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Research article

Suitability of selected Sri Lankan weeds for the formulation of organic liquid fertilizers

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Abstract: *Tithonia diversifolia*, *Sphagneticola trilobata*, *Mikania scandens*, *Lantana camara*, *Chromolaena odorata*, *Panicum maximum* and *Mimosa pigra* are common weeds in Sri Lanka. This study was aimed to assess the nutrient release potential and the weight loss dynamics during leaching of the above weeds to utilize them as organic liquid fertilizers. Thirty samples from each species of oven-dried leaves (5 g) were placed separately in 1 L of distilled water. Three samples of each species were randomly collected at 1, 3, 5, 7, 14, 28, 42, 56, 70 and 84 days and the mass-loss, electrical conductivity (EC), pH and nutrient contents of the leachates were determined. Four fertilizers (FP1; the selected weeds *Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata* (W), FP2; (W) + topsoil, FP3; (W) + topsoil + coconut husk ash and FP4; (W) + topsoil + coconut husk ash + fish waste) were formulated and based on the nutrient contents the highest nutrient containing FP3 and FP4 were applied on *Basella alba*. Mass-loss was higher ($p<0.05$) for *Mikania scandens* (97%) followed by *Tithonia diversifolia* (95.8%) and the lowest for *Panicum maximum* (63.7%). EC and pH of leachates were increased over the time indicating the highest in *Mikania scandens* (2139±4.7 µS cm^{-1}) and *Lantana camara* (7.86±0.06) respectively, and the lowest in *Panicum maximum* (877±7.6 µS cm^{-1}, 7.40±0.02). Nutrient contents of the leachates of *Tithonia diversifolia*, *Mikania scandens* and *Chromolaena odorata* were higher than those of *Panicum maximum.* FP4 revealed the highest nutrients and growth performances of shoot height (25.0±0.9 cm), number of leaves (12.0±0.6), leaf area (70.7±1.6 cm^2), plant fresh weight (56.1±1.2 g) of *Basella alba.* The results are suggestive of the potential of utilizing *Tithonia diversifolia*, *Mikania scandens* and *Chromolaena odorata* for the formulation of organic fertilizers which would in turn be a low-cost strategy for effective control of these weeds.

Keywords: Sri Lankan weeds - Organic liquid fertilizers - Nutrient leaching - Plant nutrients.

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INTRODUCTION

Invasive plants occur outside of its natural range or dispersal potential resulting negative impacts on the environment, economy and public well-being (Ratnayake 2014). The adverse impact of invasive plants is associated with alteration of ecosystem functions, profitability and limitation of the long-term sustainability of agriculture and reduction of primary productivity of agricultural and national resources in Sri Lanka and also in the world. They cause a major constraint in achieving high productivity and self-sufficiency in agriculture, by reducing yields and quality of the crop production, thereby reducing the overall productivity (Rajapakse *et al.* 2012). Moreover, invasive plants act as superior competitors for resources and thereby displace native species reducing the biodiversity and they create a number of negative impacts on human activities associated with livestock production that interfere with grazing practices, lowering yield and quality of forage and crops, increasing costs of management practices and reducing land value (Ditomaso 2000). According to the Biodiversity Secretariat Invasive Manual (2010), *Mikania scandens* (L.) Willd., *Chromolaena odorata* (L.) R.M.King & H.Rob., *Panicum maximum* Jacq., *Tithonia diversifolia* (Hemsl.) A.Gray, *Lantana camara* L.,

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Sphagneticola trilobata (L.) Pruski and *Mimosa pigra* L. were regarded as highly abundant invasive plants in Sri Lanka. However, currently, *Chromolaena odorata*, *Mikania scandens* and *Tithonia diversifolia* are not categorized under the invasive plants in Sri Lanka due to the decrease of their invasiveness over the time (BDS Invasive Manual, 2015) however, those are still considered as problematic weeds. Most of the weeds in Sri Lanka have introduced for different purposes *i.e. Panicum maximum* has introduced in 1824 as a fodder plant for cattle and horses and *Lantana camara* in has introduced in 1826 as an ornamental plant by the Royal Botanical Garden. However, *Mimosa pigra* has introduced accidently with the equipments and vehicles bought for the development projects in the country (Wijesundara *et al*. 2010). Thereafter, these weeds have invaded most of the areas and among them, *i.e. Lantana camara* in Udawalawa National Park, *Mimosa pigra* in banks of Mahaweli River in the Central province (Amarasinghe & Marambe 1997) and *Chromolaena odorata* in national parks in Sri Lanka were recorded as the highly invaded sites (Weerakoon 2008). Furthermore, Mihintale Sanctuary showed more than 25 meters distribution of these weeds, grown towards the forest interior indicating a growing threat and potential for further spread (Ranwala & Thushari 2012).

Although weeds have been reported majorly on their adverse impacts, there are considerable amounts of nutrients in some plant species (Weerakoon 2008). Among them, *Tithonia diversifolia* which has spread throughout the country is recommended as a component of compost and green manure due to its high nutrient content (N 1.76%, P 0.82% and K 3.92%), rapid growth rate and high vegetative matter turnover (Olabode *et al*. 2007). *Chromolaena odorata* is also suggested as a beneficial fallow plant rather than a weed due to its richness of organic matter, exchangeable potassium content and better adaptability on acidic soils than some leguminous plants (Koutika & Rainey 2010). Moreover, dried leaf powder of *Lantana camara* mixed with mycorrhizae was also recorded higher growth and yield of the lentil and red kidney bean in Nepal proving the effectiveness of the application of organic matter on plant growth (Vaidya & Bhattarai 2014).

With the current propaganda on the promotion of organic fertilizers and more focus towards the concept of green products worldwide and also in Sri Lanka, more demand of the local community is now adopting eco-friendly agricultural practices for sustainable food production after realizing the adverse impacts of prolong and excessive use of chemical fertilizers. Among different organic fertilizers, foliar application of liquid organic fertilizers is a widely adopted strategy in modern crop management due to the high nutrient-use efficiency. Foliar application of organic liquid fertilizers provide a path of direct nutrient absorption through plant foliage including the leaves to ensure higher crop performance. Moreover, it is highly effective under poor soil health conditions *i.e.* high nutrient leaching rates, limitations of the availability of soil-applied nutrients, an immediate requirement of specific nutrient due to nutrient deficiency in plants (Fernandez & Brown 2013), and inadequate root growth due to hindrance of the soil (Oosterhuis 2009). Furthermore, it is also reduced the adverse impacts associated with excessive soil application of nutrients *i.e.*, contamination of the groundwater, eutrophication, soil acidity, nutrient runoff and leaching (Kannan 2013). Liquid organic fertilizers are formulated with natural materials of either plant or animal origin including crop residues, livestock manure, household waste and food industrial waste (Netpae 2012). Many studies have carried out on different types of organic liquid fertilizers such as compost extracts, aerated compost teas, herbal extracts, vermicompost extracts, food stillages which are applied on to foliage or into the soil (Canfora *et al*. 2015, Jamilah & Ernita 2015, Kim *et al*. 2015). Among the available literature, few attempts have made to utilize the selected weed plants as a nutrient-rich plant-based organic source in formulating compost and application as a top-dressing on soil (Sangakkara *et al*. 2008) and fewer studies have utilized as compost teas (Akanbi *et al*. 2007, Chikuvire *et al*. 2013, Pena *et al*. 2013). *Mikania scandens* and *Chromolaena odorata* mixed with 40% poultry manure in foliar applied organic fertilizers have shown significantly higher growth performances on *Basella alba* L. and *Alternanthera sessilis* (L.) DC. (Ranasinghe *et al*. 2014). Similarly, *Tithonia diversifolia* mixed with poultry manure in another foliar-applied organic liquid fertilizer also has significantly increased the growth performances of *Abelmoschus esculentus* (L.) Moench (Jayasundara *et al*. 2016).

