TREATABILITY OF OIL PALM FROND AND RUBBER WOOD CHIPS WITH UREA FOR THE DEVELOPMENT OF SLOW RELEASE FERTILISER

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ABSTRACT

Treatability of a material is fundamental in determining how much chemicals or fillers are retained in the material before it can be used for slow release fertiliser. The aim of this study was to investigate the effect of urea retention in oil palm frond and rubber wood chips treated at different urea concentrations using pressure and non-pressure treatments. Treatability of the materials was calculated based on weight percent gain. Comparative nutrient contents of the impregnated chips were also determined. Oil palm frond and rubber wood chips were treated separately with three different concentrations of urea solution (5%, 10% and 15% w/v) using vacuum-pressure or soaking process. The results showed that type of material, treatment process and urea concentration significantly affect weight percent gain. Regardless of treatment combinations, oil palm frond chips had higher urea retention compared to rubber wood chips. For nutrient contents, treated rubber wood chips attained higher carbon content while treated oil palm frond chips had higher N content. Within the range of urea concentration studied, treatment with 15% urea using vacuum-pressure process was found to be the most efficient treatment combination in the development of wood waste slow release fertiliser. The release pattern of nitrogen from both oil palm frond chips and rubber wood chips proved that these materials are suitable for the development of slow release fertiliser.

Keywords: oil palm frond, rubber wood, weight percent gain, urea, nutrient contents.

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INTRODUCTION

Recently, slow release fertiliser (SRF) has attracted consumer attention due to its advantages and eco-friendly characteristics. Based on the Association of American Plant Food Control Officials Report (AAPFCO, 1997), slow or controlled release fertiliser is defined as a fertiliser containing a plant nutrient in a form which delays its availability for plant uptake and after application, or which extends its availability to the plant significantly longer and in slower manner than conventional water-soluble fertilisers.

A wide range of materials have been used over the past decades to produce SRF. These include conventional SRF from poultry feathers by Choi and Nelson (1996) and SRF from natural attapulgite (APT) clay (Ni *et al*., 2010; 2011). Recently, existing SRF has also been formulated with starch-g-poly (vinyl acetate) (Niu and Li, 2012). Apart from that, a new water-insoluble compound formed by inclusion of molybdenum within a long-chain polyphosphate structure has also been developed as a SRF (Bandyopadhyay *et al*., 2008).

Formulation of SRF from wood materials has also been studied. For instance, Ahmed

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et al. (2011) formulated ammonium nitrate-impregnated woodchips SRF using Japanese red pine (*Pinus densiflora*), eunsasi poplar (*Populus tomentiglandulosa*), and konara oak (*Quercus serrata*). While Kottegoda *et al*. (2011) have developed urea-modified hydroxyapatite nanoparticles that were encapsulated under pressure into soft wood of *Gliricidia sepium*. In another study, Khan *et al*. (2008) found that SRF can be produced from urea-impregnated waste paper.

Nonetheless, formulation of SRF specifically from tropical plant biomass such as from oil palm biomass (*Elaeis guineensis*) and rubber wood (*Hevea brasiliensis*) is lacking and need further exploration. As one of the world largest producers of palm oil, Malaysia has an abundant supply of oil palm biomass in the form of oil palm frond (OPF), oil palm trunk (OPT), kernel shell, empty fruit bunch (EFB), and palm oil mill effluent (POME). Based on the Malaysian Palm Oil Board statistics (MPOB, 2013), oil palm planted area in Malaysia has increased to 5 million hectares in 2012. The most generated oil palm biomass is OPF, which accounted for 70% of the total oil palm biomass produced (Abdul Khalil *et al*., 2012). The fronds are pruned regularly but as for now, little usage has been identified except for ruminant feed source whereas OPT and EFB have been successfully used to produce particleboard (Lee *et al*., 2014; 2015, Zaidon *et al*., 2008). OPF are often left rotting between the rows of palm, mainly for soil conservation, erosion control and ultimately the long-term benefit of nutrient recycling (Abu Hassan *et al*., 1994).

Rubber wood (RW) residues are also available in Malaysia due to large scale RW cultivation and wood product industry. Natural Rubber Statistics from the Lembaga Getah Malaysia (LGM, 2013) reported that RW planted area in Malaysia has expanded to about 1 million hectares. Apart from production of latex, RW is considered as a relatively cheap source and 'by-product' in rubber plantations which serve as main raw material for the wood-based industry (Puasa *et al*., 2010). Therefore, RW residues either from the plantation sites or from the industry can be alternatively used for other beneficial purposes and value-added products.

In consequence of overcoming the high waste, converting agricultural waste as carrier for SRF would be advantageous as the process involves green technology approach. In an attempt to develop new formulation for SRF, these biodegradable lignocellulosic materials have to be treated with nutrient fertiliser prior to application in the field for pot assay and field trials on several crops. One of the potential treatments is through impregnation process. This process normally involves pressure or non-pressure techniques (Dungani *et al*., 2013). The success of the treatment is influenced by treatability of the material, impregnation process and concentration of nutrient fertiliser. This article reports the potential of OPF and RW chips as substrates for SRF. The objective of this study was to determine the treatability of OPF and RW chips with urea using pressurised and non-pressurised impregnation processes. The treatability of these materials was calculated based on urea and nutrient contents retained in the substrates.

