchloric acid 9:4) digestion</td><td>Colorimetry</td><td>Bray and Curtz, 1945</td></tr>
<tr><td>6.</td><td>Total potassium</td><td>Flame photometry</td><td>Jackson, 1958</td></tr>
<tr><td>7.</td><td>Total sulphur</td><td>Turbidimetry</td><td>Chesnin and Yein, 1951</td></tr>
<tr><td>8.</td><td>Total Ca and Mg</td><td rowspan="2">ICP-OES (Model: Optima® 8x00 series)</td><td rowspan="2">Sims and Johnson, 1991</td></tr>
<tr><td>9.</td><td>Total micronutrients (Fe, Zn, Cu, Mn, B)</td></tr>
</table>

3.2.4. Analysis of water extracts during the period of experimentation

During the incubation period, about 20 g of soil samples were drawn at 7, 14, 21 and 28 days of incubation and 200 ml of distilled water was added, shaken for 30 minutes in a mechanical shaker and filtered through Whatman No.42 filter paper. The filtrates were made up to 250 ml and subjected to chemical analysis to estimate water soluble nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, boron and zinc. The methods adopted for the analysis are given in Table 3.6.

7(a)

7 (b)

Plate 7. Incubation experiment
(a) general view of incubation study
(b) periodic observation during incubation

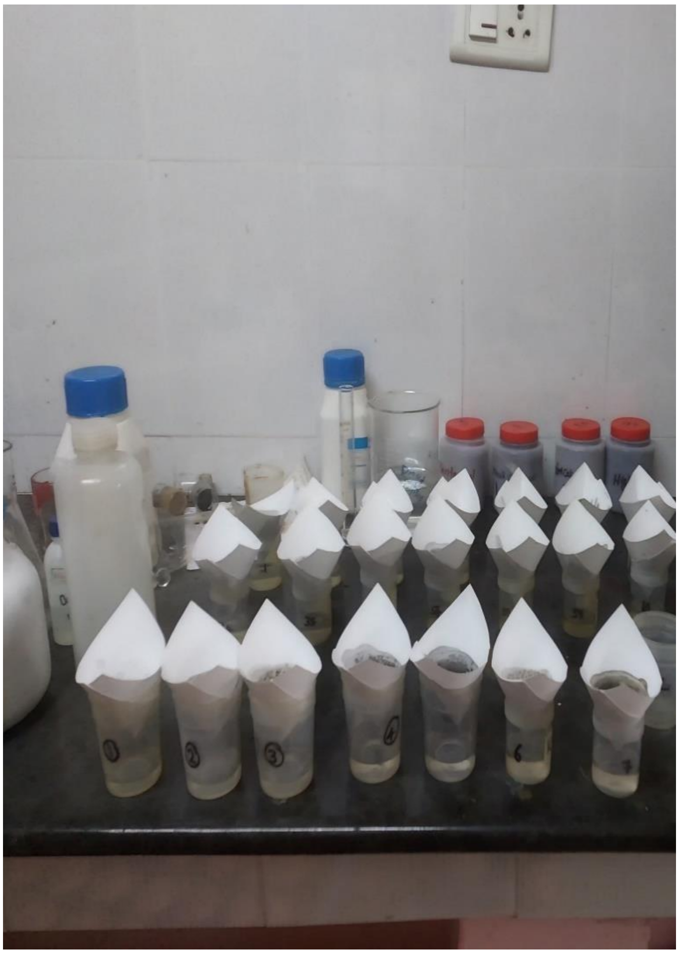


Plate 8. Laboratory analysis

Table 3.6. Analytical procedures followed for estimation of water-soluble nutrients

Sl.No	Parameter	Method of estimation	Reference
1.	pH	Potentiometry	Gupta, 1999
2.	EC	Conductometry	Gupta, 1999
3.	Water soluble nitrogen	Micro-Kjeldhal distillation	AOAC, 1950
4.	Water soluble phosphorus	Colorimetry	Murphey and Riley, 1962
5.	Water soluble potassium	Flame photometry	American Public Health Association (APHA), 1989
6.	Water soluble sulphur	Turbidimetry	Chesnin and Yien, 1951
8.	Water soluble Ca, Mg, Zn, B	ICP-OES (Model: Optima® 8x00 series)	

3.3. STATISTICAL ANALYSIS

Data on various physical and chemical properties of the composting mixtures, physical and chemical characteristics of water hyacinth co-composts and nutrient retention capacity of compost amended lateritic soils were analysed using WASP (Web Agri Stat Package) 2.0 software.

Results

4.RESULTS

The results pertaining to the current study entitled "Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil" are presented in this chapter.

Water hyacinth and co-substrates were collected from *Kole* lands and nearby areas respectively for the preparation of co-composts. The co-substrates were poultry manure, saw dust, biochar, glyricidia, paddy straw, dried leaves and cattle manure. Water hyacinth and co-substrates were characterized before the preparation of co-composts.

4.1. CHARACTERISATION OF WATER HYACINTH AND CO-SUBSTRATES

The chemical characteristics of substrates *viz.,* pH, EC and total quantity of essential nutrients (carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, copper, zinc, iron, manganese and boron) were analysed initially to have a basic information of the materials to be composted. The results are presented in table 4.1 and table 4.2.

The pH of the substrates ranged from 6.00 to 9.68. Biochar had the highest pH (9.68) among the substrates and water hyacinth had the lowest value (6.00). Paddy straw and poultry manure registered pH of 8.43 and 7.87, respectively. Sawdust, glyricidia and dried leaves had similar pH (6.61, 6.58 and 6.45, respectively). The substrates registered electrical conductivity values in the range of 0.47 to 4.72 dS m^{-1}. Highest electrical conductivity was recorded for poultry manure (4.72 dS m^{-1}) and saw dust had the lowest value. The nitrogen content in the substrates ranged from 3.38 per cent to 0.56 per cent. Glyricidia registered the highest nitrogen content whereas biochar recorded the lowest value among the substrates. Regarding carbon content biochar ranked first with 64.52 per cent carbon followed by saw dust, water hyacinth, paddy straw, glyricidia, poultry manure, cattle manure and dried leaves. The carbon content varied from 64.52 per cent to 29.30 per cent. The carbon to nitrogen ratio was highest for biochar (115.2) and lowest value was registered by glyricidia (10.19).

Phosphorus content in the substrates varied from 0.07 per cent to 0.96 per cent. Highest quantity of phosphorus was observed for poultry manure and the lowest quantity was noticed for saw dust. The co-substrates varied in their potassium content in the order biochar (3.83 %), paddy straw (2.70%), water hyacinth (2.01%), glyricidia (1.32 %), poultry manure (0.75%), cattle manure (0.66 %), dried leaves (0.38 %) and saw dust (0.26 %).

The sulphur content in the substrates ranged from 0.09 to 0.26 per cent. The highest content of sulphur was noticed in poultry manure (0.26 %) followed by water hyacinth, biochar, glyricidia, cattle manure, dried leaves, paddy straw and saw dust (0.24, 0.23, 0.19, 0.17, 0.10, 0.08 %). The highest content of calcium was observed for poultry manure (2.45 %) and the lowest value was registered by saw dust (0.36 %). Calcium content in the substrates followed the order poultry manure (2.45 %), glyricidia (1.58 %), cattle manure (1.37 %), water hyacinth (1.14%), biochar (1.06%), dried leaves (0.54 %), paddy straw (0.38 %), and saw dust (0.36 %). Magnesium was highest in glyricidia, value being 0.53 per cent and lowest content was noticed in sawdust (0.36 %).

The iron content showed a wide range from 408.5 mg/kg to 12335 mg/kg. Poultry manure registered the highest content of iron (12335 mg/kg). The lowest iron value was observed for glyricidia (408.5 mg/kg). Copper content was high in cattle manure (26.5 mg/kg) and lowest value was recorded for glyricidia (6.5 mg/kg). Regarding zinc, water hyacinth registered the highest value (95.2 mg/kg) and the lowest content (21mg/kg) was noticed for cattle manure.

The manganese content of the substrates varied from 31.87 mg/kg to 929.7 mg/kg. Water hyacinth had the highest quantity of Mn and saw dust had the lowest value. Highest quantity of boron was obtained in biochar (0.44 mg/kg) and lowest value was noticed in poultry manure (0.20 mg/kg). The content of boron in the other substrates followed the order glyricidia (0.41 mg/kg), water hyacinth (0.39 mg/kg), cattle manure (0.30 mg/kg), paddy straw (0.29 mg/kg), dried leaves (0.23 mg/kg), saw dust (0.22 mg/kg), and poultry manure (0.20 mg/kg).

Table 4.1 Chemical properties of water hyacinth and co-substrates

Sl. No	Substrate	pH	EC	C (%)	N (%)	C/N	P (%)	K (%)
1	Water hyacinth	6.00	4.33	47.56	1.61	29.54	0.14	2.01
2	Poultry manure	7.87	4.72	33.24	2.78	11.96	0.96	0.75
3	Saw dust	6.61	0.47	56.84	0.63	90.22	0.07	0.26
4	Biochar	9.68	2.87	64.52	0.56	115.21	0.45	3.83
5	Glyricidia	6.58	4.29	34.43	3.38	10.19	0.49	1.32
6	Paddy straw	8.43	2.73	46.98	0.74	63.48	0.20	2.70
7	Dried leaves	6.45	1.47	29.30	0.98	29.89	0.09	0.38
8	Cattle manure	7.19	0.61	33.06	1.89	17.49	0.42	0.66

Table 4.2. Secondary and micronutrient contents of water hyacinth and co-substrates

Sl. No	Substrate	Ca	Mg	S	Cu	Zn	Fe	Mn	B
		(%)			(mg kg^{-1})				
1	Water hyacinth	1.14	0.40	0.24	19.5	95.2	10585	929.65	0.39
2	Poultry manure	2.45	0.27	0.26	26	87	12335	483.52	0.20
3	Saw dust	0.36	0.12	0.09	22	53.5	984	31.90	0.22
4	Biochar	1.06	0.45	0.23	26	43.5	1325	43.50	0.44
5	Glyricidia	1.58	0.53	0.20	6.5	33.5	408.5	88.50	0.41
6	Paddy straw	0.38	0.35	0.09	10	48	420	283.5	0.29
7	Dried leaves	0.54	0.25	0.10	12.5	70.5	621.5	258.6	0.23
8	Cattle manure	1.37	0.43	0.17	26.5	21	1705	441.6	0.30

4.2. CHARACTERISTICS OF COMPOSTING MIXTURES DURING THE PERIOD OF COMPOSTING

4.2.1. Physical characteristics of composting mixtures (at 20, 60 and 100 days)

The major physical characteristics of the water hyacinth based composting mixtures during the period of composting *viz.*, temperature and moisture were recorded at various stages to know the performance of the composting process.

4.2.1.1. Moisture content

The data on moisture content of different water hyacinth co-composts at different intervals were statistically analysed (Table 4.3). The results indicated that there was no significant difference in the moisture content at initial period of composting (at 20 days). In all the treatments, the moisture content decreased towards the end of the composting period. Moisture levels in the composting mixtures at 100 days of composting were statistically on par except for water hyacinth biochar co-compost which recorded the lowest moisture content throughout the composting period. Among the co-composts, higher moisture content was registered by the control treatment (W+ M). The uniform moisture content (<65 per cent) of treatments at 100 days of composting indicated the compost maturity at the aforesaid time period.

At twenty days of composting, moisture content of all the treatments was high (>65 per cent) and there was no significant difference between the treatments.

At sixty days of composting, the moisture content showed a decreasing trend. The highest moisture was found in control treatment (74.6%) followed by T_4 (W+G+M), T_2 (W+S+M), T_5 (W+PS+M), T_6 (W+D+M), T_1 (W+P+M), T_1 (W+B+M). The control treatment was found to be on par with T_2 (71.47 %) and T_4 (73.47). The treatments T_1 (64.43%), T_5 (66.93%) and T_6 (66.60%) were on par.

Moisture estimation at 100 days of composting showed that the treatments T_1, T_2, T_4, T_5, T_6 and T_7 were on par with moisture contents 63.06, 64.66, 62.50, 63.47, 63.37, and 62.47 per cent, respectively. The least moisture content was noticed in T_3 (47.86 per cent).

4.2.1.2. Temperature

The temperature of composting mixtures was monitored during the course of composting at 20, 60 and 100 days. In the early stage of composting (20 days), the treatments T_1, T_2, T_3, T_4 and T_5 were statistically on par, with temperature in the range of 28.66^{0}C to 30.00^{0}C. The treatments T_6 and T_7 recorded low temperature status ie 26.67^{0}C and 26.0^{0}C, respectively.

Temperature of water hyacinth based composting mixtures at 60 days was in the range of 29.33^{0}C to 33.00^{0}C. The treatments T_1, T_2 and T_5 were on par. The treatments T_3, T_4 and T_7 were on par with a temperature of 30.00^{0}C, 30.67^{0}C, 29.33^{0}C respectively. At 100 days of composting, only slight variation was noticed among the treatments. The lowest temperature was noticed for T_5 (29.33^{0}C), which was on par with T_6 (29.67^{0}C).

4.2.2. Chemical properties of the composting mixtures (at 20, 60 and 100 days)

The chemical characteristics such as pH, EC and total nitrogen content were analysed to know the dynamics of the same at an interval of 40 days starting from 20 days of composting until 100 days (Table 4.3).

4.2.2.1. pH

Differences in pH were observed among the treatments at different periods of composting. At 20 days, the highest pH was recorded for the treatment T_5 (8.59) which was on par with the treatment T_3 (8.57). The treatments *viz.* T_1, T_2, T_4, T_6 and T_7 had comparatively lower pH and the differences between the treatments were not significant (the range being 7.38 to 7.69).

At 60 days, pH of all treatments showed a decreasing trend with highest value of 8.15 for T_5 and lowest value for T_7 (7.07). The treatments T_2, T_4 and T_7 were on par with pH ranged from 7.07 to 7.21.the treatments T_3 and T_6 were on par with pH values 7.87 and 7.78, respectively.

At 100 days of composting, the treatment with paddy straw recorded significantly higher pH than the other treatments (8.58). The treatments T_3 (W+B+M) and T_6 (W+D+M) were on par. The control treatment registered a pH 7.04 which was found to be on par with T_2 (W+S+M) and T_4 (W+G+M).

4.2.2.2. Electrical conductivity

Electrical conductivity of water hyacinth composting mixtures differed significantly at different intervals during the composting period. At 20 days highest EC was noticed for the treatment(W+PS+M) with a value of 3.35 dS m^{-1}which was significantly higher than the other treatments. Composting mixtures with poultry manure (T_1) also registered higher electrical conductivity (2.41 dS m^{-1}) than T_2, T_3, T_4, T_6 and T_7. The EC values varied from 0.5 dS m^{-1} to 3.35 dS m^{-1}.

Similar trend in EC values was noted at 60 days of composting with highest EC of 3.34 dS m^{-1} for T_5 (W+PS+M). Significantly lower values were recorded in the treatments T_2, T_3, T_4, T_6 and T_7. Composting mixtures with glyricidia and that of poultry manure registered significantly higher values than that of T_2, T_3, T_4, T_6 and T_7.

Regarding the electrical conductivity of water hyacinth co-composts at 100 days of composting, more or less similar trend was noticed in the different treatments involved in the study. Composting mixtures with paddy straw (T_5) registered significantly higher conductivity (4.06 dS m^{-1}) followed by the mixture with glyricidia (1.73 dS m^{-1}). The lowest was observed in case of T_2 (0.59 dS m^{-1}).

4.2.2.3. Total nitrogen

There was wide variation in the total nitrogen content of composting mixtures during the period of composting. Initially high nitrogen was noted in T_6 (W+D+M). The treatment with biochar registered the lowest quantity of nitrogen both at 60 and 100 days of composting.

The total nitrogen content at 20 days of composting ranged from 0.60 per cent to 1.37 per cent. The highest content was seen in T_6 (W+D+M) and the lowest was observed in T_7 (W+M). At 60 days of composting, significantly high content of nitrogen (1.36 %) was observed in T_5 (W+PS+M). Treatments T_1 and T_7 were found to be on par (1.04 % and 0.88 %, respectively). Treatment with biochar (T_3) had the lowest N (0.58 %) among the treatments.

Table.4.3. Physical and chemical properties of composting mixtures at different intervals during composting

Treatment	Moisture (%)			Temperature (°C)			pH			EC (dS/m)			Total Nitrogen (%)		
	20 days	60 days	100 days	20 days	60 days	100 days	20 days	60 days	100 days	20 days	60 days	100 days	20 days	60 days	100 days
T1 (W+P+M)	72.00	64.43^{b}	63.07^{a}	29.33^{a}	33.00^{a}	30.00^{abc}	7.58^{b}	7.50^{c}	7.35^{c}	2.41^{b}	1.79^{b}	1.36^{c}	0.81^{c}	1.04^{b}	1.49^{a}
T2 (W+S+M)	66.67	71.47^{a}	64.67^{a}	28.67^{a}	32.33^{ab}	30.67^{a}	7.69^{b}	7.17^{d}	7.08^{d}	0.49^{d}	0.58^{c}	0.59^{e}	0.80^{c}	0.69^{cd}	0.58^{e}
T3 (W+B+M)	74.67	52.20^{c}	47.87^{b}	30.00^{a}	30.00^{cd}	30.00^{abc}	8.57^{a}	7.87^{b}	7.80^{b}	0.98^{d}	0.88^{c}	0.92^{d}	0.72^{c}	0.58^{d}	0.48^{f}
T4 (W+G+M)	76.00	73.47^{a}	62.50^{a}	29.33^{a}	30.67^{cd}	30.67^{a}	7.38^{b}	7.21^{d}	7.09^{d}	2.22^{bc}	2.16^{b}	1.73^{b}	0.80^{c}	0.66^{cd}	1.19^{b}
T5 (W+PS+M)	70.67	66.93^{b}	63.47^{a}	30.00^{a}	32.67^{a}	29.33^{c}	8.59^{a}	8.15^{a}	8.01^{a}	3.35^{a}	3.34^{a}	4.06 ^{a}	0.93^{b}	1.36^{a}	1.28^{b}
T6 (W+D+M)	70.00	66.60^{b}	63.37^{a}	26.67^{b}	31.00^{bc}	29.67^{bc}	7.43^{b}	7.78^{b}	7.60^{b}	0.61^{d}	0.66^{c}	0.64^{de}	1.37^{a}	0.71^{cd}	0.93^{d}
T7 (W+M)-Control	78.00	74.60^{a}	62.47^{a}	26.00^{b}	29.33^{d}	30.33^{ab}	7.45^{b}	7.07^{d}	7.04^{d}	1.36^{cd}	0.97^{c}	1.35^{c}	0.60^{d}	0.88^{bc}	1.04^{c}
CD (0.05)	**NS**	**4.15**	**2.96**	**1.53**	**1.38**	**0.86**	**0.31**	**0.19**	**0.20**	**0.93**	**0.57**	**0.30**	**0.10**	**0.24**	**0.09**

At 100 days of composting, highest N value was noticed for water hyacinth poultry manure co-compost (1.49%) and the lowest for water hyacinth biochar co-compost (0.48 %). In T_1 the content was significantly higher followed by T_5 (W+PS+M) and T_4 (W+G+M). The treatments T_5 (W+PS+M) and T_4 (W+G+M) were on par (1.28 % and 1.19 %, respectively). Significantly lower values were registered by T_2, T_3, T_6 and T_7.

4.3. YIELD OF WATER HYACINTH CO-COMPOSTS

In the present study the finished co-compost was of dark brown colour without foul smell. The compost maturity was assessed by monitoring the changes in the maturity indices like temperature, moisture content, odour, colour and pH.

The treatments differed significantly with regard to the yield of compost (Table 4.4). The highest yield of 36.65 per cent was observed in water hyacinth biochar co-compost and lowest (14.17 %) was noticed in control treatment (W+M). The treatments involving glyricidia (T_4) and the treatment with paddy straw (T_5) registered comparatively lower yield (19.41 % and 18.21 %, respectively) than T_1, T_2, T_3 and T_6 (23.02, 22.85, 36.65 and 30.11 %, respectively).

Table 4.4. Yield of water hyacinth co-composts and their physical characteristics

Treatment	Compost yield	Bulk density	Porosity
	(%)	Mg/m^3	(%)
T1(W+P+M)	23.03^{c}	0.88^{a}	61.08^{de}
T2(W+S+M)	22.85^{c}	0.83^{c}	62.74^{b}
T3(W+B+M)	36.65^{a}	0.69^{d}	66.12^{a}
T4(W+G+M)	19.41^{d}	0.85^{b}	61.83^{c}
T5(W+PS+M)	18.21^{d}	0.88^{a}	61.69^{cd}
T6(W+D+M)	30.11^{b}	0.89^{a}	60.45 e
T7(W+M)-Control	14.11^{e}	0.89^{a}	60.84 e
CD (0.05)	**2.45**	**0.01**	**0.66**

4.4. CHARACTERISTICS OF WATER HYACINTH CO-COMPOSTS

The different water hyacinth co-composts were analysed for various physical and chemical parameters. The major physical properties analysed were bulk density and porosity. The properties *viz.* pH, EC, CEC, carbon, total nutrients (N, P, K, Ca, Mg, Fe, Zn, Mn, S and B) and C/N ratio were estimated. Compost recovery was also worked out for different treatments.

4.4.1. Physical characteristics

4.4.1.1. Bulk density

Data on bulk density showed significant variation among the treatments (Table 4.4). The values ranged from 0.69 Mg m^{-3} to 0.89 Mg m^{-3}. Co-compost with biochar (T_3) had the lowest bulk density of 0.69 Mg m^{-3} which was followed by co-compost with saw dust (T_2) with a value of 0.83 Mg m^{-3}. Co-compost with dried leaves (T_6) was on par with the treatments namely T_1, T_5 and T_7 (co-compost with poultry manure, paddy straw and water hyacinth alone, respectively) with bulk density values ranging from 0.88-0.89 Mg m^{-3}.

4.4.1.2. Porosity

The co-composts differed significantly in their porosity (Table 4.4). Water hyacinth-biochar co-compost had the highest porosity of 66.12 per cent. The treatment with paddy straw (T_5) was on par with T_4 (W+G+M) with porosity of 61.69 per cent and 61.83 per cent, respectively. Co-compost having poultry manure/ dried leaves as co-substrates was on par with control treatment (T_7) and the porosity values being 61.08, 60.45 and 60.84 per cent, respectively.

4.4.2. Chemical characteristics

The chemical properties of the co-composts viz. pH, EC, Carbon, total nutrients (N, P, K, Ca, Mg, Fe, Zn, Mn, S and B), CEC and C/N ratio were determined (Tables 4.5, 4.6, 4.7).