Moreover, many studies have revealed the effect of physical and chemical degradation of different leaf litter on soil in forested or cropland agro-forest systems (Kammer & Hagedorn, 2011, Hassanuzzaman & Hossain 2014) and few studies have revealed the leaf litter degradation in streams and the effect of leaf litter leaching on water quality in streams (Kwanbiah *et al*. 2001, Kitamura & Ijuin 2010). However, studies pertaining on the leaching of the selected weeds leaf materials in water is not available in the scientific literature. Hence, leaching experiment was carried out using seven common weeds and invasive plants (*Chromolaena odorata*, *Mikania scandens*, *Panicum maximum*, *Tithonia diversifolia*, *Lantana camara*, *Sphagneticola trilobata* and *Mimosa pigra*) in Sri Lanka. Therefore, the present study aimed to investigate the nutrient releasing potential and the weight loss dynamics of the selected weeds with the view of identifying the fast decomposing species for the formulation of organic liquid fertilizers. The hypothesis of this study was that the selected weeds can be used as nutrient-rich sources to formulate organic liquid fertilizers.

MATERIALS AND METHODS

Collection of weed plants

According to the available literature and the field observations in different climatic zones in Sri Lanka, the weeds *i.e.* *Chromolaena odorata*, *Mikania scandens*, *Panicum maximum*, *Tithonia diversifolia*, *Lantana camara*, *Sphagneticola trilobata* and *Mimosa pigra* were identified as potential sources to formulate fertilizers. Fresh leaves and tender shoots of the selected weeds were collected with three replicates from unpolluted and non-cultivated areas, away from the roadsides from Gampaha, Kandy, Kurunegala, Anuradhapura, Hambanthota and Kalutara areas.

Determination of physiochemical characteristics of selected weeds

i. Preparation of samples for analysis:Samples collected in polythene bags were transported to the laboratory at the Department of Botany, University of Kelaniya. Samples were washed twice with distilled water to remove any contaminants or dust particles that present on plant materials and air-dried at room temperature and oven-dried at 80^{o}C for constant weight. The dried samples were homogenized using a cleaned mortar and pestle and sieved through a 2 mm mesh. Subsequently, the sieved samples were packed and sealed in clean plastic bottles and stored at room temperature until chemical analysis.

ii. Nutrient analysis of plant materials: Nutrients contents of the plant materials were analyzed at the Horticultural Research and Development Institute, Gannoruwa and Soil and Plant Analytical Laboratory, CIC Agri Businesses (Pvt.) Ltd., Dambulla. Total nitrogen concentration in plant materials was determined by Kjeldahl method (Motsara & Roy 2008). Acid digested samples (HNO_3, H_2SO_4 and $HClO_4$ in the ratio of 9:4:1) were analyzed for phosphorus using spectrophotometric vanadium-phosphomolybdate method and K, Ca, Mg, Cu, Fe, Zn and Mn using Atomic Absorption Spectrophotometer (Varian Spectra A-110) using the protocol described by Motsara & Roy (2008). The organic carbon content of plant materials was determined according to Walkley- Black method (AOAC 2000). Moreover, crude fiber, ash and dry matter contents were determined according to AOAC (2000).

Identification of easily decomposing plant species

Fresh leaves and tender shoots of the selected weeds were collected from the three undisturbed locations in Gampaha district, Sri Lanka. Samples were washed twice with distilled water and air-dried at room temperature and oven-dried at 80^{o}C to constant weight. For each species, thirty dried leaves and immature shoots samples of 5.0 g were placed into 0.18 × 0.18 m^2 single layer nylon mesh bags with 2 mm mesh size and immersed separately in 1 L of distilled water in plastic containers at the room temperature with three replicates each. Mesh bags without leaves and shoots submerged in distilled water were used as the control. Three mesh bags of each plant species were randomly collected at 1, 3, 5, 7 and 14 days intervals for first two weeks and thereafter twice a week for next three months (28, 42, 56, 70 and 84 days). Electrical conductivity and pH of the leachates and the weight loss of plant material after drying in an oven at 80^{o}C to constant weight were determined over time. At the end of the leaching experiment after three months, nutrient contents of the leachates (N, P, K, Mg, Ca, Cu, Zn, Fe, Mn) were determined as described above.

Formulation of organic liquid fertilizers from selected plant materials

Based on the results of the nutrient analysis and the leaching experiment, two kilograms of fresh leaves and immature twigs of the selected plant species *i.e.* *Tithonia diversifolia*, *Mikania scandens* and *Chromolaena odorata* were collected from Gampaha district, Sri Lanka. Plant materials were washed thoroughly with distilled water and chopped into small pieces (nearly 2 cm) separately. Each chopped plant species were mixed with 1 L of distilled water in a 25 L plastic containers separately and allowed to decompose for two weeks with daily stirring. Subsequently, partially-decomposed extracts of all three plant species were mixed together with additional 1 L of distilled water and samples were allowed to further decompose for another six weeks. During the decomposition period, containers were kept covered with 2 mm nylon mesh and mixed regularly and daily aerated two hours using an aerator to accelerate the decomposition. The decomposed extracts were filtered separately using a muslin cloth after completion of eight weeks and filtrates were subjected to macro and micronutrient analysis as described above.