MATERIALS AND METHODS

Collection and Preparation of Raw Materials

Freshly pruned OPF collected from the Universiti Putra Malaysia and RW residues from RW mill were used in this study. The density of the OPF used in this study ranged from 140 kg m^{-3} to 600 kg m^{-3} whereas the density of the RW ranged from 640 kg m^{-3} to 800 kg m^{-3}. The fronds were cut into 1 m long from the base and the leaflets were removed. All the fronds were then transported to the laboratory and were chipped to 25 mm × 15 mm × 30 mm using a wood chipper. After chipping, the chips were air dried to equilibrium moisture content (EMC, approximately 15%). Commercial grade urea, [$CO(NH_2)_2$] that contains 46% nitrogen was obtained from Petronas Fertiliser Chemical, Malaysia and it was used as treating solution.

Impregnation

Impregnation processes employed in this study were vacuum-pressure and soaking. The vacuum-pressure process was adopted after Ahmed *et al*. (2011) with some modifications. Three different urea concentrations (5%, 10%, and 15% w/v) were used. The OPF and RW chips were treated separately. Approximately 500 g of oven dried sample was placed in air tight vacuum pressure apparatus and vacuum of 87 kPa was applied for 15 min to remove as much air as possible from the chips. While maintaining the vacuum, the cylinder was filled with urea solutions until the wood chips were completely submerged in the solution. After the cylinder was filled with urea solution, external pressure of 862 kPa was applied for 30 min. At the end of the impregnation process, the treated chips were blotted with filter paper and dried in a forced circulation oven until constant weight. For the non-pressure technique, the oven-dried chips were soaked in the urea solutions separately for 24 hr. The treatability of the materials were measured based on weight percent gained (WPG) and calculated using Equation (1).

$$WPG\ (\%) = 100\ [(W_f - W_o)\ /\ W_o] \qquad (1)$$

where, W_f is the oven-dry weight of samples after treatment (g), and W_o is the oven-dry weight of samples before treatment (g).

Determination of Nutrient Contents

For the determination of carbon and nitrogen contents, the impregnated chips were first ground using a wood grinder. Three grammes of ground particles from each treated material was analysed using LECO TruMac carbon/nitrogen/sulphur (CNS) determinator based on Dumas method of combustion (Gustin, 1957). Pre-weighed sample was placed into a ceramic boat and loaded into the purge chamber to remove the atmospheric gas from the sample. After that, the ceramic boat was introduced into the furnace regulated at a temperature of 1100°C. Complete oxidation of the sample was ensured by the pure oxygen environment within the furnace with additional oxygen being directed onto the sample via a ceramic lance. The ceramic boat and all ash from the sample were removed from the furnace at the end of combustion, leaving the furnace free of ash build-up. The combustion gases were swept from the furnace into a thermo-electric cooler where the moisture was efficiently removed without the use of chemicals. The remaining combustion gases were collected and equilibrated in a ballast where an aliquot was taken for nitrogen and carbon determination.

Slow Release Test of Woodchips Fertiliser

To examine the ion release pattern, impregnated woodchips weighing 1.5 g was immersed in 100 ml distilled water (sample solution) and incubated at room temperature. One millilitre of the sample solution was collected at time intervals of 12 hr, 24 hr, 48 hr, 96 hr, 192 hr, and 384 hr, respectively, to determine the concentrations of the ion released into the sample solution. The sample solution was replenished with 1 ml of fresh distilled water every time after the sample collection in order to sustain the volume of the sample solution. Release of N was determined with an elemental analyser (Vario EL III). The release test was replicated three times for each species.

Statistical Analyses

Two-way factorial analysis, *i.e.*, two levels of materials, two levels of impregnation processes and three levels of urea concentrations was carried out on WPG and nutrient content values to determine if any significant difference existed between the treatment combinations. Treatment means were separated using Least Significant Different (LSD) at $p<0.05$ level.

RESULTS AND DISCUSSION

Treatability of OPF and RW Chips with Urea

Table 1 exhibits the summary of analysis of variance (ANOVA) on the effects of material, impregnation technique and urea concentration on weight percent gain and nutrient content. The results showed that the materials used, impregnation process and urea concentration significantly affected the WPG. Interactions were only found between material and impregnation process and between material and urea concentration. For nutrient contents, carbon and nitrogen were significantly affected by the materials and urea concentrations. The impregnation process did not show significant effect on nitrogen content but was found to significantly affect the carbon content. There was interaction among the factors for carbon content but no interaction for nitrogen content.