4.4.2.1. pH

The treatments varied significantly in pH, the range being 7.50 to 8.63. The highest value was registered for water hyacinth paddy straw co-compost (T_5) with pH 8.63 and the lowest was shown by control (T_7) treatment (7.50). The treatments T_1 (W+P+M) and T_6 (W+D+M) were on par with pH of 7.75 and 7.85, respectively. The treatments T_4 (with glyricidia), T_2 (with saw dust) and T_7 (water hyacinth alone) recorded on par pH values (7.59,7.56 and 7.50, respectively).

4.4.2.2. Electrical conductivity

Significant differences were noticed in the electrical conductivity of co-composts. The EC values varied from 0.49 dS m^{-1} to 3.68 dS m^{-1}. The highest value of 3.68 dS m^{-1} was shown by water hyacinth paddy straw co-compost (T_5) which was followed by the co-compost with glyricidia (T_4) and poultry manure (T_1), the EC values being 1.89 and 1.74 dS m^{-1}, respectively. Significantly lower values were registered by T_2 (with sawdust) and T_6 (with dried leaves) and they were on par (0.49 and 0.61 dS m^{-1}, respectively).

4.4.2.3. Total carbon

Water hyacinth co-composts showed significant variation in terms of total carbon content. It varied from 15.62 to 40.17 per cent. Water hyacinth sawdust (T_2) co-compost (40.17 %) was on par with water hyacinth biochar (T_3) co-compost (38.66 %) which were significantly superior to all the other five treatments. Water hyacinth alone (T_1) was significantly inferior (15.63 %) to other six treatments.

4.4.2.4. Total nitrogen

Regarding the content of total nitrogen, the values ranged from 0.56 per cent to 1.59 per cent. Highest nitrogen content was recorded in water hyacinth poultry manure co-compost (1.59 %). Significantly lower values were registered by T_2 (with saw dust) and T_3 (with biochar), the nitrogen content being 0.68 and 0.56 per cent, respectively. The treatments T_4, T_6 and T_7 were on par with nitrogen contents of 1.17,1.03 and 1.07 per cent, respectively.

4.4.2.5. Total phosphorus

The data on total phosphorus content of co-composts are presented in Table 4.6. Phosphorus content varied from 0.06 per cent to 0.35 per cent. Water hyacinth poultry manure co-compost had the highest phosphorus content (0.35%) which was significantly superior to all other treatments. The lowest value was recorded for water hyacinth sawdust co-compost (0.06%). The treatments T_3 (W+B+M) and T_7 (W+M) were found to be on par with phosphorus values of 0.25 per cent and 0.23 per cent, respectively.

4.4.2.6. Total potassium

Total potassium content of water hyacinth co-composts varied significantly with a range of values from 0.34 per cent to 1.46 per cent. The highest value (1.46 %) was registered by water hyacinth paddy straw co-compost and the lowest K content (0.34 %) was noticed in water hyacinth saw dust co-compost. The treatments T_4 (W+G+M) and T_6 (W+D+M) were on par with the control treatment (W+M), the K content being 0.51, 0.47 and 0.50 per cent, respectively.

4.4.2.7. Total sulphur

The data on total sulphur content of the treatments showed a significant difference with a range of values from 0.08 per cent to 0.32 per cent. The total sulphur content was highest in water hyacinth poultry manure co-compost (0.32 %) which was significantly superior to all other treatments. Water hyacinth saw dust co-compost had the lowest content of total sulphur (0.08%). The treatments T_5 (W+PS+M), T_6 (W+G+M) and T_7 ((W+M) were on par, total sulphur content being 0.18, 0.17, 0.19 per cent, respectively.

4.4.2.8. Total calcium

Data on total calcium content of the treatments showed significant variation with a range of values from 0.76 per cent to 1.77 per cent. The highest value was recorded for the treatment W+P+M (1.77 %) while the lowest value was observed in co-compost with saw dust (0.76 %), which was on par with T_5 (paddy straw co-compost) and T_6 (dried leaves co-compost). Water hyacinth alone (T_7) treatment

Table 4.5. Chemical characteristics of water hyacinth co-composts

Treatment	pH	EC (dS/m)	Total carbon (%)	Total Nitrogen (%)	Total Phosphorus (%)	Total Potassium (%)	C/N	CEC (cmol (+) kg^{-1})
T1(W+P+M)	7.75[cd]	1.74[b]	22.813[cd]	1.59[a]	0.35[a]	0.60[c]	14.36[e]	34.23[c]
T2(W+S+M)	7.56[de]	0.49[e]	40.173[a]	0.68[d]	0.06[e]	0.34[e]	59.54[b]	49.37[a]
T3(W+B+M)	8.08[b]	0.98[d]	38.667[a]	0.56[d]	0.25[c]	1.35[b]	69.05[a]	47.80[b]
T4(W+G+M)	7.59[de]	1.89[b]	21.653[d]	1.17[c]	0.30[b]	0.51[d]	18.51[d]	48.20[ab]
T5(W+PS+M)	8.633[a]	3.68[a]	30.543[b]	1.33[b]	0.11[d]	1.46[a]	22.97[c]	46.76[b]
T6(W+D+M)	7.85[c]	0.61[e]	25.520[c]	1.03[c]	0.11[d]	0.47[d]	24.82[c]	46.96[b]
T7(W+M)-Control	7.50[e]	1.36[c]	15.627[e]	1.07[c]	0.23[c]	0.50[d]	14.60[e]	47.63[b]
CD (0.05)	**0.21**	**0.28**	**3.85**	**0.16**	**0.03**	**0.09**	**3.67**	**1.54**

registered total calcium content of 1.23 per cent which was followed by biochar treatment (0.98 %).

4.4.2.9. Total magnesium

Treatments differed significantly in their magnesium content (0.20 to 0.58 %). The treatments T_4 (W+G+M), T_5 (W+PS+M) and T_7(W+M) were statistically on par, the values being 0.41, 0.40 and 0.42 per cent, respectively. The highest magnesium content (0.58 %) was recorded by treatment T_1 (W+P+M) and the lowest quantity of 0.20 per cent was noticed in T_2 (W+S+M).

4.4.2.10. Total copper

Copper content of the treatments followed the order water hyacinth poultry manure co-compost (34.83 mg kg^{-1}) > water hyacinth biochar co-compost (27.50 mg kg^{-1}) > water hyacinth compost (25.50 mg kg^{-1}) > water hyacinth dried leaves co-compost (18.17 mg kg^{-1}) > water hyacinth sawdust co-compost (16.83 mg kg^{-1}) >water hyacinth glyricidia co-compost (12.83 mg kg^{-1}) > water hyacinth paddy straw co-compost (9.00 mg kg^{-1}).

4.4.2.11. Total zinc

The co-compost with poultry manure showed significantly higher zinc content (90.90 mg kg^{-1}) than the other treatments. Zinc content in the other treatments followed the order T_6 (80.97 mg kg^{-1}), T_2 (72.86 mg kg^{-1}), T_5(70.80 mg kg^{-1}), T_3(69.94 mg kg^{-1}), T_4 (64.45 mg kg^{-1}), T_7 (60.13 mg kg^{-1}).

4.4.2.12. Total manganese

The total content of manganese in co-composts varied from 405.83 mg kg^{-1} to 841.66 mg kg^{-1}. The difference was significant and the highest manganese content was recorded in control treatment (W+M) and the lowest content was noted in T_2 (W+S+M). The treatments T_3 and T_4 were on par, manganese contents being 477, 484.83 mg kg^{-1}, respectively.

Table 4.6. Secondary nutrient content of water hyacinth co-composts

Treatment	Ca	Mg	S
	(%)		
T1(W+P+M)	1.77[a]	0.58[a]	0.32[a]
T2(W+S+M)	0.76[e]	0.20[d]	0.08[e]
T3(W+B+M)	0.98[d]	0.25[cd]	0.22[b]
T4(W+G+M)	1.34[b]	0.41[b]	0.21[bc]
T5(W+PS+M)	0.82[e]	0.40[b]	0.18[d]
T6(W+D+M)	0.84[e]	0.30[c]	0.17[d]
T7(W+M)-Control	1.23[c]	0.42[b]	0.19[cd]
CD (0.05)	**0.11**	**0.08**	**0.03**

Table 4.7. Micronutrient contents of water hyacinth co-composts

Treatment	Cu	Zn	Fe	Mn	B
	(mg kg^{-1})				
T1(W+P+M)	34.83[a]	90.90[a]	10801.47[a]	786.83[ab]	0.19[e]
T2(W+S+M)	16.83[de]	72.86[c]	6063.75[b]	405.83[e]	0.22[de]
T3(W+B+M)	27.50[ab]	69.94[d]	5838.12[bc]	477.00[de]	0.42[a]
T4(W+G+M)	12.83[de]	64.45[e]	5005.67[d]	484.83[de]	0.28[cd]
T5(W+PS+M)	9.00[e]	70.80[cd]	5264.84[cd]	589.33[cd]	0.28[cd]
T6(W+D+M)	18.17[cd]	80.97[b]	5631.24[bcd]	653.17[bc]	0.30[bc]
T7(W+M)-Control	25.50[bc]	60.13[f]	10412.51[a]	841.67[a]	0.37[ab]
CD (0.05)	**7.88**	**2.15**	**672.42**	**147.98**	**0.08**

4.4.2.13. Total Iron

Data on total iron content indicated that the co-compost prepared with poultry manure was on par with control treatment (W+M), the total iron content of these two treatments were 10801 and 10412 mg kg^{-1}, respectively. The lowest value was recorded by T_4 (5005 mg kg^{-1}). The treatments with saw dust (T_2), biochar (T_3) and dried leaves (T_6) were also on par with iron content of 6063, 5838 and 5631mg kg^{-1}, respectively.

4.4.2.14. Total Boron

The boron content in the co-composts followed the order T_3 (0.42 mg kg^{-1}) > T_7 (0.37 mg kg^{-1}) > T_6 (0.30 mg kg^{-1}) > T_5(0.28 mg kg^{-1}) > T_4(0.27 mg kg^{-1}) > T_2 (0.22 mg kg^{-1}) > T_1 (0.19 mg kg^{-1}). Water hyacinth alone treatment (T_7) was on par with biochar treatment (T_3). Poultry manure treatment registered the lowest value (T_1).

4.4.2.15. CEC

The CEC values differed significantly and ranged from 34.23 cmol (+) kg^{-1} to 49.37 cmol (+) kg^{-1}. The highest exchange capacity was recorded by co-compost with sawdust (49.37 cmol (+) kg^{-1}), which was on par with glyricidia co-compost (T_4), the CEC being 48.20 cmol (+) kg^{-1}. Poultry manure treatment registered the lowest CEC value of 34.23 cmol (+) kg^{-1}. The treatments with biochar (T_3), paddy straw (T_5), dried leaves (T_6) and control (T_7) were on par and registered CEC 47.80, 46.70, 46.96, 47.63 cmol (+) kg^{-1}, respectively.

4.4.2.16. C/N ratio

Significantly higher C/N ratio was noticed for water hyacinth biochar co-compost (69.06 %) followed by the treatment with saw dust (59.54 %). The lowest ratio was shown by water hyacinth poultry manure co-compost (14.35 %). The treatments T_5 and T_6 were on par with C/N ratio 22.97 and 24.82, respectively.

4.4. EVALUATION OF NUTRIENT RETENTION CAPACITY OF DIFFERENT WATER HYACINTH CO-COMPOSTS IN LATERITIC SOIL

Seven water hyacinth co-composts prepared in experiment 1 were mixed with lateritic soil collected from Instructional Farm, Vellanikkara in a proportion as per the quantity of organic manure recommended for vegetables (25 t/ha) as per KAU P.O.P. Compost amended soils were incubated for a period of 28 days and water-soluble nutrients were extracted from the incubated soil at different periods of incubation to evaluate the nutrient retention capacity of the same in lateritic soil.

4.4.1. Chemical characteristics of the experimental soil (Before application of treatments)

The major chemical characteristics of the soil *viz.*, pH, EC, organic carbon and total essential nutrients (N, P, K, Ca, Mg, S, B, Cu, Zn, Fe, Mn) were analysed prior to the incubation experiment. The data are presented in table 4.8.

Table 4.8 Initial characteristics of experimental soil

Sl.No.	Parameter	Value
1.	pH	5.78
2.	Electrical Conductivity (EC) (dS/m)	0.05
3.	Organic carbon (OC) (%)	0.72
4.	Total nitrogen (%)	0.14
5.	Total phosphorus (mg kg^{-1})	657.6
6.	Total potassium (mg kg^{-1})	1744
7.	Total calcium (mg kg^{-1})	805.4
8.	Total magnesium (mg kg^{-1})	1105
9.	Total sulphur (mg kg^{-1})	260.9
10.	Total boron (mg kg^{-1})	14
11.	Total copper (mg kg^{-1})	30
12.	Total zinc (mg kg^{-1})	19.87
13.	Total iron (mg kg^{-1})	55000
14.	Total manganese (mg kg^{-1})	375.4

4.4.2. Estimation of nutrient retention capacity of water hyacinth co-composts

Nutrient retention capacity of the water hyacinth co-composts was estimated by deducting the water-soluble nutrients from the total quantity of respective nutrients initially present in the compost amended lateritic soil. The retention capacity of water hyacinth co-composts for nutrients *viz.*, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, boron and zinc were estimated at 7, 14, 21, 28 days, respectively.

4.4.2.1. Nitrogen retention capacity at 7, 14, 21, 28 days of incubation

The data on nitrogen retention capacity of different water hyacinth co-composts at different periods of incubation are presented in table 4.9.

4.4.2.1.1. Nitrogen retention capacity at 7 days of incubation

The data indicated that the nitrogen retention capacity of the compost amended soils varied significantly, values ranged from 9.09 per cent to 44.62 per cent. The soil with water hyacinth-poultry manure co-compost had the highest N retention capacity (44.62 %), which was on par (41.18%) with T_3 (soil with water hyacinth-biochar co-compost). The treatments T_2, T_6 and T_7 were on par, the N retention capacities being 33.33, 33.33, 31.55 per cent, respectively. The water hyacinth-paddy straw co-compost amended soil showed the N retention capacity of 20.94 per cent. The control treatment (soil alone) registered the lowest nitrogen retention capacity (9.09 %).

4.4.2.2.2. Nitrogen retention capacity at 14 days of incubation

The treatments differed significantly in their nitrogen retention capacity with a range of values from 9.09 per cent to 44.31 per cent. The soil with water hyacinth-poultry manure co-compost (T_1) and soil with water hyacinth-biochar co-compost (T_3) were on par with N retention capacities of 44.31 and 41.18 per cent, respectively. The treatments T_2, T_6 and T_7 were on par, the N retention capacities being 33.33, 33.33, 31.54 per cent, respectively. The water hyacinth-paddy straw co-compost amended soil showed the lowest N retention capacity of 20.94 per cent, among the compost amended soils. It was seen that nitrogen retention capacity of water hyacinth co-compost at 14 days followed the same trend as that of 7 days.

4.4.2.2.3. Nitrogen retention capacity at 21 days of incubation

The superiority of biochar in the retention of nitrogen was noticed at 21 days after incubation also. Significant variation was observed in the nitrogen retention capacity of compost amended soils, the range being 9.09 to 41.18 per cent. The soil with water hyacinth-biochar co-compost registered N retention capacity of 41.18 per cent, which was on par with treatments T_1, T_2 and T_6 (soils with water hyacinth-poultry manure co-compost, water hyacinth-sawdust co-compost and water hyacinth-dried leaves co-compost), N retention values of 36.53, 33.33, 33.33 per cent, respectively. The soils with water hyacinth compost (T_7) and water hyacinth-paddy straw co-compost (T_5) registered significantly lower N retention capacity values (21.13 and 20.94 %, respectively).

4.4.2.2.4. Nitrogen retention capacity at 28 days of incubation

Nitrogen retention capacity of compost amended soils varied significantly, highest value was recorded by water hyacinth-biochar co-compost (41.18 %), which was on par with treatments T_1, T_2 and T_6 (soils with water hyacinth-poultry manure co-compost, water hyacinth-sawdust co-compost and water hyacinth-dried leaves co-compost), N retention values of 36.53, 33.33, 33.33 per cent, respectively. The soils with water hyacinth compost (T_7) and water hyacinth-paddy straw co-compost (T_5) showed significantly lower N retention capacity (21.13 and 20.94 %, respectively).

4.4.2.2. Phosphorus retention capacity at 7, 14, 21, 28 days of incubation

The data on phosphorus retention capacity of different water hyacinth co-composts at different periods of incubation are presented in table 4.9.

4.4.2.2.1. Phosphorus retention capacity at 7 days of incubation

Phosphorus retention capacity of compost amended soils recorded high values ranging from 99.82 per cent to 100 per cent. Water extractable phosphorus was negligible in all treatments. The treatments T_8, T_7, T_6, T_4 and T_2 were on par with phosphorus retention capacities of 100.00, 99.98, 99.99, 99.99 and 99.96 per cent, respectively.

Table 4.9. Nitrogen and phosphorus retention capacity of water hyacinth co-composts

Treatment	Nitrogen retention capacity (%)				Phosphorus retention capacity (%)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	44.62^{a}	44.31^{a}	36.53^{ab}	36.53^{ab}	99.91^{b}	100.00	100.00	100.00
T_2 (Soil+compost2)	33.33^{c}	33.33^{c}	33.33^{abc}	33.33^{abc}	99.96^{a}	100.00	100.00	100.00
T_3 (Soil+compost3)	41.18^{ab}	41.18^{ab}	41.18^{a}	41.18^{a}	99.87^{c}	100.00	100.00	100.00
T_4 (Soil+compost4)	34.56^{bc}	34.56^{bc}	24.75^{bc}	24.75^{bc}	99.99^{a}	100.00	100.00	100.00
T_5 (Soil+compost5)	20.94^{d}	20.94^{d}	20.94^{cd}	20.94^{cd}	99.82^{d}	100.00	100.00	100.00
T_6 (Soil+compost6)	33.33^{c}	33.33^{c}	33.33^{abc}	33.33^{abc}	99.99^{a}	100.00	100.00	100.00
T_7 (Soil+compost7)	31.55^{c}	31.55^{c}	21.13^{cd}	21.13^{cd}	99.99^{a}	100.00	100.00	100.00
T_8 (Soil alone-control)	9.09^{e}	9.09^{e}	9.09^{d}	9.09^{d}	100.00^{a}	100.00	100.00	100.00
CD (0.05)	6.76	1.38	14.15	14.15	0.04	NS	NS	NS

respectively. The lowest P retention capacity was registered by soils amended with water hyacinth-paddy straw co-compost (99.82 %).

4.2.2.2. Phosphorus retention capacity at 14 days of incubation

No water-soluble phosphorus was obtained in the co-compost amended soils.

4.2.2.3. Phosphorus retention capacity at 21 days of incubation

No water-soluble phosphorus was obtained in the co-compost amended soils.

4.2.2.4. Phosphorus retention capacity at 28 days of incubation

No water-soluble phosphorus was obtained in the co-compost amended soils.

4.4.2.3. Potassium retention capacity at 7, 14, 21, 28 days of incubation

The data on potassium retention capacity of different water hyacinth co-composts at different periods of incubation are presented in table 4.10.

4.4.2.3.1. Potassium retention capacity at 7 days of incubation

Regarding the potassium retention capacity of compost amended soils, the values ranged from 95.30 to 99.28 per cent. Significantly higher values were registered by soils with water hyacinth-biochar co-compost (99.28 %) and water hyacinth-paddy straw co-compost (99.07 %) and they were found to be on par. The treatments T_7, T_6 and T_2 (soils with water hyacinth compost, water hyacinth-dried leaves co-compost and water hyacinth-saw dust co-compost) registered similar potassium retention capacities of 98.60, 98.78 and 98.68 per cent, respectively. Soils amended with water hyacinth-glyricidia co-compost (T_4) and water hyacinth-poultry manure co-compost(T_1) were on par, K retention capacities being 98.19 and 98.06 per cent, respectively.

4.4.2.3.2. Potassium retention capacity at 14 days of incubation

Significantly higher potassium retention capacity was noticed in soil amended with water hyacinth-biochar co-compost (99.39 %) and water hyacinth compost (98.87 %) followed by the treatments T_2, T_6, T_5, T_4, T_1 and T_8 (soil amended with water hyacinth-sawdust co-compost, water hyacinth-dried leaves co-compost, water hyacinth-paddy straw co-compost, water hyacinth-glyricidia co-compost, water hyacinth-poultry manure co-compost and soil alone) registered potassium retention capacity values of 98.75, 98.47, 98.43, 98.26, 97.75 and 95.31 per cent, respectively.

4.4.2.3.3. Potassium retention capacity at 21 days of incubation

Potassium retention capacities of the compost amended soils at 21 days of incubation followed the order soil with water hyacinth-biochar co-compost (98.02 %), water hyacinth-paddy straw co-compost (97.99 %), water hyacinth compost (95.02 %), water hyacinth-poultry manure co-compost (93.71 %), water hyacinth-glyricidia co-compost (93.48 %), water hyacinth-dried leaves co-compost (93.41 %), water hyacinth-sawdust co-compost (93.33 %), and soil alone (92.72 %). Water hyacinth-biochar co-compost and water hyacinth-paddy straw co-compost were on par.

4.4.2.3.4. Potassium retention capacity at 28 days of incubation

Regarding potassium retention capacities of the compost amended soils, the treatments T_1, T_3, T_5 and T_7 registered higher values among the treatments (96.93, 97.98, 97.50, 96.93 per cent, respectively). Soil with water hyacinth-sawdust had comparatively lower K retention capacity value of 95.92 per cent followed by the control treatment (92.39 %).

4.4.2.3. Calcium retention capacity at 7, 14, 21, 28 days of incubation

The data on calcium retention capacity of different water hyacinth co-composts at different periods of incubation are presented in table 4.10.

4.4.2.3.1. Calcium retention capacity at 7 days of incubation

Calcium retention capacity of the compost amended soils followed the order T_3 (water hyacinth-biochar co-compost) > T_4 (water hyacinth-glyricidia co-compost) > T_5 (water hyacinth-paddy straw co-compost)> T_2(water hyacinth-sawdust co-compost) > T_1(water hyacinth-poultry manure co-compost) > T_6 (water hyacinth-dried leaves co-compost)> T_7 (water hyacinth compost) > T_8 (soil alone), values are 98.84, 98.00, 97.88, 97.82, 97.76, 96.48, 96.17, 95.80 per cent, respectively. The treatments T_1, T_2, T_4 and T_5 were on par. Water hyacinth-biochar co-compost (T_3) registered significantly higher values than the other treatments. Water hyacinth alone treatment (T_7) was on par with water hyacinth-dried leaves co-compost.