Enrichment of the formulated organic liquid fertilizers

Based on the nutrient contents, plant materials were enriched with adding 200 g of powdered fish waste and 50 g of coconut husk ash in combinations to increase nitrogen and potassium contents respectively. Moreover, topsoil with decomposed plant litter materials collected from the Botanical Garden of University of Kelaniya, Sri Lanka was incorporated as an inoculant of favorable saprophytic fungal and bacterial species to facilitate the decomposition process. Four liquid fertilizers (FP1; 2 kg each of the selected weeds *i.e. Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata*, FP2; selected weeds + topsoil (150 g), FP3; selected weeds + topsoil (150 g) + coconut husk ash (50 g) and FP4; selected weeds + topsoil (150 g) + coconut husk ash (50 g) + fish waste (200 g) were formulated with 4 L of distilled water separately and allowed to decompose for eight weeks. Coconut husk ash (50 g) was added at the end and the final filtrates were subjected to nutrient analysis as mentioned above.

Application of selected fertilizers on Basella alba

The highest nutrient containing two fertilizer combinations; FP3 and FP4 were selected for the application on the leafy vegetable, *Basella alba* grown in plastic pots filled with sieved and solarized normal garden soil. They were grown in a completely randomized block design with five replicates in the plant house of the Botanical Garden at the University of Kelaniya (6° 58'26.4" N, 79° 54'54.72" E). During the experimental period, the average monthly temperature and relative humidity ranged from 28–32 °C and 65% respectively. *B. alba* seeds obtained from Department of Agriculture, Peradeniya, Sri Lanka were allowed to germinate initially in a soil tray with sieved garden soil in the nursery stage. Three weeks after germination, healthy seedlings were transplanted separately into plastic pots (height of 15 cm × diameter of 16 cm) with drainage holes, filled with sieved garden soil. Application of formulated liquid fertilizers were started one week after the transplant and 5 ml of 1: 50 diluted formulated liquid fertilizers were sprayed on foliar parts on each plant twice a week for a period of three months. Distilled water was used as the negative control and commercially available liquid organic fertilizer (M) was used as positive control. After three months of fertilizer treatments the growth parameters *i.e.* shoot height, the number of leaves, leaf area (one surface), fresh and dry weights of the whole plants were measured.

Statistical analysis

All the physiochemical data and plant growth parameters obtained were analyzed statistically using one-way analysis of variance (ANOVA, $p<0.05$) followed by Tukey's pair-wise multiple comparison to compare the means using IBM SPSS software package (SPSS version 20 for Windows).

RESULTS

Physicochemical characteristics of the selected plant materials

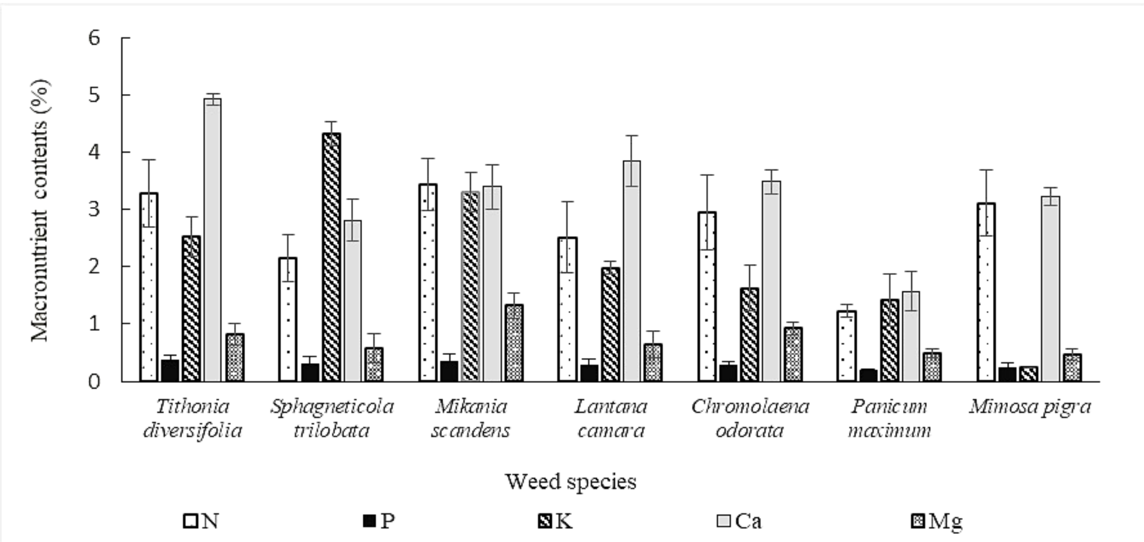

Figure 1. Macronutrient contents of the selected plant species. [Each data point represents the mean of eighteen replicates ± standard error]

Nutrient contents: The highest nitrogen content was recorded in *Mikania scandens* (3.44%) followed by *Tithonia diversifolia* (3.39 %) and the least N content was observed in *Panicum maximum* (1.20%). The highest phosphorus content was recorded in *Tithonia diversifolia* (0.37%) followed by *Mikania scandens* (0.35%) and

Mimosa pigra (0.20%) possessed the minimum P content. The highest potassium content was recorded in *Sphagneticola trilobata* (4.32%) followed by *Mikania scandens* (3.30%). The least K content was resulted in *Mimosa pigra* (0.24%). The highest Ca content was recorded in *Tithonia diversifolia* (4.90%) whereas, *Panicum maximum* (1.57%) showed the minimum. The highest Mg content was recorded in *Mikania scandens* (1.33%) and the least Mg content was recorded in *Mimosa pigra* (0.47%) (Fig. 1). Of the micronutrient analysis of weed plants, *Mikania scandens* recorded the highest Cu, Fe and Zn contents 33.5, 671.0, 393.0 mg kg^{-1} respectively, whereas *Panicum maximum* possessed the minimum Cu and Fe contents (8.70 and 263 mg kg^{-1}) respectively. *Sphagneticola trilobata* possessed the minimum Zn content (76 mg kg^{-1}). The highest Mn content was observed in *Mimosa pigra* (268 mg kg^{-1}) and the least was recorded in *Tithonia diversifolia* followed by *Panicum maximum* (71 and 72 mg kg^{-1}) respectively (Fig. 2).

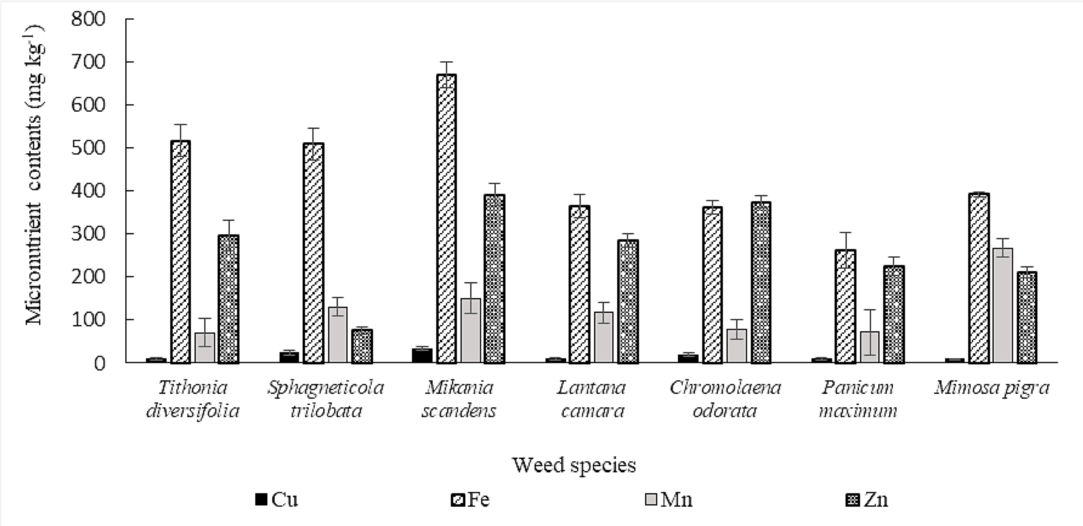

Figure 2. Micronutrient contents of the selected plant species. [Each data point represents the mean of eighteen replicates ± standard error]

The initial C/N ratios of the studied weeds were significantly lower for most of the species including *Tithonia diversifolia* (12.9±0.4), *Chromolaena odorata* (13.1±0.4) and *Mikania scandens* (13.5±1.3) than *Panicum maximum* which recorded the highest (38.8±1.6) as shown in table 2. Accordingly, the highest average crude fiber content was resulted in *Panicum maximum* (34.1±2.0%) and the lowest was observed in *Mikania scandens* (10.8±1.0%) showing no significant differences at p>0.05 with *Tithonia diversifolia* (13.8±1.4%), *Chromolaena odorata* (14.4±0.8%) and *Sphagneticola trilobata* (12.6±2.3%). The highest average ash content was recorded in *Mikania scandens* (22.8±1.9%) followed by *Tithonia diversifolia* (22.0±2.1%) and there were no significant differences (p<0.05). *Mimosa pigra* (9.3±2.2%) possessed the least amount of ash content. Moreover, the highest dry matter content was recorded in *M. pigra* (27.6±2.6%) followed by *Lantana camara* (25.9±2.7%) and *Panicum maximum* (24.1±1.9%) with no significant differences at p<0.05 and the lowest was recorded in *Mikania scandens* (9.7±1.6%) (Table 1).

Table 1. Quality parameters of the selected weeds.

Plant species	C/N ratio	Crude fiber content (%)	Ash content (%)	Dry matter content (%)
Tithonia diversifolia (Hemsl.) A.Gray	12.9 (±0.4)^{a}	13.8 (±1.4)^{a}	22.0 (±2.1)^{a}	13.8 (±1.2)^{b}
Sphagneticola trilobata (L.) Pruski	17.2 (±0.9)^{b}	12.6 (±2.3)^{a}	13.9 (±2.3)^{b}	14.3 (±1.8)^{b}
Mikania scandens (L.) Willd.	13.5 (±1.3)^{a}	10.8 (±1.0)^{a}	22.8 (±1.9)^{a}	9.7 (±1.6)^{a}
Lantana camara L.	19.0 (±0.3)^{c}	25.9 (±2.1)^{b}	16.9 (±1.0)^{b}	25.9 (±2.7)^{d}
Chromolaena odorata (L.) R.M.King & H.Rob.	13.1 (±0.4)^{a}	14.4 (±0.8)^{a}	14.5 (±1.5)^{b}	20.3 (±1.7)^{c}
Panicum maximum Jacq.	38.8 (±1.6)^{d}	34.1 (±2.0)^{d}	12.7 (±1.0)^{bc}	24.1 (±1.9)^{d}
Mimosa pigra L.	13.6 (±0.5)^{a}	28.5 (±1.1)^{c}	9.3 (±2.2)^{c}	27.6 (±2.6)^{d}

Note: Each data point represents the mean of six replicates ± standard deviation. Means with different letter(s) in each column are significantly different at p<0.05 (one-way ANOVA)

Identification of easily decomposing weeds using the nutrient leachability

Nutrient contents of the leachates: *Chromolaena odorata* resulted in significantly the highest (p <0.05) total N contents 190.0 (± 10.0) mg L^{-1}, followed by *Tithonia diversifolia* and *Lantana camara* respectively 160.4 (±2.1) and 165.0 (± 5.0) mg L^{-1} whereas *Panicum maximum* possessed the minimum 71.0 (±3.6) mg L^{-1} (Fig.

3). Leachability of phosphorus was comparatively low compared to other major nutrients while the highest was resulted in *Mikania scandens* 11.1 (±1.6) mg L^{-1} and the lowest was recorded in *Mimosa pigra* 3.5 (±0.5) mg L^{-1}. Among all the nutrients, potassium was the most abundantly leached cation in the present study. *Sphagneticola trilobata* resulted in the highest K content ($p<0.05$) 636.0 (±10.0) mg L^{-1}, whereas it showed no significant differences with *Mikania scandens*, *Tithonia diversifolia* and *Chromolaena odorata* respectively 464.3 (±9.0), 349.0 (±3.0) and 338.7 (±2.5) mg L^{-1}. The highest Mg content was recorded in *Lantana camara* 59.0 (±5.0) and *Mikania scandens* 21.6 (±0.7) mg L^{-1} showed the minimum. The Ca content was very low in all leachates and below the detectable level (Fig. 3).