Table 4.10. Potassium and calcium retention capacity of water hyacinth co-composts

Treatment	Potassium retention capacity (%)				Calcium retention capacity (%)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	98.07^{c}	97.75^{d}	93.71^{bc}	96.93^{abc}	97.76^{b}	96.61^{e}	76.98^{bc}	67.74^{c}
T_2 (Soil+compost2)	98.68^{b}	98.75^{bc}	93.33^{bc}	95.92^{c}	97.82^{b}	98.85^{b}	74.38^{c}	64.63^{d}
T_3 (Soil+compost3)	99.28^{a}	99.39^{a}	98.02^{a}	97.98^{a}	98.85^{a}	99.30^{a}	82.47^{a}	76.84^{a}
T_4 (Soil+compost4)	98.19^{c}	98.26^{cd}	93.48^{bc}	96.22^{bc}	98.00^{b}	98.82^{b}	81.66^{a}	74.91^{a}
T_5 (Soil+compost5)	99.07^{a}	98.43^{bc}	97.99^{a}	97.50^{ab}	97.89^{b}	98.92^{b}	77.22^{b}	68.70^{b}
T_6 (Soil+compost6)	98.78^{b}	98.47^{bc}	93.42^{bc}	96.40^{bc}	96.48^{c}	96.99^{d}	71.08^{d}	61.33^{e}
T_7 (Soil+compost7)	98.60^{b}	98.87^{ab}	95.02^{b}	96.93^{abc}	96.17^{cd}	97.93^{c}	75.60^{bc}	65.60^{cd}
T_8 (Soil alone-control)	95.30^{d}	95.31^{e}	92.72^{c}	92.39^{d}	95.81^{d}	95.25^{f}	60.88^{e}	51.31^{f}
CD (0.05)	0.22	0.53	1.96	1.39	0.55	0.22	2.65	2.53

4.4.2.3.2. Calcium retention capacity at 14 days of incubation

The highest calcium retention capacity was observed in soil with water hyacinth-biochar co-compost (99.30 %). The treatments T_2, T_4 and T_5 were on par, the calcium retention capacities being 98.85, 98.82 and 98.92 per cent, respectively. The soil with poultry manure compost had significantly lower Ca retention capacity among the treatments (96.61 %).

4.4.2.3.3. Calcium retention capacity at 21 days of incubation

Regarding the calcium retention capacity of compost amended soils, significantly higher values were registered by soils with water hyacinth-biochar co-compost (82.47 %) and water hyacinth-glyricidia co-compost (81.66 %), they were found to be on par. The treatment T_5 (soil with water hyacinth-paddy straw co-compost) had a K retention capacity of 77.22 per cent followed by the treatments T_1, T_7, T_2, T_6 and T_8 (76.98, 75.60, 74.38, 71.08 and 60.88 per cent, respectively).

4.4.2.3.4. Calcium retention capacity at 28 days of incubation

Calcium retention capacity of compost amended soils followed the order soil with water hyacinth-biochar co-compost (T_3)> water hyacinth-glyricidia co-compost (T_4) > water hyacinth-paddy straw co-compost (T_5) > water hyacinth-poultry manure co-compost(T_1) > T_7 (water hyacinth compost) > T_2(water hyacinth-sawdust co-compost) water hyacinth-dried leaves co-compost >T_8 (soil alone), values being 76.84, 74.91, 68.69, 67.74, 65.59, 64.63, 61.33, 51.31 per cent, respectively.

4.4.2.4. Magnesium retention capacity at 7, 14, 21, 28 days of incubation

The data on magnesium retention capacity of different water hyacinth co-composts at different periods of incubation are presented in table 4.11.

4.4.2.4.1. Magnesium retention capacity at 7 days of incubation

The data on magnesium retention capacity of the treatments indicated that the treatments T_1, T_3, T_4 and T_5 were on par, the values being 99.52, 99.63, 99.51 and 99.56 per cent, respectively. Soils with water hyacinth-sawdust co-compost and water hyacinth compost showed similar Mg retention capacities of 99.47 and 99.42 per cent, respectively. The treatment T_6 (soil+water hyacinth dried leaves co-compost) registered significantly lower magnesium retention capacity of 99.24 per cent, which was on par (99.20%) with the control (soil alone).

4.4.2.4.2. Magnesium retention capacity at 14 days of incubation

Significant variation was observed in the Mg retention capacities of treatments with range of values from 99.05 to 99.72 per cent. The treatments T_2, T_4 and T_5 were on par, the values being 99.63, 99.63, 99.72 per cent, respectively. Lower Mg retention capacities were shown by the treatmentsT_1 and T_6 (soil + water hyacinth poultry manure co-compost and soil + water hyacinth dried leaves co-compost (99.37and 99.36 per cent, respectively).

4.4.2.4.3. Magnesium retention capacity at 21 days of incubation

Mg retention capacity of the treatments showed variation and the retention capacity was in the order of T_5 (98.64 %), T_4(98.36 %), T_1(98.32 %), T_2(97.91 %), T_7(96.97 %), T_7(96.96 %), T_3(96.90 %), and T_8 (96.53 %).

4.4.2.4.4. Magnesium retention capacity at 28 days of incubation

Data on magnesium retention capacity indicated that significantly high value was registered by soil with water hyacinth paddy straw co-compost (97.49 %). The treatments T_1, T_2, T_4 and T_7 were on par, Mg retention capacities of 96.79, 96.66, 96.76,96.56 per cent, respectively. Soil with water hyacinth-boichar co-compost and water hyacinth-dried leaves co-compost registered relatively lower values, 95.85 per cent and 95.87 per cent, respectively.

4.4.2.4. Sulphur retention capacity at 7, 14, 21, 28 days of incubation

The data on sulphur retention capacity of different water hyacinth co-composts at different periods of incubation are presented in Table 4.11.

4.4.2.4.1. Sulphur retention capacity at 7 days of incubation

The highest sulphur retention capacity was shown by the soil with water hyacinth-glyricidia co-compost (96.05 per cent). The treatments T_1, T_3 and T_6 were on par, the S retention capacities being 96.08, 95.82, 95.16 per cent, respectively.

Significantly lower S retention capacities were registered by T_2 (soil with water hyacinth-sawdust co-compost) and T_5 (soil with water hyacinth-paddy straw co-compost) which were on par with the control treatment (soil alone), values being 93.74, 93.01 and 94.15 per cent, respectively.

4.4.2.4.2. Sulphur retention capacity at 14 days of incubation

The data on sulphur retention capacity (Table 4.11) indicated that soils with water hyacinth-glyricidia co-compost, water hyacinth-biochar co-compost and water hyacinth-poultry manure co-compost were on par (suphur retention capacity of 98.29, 97.91 and 97.67 per cent, respectively). The water hyacinth-dried leaves co-compost amended soil registered relatively low S retention capacity (95.77 %), which was on par with the control (94.88 %) treatment (soil alone).

4.4.2.4.3. Sulphur retention capacity at 21 days of incubation

Significantly higher sulphur retention capacities were registered by the treatments T_1, T_3 and T_4, and they were on par, values being 97.67, 97.91 and 98.29 per cent, respectively. The soils with water hyacinth co-compost and water hyacinth sawdust co-compost were on par (sulphur retention capacity values of 96.72 and 97.67 per cent, respectively). The water hyacinth-dried leaves co-compost amended soil registered relatively low S retention capacity (95.77 %), which was on par with the control treatment (94.88).

4.4.2.4.4. Sulphur retention capacity at 28 days of incubation

Significantly higher sulphur retention capacities were registered by the treatments at 28 days of incubation. The treatments T_3, T_4, T_5 and T_6 were on par (suphur retention capacity of 100 per cent). Soil with water hyacinth co-compost registered relatively low S retention capacity (98.83 %) among the compost amended soil.

Table 4.11. Magnesium and sulphur retention capacity of water hyacinth co-composts

Treatment	Magnesium retention capacity (%)				Sulphur retention capacity (%)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	99.52^{ab}	99.37^{d}	98.32^{a}	96.79^{b}	96.08^{b}	97.67^{abc}	97.67^{abc}	99.16^{c}
T_2 (Soil+compost2)	99.47^{b}	99.63^{ab}	96.97^{a}	96.66^{b}	93.74^{de}	96.67^{bcd}	96.67^{bcd}	99.67^{b}
T_3 (Soil+compost3)	99.63^{a}	99.59^{bc}	96.91^{b}	95.85^{c}	95.82^{bc}	97.91^{ab}	97.91^{ab}	100.00^{a}
T_4 (Soil+compost4)	99.51^{ab}	99.63^{ab}	98.37^{a}	96.76^{b}	98.05^{a}	98.29^{a}	98.29^{a}	100.00^{a}
T_5 (Soil+compost5)	99.56^{ab}	99.72^{a}	98.64^{a}	97.49^{a}	93.01^{e}	94.88^{e}	96.28^{cde}	100.00^{a}
T_6 (Soil+compost6)	99.24^{c}	99.36^{d}	96.96^{b}	95.87^{c}	95.16^{bcd}	95.77^{de}	95.77^{de}	100.00^{a}
T_7 (Soil+compost7)	99.42^{b}	99.52^{c}	97.97^{b}	96.56^{b}	94.18^{cde}	96.72^{bcd}	96.72^{bcd}	98.83^{d}
T_8 (Soil alone-control)	99.20^{c}	99.05^{e}	96.53^{b}	95.59^{c}	94.15^{cde}	96.28^{cde}	94.88^{e}	98.51^{e}
CD (0.05)	0.16	0.10	0.76	0.64	1.69	1.46	1.46	0.24

4.4.2.5. Zinc retention capacity at 7, 14, 21, 28 days of incubation

The data on zinc retention capacity of different water hyacinth co-composts at different periods of incubation are presented in table 4.12.

4.4.2.5.1. Zinc retention capacity at 7 days of incubation

Data on zinc retention capacity of compost amended soils are presented in table 4.12. It indicated that Zn retention capacity was comparable for the soils amended with water hyacinth-biochar co-compost (99.64 %), water hyacinth-dried leaves co-compost (99.57 %) and water hyacinth-glyricidia co-compost (99.53 %). The treatments T_1 and T_2 were on par, Zn retention capacity values being 99.20 per cent and 99.23 per cent, respectively. The treatment T_7 (soil with water hyacinth compost) registered the lowest value of 99.06 per cent among the compost amended soils.

4.4.2.5.2. Zinc retention capacity at 14 days of incubation

Zinc retention capacity of compost amended soils showed a range of values from 98.39 to 99.63 per cent. The treatments with water hyacinth-biochar co-compost (99.63 %), water hyacinth-dried leaves co-compost (99.50 %) and water hyacinth-glyricidia co-compost (99.55 %) were on par. The treatments T_1 and T_7 were on par, Zn retention capacity values being 99.10 per cent and 98.97 per cent, respectively.

4.4.2.5.3. Zinc retention capacity at 21 days of incubation

Zinc retention capacity of compost amended soils differed significantly with a range of values from 97.65 to 99.54 per cent. The treatments T_5 and T_6 (soil with water hyacinth-paddy straw co-compost and water hyacinth-dried leaves co-compost) were found to be on par, registered values being 99.27 and 99.33 per cent, respectively. The treatments T_1 and T_7 registered comparatively lower zinc retention capacities of 98.58 and 98.71 per cent, respectively.

4.4.2.5.4. Zinc retention capacity at 28 days of incubation

Zinc retention capacity of compost amended soils differed significantly, the range being 97.74 to 99.56 per cent. The treatment with water hyacinth-biochar co-compost registered S retention capacity of 99.56 per cent, which was on par with T_4 and

T_6 (soil with water hyacinth-glyricidia co-compost and water hyacinth-dried leaves co-compost) with values being 99.46 and 99.40 per cent, respectively. The treatment T_7 registered comparatively lower zinc retention capacity of 98.64 per cent.

4.4.2.6. Boron retention capacity at 7, 14, 21, 28 days of incubation

The data on boron retention capacity of different water hyacinth co-composts at different periods of incubation are given below.

4.4.2.6.1. Boron retention capacity at 7 days of incubation

No water-soluble boron was obtained in the co-compost amended soils.

4.4.2.6.2. Boron retention capacity at 14days of incubation

No water-soluble boron was obtained in the co-compost amended soils.

4.4.2.6.3. Boron retention capacity at 21 days of incubation

No water-soluble boron was obtained in the co-compost amended soils.

4.4.2.6.4. Boron retention capacity at 28 days of incubation

No water-soluble boron was obtained in the co-compost amended soils

Table 4.12. Zinc retention capacity of water hyacinth co-composts

Treatment	Zinc retention capacity (%)			
	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	99.20[c]	99.10[cd]	98.58[d]	98.69[cd]
T_2 (Soil+compost2)	99.23[c]	99.17[c]	98.93[c]	98.90[c]
T_3 (Soil+compost3)	99.64[a]	99.63[a]	99.54[a]	99.56[a]
T_4 (Soil+compost4)	99.53[a]	99.55[ab]	99.40[ab]	99.46[ab]
T_5 (Soil+compost5)	99.40[b]	99.39[b]	99.27[b]	99.33[b]
T_6 (Soil+compost6)	99.57[a]	99.50[ab]	99.33[b]	99.40[ab]
T_7 (Soil+compost7)	99.06[d]	98.97[d]	98.71[d]	98.64[d]
T_8 (Soil alone-control)	98.52[e]	98.39[e]	97.65[e]	97.74[e]
CD (0.05)	0.07	0.19	0.19	0.21

Discussion

5.DISCUSSION

The major findings obtained from the project entitled "Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil" are discussed in this chapter.

Water hyacinth and co-substrates were collected from near-by areas and they were analysed for chemical properties before the preparation of water hyacinth co-composts. The results are discussed in section 5.1. The composting mixtures were characterized during composting and the results of the same are discussed in section 5.2. Physical and chemical characteristics of water hyacinth co-composts (finished product) were analysed and results are discussed in section 5.3. The water hyacinth co-composts were evaluated for their nutrient retention capacity in lateritic soil. The results of the incubation study to evaluate the nutrient retention capacity of the water hyacinth co-composts are discussed in sections 5.4 and 5.5.

5.1. CHARACTERISATION OF WATER HYACINTH AND CO-SUBSTRATES

The water hyacinth and co-substrates were analysed for their chemical properties. Among the substrates, biochar registered highest pH of 9.68. It has been reported that biochar has an alkaline pH due to high pyrolysis temperature developed during the process of biochar preparation (Novak *et al.,* 2009). All the substrates had pH in the alkaline range except for saw dust, glyricidia and dried leaves. Results indicated that higher electrical conductivity was recorded by all the substrates except saw dust and cattle manure. Regarding the total nitrogen content, glyricidia ranked first with a total nitrogen content of 3.38 per cent. High nitrogen content in glyricidia and its utilization as green manure in alley cropping was established by Yamoah *et al.* (1986). Cattle manure and water hyacinth were also rich in nitrogen (1.89 and 1.61 % respectively). It is seen that total carbon content was high in biochar (64.52 %) and hence the C/N ratio (115.2 %). Sawdust also registered higher C/N ratio of 90.22. Glyricidia had the lowest C/N ratio of 10.19 per cent. Similar results were obtained by Beedy *et al.* (2010). Poultry manure registered the highest phosphorus (0.96 %) content among the substrates. Parker *et al.* (1959) reported that the phosphorus content in poultry manure was in the range of 1.00 to 1.69 per cent. Sawdust and dried leaves were poor in phosphorus content. The potassium content was more in biochar (3.83 %). The result was in consonance with the findings of Gopal *et al.* (2020). Water hyacinth and paddy straw also registered higher K.

Highest calcium and sulphur content were noticed in poultry manure (2.45 % and 0.26 % respectively). Glyricidia had the highest content of total magnesium (0.53%). Water hyacinth, biochar and cattle manure had comparable quantities of secondary nutrients *viz.*, Ca, Mg and S.

Data on micronutrient content showed that water hyacinth and poultry manure had high content of iron and manganese. Copper, Zn and boron contents were also higher in these two substrates. Highest content of zinc and manganese was registered by water hyacinth (95.2 and 929.65 mg kg^{-1}, respectively). Thampatti *et al.* (2007) reported that plants like *Hydrilla verticillata*, *Eichhornia crassipes* and *Cyperus pangora* showed hyper accumulation of heavy metals like Fe, Mn, Zn, Cu and Al. Indulekha (2018) opined that the order of accumulation of heavy metals in water hyacinth was in the order, Fe > Al > Mn >Zn>Cr> Ni>Co>Hg>Pb>As. Boron content was high in biochar and highest content of copper was recorded by cattle manure. All the substrates under study had higher micronutrient contents.

5.2. CHARACTERISTICS OF COMPOSTING MIXTURES DURING THE PERIOD OF COMPOSTING

5.2.1 Physical characteristics of composting mixtures

The major physical parameters such as moisture content and temperature were recorded at 20, 60, 100 days of composting.

5.2.1.1. Moisture content

Initially, all treatments were similar in their moisture content (66.67 % to 78 %) The data on moisture content of composting mixtures at 100 days revealed that there was significant reduction in the moisture content particularly for biochar treatment (47.87 %). Jain *et al.* (2019) reported that higher reduction in the moisture content was observed when biochar was added as co-substrate while composting water hyacinth. Moisture loss during the composting process can be taken as an index of decomposition

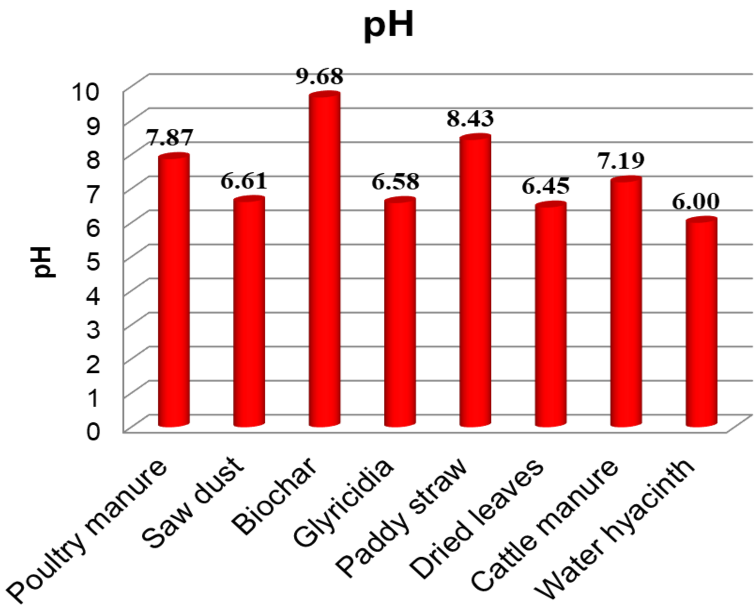


Fig.1. pH of water hyacinth and co-substrates

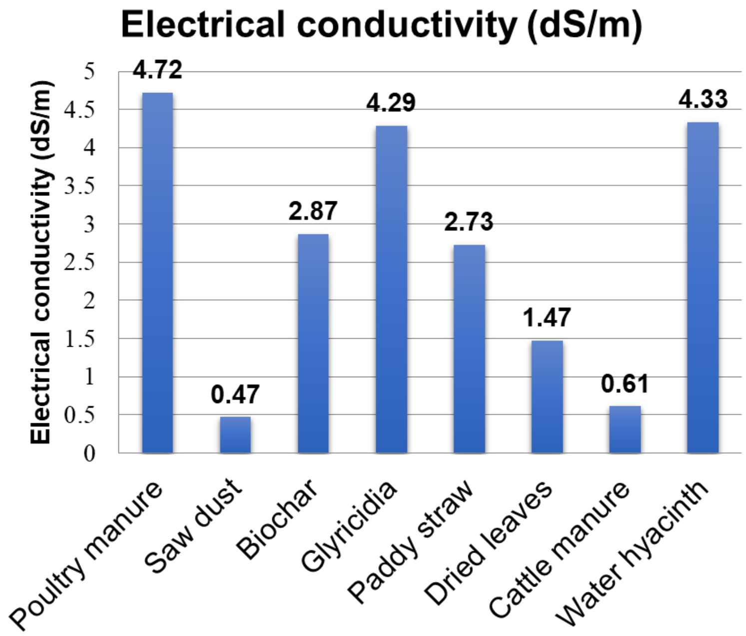


Fig.2. EC of water hyacinth and co-substrates

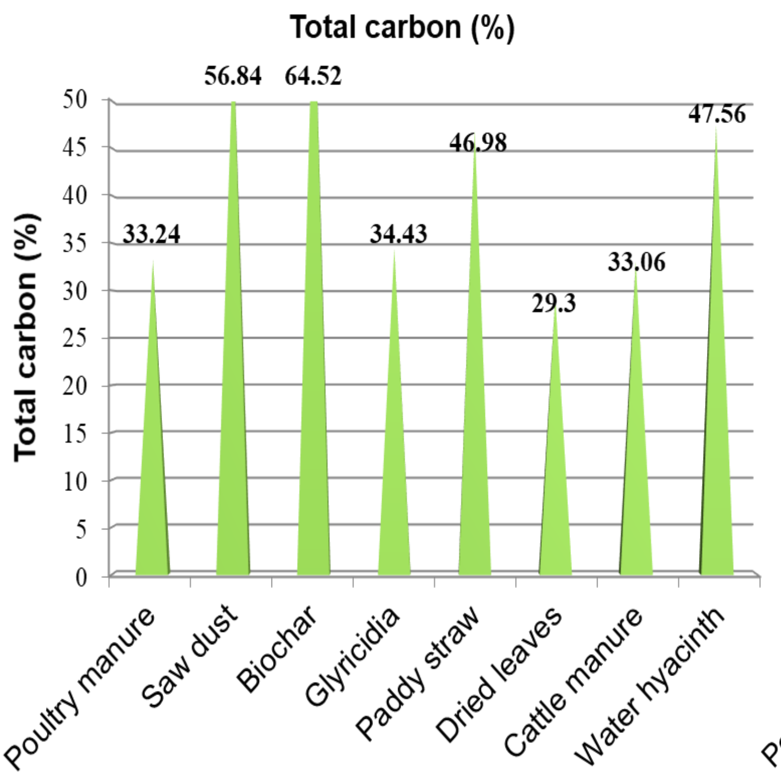


Fig.3 Total C content of water hyacinth and co-substrates

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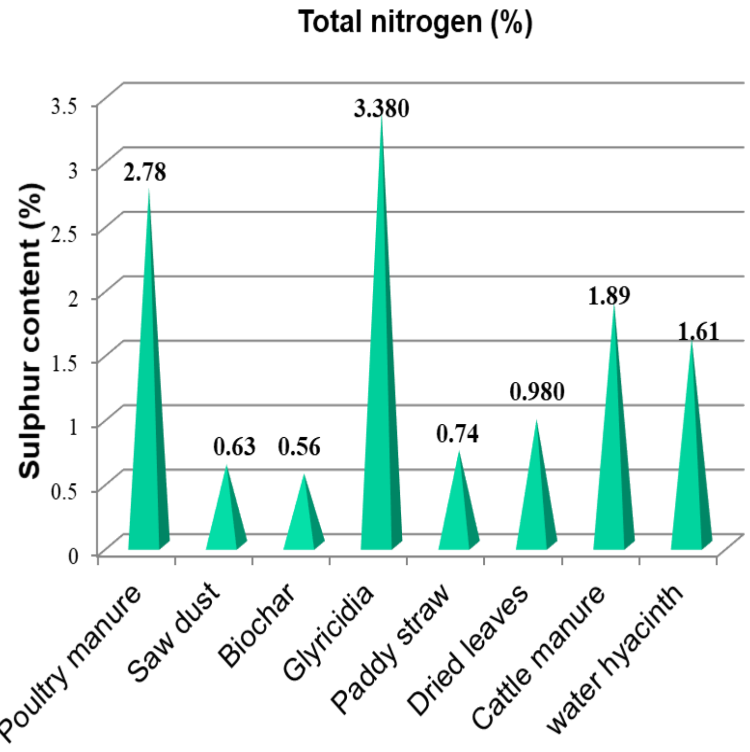