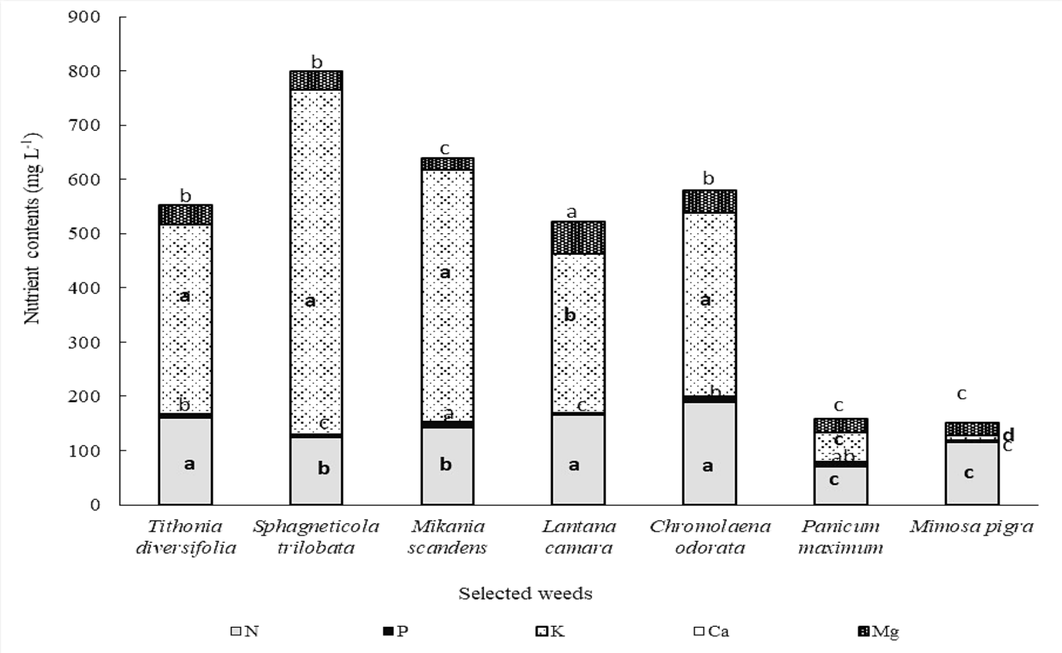

Figure 3. Macronutrient contents of leachates of the selected weeds at the end of three months leaching period. [Each data point represents the mean of three replicates ± standard deviation. Values followed by the same letter with respect to each fragment in same pattern of the each column are not significantly different at $p<0.05$]

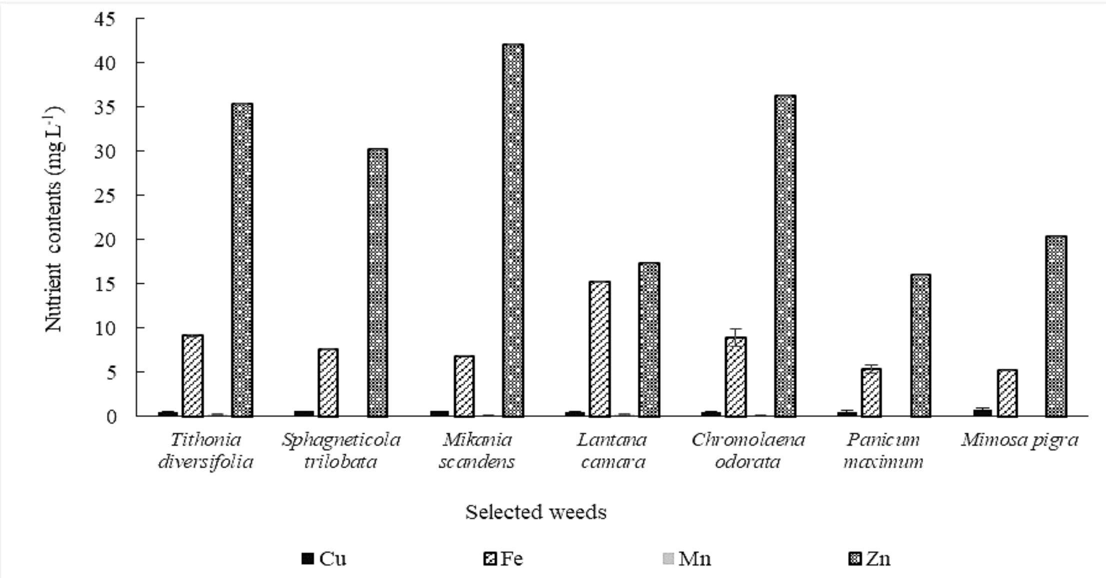

Figure 4. Micronutrient contents of leachates of the selected weeds at the end of three months leaching period. [Each data point represents the mean of three replicates ± standard deviation. Values followed by the same letter (s) in each micro nutrient are not significantly different at $p<0.05$]

Among the micronutrients, *Mimosa pigra* recorded the highest ($p<0.05$) total Cu contents 0.8 (±0.1) mg L^{-1}, whereas there were no significant differences among other species (Fig. 4). The highest Fe content was recorded in *Lantana camara* 15.2 (±0.1) mg L^{-1} and the least was recorded in *Mimosa pigra* 5.2 (±0.05) mg L^{-1}. All the weed plant materials had high amounts of Zn contents compared to other micronutrients and *Mikania scandens* showed the highest Zn content 42 (±0.2) mg L^{-1}, while *Panicum maximum* possessed the lowest 16.3 (±0.1) mg

L^{-1}. Mn content in all weeds were very low while *Tithonia diversifolia* recorded the highest 0.23 (±0.06) mg L^{-1} and *Sphagneticola trilobata*, *Panicum maximum* and *Mimosa pigra* were below the detectable level.

Electrical conductivity of the leachates of selected weeds

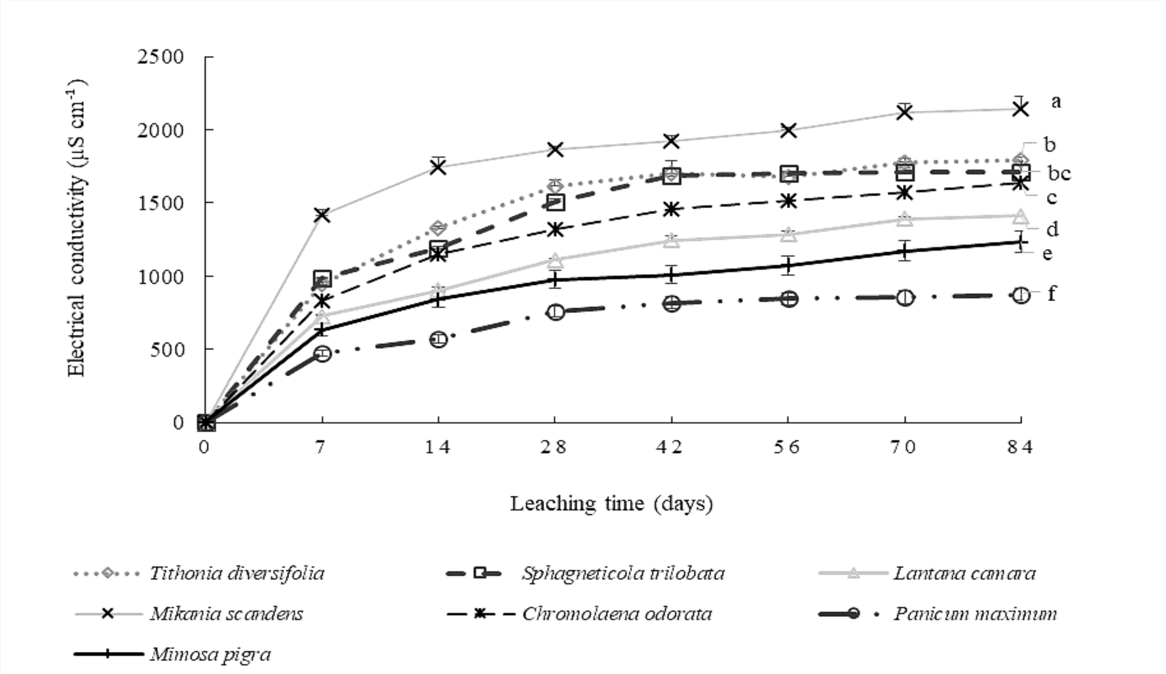

Figure 5. Electrical conductivity of leachates of the selected weeds over the three months of leaching period. [Each data point represents the mean of three replicates ± standard deviation. Values followed by the same letter (s) at the end of 84 days leaching period are not significantly different at $p<0.05$]

The initial EC of distilled water was 2.47 µS cm^{-1}. The EC increased with time in all the leachates up to 70 days and thereafter it became generally constant (Fig. 5). Based on the mean values at the end of 84 days leaching period, there were significant differences ($p<0.05$) of the EC values among all the plant species studied. The highest EC was observed in *Mikania scandens* 2139.7 (±84.7) µS cm^{-1} followed by *Tithonia diversifolia* 1791.0 (±21.0) µS cm^{-1}, *Sphagneticola trilobata* 1714.8 (±68.8) µS cm^{-1} and *Panicum maximum* showed the minimum 877 (±7.60) µS cm^{-1}.

The pH of the leachates of the selected plant species

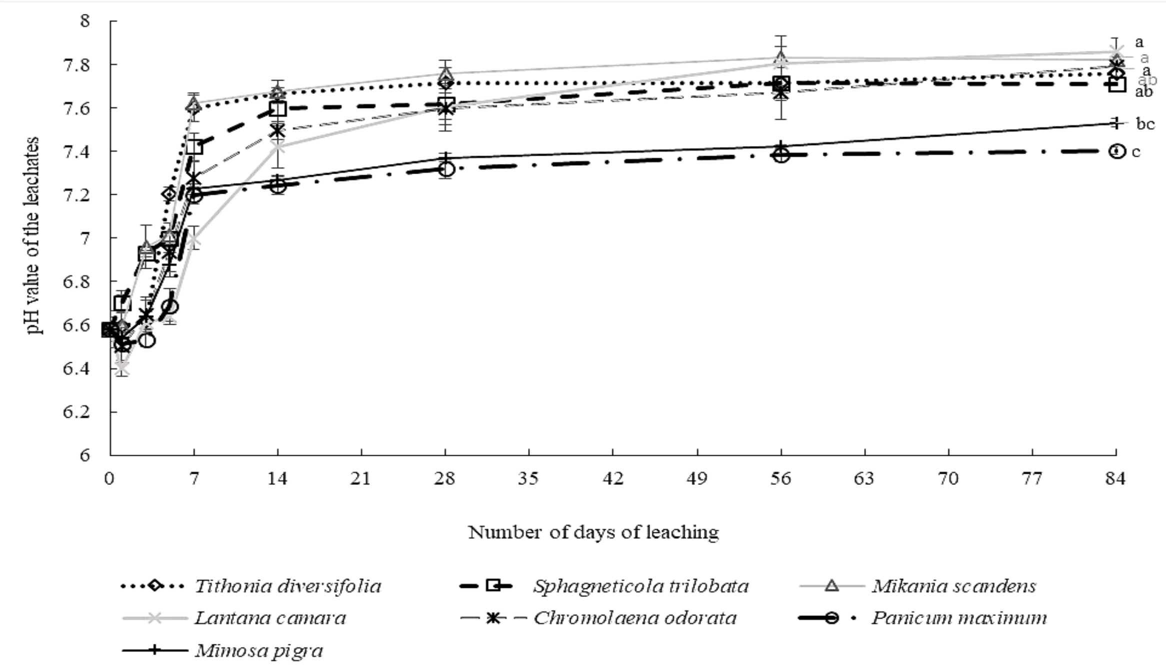

Figure 6. pH of leachates of the selected plant species over the three months of leaching period. [Each data point represents the mean of three replicates ± standard deviation. Values followed by the same letter at the end of 84 days leaching period are not significantly different at $p<0.05$]

The initial pH of distilled water was 6.58 and a rapid decrease in the initial pH after 24 hours was noted due to the leaching of acidic plant materials (Fig. 6). Thereafter, pH was drastically increased over the time up to 07 days and remained generally constant throughout 84 days of the studied period in most species. The mean pH values of leachates after 84 days were ranging from 7.40 (±0.02) to 7.86 (±0.06) respectively for *Panicum maximum* and *Lantana camara.*

Remaining mass of the plant materials at the end of three months leaching period

The initial dry mass of leafy materials of *Mikania scandens* and *Tithonia diversifolia* were significantly ($p<0.05$) decreased 65.6% and 66.1% respectively after 24 hours (Fig. 7). Plant materials of all species had lost on average 81% of the initial dry weight after 84 days. The lowest remaining mass was observed in *Mikania scandens* 3.0 (±0.20)% followed by *Tithonia diversifolia* and 4.3 (±0.40)% with no significant differences at ($p<$ 0.05) and the highest remaining mass was observed in *Panicum maximum* 36.3 (±0.20)%.

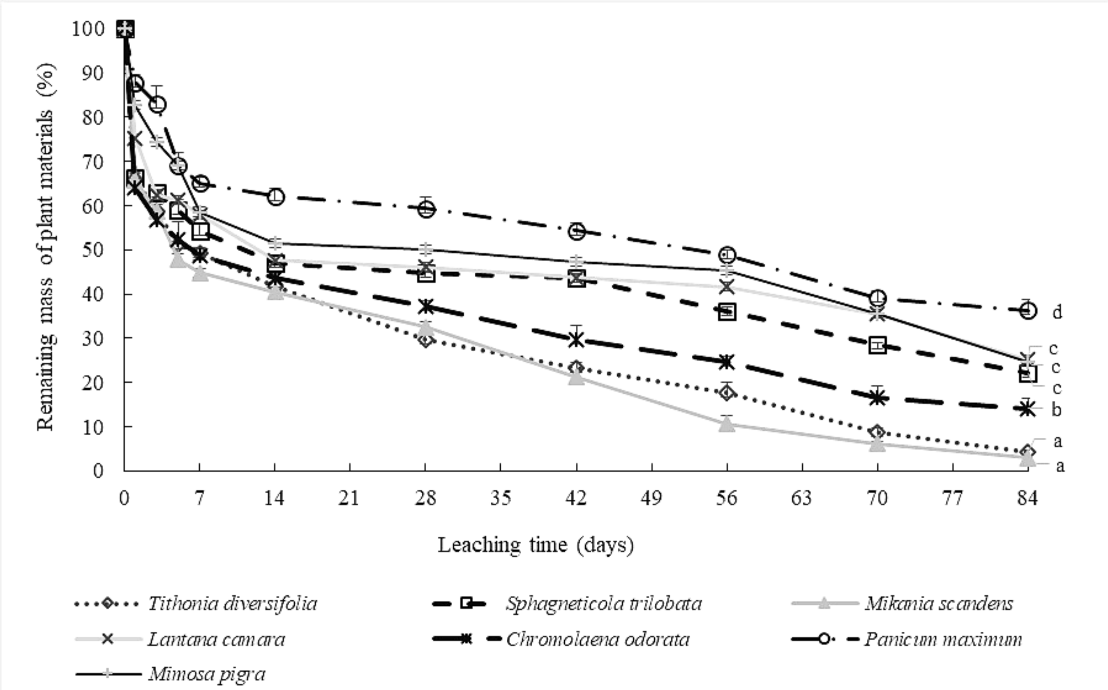

Figure 7. Remaining mass of plant materials of the selected weeds at the end of the three months of leaching period. [Each data point represents the mean of three replicates ± standard deviation. Values followed by the same letter at the end of 84 days leaching period are not significantly different at $p<0.05$]