Fig.4 Total N content of water hyacinth and co-substrates

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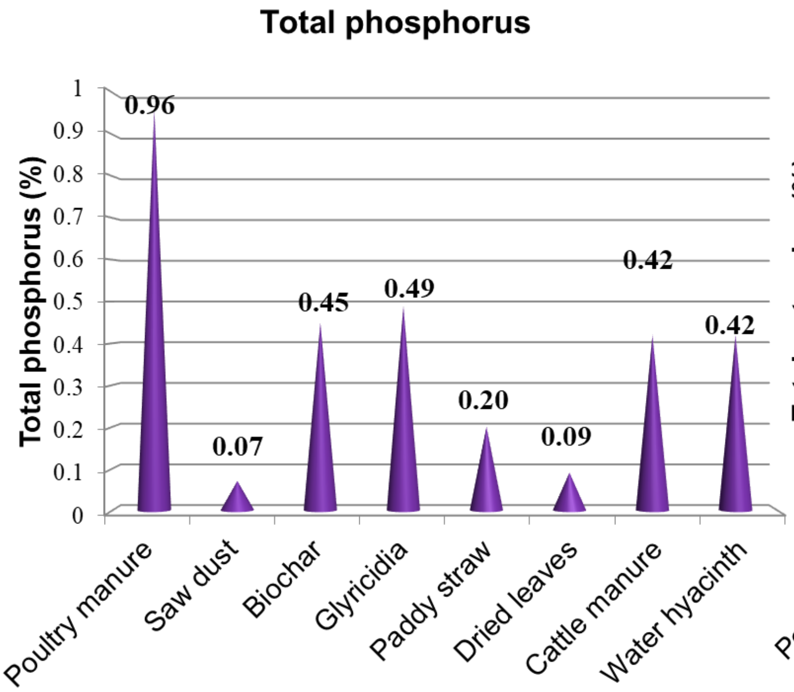

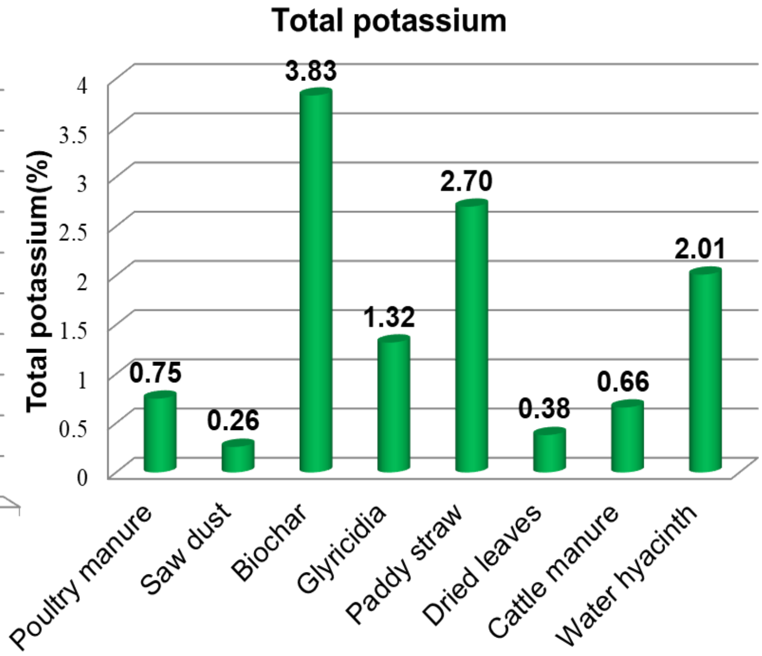

Fig.5 Total P content of water hyacinth and co-substrates

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Fig.6 Total K content of water hyacinth and co-substrates

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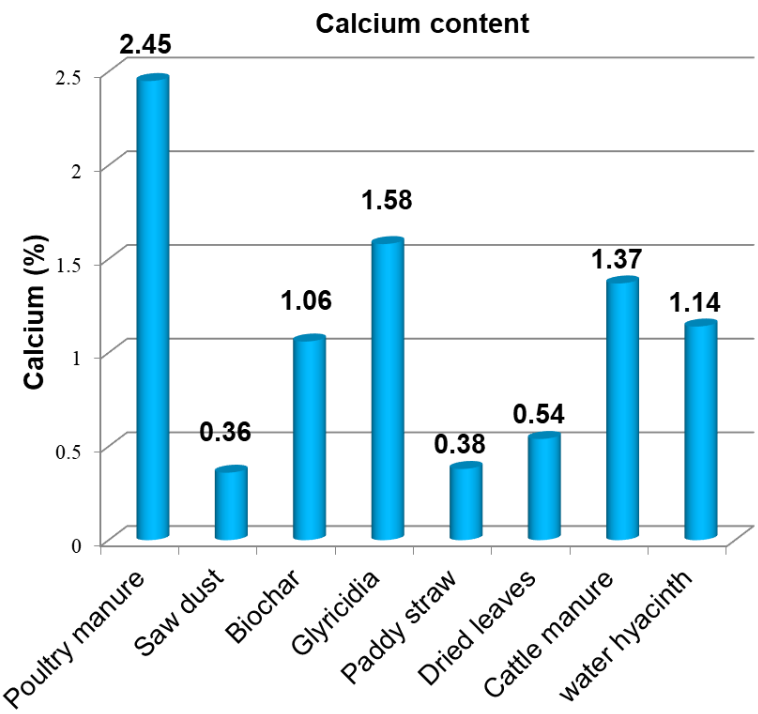

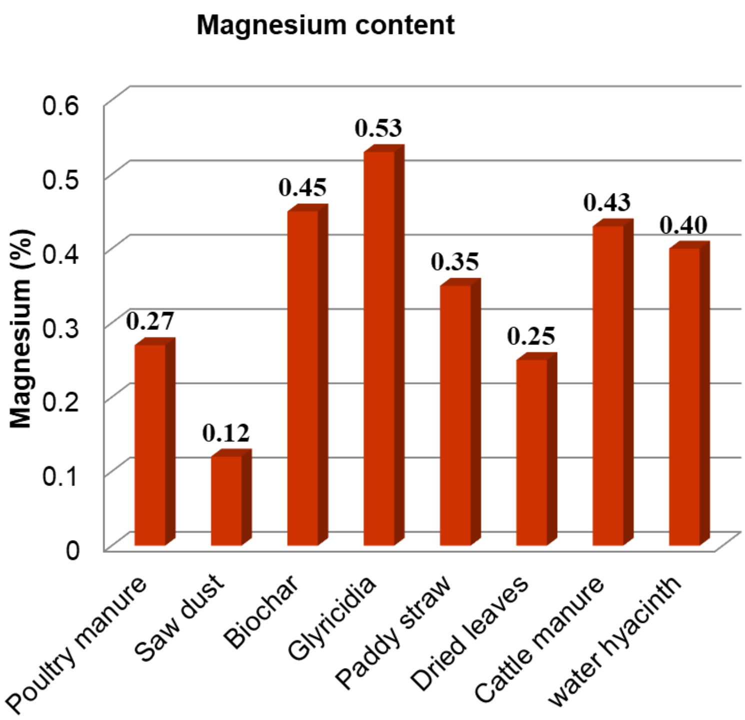

Fig.7 Total Ca content of water hyacinth and co-substrates

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Fig.8 Total Mg content of water hyacinth and co-substrates

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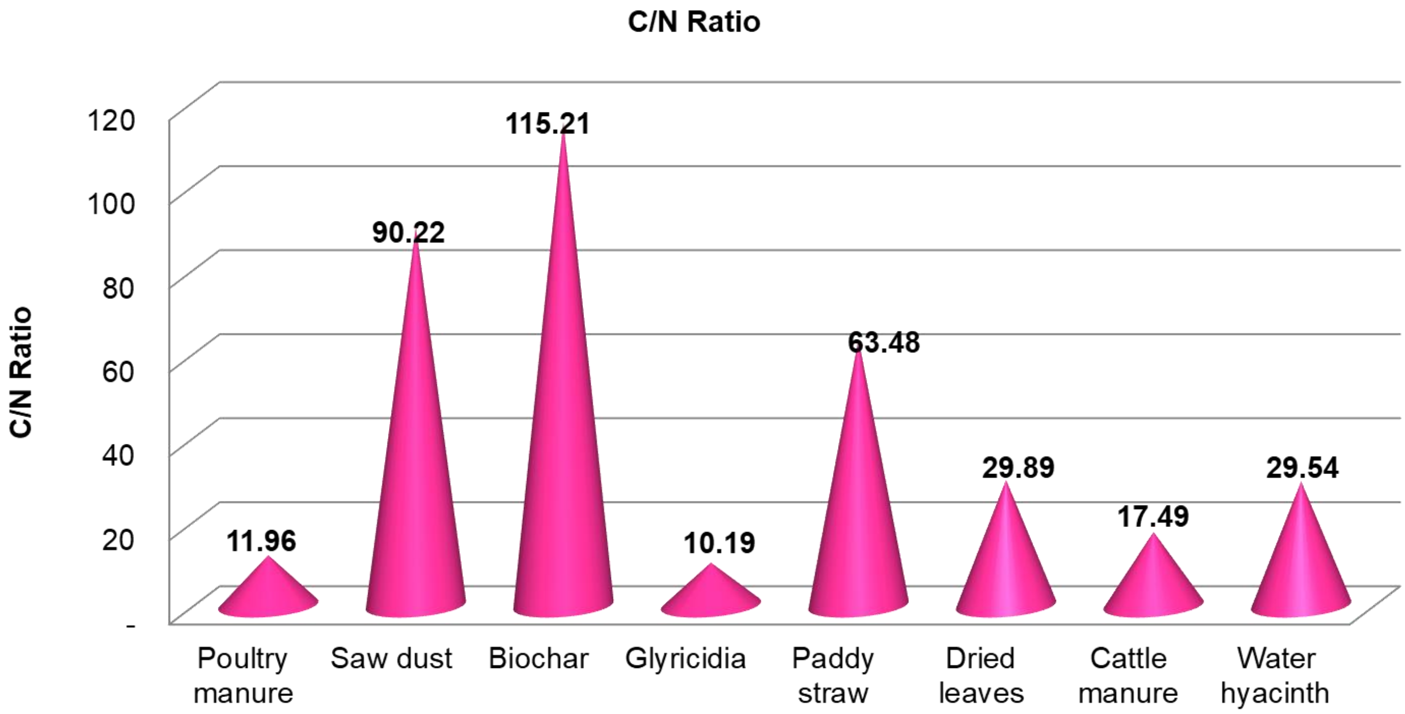

Fig.9 Carbon to nitrogen ratio of water hyacinth and co-substrates

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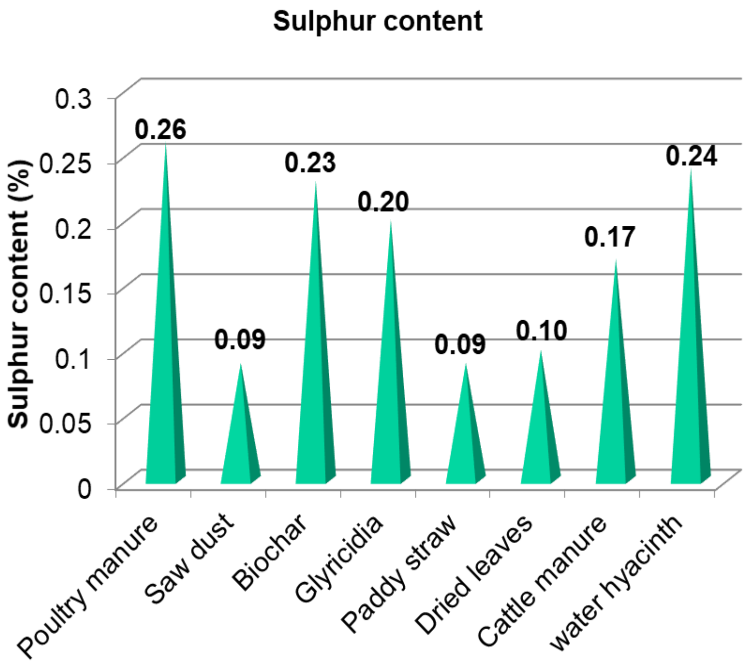

Fig.10 Total S content of water hyacinth and co-substrates

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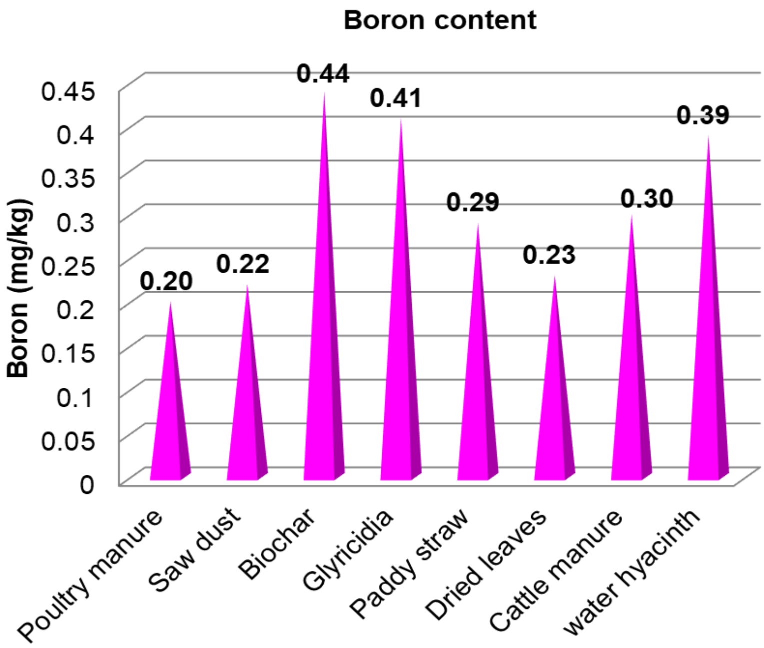

Fig.11 Total B content of water hyacinth and co-substrates

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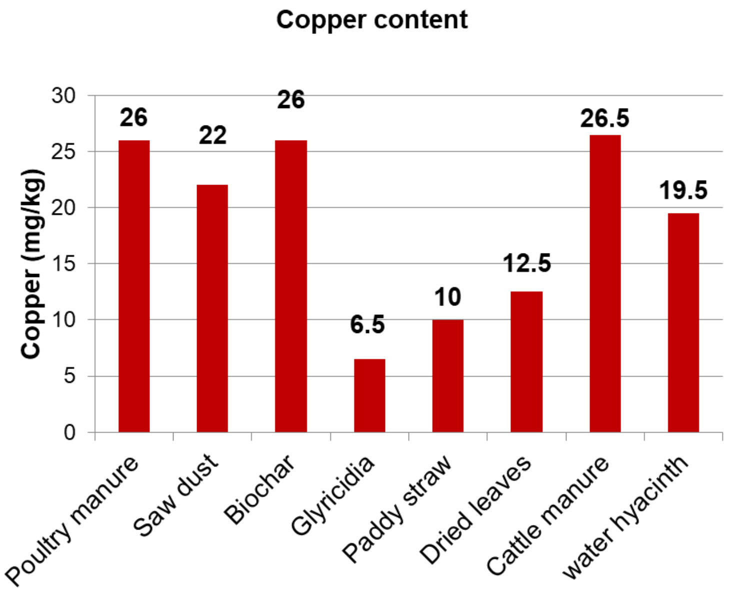

Fig.12 Total Cu content of water hyacinth and co-substrates

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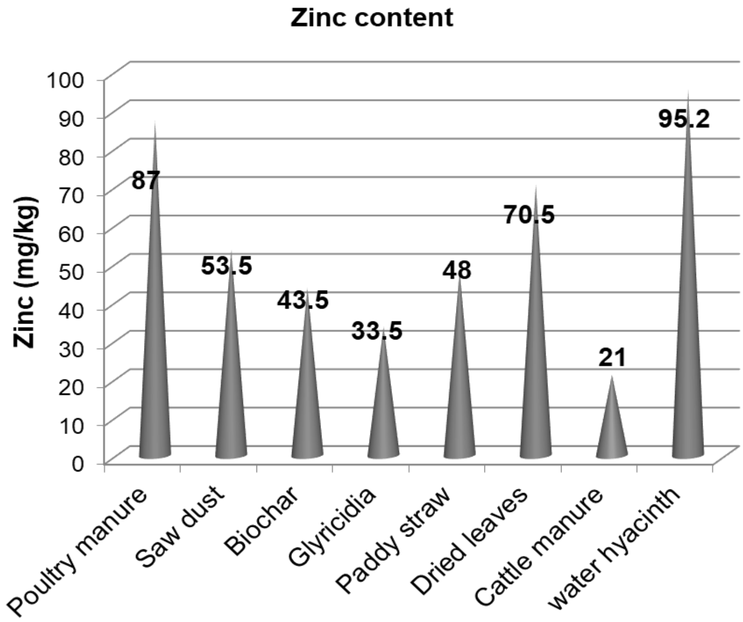

Fig.13 Total Zn content of water hyacinth and co-substrates

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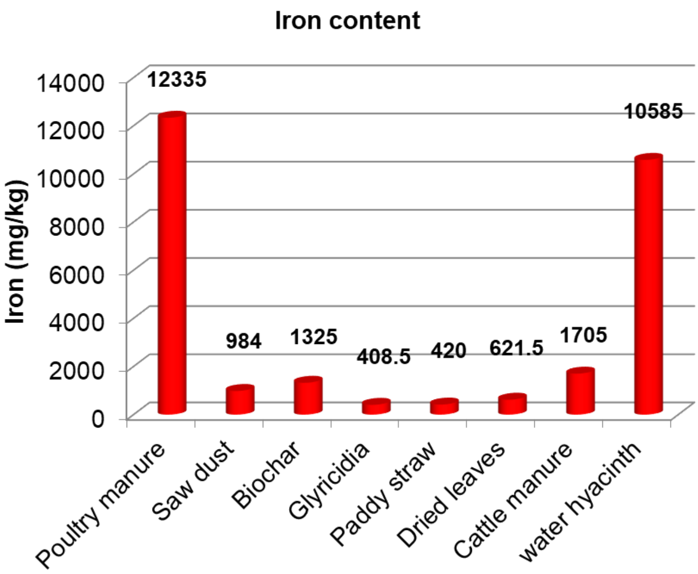

Fig.14 Total B content of water hyacinth and co-substrates

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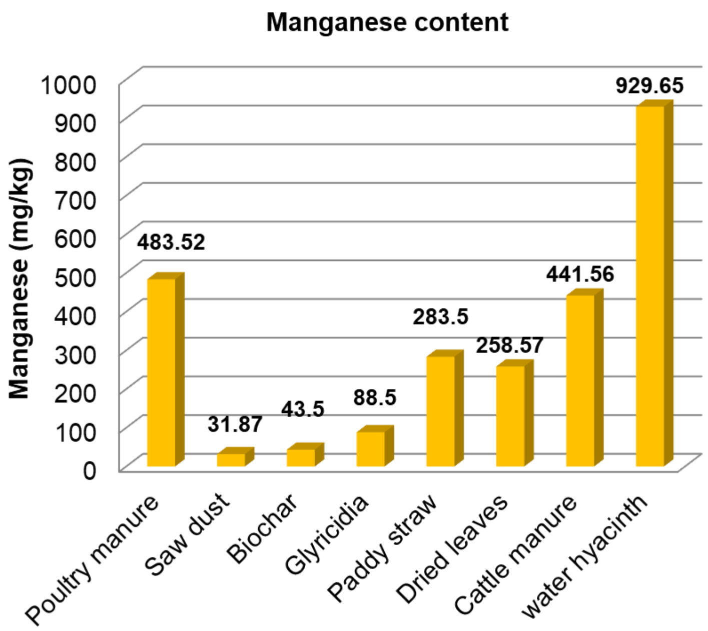

Fig.15 Total B content of water hyacinth and co-substrates

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rate, since heat generation during decomposition drives off the moisture from compost pits (Liao *et al.,* 1997).

5.2.1.2. Temperature

The temperature of the composting mixtures was monitored at 20, 60, 100 days of composting. There was significant variation noticed among the treatments. The temperature values ranged from 28.66^{0}C to 30.0^{0}C at 20 days, thereafter the same trend was noticed at 60 days. Temperature at 100 days was equivalent to ambient temperature, which indicated the stage of compost maturity. This trend was also observed by many researchers (Sharma *et al.,* 2014)

5.2.2. Chemical characteristics of composting mixtures

The major chemical characteristics of composting mixtures *viz.,* pH, EC and total nitrogen content were analysed at 20, 60, 100 days of composting.

5.2.2.1. pH

Initially, water hyacinth substrate had a pH of 6.00 only (acidic range). Dried leaves and glyricidia also had lower pH. However, during the periods of composting all the composting mixtures attained neutral to alkaline reaction.

At 20 days, the highest pH was recorded by the treatment T_5 (8.58) which was on par with the treatment T_3 (8.56). With the progress of composting, at 60 days, a slight reduction in pH was noticed in all the treatments except dried leaves. Reduction in pH could be attributed to the action of nitrifying bacteria, which lower the pH of the medium due to the liberation of hydrogen ions resulted in lower pH compared to start of the process (Sanchez-Monedero *et al.,* 2001). The pH of the composting mixtures was neutral to alkaline at the end of the process. It has been reported that as composting proceeds, the organic acids become neutralized and compost tends toward a neutral pH (Ko *et al.,* 2008). Increased aeration in the compost tanks by periodic turning will tend to decrease CO_2 levels in the composting mixtures, which in turn increase pH of the final compost (Haug, 1993). The highest pH was recorded by the treatment with paddy straw (8.58) which was followed by biochar treatment (7.80) and this may be due to the to mineralization of organic N to NH_4. The result was in consonance with the findings of Shukla *et al.* (2016).