Nutrient contents of the formulated liquid fertilizers

Among the formulated liquid fertilizers, FP4 (*Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata* + Fertile soil + Powdered fish waste + Coconut husk ash) recorded the highest N, P and K contents (2166.7±57.7, 270±5.0 and 4923.7±63.9 mg L^{-1} respectively) next to the standard liquid fertilizer (2422.0±19.3, 92.0±0.1, 3653.7±165.0 mg L^{-1} respectively) (Table 3). The least amount of N, P and K were recorded in FP1 fertilizer (*Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata*) which was consisted only the selected plant materials (Table 2). FP2 fertilizer that consisted with plant materials mixed with topsoil + litter sample obtained higher values compared to FP1, however it was not significant ($p<0.05$).

Table 2. The nutrient contents of the formulated liquid fertilizers.

Fertilizer	Macronutrient contents (mg L^{-1})				
	N	P	K	Ca	Mg
FP1	620.0 ± 10.0 [a]	60.6 ± 3.1[a]	3053.3 ± 30.5[a]	77.3 ± 0.5[a]	115 ± 5.0[a]
FP2	706.7 ± 12.7[a]	70.0 ± 1.0[a]	3713.3 ± 75.7[b]	71.3 ± 1.5[a]	118.3 ± 2.5[a]
FP3	896.7 ± 5.8[b]	105.0 ± 5.0[c]	4433.3 ± 57.7[c]	90.7 ± 4.0[a]	179.0 ± 3.6[b]
FP4	2166.7 ± 57.7[c]	270.0 ± 5.0[d]	4923.6 ± 63.8[d]	292.0 ± 2.6[b]	258.6 ± 3.2[c]
Standard	2422.0 ± 19.3[d]	92.0 ± 0.1[b]	3653.7 ± 165.0[b]	300.1 ± 3.7[b]	261.0 ± 8.0[c]

Note: FP1; *Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata*, FP2; *Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata* + topsoil, FP3; *Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata* + topsoil + coconut husk ash, FP4; *Tithonia diversifolia* + *Mikania scandens* + *Chromolaena odorata* + topsoil + powdered fish waste + coconut husk ash.

Each data point represent the mean of three replicates ± standard deviation; Means sharing the same letter in each column are not significantly different at $p<0.05$.

Effect of formulated liquid fertilizers on the growth of Bassella alba

Bassella alba plants were treated with the selected fertilizers FP3 and FP4 along with the commercially available standard liquid fertilizer and the control. After the twelve weeks growth period, the plants shoot height of *B. alba* increased (Table 3).

The highest average shoot height, *i.e.* 26.06±1.0 cm of *B. alba* was obtained in plants treated with the standard liquid fertilizer however, it was no significant difference that of FP4 combination (24.96±0.9 cm) at p>0.05. The lowest shoot height was recorded for the control (16.5±0.8 cm). The highest number of leaves per plant of *B. alba* also obtained for the standard (14.0±0.7) followed by FP3 and FP4 (12.0±0.8 and 12.2±0.6 respectively) whereas the control possessed the minimum (10.0±0.5). The other growth parameters, *i.e.* leaf area, plant fresh weight and dry weights of *B. alba*, the maximum were observed with the standard (71.3±1.2 cm^2, 56.3±0.9 g and 4.7±0.1 g respectively) followed by FP4 (70.7±1.6 cm^2, 56.1±1.2 g and 4.8±0.1 g respectively) which showed no significant differences at p>0.05 using one-way ANOVA and the least was recorded for the control (53.3±1.4 cm^2, 41.9±0.8 g and 3.5±0.1 g respectively) (Table 3).

Table 3. Effect of selected liquid organic fertilizers on the growth performance of *Basella alba* L.

Growth parameter	FP3	FP4	Standard	Control
Shoot height (cm)	$22.1±0.6^b$	$25.0±0.9^c$	$26.0±0.9^c$	$16.5±0.8^a$
Number of leaves/ plant	$12.0±0.8^b$	$12.0±0.6^b$	$14.0±0.7^c$	$10.0±0.5^a$
Leaf area (cm^2)	$63.7±0.8^b$	$70.7±1.6^c$	$71.3±1.2^c$	$53.3±1.4^a$
Plant fresh weight (g)	$53.4±0.9^b$	$56.1±1.2^c$	$56.3±0.9^c$	$41.9±0.8^a$
Plant dry weight (g)	$4.28±0.1^b$	$4.8±0.1^c$	$4.7±0.1^c$	$3.5±0.1^a$

Note: Each data point represent the mean of five replicates ± standard deviation; Means sharing the same letter in each row are not significantly different at p<0.05 by Tukey's multiple comparison test.

DISCUSSION

Based on the nutrient analysis of the leaves and tender shoots of the selected weeds *Mikania scandens* and *Tithonia diversifolia* resulted in significantly higher macro and micro-nutrient contents whereas, *Panicum maximum* recorded the lowest. Similarly, Nyasimi *et al.* (1997) reported that *Tithonia diversifolia* contained higher macro nutrients of 3.17% N, 0.3% P, 3.22% K, 2% Ca and 0.3% Mg. However, higher nitrogen contents of *Tithonia diversifolia, Chromolaena odorata* and *Panicum maximum* (3.3%, 2.9% and 1.2% N respectively) were resulted in this study compared to Olabode *et al.* (2007) which has reported as 1.76%, 1.26% and 1.12% N respectively in Nigeria and this might be due to the variation of soil nutrients among the different geographical regions.

According to the results of the leaching experiment, *Chromolaena odorata*, *Tithonia diversifolia* and *Lantana camara* resulted in significantly higher total N content in the leachate after 84 days ranging between 190–160 mg L^{-1} as they contained higher amounts of initial N in plant materials whereas *Panicum maximum* possessed the lowest N in the leachates 71($\pm$3.6) mg L^{-1} as it contained the lowest initial Mahmood *et al*. (2009) stated that initially high total nitrogen content indicates the high potential of nutrient leachability as most nitrogen is contained in the chlorophylls in leaves therefore, it prone to leach in larger quantity. Similarly, Kwanbiah *et al*. (2001) reported that *Tithonia diversifolia* and *Lantana camara* indicated higher nitrogen releasing potential of 65% and 46% respectively after 7 days and complete removal after 77 days using the litterbags technique that buried 1 cm below the soil surface compared to the other treatments. However, leachability of phosphorus was comparatively low compared to other major nutrients as there were low initial P contents in the plant materials studied ranging from 0.37–0.20 %. Among all the nutrients, potassium was the most abundantly leached cation in the present study as it usually present in soluble form in cells and rapidly leached out. A similar observation of the highest potassium leaching accounting value of 70% among other cations ($K^+ > Mg^{+2} > NH_4^+ > Na^+ > Ca^{+2}$) was reported by Kitamura & Ijuin (2010) using the leaves of two evergreen plant species *i.e. Castanopsis* sp. and *Quercus glauca* Thunb. in Japan at 25ºC. Moreover, focusing on the concentration of leached major nutrients, the results obtained were supported by the similar observation of $K^+ > NH_4^+ > PO_4^{-3}$ using twelve different cropland agroforestry trees in Bangladesh (Hassanuzzaman & Hossain 2014). Mahmood *et al*. (2009) stated that, K^+ ion has higher mobility than NH_4^+ and PO_4^{-3} as it is not structurally bounded and accumulates in active plant tissues of leaves. According to the data of leaching experiments, different nutrients showed different leachabilities, as they belonged to different genera and families. Among them, *Mikania scandens*, *Tithonia diversifolia*, *Chromolaena odorata* and *Sphagneticola trilobata* which belonged to the family: Asteraceae resulted in the highest leached amounts of nutrients and

Panicum maximum which belong to the family: Poaceae showed the least. Furthermore, as Mahmood & Saberi (2007) stated, nutrients leached from different plant families also depend on the varying rates of nutrient uptake, mobility, growth stage, characteristics of nutrients and nutrient involvements in structural properties of different plant cells.

Among physiochemical parameters electrical conductivity which indicates the amount of dissolved substances was continued to increase in all samples up to 70 days and then became constant. The highest nutrient containing *Mikania scandens*, *Tithonia diversifolia* and *Sphagneticola trilobata* showed the highest EC ranging from 1715–2139 µS cm^{-1} as they leached more dissolved substances. Moreover, similar observation of a rapid increase of EC from 573–3247 µS cm^{-1} during 192 hours of leaching process was recorded in Bangladesh for the leaves of *Artocarpus heterophyllus* Lam., *Azadirachta indica* A.Juss. and *Mangifera indica* L. (Hassanuzzaman & Hossain 2014). With the view of utilizing these weed plant materials as organic liquid fertilizers, the potential of releasing more dissolved substances showing higher EC values is highly important as it indirectly indicates the strength of the nutrients in the solution. Moreover, the optimum EC for plant growth is range from 1500–2500 µS cm^{-1}. EC values higher than that range lowers nutrient absorption due to the increase in osmotic pressure and nutrient toxicities whereas even below the optimum range also lowers plant health and yield (Anonymous 2002, Leukebandara *et al*. 2015).

The pH value was decreased from 6.58 to 6.40 soon after the dipping in distilled water until 03 days and then it was increased up to 7.23–7.62 during the next one week period and thereafter remained constant with the range of 7.40–7.86 at average room temperature of 27ºC. Reduction of pH is usually attributed due to the leaching of acidic compounds from the vacuolar sap (Berg & McClaugherty 2003). Kitamura & Ijuin (2010) also recorded a similar observation of an initial rapid decrease of pH soon after the 24 hours of submergence of *Castanopsis* sp. and *Quercus glauca* leaves. They further stated that it could be mostly due to the acidic nature of the plant materials as the leaves of temperate deciduous trees have the pH within 5.0–6.5 range and conifers recorded more acidity of pH 3.5–4.2. Moreover, foliar fertilizers with pH 6.5–7.7 are favorable for availability of nutrients without resulted in any phytotoxicity problems (Fernandez *et al*. 2013).

At the end of 84 days of leaching, the highest mass loss was observed in *M. scandens* followed by *Tithonia diversifolia* and *Chromolaena odorata* (97%, 95.7% and 86.16% respectively) indicating their fast decomposability. The low C/N ratios (12.9–13.5) and low crude fiber contents (10.8–14.4 %) of these species supported the fast decomposability. Moreover, the lower lignin content (6.5%) and polyphenols content (1.6%) of *Tithonia diversifolia* has contributed to higher mass loss (Olabode *et al.* 2007). *Panicum maximum* which showed the lowest mass loss (36.3%) contained the highest C/N ratio (38.8) and crude fiber content (34.1%) revealing its slow decomposability. Similarly, the high C: N ratio (30:1), crude fiber content (17.3%) (Olabode *et al*. 2007), high concentration of lignin and presence of physically tougher leaves with high silica concentration resulted in slower decomposition in *P. maximum* (Cornelissen 1996, Nurdiawati *et al.* 2015).

The leaching experiment has successfully driven towards the identification of easily decomposing, nutrient-rich weed species for the formulation of organic liquid fertilizers. However, fertilizer formulated alone with the selected weed materials (FP1) showed lower nutrient contents compared to the positive control. Hence, additional organic materials i.e. powdered fish waste and coconut husk ash were significantly increased N and K contents in the plant-based fertilizer in order to obtain high concentrated and nutrient-rich organic fertilizers. Similarly, Herath (2014) also found that application of coconut husk ash has a great potential of supplying K, Mg and P to enhance the crop growth. Both formulated organic fertilizers have induced with a significant increase in plant growth as compared to the unfertilized control, particularly the FP4 fertilizer. With respect to the measured growth parameters in *Basella alba i.e.* shoot height, leaf area, plant fresh and dry weights, the formulated FP4 fertilizer showed no significant differences ($p<0.05$) compared to the positive control proving that its capability in improving plant growth as it contained higher amount of nutrients followed by FP3 fertilizer.

CONCLUSIONS

The results obtained in this study revealed that the weeds, *Mikania scandens*, *Tithonia diversifolia* and *Chromolaena odorata* can be used effectively for the formulation of liquid organic fertilizers as they possessed higher macro and micro-nutrients, higher nutrient leachability, lower C/N ratio and lower crude fiber contents compared to those of other four weeds. Out of the four fertilizer combinations formulated, FP4 fertilizer resulted in the highest nutrient content and proved to be the best liquid organic fertilizer for the growth of *Basella alba* followed by the positive control. Utilization of these weeds for the formulation of eco-friendly organic fertilizers will also contribute to control them effectively without much of their adverse ecological impacts.

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