5.2.2.2. Electrical conductivity

The data showed that EC values decreased considerably in the composting mixtures during the period of composting except for paddy straw treatment. Significantly higher values were recorded by the treatments with paddy straw and biochar (3.34 and 2.41 dS m^{-1}, respectively). Similar trend was noticed at 60 days of composting. Later at 100 days it was seen that treatment with paddy straw registered the highest EC of 4.05 dS m^{-1} and the lowest EC was shown by water hyacinth with sawdust co-compost. It has been reported that salt content of compost is due to the presence of sodium, chloride, potassium, nitrate, sulphate and ammonia salts (Brinton, 2003). Electrical conductivity of the final compost was the reflection of EC of component substrates except for the treatment with paddy straw. In the paddy straw treatment, there was an increase in the concentration of salts compared to the initial material due to the decomposition and consequent volume reduction. Addition of sawdust, biochar and dried leaves helped in the reduction of salt content in the final compost prepared from water hyacinth.

5.2.2.3. Total nitrogen content

Compared to the initial materials, nitrogen content of the composting mixtures was considerably lower. However, an increasing trend was noticed from the initial stage towards the final stages of composting. At 100 days more or less stable contents of total nitrogen was recorded in all treatments with highest content in water hyacinth-poultry manure co-compost (1.49 %) and lowest content was noticed in water hyacinth biochar co-compost (0.48%). The superiority in total nitrogen content of water hyacinth-poultry manure compost was also reported by many researchers (Beesigamukama *et al.,* 2018). The lowest nitrogen content in water hyacinth-biochar composting mixture was attributed to the volatilization losses of ammonia during the period of composting. Tiquia and Tam (2002) reported that the loss of N by NH_3 volatilization was significant at pH levels above 7.0. Even though the nitrogen content in the water hyacinth was reasonably high it has been reported that the nitrogen content of the final compost is more or less independent of the quantity of water hyacinth used in the composting mixture (Gupta *et al.*, 2007).

5.3. YIELD OF WATER HYACINTH CO-COMPOSTS

The compost yield was very low in the water hyacinth sole compost (14.11 %). The yield of co-compost followed the order biochar > dried leaves > poultry manure > sawdust>glyricidia>paddy straw>water hyacinth sole compost. Significantly higher recovery of compost (compost yield) was obtained when biochar was used as a co-substrate. Dried leaves also helped to improve the yield of water hyacinth co-compost (113.4 %) The extent of increase in the yield over water hyacinth sole compost ranged from 14.88 (paddy straw co-compost) to 159.7 per cent (biochar co-compost).

Percentage change in compost yield of water hyacinth co-composts with respect to control was worked out and given in table 5.1. Maximum increase in yield over control was observed in biochar co-compost (159.7 %) followed by dried leaves co-compost (113.4 %). All the co-composts showed an increased yield with respect to control.

5.4. CHARACTERISTICS OF WATER HYACINTH CO-COMPOSTS

The different water hyacinth co-composts were analysed for physical and chemical properties *viz.*, bulk density, porosity, pH, EC, CEC, carbon, total nutrients (N, P, K, Ca, Mg, Fe, Zn, Mn, S and B) and C/N ratio. The compost recovery per cent was also estimated. The results are discussed here under the following subsections.

5.4.1. Physical characteristics

5.4.1.1. Bulk density

Bulk density of majority of treatments was similar, the range being 0.85 to 0.89 Mg m^{-3} (Figure 5.1). Comparatively lower values were recorded by the treatments with biochar and saw dust (0.69 Mg m^{-1} and 0.83 Mg m^{-3}). These two substrates possessed low mass per unit volume due to the porous nature of the particles. Similar results were obtained by Shenbagavalli and Mahimairaja (2012). The results indicated that with the addition of co-substrates like biochar, an improvement of bulk density to an extent of 22.5 per cent over water hyacinth alone treatment. In any case addition of co-substrate decreased the bulk density of water hyacinth compost. It has been reported that biochar addition decreased the bulk density by 7.0 per cent in the initial feedstock (Jain *et al.*, 2019). Percentage change in bulk density of different treatments over control was assessed, the data indicated that the bulk density was reduced by co-composting. Percentage reduction was maximum in the treatment with biochar (-22.47 %) and no change was observed in dried leaves co-compost.

5.4.1.2. Porosity

Porosity indicates the volume of pore space in compost. Porosity of different water hyacinth co-composts are depicted in figure 5.2. Data on porosity of the treatments revealed that water hyacinth-biochar co-compost is highly porous in nature (66.11 %). This finding concurred with the result of Hernandez-Mena *et al*. (2014) when they studied the characteristics of different biochar. Porosity increased with decreasing bulk density (Ahn *et al.*, 2008) and was evident in water hyacinth-biochar co-compost and water hyacinth-sawdust co-compost. Jain *et al.* (2019) also noticed similar increase in porosity of composting mixture with biochar**.** The data on percentage change in porosity of different co-composts over control indicated that porosity of water hyacinth-biochar co-compost showed an increase in bulk density of 8.68 per cent, which was highest among the treatments (Table 5.1).

Table 5.1. Percentage change in yield and physical characteristics of water hyacinth co-composts with respect to control

Treatment	Compost yield	Bulk density	Porosity
	(%)*		
T1(W+P+M)	63.22	-1.12	0.39
T2(W+S+M)	61.94	-6.74	3.12
T3(W+B+M)	159.74	-22.47	8.68
T4(W+G+M)	37.56	-4.49	1.63
T5(W+PS+M)	29.06	-1.12	1.40
T6(W+D+M)	113.39	0.00	0.01

∗: percentage change with respect to T_7 (water hyacinth sole compost)

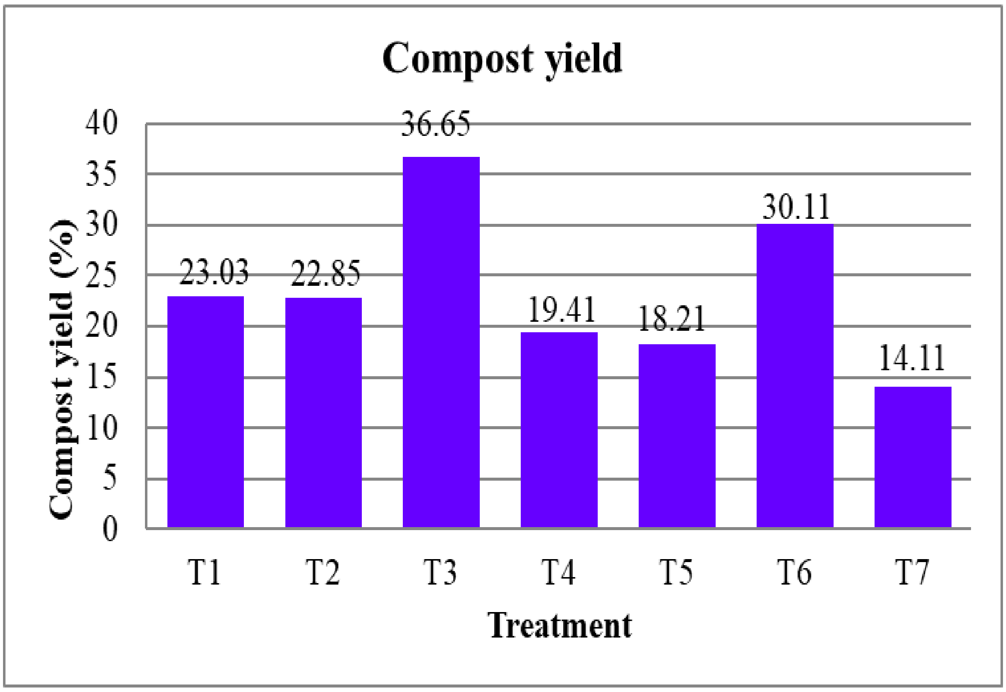

Fig.16 Yield of water hyacinth co-composts

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5.4.2. Chemical characteristics

5.4.2.1. pH

Data on pH of different treatments are presented in figure 5.3. Significantly higher pH was registered by water hyacinth paddy straw co-compost (8.63) which was followed by water hyacinth biochar co-compost (8.08). These two composts were alkaline in reaction. In the other two treatments pH was neutral, values ranging from 7.5 to 7.85. Arora and Kaur (2019) reported similar pH values for paddy straw compost when they composted paddy straw using microorganisms.

The percentage change in pH of different treatments over control was worked out and given in table 5.2. All the co-composts registered increased pH with respect to control and maximum increase was noticed in paddy straw co-compost and minimum increase was noted in sawdust co-compost.

5.4.2.2. Electrical conductivity

Significant differences were noticed in the electrical conductivity of final compost compared to that of composting mixtures (Figure 5.4). The EC value reflected the presence of salts in the compost, indicating its possible phytotoxic effects on the growth of plant if applied to soil (Huang *et al.,* 2004). Water hyacinth-paddy straw co-compost had the highest electrical conductivity (3.68 dS m^{-1}), since it contained higher quantity of salts compared to other substrates. The other treatments had EC values below the established critical limit for plant growth (3.00 dS m^{-1}) as reported by Lazcano *et al.* (2008). The decrease in EC compared to the initial value is due to humification. As humification proceeds, the free ions get complexed with humic fractions resulted in decreased electrical conductivity of final compost (Rao, 2007). The volatilization of ammonia and the precipitation of mineral salts could be the possible reasons for the decrease in EC at later phase of composting (Wong *et al.*, 1995).

Percentage variation in EC of different co-composts with respect to control was given in Table 5.2. Maximum increase in EC was observed for paddy straw co-compost (170.6 %) and was found unfavourable. Poultry manure co-compost and glyricidia co-compost also showed an increase in EC over control (27.94 and 38.97, respectively), but the values were within the permissible limit for plant growth. Electrical conductivity of rest of the co-composts showed a decrease over control and maximum reduction was noted in co-compost with sawdust (-63.97 %).

5.4.2.3. Total carbon

Water hyacinth co-composts recorded significant variation with respect to total carbon content. Two treatments *viz.,* water hyacinth-sawdust co-compost and water hyacinth biochar co-compost registered superior values among the treatments (40.17 and 38.66 %, respectively). In the other treatments the content of carbon was decreased as a result of microbial decomposition of organic matter and subsequent release of C as CO_2. It has been reported that part of the carbon in the decomposing organic residues evolved as CO_2 and a part was assimilated by the microbial biomass (Cabrera *et al.,* 2005). Total carbon content of final compost (water hyacinth co-compost) was dependent upon the co-substrate added to the composting mixture. Water hyacinth alone treatment had the lowest total carbon content in the final compost. The results concurred with the findings of Singh and Kalamdhad (2013).

Data on percentage change in total carbon content of water hyacinth co-composts with respect to control (Table 5.2.) indicated that total carbon content was increased in all treatments and was highest in treatment with sawdust (157 %) followed by biochar treatment (147.4 %).

5.4.2.4. Total nitrogen

Highest nitrogen content was registered in water hyacinth poultry manure co-compost (1.59 %). Similar result was obtained in the study conducted by Beesigamukama *et al.* (2018). This is due to the higher content of nitrogen in poultry manure. Nitrogen content in water hyacinth-paddy straw co-compost was also reasonably high (1.33 %). This was attributed to net loss of organic matter as CO_2 during organic matter decomposition. Initial characterization of the substrates indicated that nitrogen was high in glyricidia (3.38 %) but the mineralization and subsequent leaching of N during the composting process resulted in a reduction in nitrogen content of final compost (1.16 %). The results match with the findings of Sierra *et al.,* (2013), during the vermi composting of green manures with cattle dung.

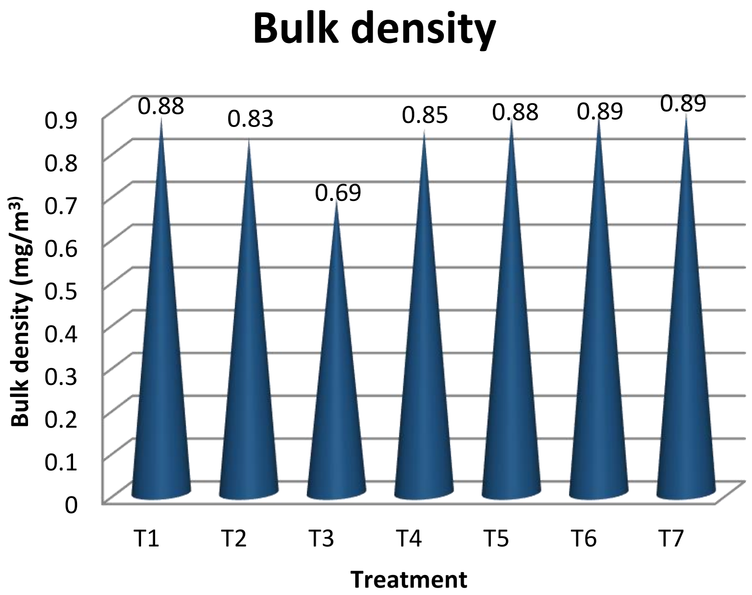

Fig.17 Bulk density of water hyacinth co-composts

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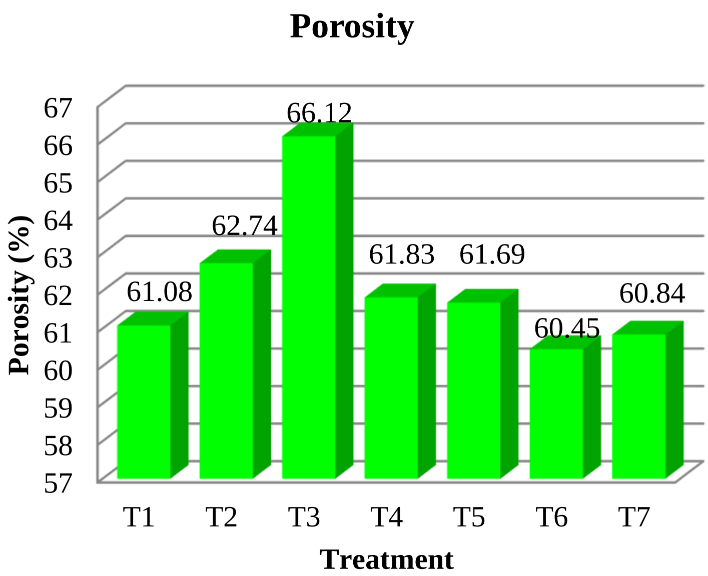

Fig.18 Porosity of water hyacinth co-composts

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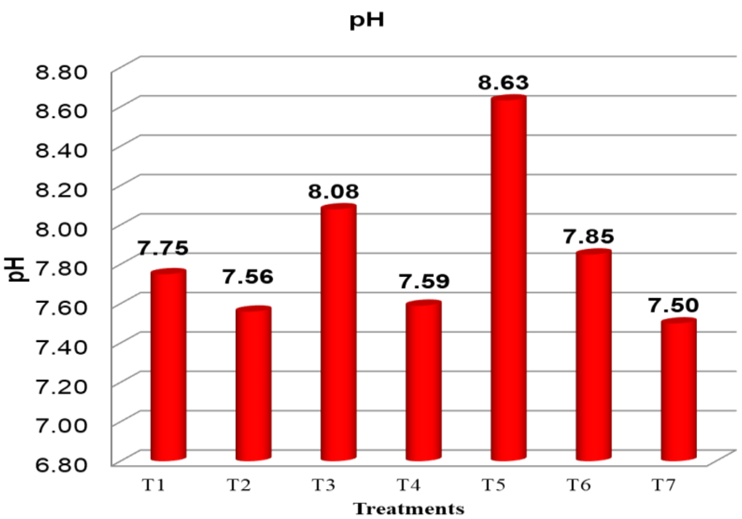

Fig.19 pH of water hyacinth co-composts

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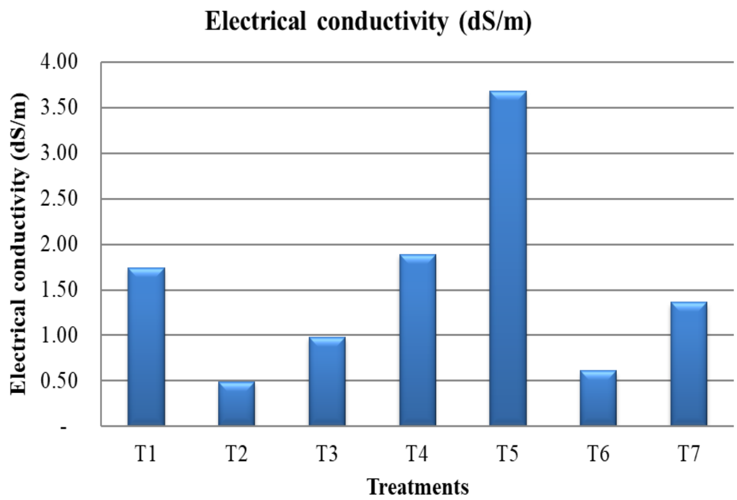

Fig.20 EC of water hyacinth co-composts

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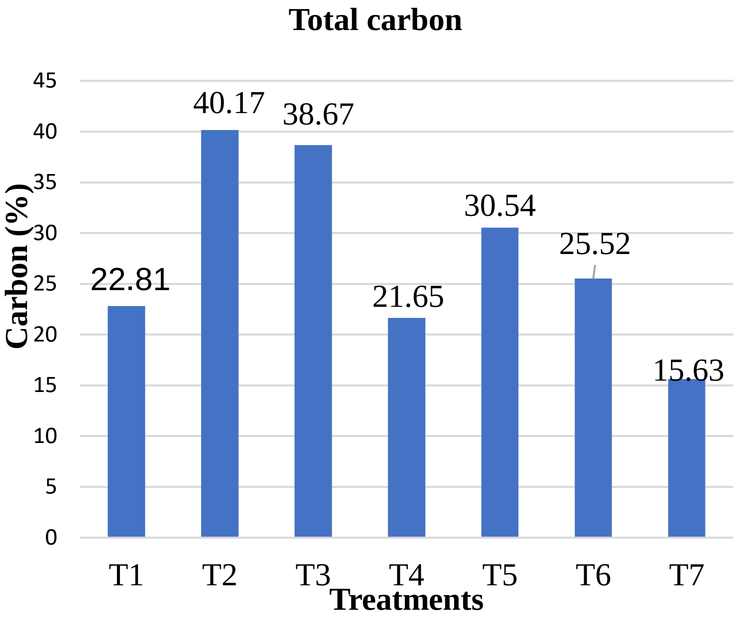

Fig.21 Total C content of water hyacinth co-composts

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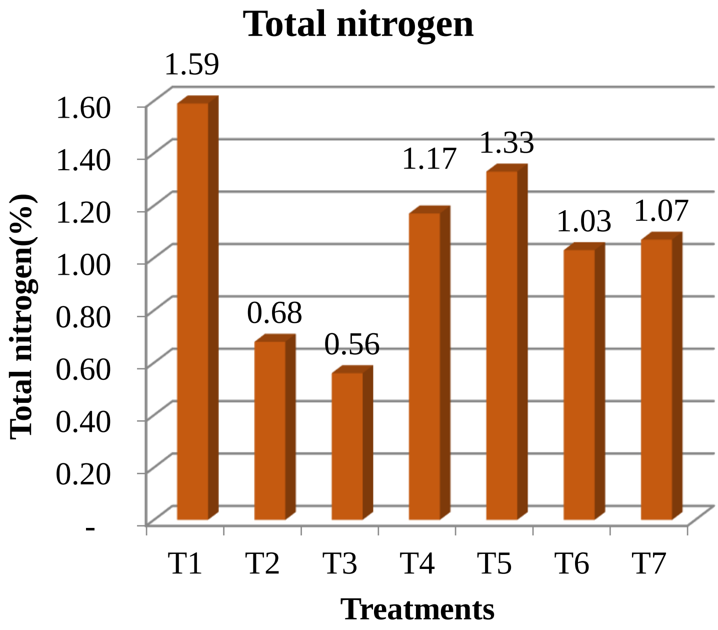

Fig.22 Total N content of water hyacinth co-composts

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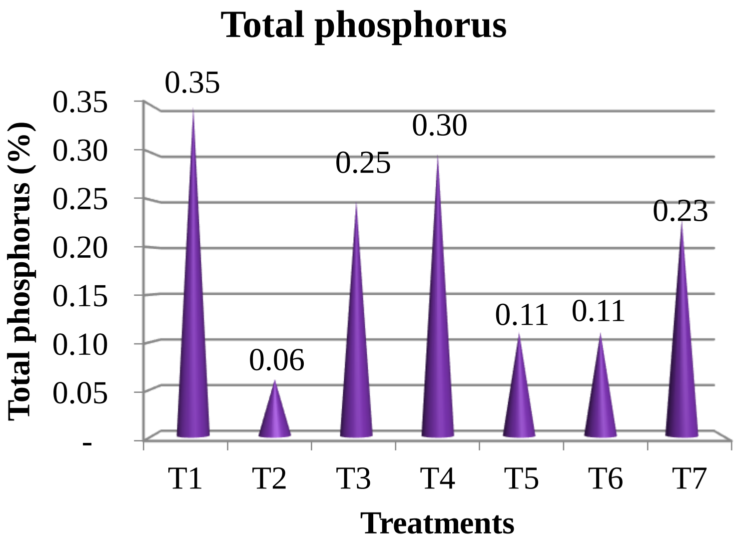

Fig.23 Total P content of water hyacinth co-composts

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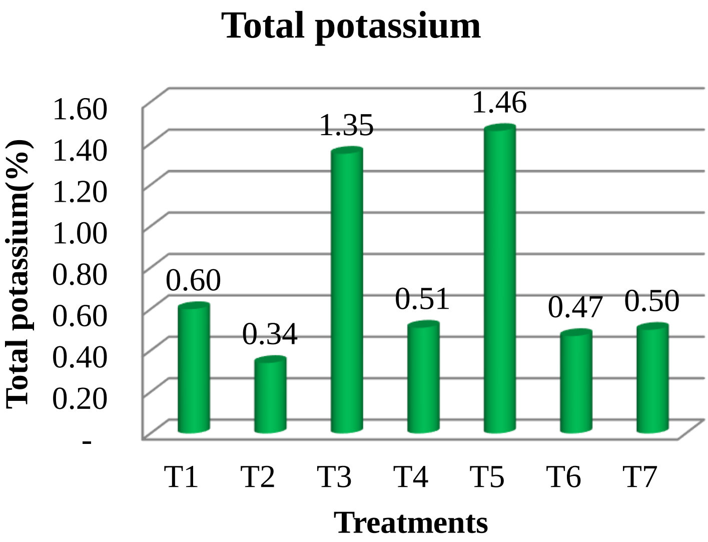

Fig.24 Total K content of water hyacinth co-composts

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Percentage change in total nitrogen content of water hyacinth co-composts over control is given in table 5.2. An increase in nitrogen content was observed in treatments with poultry manure (48.60 %), paddy straw (24.30 %) and glyricidia (9.35 %). Reduction in nitrogen content was noted in rest of the treatments with maximum reduction in biochar co-compost (-47.66 %).

5.4.2.5. Total phosphorus

The total phosphorus content was high in water hyacinth-poultry manure co-compost (0.35 %) and was due to the high content in the initial substrate (poultry manure). Phosphorus content was significantly lower in all the other treatments which was in accordance with the original P content of the co-substrates added.

Data on percentage change in phosphorus content of water hyacinth co-composts over control was worked out and given in table 5.2. Highest improvement was noted in poultry manure co-compost (52.17 %) and maximum reduction was observed in treatments with paddy straw and dried leaves co-composts (-52.17 %).

5.4.2.6. Total potassium

Water hyacinth paddy straw co-compost had the highest potassium content (1.46 %) among the treatments. Dobermann and Fairhurst (2002) reported that about 80.00 to 85.00per cent of the potassium taken up by rice remains in vegetative plant parts at crop maturity and the content of potassium was in the range of 1.4-2.0 per cent of K_2O per unit quantity of dry matter, but by incorporating raw paddy straw in the field, high C: N ratio in paddy straw sometimes results in initial nutrient starvation for plants (Sarkar *et al.*, 2017). Hence co-composting with water hyacinth improved the potassium use efficiency of paddy straw as an organic fertilizer. Co-composting with biochar also improved the potassium content of water hyacinth compost. Differences in the potassium content of water hyacinth-biochar co-compost and water hyacinth paddy straw co-compost could be attributed to the higher rate of decomposition of paddy straw compared to biochar.

The percentage change in potassium content of water hyacinth co-composts over control was comparatively higher in co-compost with paddy straw (192.00 %), followed by biochar co-compost (170.00 %). Maximum reduction was noted in co-compost with sawdust (-32.00 %).

5.4.2.7. Total calcium

Highest calcium content was noticed in the co-compost with poultry manure (1.77 per cent) and lowest was noticed for saw dust (0.76 %). Boateng *et al.* (2006) observed high content of calcium (3.6 %) in poultry manure in a study involved assessment of effect of poultry manure on growth and yield of maize. The percentage variation in total calcium content of water hyacinth co-composts with respect to control treatment is given in table 5.3. Maximum improvement was observed in poultry manure co-compost (43.90 %) and minimum was noted in paddy straw co-compost (-33.33 %).

5.4.2.8. Total magnesium

The total magnesium content of the treatments indicated the influence of magnesium content in co-substrates. The highest magnesium content was registered by water hyacinth poultry manure co-compost (0.58 %) and lowest content was noticed in water hyacinth-sawdust co-compost (0.20 %). Among the treatments, only the poultry manure co-compost registered percentage increase in phosphorus content with respect to control (38.09 %).

5.4.2.9. Total sulphur

The data on total sulphur content indicated the superiority of water hyacinth-poultry manure co-compost among the treatments (0.32 %). The result was a reflection of high total sulphur content in poultry manure as a co-substrate. Sulphur content of water hyacinth compost could be improved by adding poultry manure as co-substrate.

Percentage increase in total sulphur content with respect to control was realized in poultry manure co-compost and glyricidia co-compost (68.42 and 10.53 %, respectively). All other treatments showed a reduction in total sulphur content compared to control and maximum reduction was noticed in sawdust co-compost (-57.89 %)

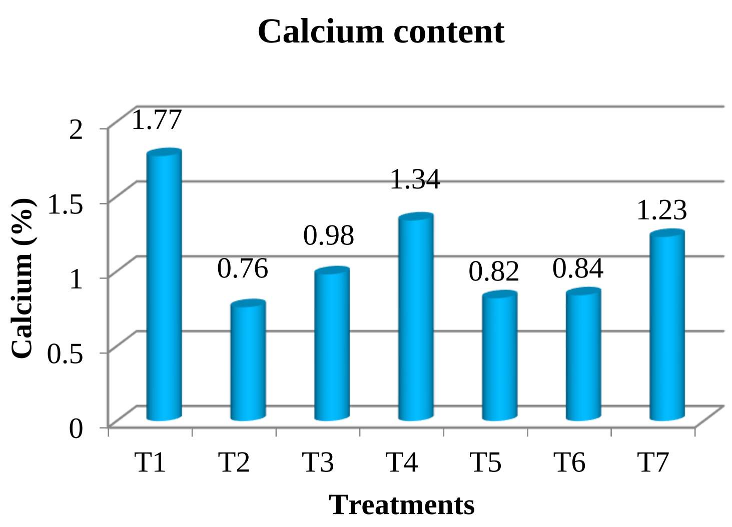

Fig.25 Total Ca content of water hyacinth co-composts

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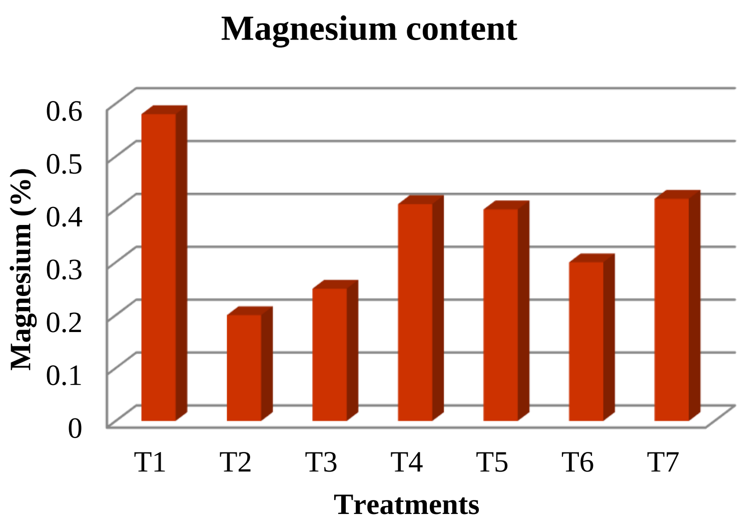

Fig.26 Total Mg content of water hyacinth co-composts

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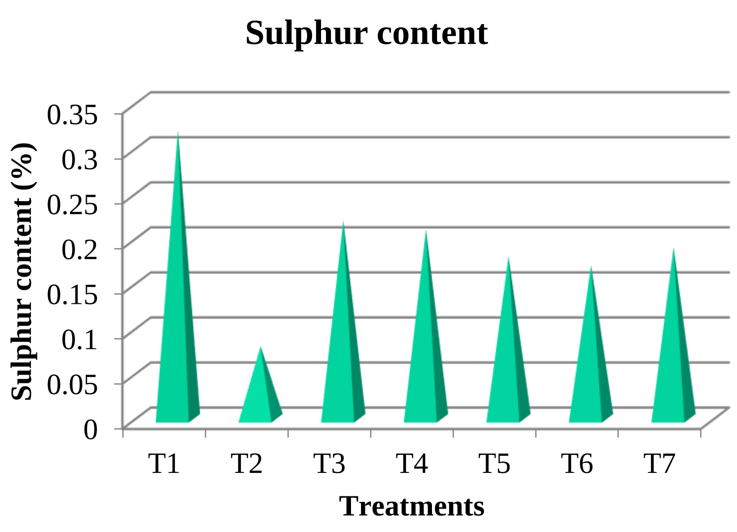

Fig.27 Total S content of water hyacinth co-composts

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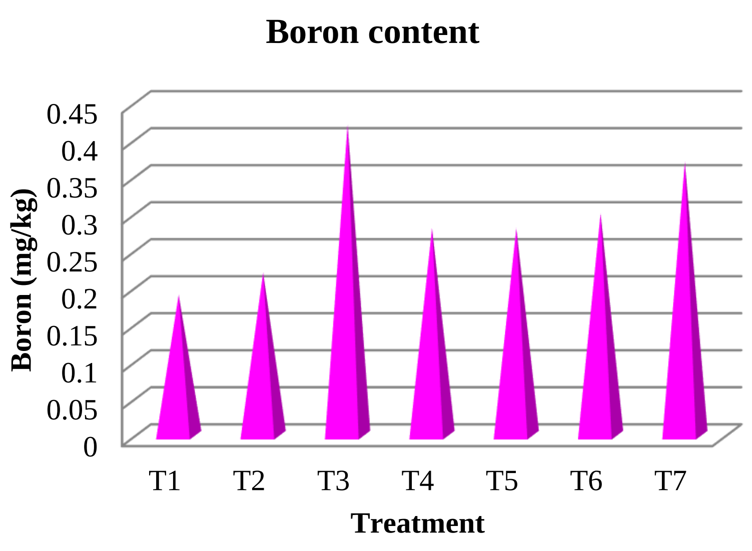

Fig.28 Total B content of water hyacinth co-composts

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Table 5.2. Percentage change in chemical characteristics of water hyacinth co-composts with respect to control (T_7)

Treatment	pH	EC	Total C	Total N	Total P	Total K	C/N	CEC
	(%)*							
T1(W+P+M)	3.33	27.94	45.94	48.60	52.17	20.0	-1.64	-28.13
T2(W+S+M)	0.80	-63.97	157.0	-36.45	-73.91	-32.0	307.8	3.65
T3(W+B+M)	7.73	-27.94	147.4	-47.66	8.70	170.0	373.0	0.36
T4(W+G+M)	1.20	38.97	38.52	9.35	30.43	2.00	26.78	1.20
T5(W+PS+M)	15.11	170.59	95.39	24.30	-52.17	192.0	57.33	-1.83
T6(W+D+M)	4.67	-55.15	63.28	-3.74	-52.17	-6.0	70.0	-1.41

*: percentage change with respect to T_7 (water hyacinth sole compost

5.4.2.10. Total copper

Data on total copper content in the different co-composts indicated that water hyacinth co-compost registered copper contents in consonance with that in co-substrates. However, the treatments with poultry manure (T_1), biochar (T_3) and water hyacinth alone (T_7) had significantly higher contents of copper, the values were 34.83, 27.50, 25.50 mg/kg. Among the treatments water hyacinth-glyricidia co-compost and water hyacinth paddy straw co-compost registered relatively lower content of copper.

Percentage change in total copper content of different co-composts with respect to control was estimated and given in table 5.4. The total copper content increased by an extent of 36.59 per cent in poultry manure co-compost and maximum reduction in copper content was noted in paddy straw co-compost (-64.71 %).

5.4.2.11. Total zinc

Among the treatments, water hyacinth poultry manure co-compost registered higher zinc content, which indicates the influence of zinc content of co-substrate ie. poultry manure. All the treatments had substantially good content of zinc in the finished product.

Percentage increase in total zinc content with respect to control was observed in all co-composts irrespective of treatments (Table 5.4.). Poultry manure co-compost had the highest percentage increase in zinc content (51.17 %) followed by dried leaves co-compost (34.66 %), sawdust co-compost (21.17 %), paddy straw co-compost (17.74 %), biochar co-compost (16.31 %) and glyricidia co-compost (7.18%).

5.4.2.12. Total manganese

The superiority in manganese content of water hyacinth alone compost was the reflection of high Mn content in the water hyacinth. The result agrees with the finding of Beegum (2016), which indicated that water hyacinth is an excellent phytoextractor of heavy metals and their content in water hyacinth followed the order Fe>Mn >Al>Zn>Cr>Cu>Pb. Reduction in manganese content with respect to control was observed in all the treatments. Maximum percentage reduction was noticed in water hyacinth-sawdust co-compost (-51.78 %).

5.4.2.13. Total iron

The treatment with poultry manure recorded high iron content (10801mg kg^{-1}) followed by water hyacinth alone treatment (10412 mg kg^{-1}). The influence of iron content of substrates viz., poultry manure and water hyacinth were reflected in the results. Poultry manure likely to contain micronutrient food supplement of the birds which would contribute towards the high iron content of the substrate. Water hyacinth was proved to be a good iron extractor in Kole land ecosystems of the state as reported by Indulekha (2018) and accumulation of heavy metals in water hyacinth was in the order, Fe > Al > Mn >Zn >Cr > Ni >Co >Hg >Pb >As. Percentage reduction in iron content compared to control was observed in all the treatments except poultry manure co-compost (3.74 %).

5.4.2.14. Total Boron

Total boron content in the water hyacinth co-composts was in accordance with the boron content of different substrates. Significantly higher levels of boron were noticed in water hyacinth biochar co-compost and water hyacinth sole compost (0.42 mg kg^{-1} and 0.37 mg kg^{-1}). The lowest content of boron was noticed in water hyacinth poultry manure co-compost (0.19 mg kg^{-1}). Boron content in poultry manure depend on the boron content of the feed supplement of birds as noticed by Kucharski and Białecka (2019). This indicated that low boron content of poultry manure co-compost was due to the boron deficient feeds given to the birds in the poultry farm from where the manure was collected for composting. The percentage reduction in total boron content was noticed in all the treatments except for water hyacinth-biochar co-compost (13.51 %).

5.4.2.15. CEC

The CEC was lowest in poultry manure (34.23 cmol (+) kg^{-1}) and highest in sawdust (49.37 cmol (+) kg^{-1}). The highest CEC of sawdust compost is due to the presence of functional groups. The results concurred with the findings of Lim *et al.* (2008).

Data on percentage change in CEC with respect to control is given in table 5.2. Percentage increase in CEC was observed in treatments with biochar (3.65 %), glyricidia (1.20 %) and biochar (0.36 %). The percentage reduction was maximum for poultry manure co-compost (-28.13 %).

5.4.2.15 Carbon to nitrogen ratio

The treatment with biochar recorded highest C/N ratio (69.06 %). This was in concurrence with the carbon content in the initial substrate. The treatment with sawdust also recorded high C/N ratio compared to the rest of the treatments (59.54 %). The carbon to nitrogen ratio was significantly lower in the treatment with poultry manure (14.35 %) as well as in water hyacinth sole compost (14.60 %). The reduction in C/N ratio is attributable to the organic matter decomposition and loss of carbon as CO_2. The results agree with the findings of Goyal et al. (2005).

Data on percentage change in C/N ratio with respect to control is given in table 5.2. Percentage increase in C/N ratio was maximum for water hyacinth-biochar co-compost (373 %) and reduction by a magnitude of -1.64 per cent was noticed for poultry manure co-compost.

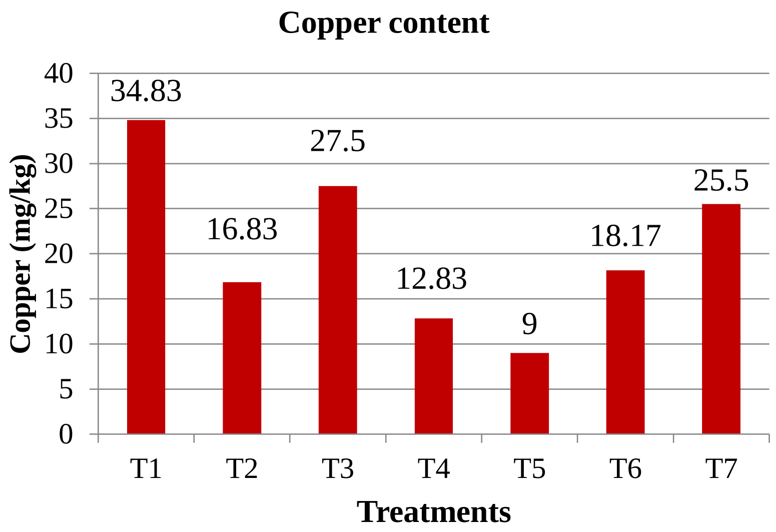

Fig.29 Total Cu content of water hyacinth co-composts

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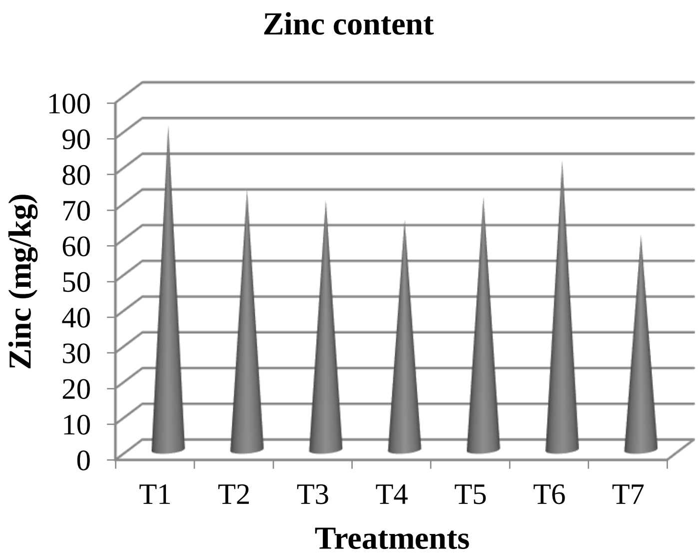

Fig.30 Total Zn content of water hyacinth co-composts

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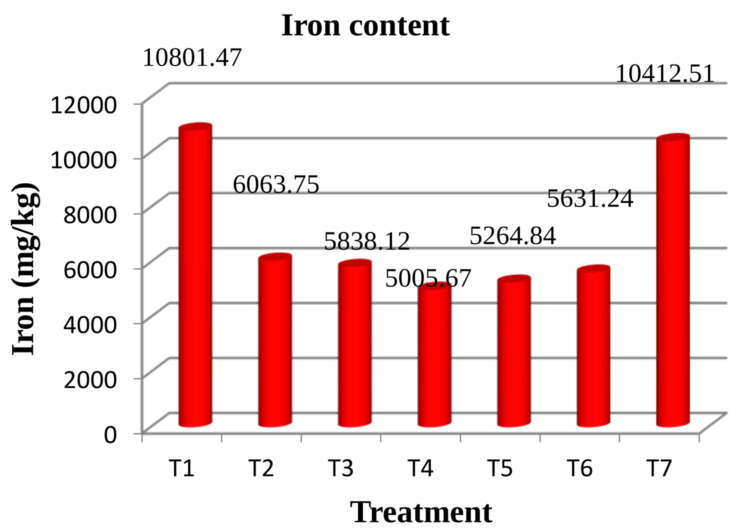

Fig.31 Total Fe content of water hyacinth co-composts

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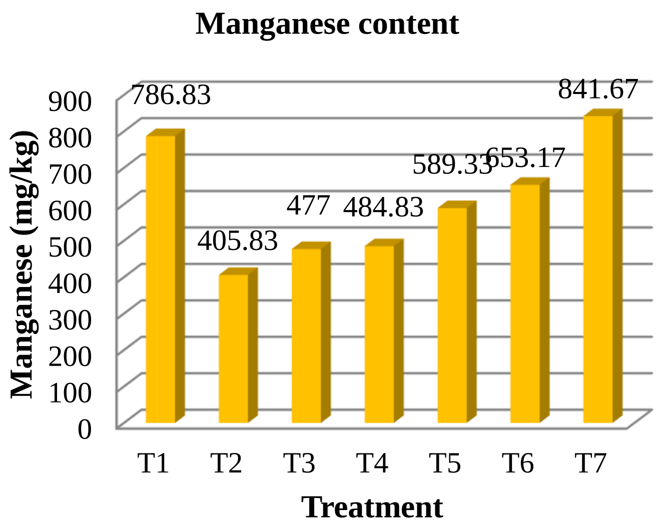

Fig.32 Total Mn content of water hyacinth co-composts

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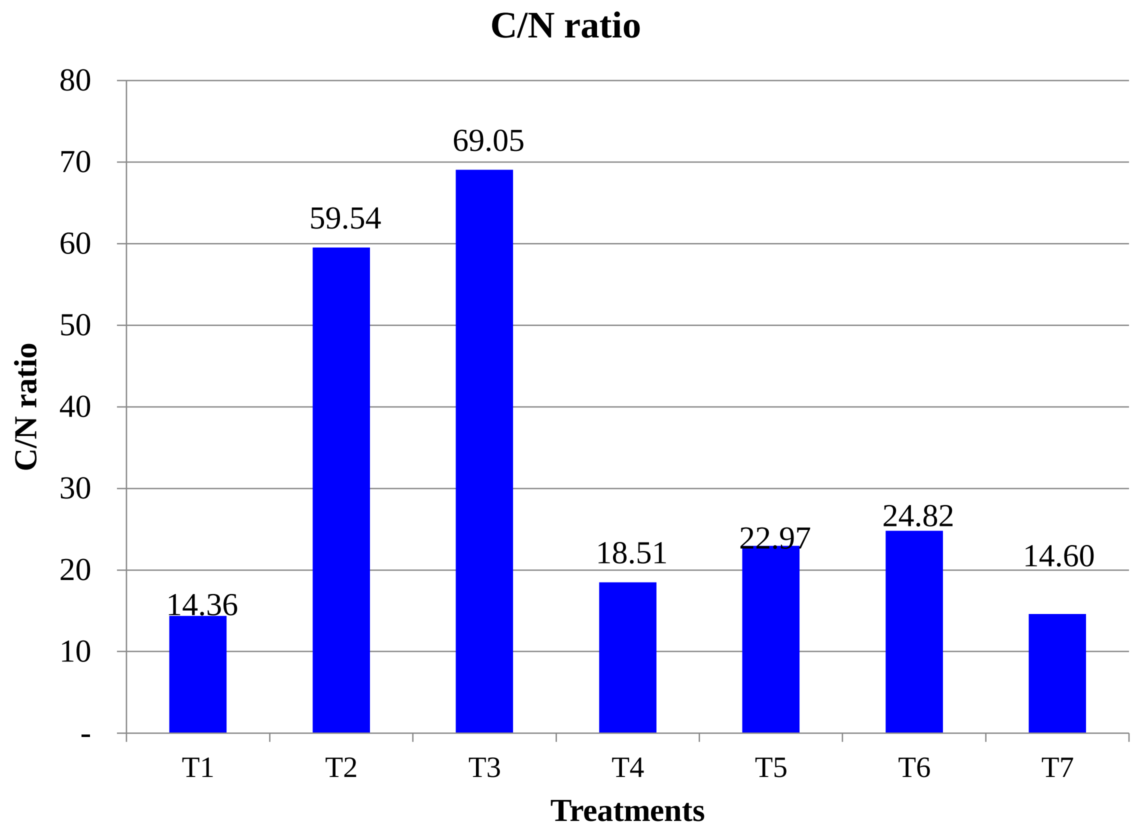

Fig.33 Carbon to nitrogen ratio of water hyacinth co-composts

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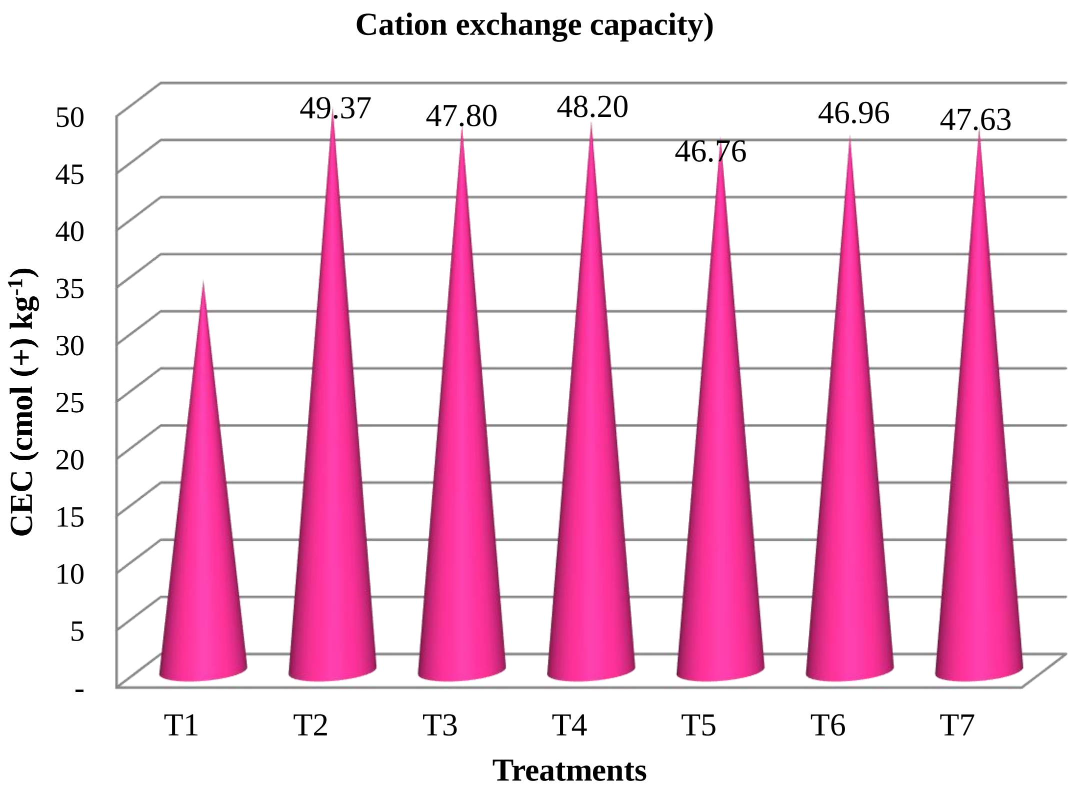

Fig.34 Cation exchange capacity of water hyacinth co-composts

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Table 5.3. Percentage change in secondary nutrient contents of water hyacinth co-composts with respect to control (T_7)

Treatment	Ca	Mg	S
	(%)*		
T1(W+P+M)	43.90	38.09	68.42
T2(W+S+M)	-38.21	-52.38	-57.89
T3(W+B+M)	-20.32	-40.47	15.79
T4(W+G+M)	8.94	-2.38	10.53
T5(W+PS+M)	-33.33	-4.76	-5.26
T6(W+D+M)	-31.71	-28.57	-10.52

*: percentage change with respect to T_7 (water hyacinth sole compost)

Table 5.4. Percentage change in micronutrient contents of water hyacinth co-composts with respect to control (T_7)

Treatment	Cu	Zn	Fe	Mn	B
	(%)*				
T1(W+P+M)	36.59	51.17	3.74	-6.52	-48.65
T2(W+S+M)	-34.00	21.17	-41.76	-51.78	-40.54
T3(W+B+M)	7.84	16.31	-43.93	-43.33	13.51
T4(W+G+M)	-49.69	7.18	-51.93	-42.40	-24.32
T5(W+PS+M)	-64.71	17.74	-49.44	-29.98	-24.32
T6(W+D+M)	-28.75	34.66	-45.92	-22.40	-18.92

*: percentage change with respect to T_7 (water hyacinth sole compost)

Table 5.5. Influence of co-substrates on the quality of water hyacinth co-composts

Sl.No.	Co-substrate	Yield	Bulk Density	Porosity	pH	EC	C	N	C/N	P	K	CEC	Ca	Mg	S	Cu	Zn	Fe	Mn	B
1.	Poultry manure	+	+	+	+	**0**	+	+	+	+	+	-	+	+	+	+	+	+	-	-
2.	Saw dust	+	+	+	+	+	+ +	-	- - -	-	-	+	-	-	-	-	+	-	-	-
3.	Biochar	+ +	+	+	+	+	+ +	-	- - -	+	+ +	+	-	-	+	+	+	-	-	+
4.	Gliricidia	+	+	+	+	**0**	+	+	-	+	+	+	+	-	+	-	+	-	-	-
5.	Paddy straw	+	+	+	+	- -	+	+	-	-	+ +	-	-	-	-	-	+	-	-	-
6.	Dried leaves	+ +	**0**	**0**	+	+	+	-	-	-	-	-	-	-	-	-	+	-	-	-

0: no change +/-: 1-100 percentage change + +/- -: 100-200 percentage change - - -: 200-300 percentage change

5.4. EVALUATION OF NUTRIENT RETENTION CAPACITY OF DIFFERENT WATER HYACINTH CO-COMPOSTS

Nutrient retention capacity of soil amended with water hyacinth co-composts was estimated at 7, 14, 21, 28 days of incubation and results of the same are discussed here under the following subsections. It has been reported that co-composts releases nutrients at a slow rate by microbially mediated mineralization process and make it less susceptible to large nutrient losses during a single rain event (Guster *et al*., 2005). Hagemann *et al.* (2017) reported that a complex, nutrient-rich organic coating on co-composted biochar adds hydrophilicity, redox-active moieties, and additional mesoporosity, which strengthens biochar water interactions and thus enhances nutrient retention. It was clear from the results that compost amendment improved nutrient retention capacity of lateritic soil under study.

5.4.1. Nitrogen retention capacity

Nitrogen retention capacity of soil samples amended with different water hyacinth co-composts is presented in fig.5.19. All the treatments improved nitrogen retention capacity of lateritic soil. The treatments T_1, T_2, T_3, T_4, T_5, T_6 and T_7 retained nitrogen to the tune of 36.53, 33.33, 41.18, 24.75, 20.94, 33.33 and 21.13 per cent, respectively (at 28 days of incubation). It was observed that treatment with biochar co-compost (T_3) retained highest quantity of nitrogen at both the intervals *ie.* 21 days and 28 days after incubation (41.18 per cent). Even though poultry manure treatment had the highest nitrogen retention capacity (44.62 % and 45.31 %), at 7 and 14 days after incubation, the retention was lower than that of biochar treatment at later periods of incubation. It was seen that among the treatments water hyacinth-biochar co-compost registered 94.89 per cent increased N retention capacity over the water hyacinth alone treatment (Table 5.6.). Water hyacinth paddy straw co-compost had comparatively lower N retention capacity to that of other treatments at 7 days after incubation (33.63 per cent decrease in N retention capacity over water hyacinth alone treatment). Highest N retention capacity of biochar is due to the presence of cation exchange sites on the biochar surface and consequent NH_4^+ retention in biochar co-compost amended soil. Similar results were observed in a study conducted by Major *et al.* (2009).

5.4.2. Phosphorus retention capacity

Not much difference in phosphorus retention capacity was noticed with the application of water hyacinth co-composts to lateritic soil. Phosphorus-organic matter interaction is found to be so strong in the soil. Elango *et al.* (2009) opined that water solubility of phosphorous decreases with humification. Hence little quantity of water-soluble phosphorus was obtained at 14, 21, 28 days after incubation. Phosphorus fixation is very high in lateritic soil and the results are indicative of the same. The phosphorus retention capacity of soils amended with water hyacinth co-composts are depicted in figure 5.20

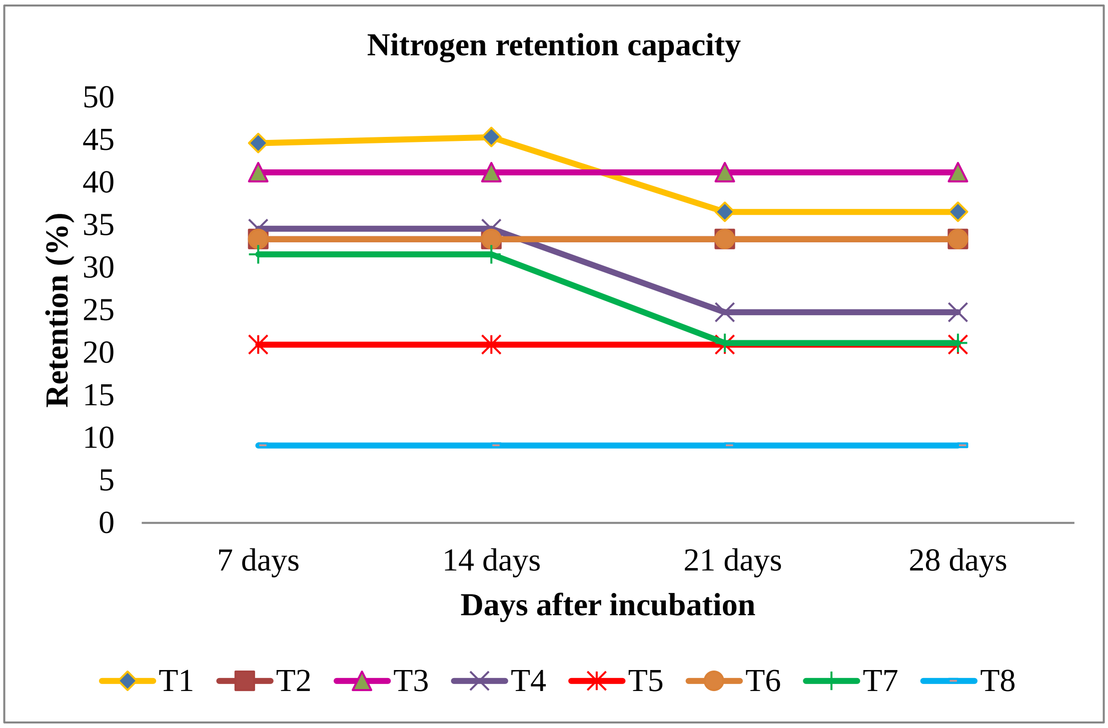

Fig.35 Nitrogen retention capacity of water hyacinth co-composts

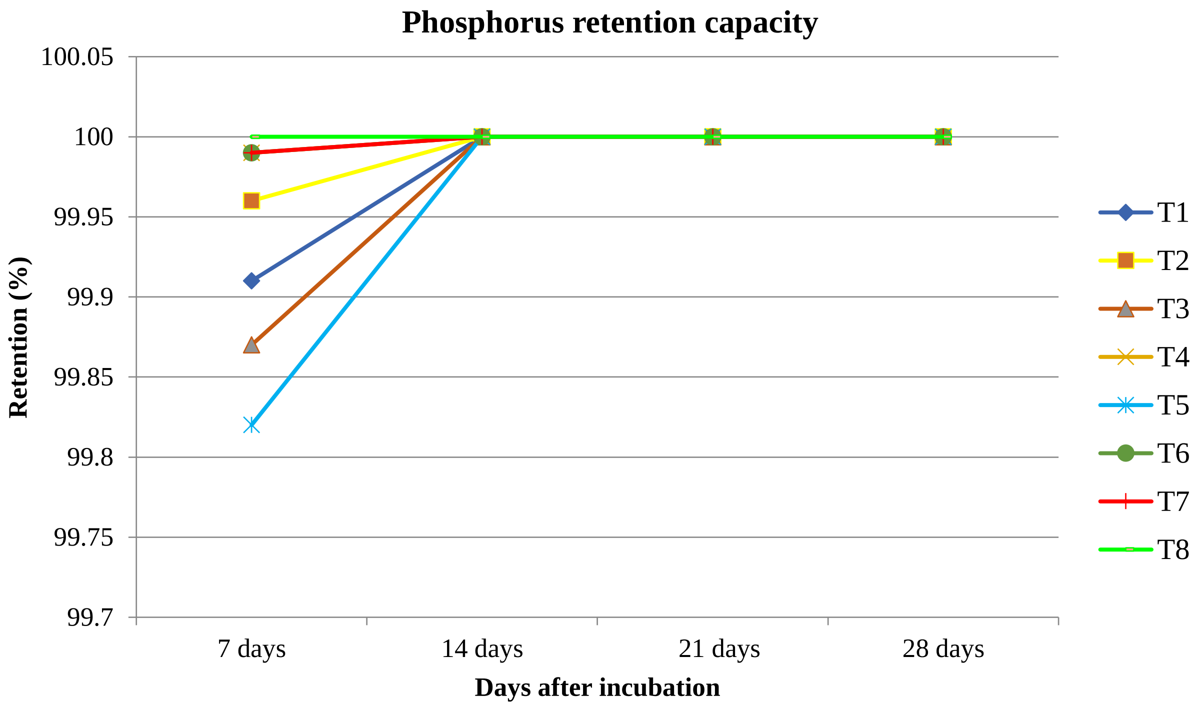

Fig.36 Phosphorus retention capacity of water hyacinth co-composts

Table 5.6. Percentage change in nitrogen and phosphorus retention capacity of water hyacinth co-composts with respect to T_7

Treatment	Nitrogen retention capacity (%)*				Phosphorus retention capacity (%)*			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	41.43	43.61	72.88	72.88	-0.08	0.00	0.00	0.00
T_2 (Soil+compost2)	5.64	5.64	57.74	57.74	-0.03	0.00	0.00	0.00
T_3 (Soil+compost3)	30.52	30.52	94.89	94.89	-0.12	0.00	0.00	0.00
T_4 (Soil+compost4)	9.54	9.54	17.13	17.13	0.00	0.00	0.00	0.00
T_5 (Soil+compost5)	-33.63	-33.63	-0.90	-0.90	-0.17	0.00	0.00	0.00
T_6 (Soil+compost6)	5.64	5.64	57.74	57.74	0.00	0.00	0.00	0.00
T_7 (Soil+compost7)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_8 (Soil alone-control)	-71.19	-71.19	-56.98	-56.98	0.01	0.00	0.00	0.00

*: percentage change with respect to T_7 (water hyacinth sole compost)

5.4.3. Potassium retention capacity

Percentage change in potassium retention capacity of different co-composts with respect to water hyacinth sole compost was worked out and presented in table 5.7. Percentage increase was slightly higher in treatments with biochar co-compost (1.08 %) and paddy straw co-compost (0.59 %) at 28 days of incubation. Potassium retention capacities are relatively higher than calcium retention capacity due to the fact that binding strength of potassium is much stronger and easily outcompetes magnesium and calcium at exchange sites in the compost amended soil. The results are in consonance with the findings of Agbenin and Yakubu (2006). Preferential adsorption of potassium over calcium and magnesium is evidenced from the results.

5.4.4. Calcium retention capacity

It was seen that over a period of 7-28 days of incubation calcium content in the treatments decreased. The calcium retention capacity decreased to a magnitude ranging from 61.33 to 76.84 per cent. Soil alone treatment registered calcium retention capacity of 51.31 per cent. Biochar and glyricidia co-composts retained more calcium compared to other water hyacinth-based composts. Calcium retention capacity of water hyacinth co-composts was lower compared to that of potassium and magnesium. The results concurred the findings of Agbenin and Yakubu (2006).

Data on percentage variation in calcium retention capacity is presented in table 5.6. Percentage change was positive in all the treatments except sawdust and dried leaves co-compost (Table 5.7). The highest percentage increase in calcium retention capacity was observed in soil amended with water hyacinth-biochar co-compost (17.13 %).

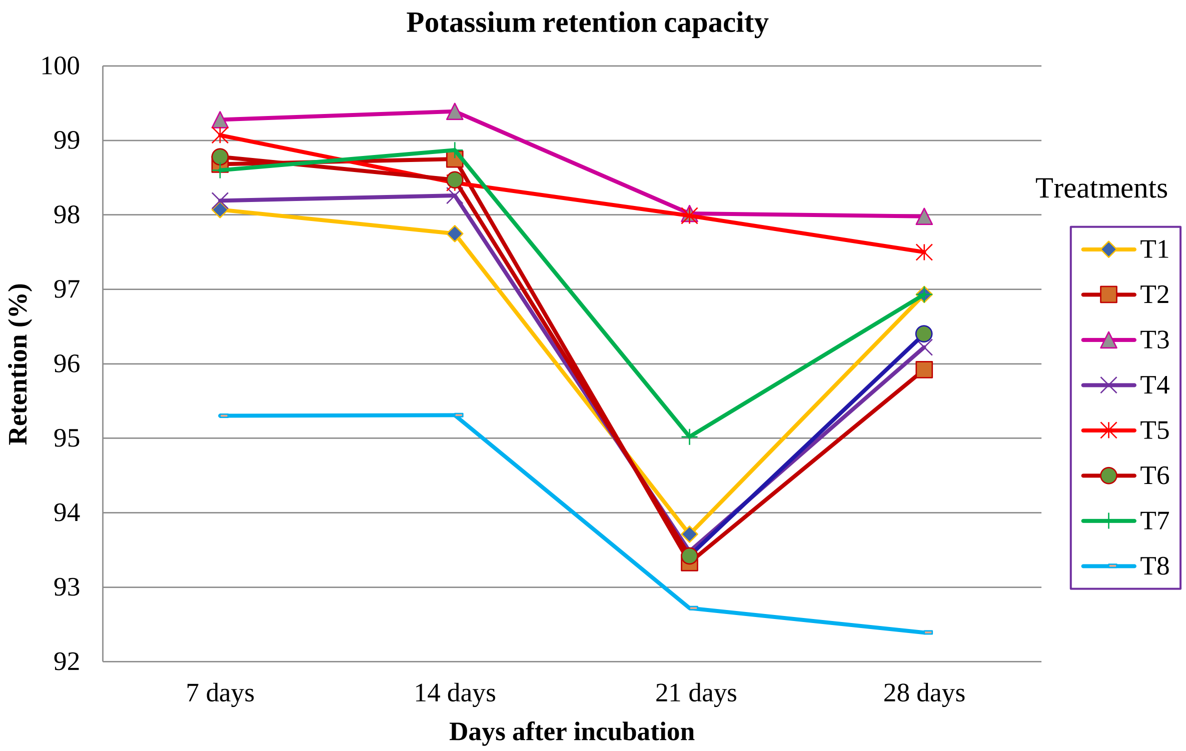

Fig.37 Potassium retention capacity of water hyacinth co-composts

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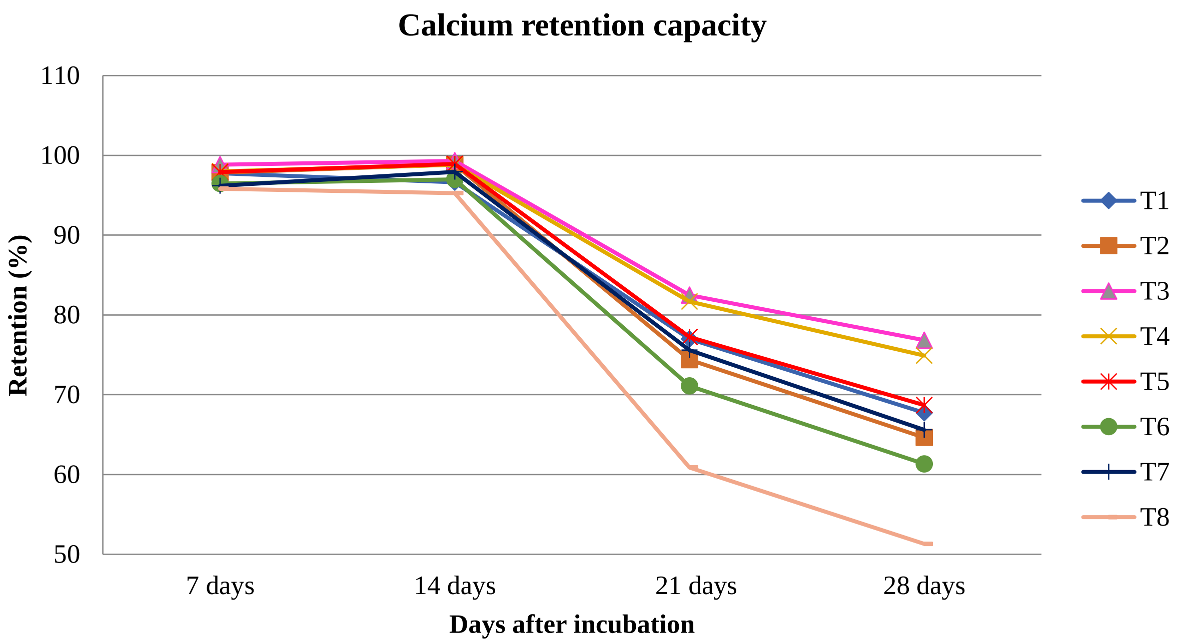

Fig.38 Calcium retention capacity of water hyacinth co-composts

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Table 5.7. Percentage change in potassium and calcium retention capacity of water hyacinth co-composts with respect to T_7

Treatment	Potassium retention capacity (%)*				Calcium retention capacity (%)*			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	-0.54	-1.13	-1.38	0.00	1.65	-1.35	1.83	3.26
T_2 (Soil+compost2)	0.08	-0.12	-1.78	-1.04	1.72	0.94	-1.61	-1.48
T_3 (Soil+compost3)	0.69	0.53	3.16	1.08	2.79	1.40	9.09	17.13
T_4 (Soil+compost4)	-0.42	-0.62	-1.62	-0.73	1.90	0.91	8.02	14.19
T_5 (Soil+compost5)	0.48	-0.45	3.13	0.59	1.79	1.01	2.14	4.73
T_6 (Soil+compost6)	0.18	-0.40	-1.68	-0.55	0.32	-0.96	-5.98	-6.51
T_7 (Soil+compost7)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_8 (Soil alone-control)	-3.35	-3.60	-2.42	-4.68	-0.37	-2.74	-19.47	-21.78

*: percentage change with respect to T_7 (water hyacinth sole compost)

5.4.5. Magnesium retention capacity

Magnesium retention capacity of soil with different co-composts was higher than that of calcium and range being, 99.22 to 99.63 per cent at 7 days and 95.56 to 97.49 per cent at 28 days. This could also be explained based on the findings of Agbenin and Yabuku (2006). The percentage increase in magnesium retention capacity with respect to water hyacinth sole compost is given in table 5.8. At 28 days of incubation the highest percentage increase was noticed for treatment with paddy straw co-compost (0.96 %).

5.4.6. Sulphur retention capacity

Compared to calcium and magnesium, sulphur retention capacity of soil amended with co-compost showed an increasing trend over a period of 7 days to 28 days. Among the co-composts water hyacinth with biochar, glyricidia, paddy straw and dried leaves registered 100 per cent retention of sulphur in the soil under study. In the other treatments sulphur retention capacity ranged from 98.51 to 99.67 per cent. Percentage increase in sulphur retention capacity with respect to water hyacinth sole compost was noticed in all treatments (Table 5.8).

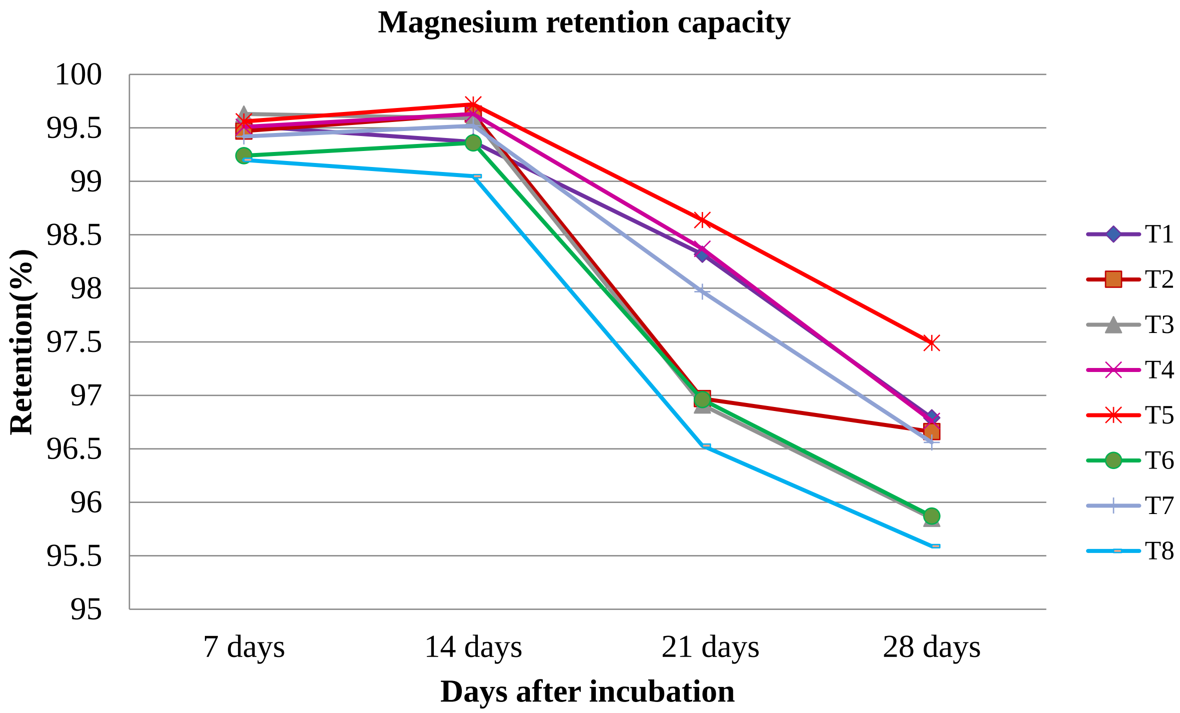

Fig.39 Magnesium retention capacity of water hyacinth co-composts

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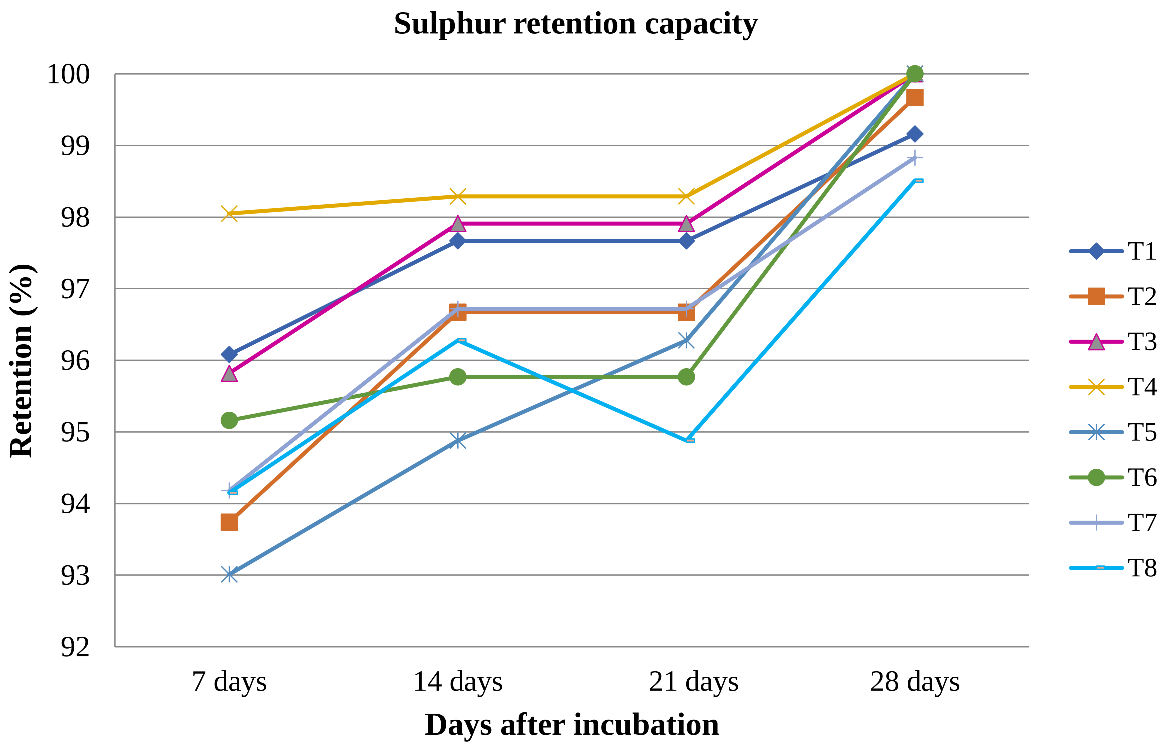

Fig.40 Sulphur retention capacity of water hyacinth co-composts

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Table 5.8. Percentage change in magnesium and sulphur retention capacity of water hyacinth co-composts with respect to T_7

Treatment	Magnesium retention capacity (%)*				Sulphur retention capacity (%)*			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	0.10	-0.15072	0.36	0.24	2.02	0.98	0.98	0.33
T_2 (Soil+compost2)	0.05	0.110531	-1.02	0.10	-0.47	-0.05	-0.05	0.85
T_3 (Soil+compost3)	0.21	0.070338	-1.08	-0.74	1.74	1.23	1.23	1.18
T_4 (Soil+compost4)	0.09	0.110531	0.41	0.21	4.11	1.62	1.62	1.18
T_5 (Soil+compost5)	0.14	0.200965	0.68	0.96	-1.24	-1.90	-0.45	1.18
T_6 (Soil+compost6)	-0.18	-0.16077	-1.03	-0.71	1.04	-0.98	-0.98	1.18
T_7 (Soil+compost7)	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00
T_8 (Soil alone-control)	-0.22	-0.47227	-1.47	-1.00	-0.03	-0.45	-1.90	-0.32

*: percentage change with respect to T_7 (water hyacinth sole compost)

5.4.7. Zinc retention capacity

Zinc retention capacity of the soil amended with different co-composts ranged from 98.52 (soil alone) to 99.20 (soil amended with poultry manure compost) at 7 days and 97.74 to 99.56 per cent (soil + biochar co-compost). Leaching losses of zinc is considerably less. Percentage variation in zinc retention capacity of the treatments indicated in Table 5.9.

5.4.8. Boron retention capacity

Boron retention was 100 per cent in all the treatments at all the periods of incubation. It is evident that boron is tightly bound to organic matter (Goli *et al.*, 2019).

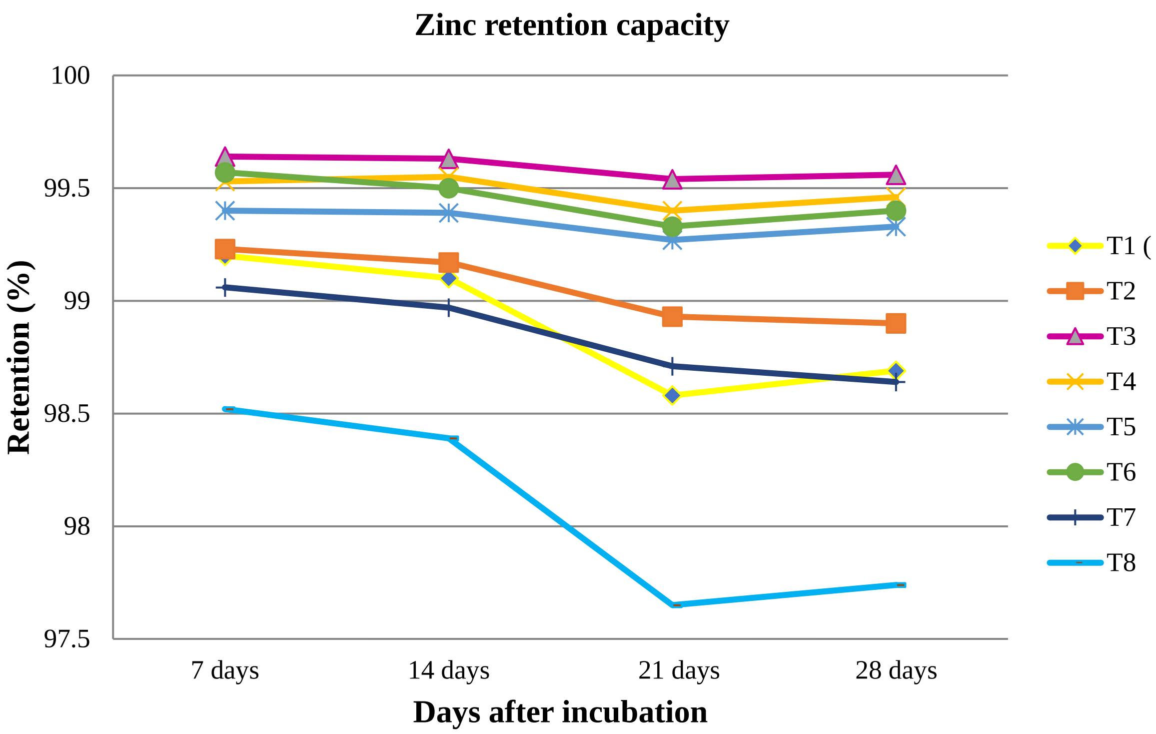

Fig.41 Zinc retention capacity of water hyacinth co-composts

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Table 5.9. Percentage change in zinc retention capacity of water hyacinth co-composts with respect to T_7

Treatment	Zinc retention capacity (%)*			
	7 days	14 days	21 days	28 days
T_1 (Soil+compost1)	0.14	0.13	0.00	0.05
T_2 (Soil+compost2)	0.17	0.20	0.00	0.26
T_3 (Soil+compost3)	0.59	0.67	0.01	0.93
T_4 (Soil+compost4)	0.47	0.59	0.01	0.83
T_5 (Soil+compost5)	0.34	0.42	0.01	0.70
T_6 (Soil+compost6)	0.51	0.54	0.01	0.77
T_7 (Soil+compost7)	0.00	0.00	0.00	0.00
T_8 (Soil alone-control)	-0.55	-0.59	-0.01	-0.91

*: percentage change with respect to T_7 (water hyacinth sole compost)

Summary

6. SUMMARY

The investigation entitled "Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil" was under taken in the Department of Soil Science and Agricultural Chemistry at College of Agriculture, Vellanikkara during 2020-2021. The research programme consisted of preparation of different water hyacinth co-composts, their physical and chemical characterization and an incubation study. The studies were under taken to evaluate the compost quality of water hyacinth co-composts and to estimate the nutrient retention capacity of the same in lateritic soil.

Six co-substrates *viz.*, poultry manure, sawdust, biochar, glyricidia, paddy straw, and dried leaves along with cattle manure were collected from nearby areas and water hyacinth was collected from Kole lands of Thrissur. Water hyacinth and co-substrates were characterized prior to composting. Vermi technology was adopted to prepare water hyacinth co-composts using the aforesaid substrates in concrete tanks. The physical and chemical properties of the composting mixtures were analysed at 40 days interval starting from 20 days of composting until 100 days. The yield of water hyacinth co-composts was estimated and the various co-composts were characterized for their physical and chemical properties.

Incubation study was conducted to evaluate the nutrient retention capacity of different water hyacinth co-composts prepared in the experiment 1 in lateritic soil during December 2020 with eight treatments and three replications (soil+ composts and soil alone as absolute control). The lateritic soil used for study was collected from Instructional Farm, Vellanikkara and analysed for chemical properties. Compost amended soils were incubated for a period of 28 days and nutrient retention capacity (N, P, K, Ca, Mg, S, B, Zn) was estimated at 4 different time intervals after incubation (7, 14, 21, 28 days).

The salient findings of the present investigation are listed below;

- The co-substrates varied in their chemical properties and nutrient content. Among them, poultry manure possessed many favourable characteristics.

- Physical and chemical properties of composting mixtures at different intervals during composting indicated the progress of the process and stage of compost maturity.
- All the co-substrates improved yield of water hyacinth co-composts. A notable increase in compost yield to an extent of 160 per cent was realized in the biochar treatment.
- Addition of co-substrates improved the bulk density and porosity of water hyacinth co-composts. Significant decrease in the bulk density was noticed in biochar treatment (-22.47 %). Porosity was also higher in biochar treatment.
- Application of co-substrates improved the pH of final compost. Highest increase was noticed in the treatment with paddy straw. The extent of increase was in the range of 0.8 to 15.11 per cent.
- Electrical conductivity of final compost was highly dependent on the co-substrates included in the composting mixture. Significant decrease in EC of water hyacinth compost was noticed with the use of sawdust, dried leaves and biochar. The magnitude of favourable change was in the range of -27.94 (biochar) to -66.97 (sawdust) per cent. Poultry manure, glyricidia and paddy straw increased EC of the final compost. However, the co-substrates *viz.*, poultry manure and glyricidia did not increase the EC of the final compost beyond the established critical limit for plant growth. Addition of paddy straw had significant adverse effect on the electrical conductivity of final co-compost (170 % increase in EC over water hyacinth sole treatment).
- The total carbon content of all the co-composts was higher than water hyacinth sole compost. Among the co-substrates sawdust and biochar increased total carbon to an extent of approximately 150 per cent.
- Co-composts with sawdust, biochar and dried leaves had significantly lower quantity of nitrogen compared to water hyacinth sole compost. Nitrogen content of the co-compost was improved to a greater extent by the application of paddy straw and poultry manure. The percentage increase in the total nitrogen by the inclusion of co-substrates viz., poultry manure and paddy straw were 48.6 and 24.2 per cent, respectively.

- Glyricidia and poultry manure were highly effective in improving total phosphorus content of the co-compost, the magnitude of increase being 30.43 and 52.17 per cent, respectively.
- Total potassium content of water hyacinth compost was significantly improved with the addition of co-substrates like paddy straw and biochar, the extent of increase being 192 and 170 per cent, respectively.
- Carbon to nitrogen ratio of water hyacinth co-compost could be significantly lowered by using poultry manure as a co-substrate.
- Poultry manure, paddy straw and dried leaves were ineffective in improving the quality of co-compost with respect to CEC. The cation exchange capacity of co-compost with poultry manure was 28.13 per cent lower than that of water hyacinth sole compost.
- Addition of poultry manure improved all the three secondary nutrients *viz.*, Ca, Mg and sulphur to a higher magnitude.
- No favourable effect was noticed on the boron content of co-compost by the addition of different co-substrates. However, Fe and Mn levels of final co-composts were considerably lower than the water hyacinth sole compost. This could be considered as a favourable effect of co-composting of water hyacinth with different substrates. Zinc content of the co-compost was significantly improved by the inclusion of co-substrate particularly with the use of poultry manure and dried leaves. Copper content of the co-compost was significantly higher with the addition of poultry manure as co-substate.
- The addition of water hyacinth co-composts to lateritic soil, improved retention of nutrients particularly nitrogen. The only exception was co-compost with paddy straw (0.9 per cent decrease in the nitrogen retention capacity). During the whole period of incubation biochar co-compost retained higher quantity of nitrogen in the soil under study (41.18 %).
- Irrespective of the treatments, co-composts retained all the phosphorus present in the co-compost amended soil.
- Potassium retention capacity of the soil was improved when amended with water hyacinth co-compost. Among the different co-composts, co-compost with biochar showed superiority over the other treatments.

- ❖ Compared to potassium and magnesium, calcium retention capacity of co-compost amendment was considerably of lower magnitude.
- ❖ Boron was completely retained in all soils irrespective of the treatments.
- ❖ High zinc retention capacity was noticed in all soils amended with water hyacinth co-composts.
- ❖ In general, soil with biochar co-compost showed significantly high retention capacity with respect to plant nutrients particularly nitrogen.

Future line of work

- Identify suitable combinations of substrates and substrate ratios (Eg. 6:2:1-W:PS:M) to eliminate the adverse effects of co-substrates like paddy straw
- Assessment of retention and availability of nutrients with the use of co-composts under different field conditions
- Use of other organic waste materials and crop residues for co-compost preparation
- Effect of different co-composts on soil microflora

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EVALUATION OF WATER HYACINTH CO-COMPOSTS FOR NUTRIENT RETENTION IN LATERITIC SOIL

by

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ABSRACT OF THE THESIS

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“Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil”

ABSTRACT

Water hyacinth is a serious menace in low land ecosystems and it’s spread has threatened water quality and aquatic life. Various biological, chemical and physical methods that have been employed to control the weed has yielded minimal results. Hence management through utilization is a viable strategy. It can be effectively utilized in many ways to support crop production.

Co-composting has been proved as a promising technique for safe and quick disposal of the weed by utilizing the co-substrates *viz.,* poultry manure, sawdust, biochar, glyricidia, paddy straw, dried leaves and cattle manure. As the weed accumulates N, P, K and other essential nutrients, compost made from water hyacinth can be utilized for improving soil fertility and crop production. Hence, the present investigation entitled “Evaluation of water hyacinth co-composts for nutrient retention in lateritic soil” was under taken in the Department of Soil Science and Agricultural Chemistry at College of Agriculture, Vellanikkara during 2020-2021. The objectives were; (i) To find out the suitable combination of water hyacinth and co-substrates for enhancing the quality of water hyacinth composts (ii) To assess the nutrient retention capacity of different co-composts in lateritic soil.

Different co-substrates were collected from nearby areas and water hyacinth was collected from Kole lands of Thrissur. Water hyacinth and co-substrates were characterized prior to composting. Water hyacinth co-composts (vermi compost) were prepared using the aforesaid substrates in concrete tanks. The physical and chemical properties of the composting mixtures were recorded at 40 days interval starting from 20 days of composting until 100 days. The yield of water hyacinth co-composts was estimated and the various co-composts were characterized for their physical and chemical properties.

Incubation study was conducted to evaluate the nutrient retention capacity of different water hyacinth co-composts in lateritic soil during December 2020 with eight treatments and three replications (soil+ 7 co-composts and soil alone as absolute

control). The lateritic soil for study was collected from Instructional Farm, Vellanikkara and analysed for chemical properties. Compost amended soils were incubated for a period of 28 days and nutrient retention capacity (N, P, K, Ca, Mg, S, B, Zn) was estimated at 4 different time periods after incubation (7, 14, 21, 28 days).

Data on characterization of co-substrates revealed that substrates vary in their chemical properties and nutrient content. Among the co-substrates, poultry manure possessed many favourable characteristics. Changes in physical and chemical properties of composting mixtures at different intervals indicated the progress of composting process and stage of compost maturity. All the co-substrates gave reasonably good yield of water hyacinth co-composts. A notable increase in compost yield to an extent of 159.7 per cent was realized in the biochar treatment. Addition of co-substrates improved the bulk density and porosity of water hyacinth co-composts. Application of co-substrates improved the pH of final compost. Highest increase was noticed in the treatment with paddy straw. Addition of paddy straw had significant adverse effect on the electrical conductivity of final co-compost (170.6 % increase in EC over water hyacinth sole treatment) and all the other treatments showed EC below maximum permissible limit for plant growth.

The total carbon content of all the co-composts was higher than water hyacinth sole compost. Nitrogen content of the co-compost was improved to a greater extent by the application of paddy straw and poultry manure. Co-composts with sawdust, biochar and dried leaves had significantly lower quantity of nitrogen compared to water hyacinth sole compost. Glyricidia and poultry manure were highly effective in improving total phosphorus content of the co-compost. Total potassium content of water hyacinth compost was significantly improved with the addition of co-substrates like paddy straw and biochar, the extent of increase being 192 and 170 per cent, respectively. Carbon to nitrogen ratio of water hyacinth co-compost was significantly lowered by using poultry manure as a co-substrate.

Addition of poultry manure improved all the three secondary nutrients *viz.*, Ca, Mg and sulphur to a higher magnitude. No favourable effect was noticed on the boron content of co-compost by the addition of different co-substrates. However, Fe and Mn levels of final co-composts were considerably lower than the water hyacinth sole compost. This could be considered as a favourable effect of co-composting of water hyacinth with different substrates. Zinc content of the co-compost was significantly improved by the inclusion of co-substrate particularly with the use of poultry manure and dried leaves. Copper content of the co-compost was significantly higher with the addition of poultry manure as co-substate.

The addition of co-compost to lateritic soil, improved retention of nutrients particularly nitrogen. The only exception was co-compost with paddy straw (0.9 per cent decrease in the nitrogen retention capacity). Irrespective of the treatments, co-compost retained all the phosphorus and boron present in the co-compost amended soil. The soil's potassium, magnesium, sulphur and zinc retention capacity could be improved when amended with water hyacinth co-compost. In general, soil with biochar co-compost showed significantly high retention capacity with respect to plant nutrients particularly nitrogen.

Further study should be focused on field experiments to test the agronomic efficiency of different water hyacinth co-composts, testing suitability of various crop residues and organic wastes as co-substrates and to derive suitable substrate combinations and ratios to eliminate the adverse effects of co-substrate on compost quality.