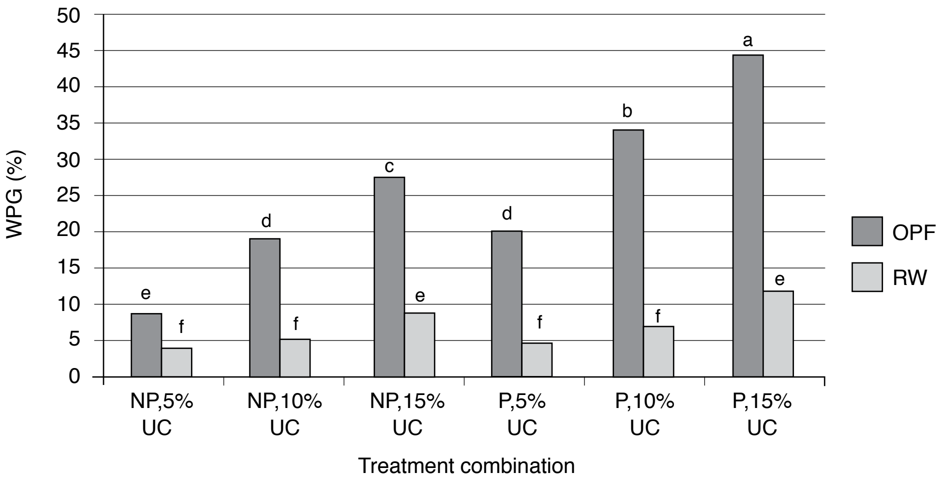
The mean WPG for OPF and RW samples treated with different treatment combinations are shown in *Figure 1*. The results showed that regardless of treatment combinations, the WPG for OPF were markedly higher than WPG for RW. The highest WPG values were obtained by materials treated under pressure at 15% urea concentration, *i.e.* 44.30% for OPF and 11.49% for RW chips. The lowest values were found for materials treated at 5% urea by soaking, *i.e.*, 8.77% for OPF and 3.96% for RW chips. The difference in WPG attained by OPF and RW was plausibly due to the anatomical characteristic of the materials. RW contains about 9.5% vessels and 11.5% axial parenchyma only (Teoh *et al.*, 2011; Francis, 2003), whereas OPF has two to three times higher than RW (Mohd Ashriq, 2010). High content of vessel elements facilitates penetration of preservative or chemical into the wood as well as increase bulk, and *vice versa* (Priyadarshan, 2011; Colley, 1973). Probably because of this characteristic, OPF has a better capability to retain urea as vessel and parenchyma are the major elements that can provide to the effectiveness of fluid flow during impregnation process.

Furthermore, density of the materials was also a crucial factor that decides the amount of chemicals that can be introduced into the materials as positive correlation between density and weight percent gain was reported by Purba *et al*. (2014). In this study, OPF had a lower density than RW and hence OPF had higher urea retention compared to RW. These findings were in agreement with Yap *et al*. (1990) who suggested that lower density woods gain higher amounts of chemical and *vice versa*. *Figure 2* illustrates the structure of OPF vascular bundle that influences the capability to obtain high WPG. Anatomically, the internal structure of oil palm frond is similar and bears a superficial resemblance of the oil palm stem in terms of distribution of

TABLE 1. SUMMARY OF ANOVA (p≤ 0.05) OF IMPREGNATED WOODCHIPS AT DIFFERENT TREATMENT COMBINATIONS

Treatment	df	Pr > F		
		WPG	C	N
M	1	0.000	0.000	0.000
T	1	0.000	0.047	0.939
UC	2	0.000	0.016	0.000
M x T	1	0.000	0.392	0.214
M x UC	2	0.000	0.041	0.714
T x UC	2	0.154	0.000	0.255
M x T x UC	2	0.540	0.001	0.199

Note: M - material, T - impregnation technique, UC - urea concentration, WPG - weight percent gain, C - carbon content, N - nitrogen content. ANOVA – analysis of variance.



Note: *Mean values with same letter (a,b,c,d,e,f) are not significantly different at P≤0.05.
**P - pressurised, NP - non-pressurised, UC - urea concentration.

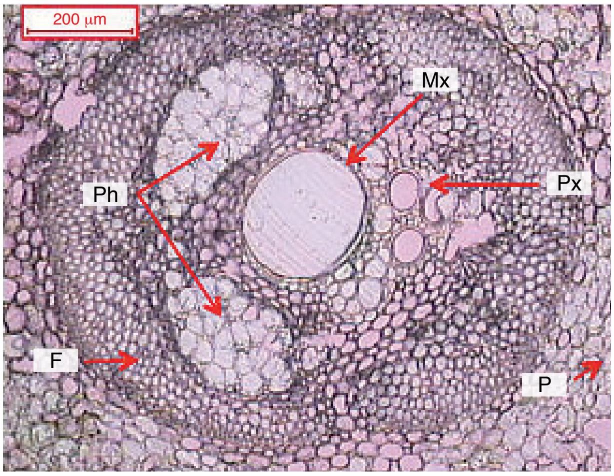
Figure 1. Weight percent gain (WPG) of oil palm frond (OPF) and rubber wood (RW) samples treated at different treatment combination.

vascular bundles, with a slight different in shape of the vascular bundles (Shirley, 2002). The vascular bundle is made up of a fibrous sheath, vessels, fibres, phloem, and parenchymatous tissue. In another research, Reghu (2002) stated that the lumen of the RW vessels is usually filled with tyloses. Tyloses are balloon-liked parenchymatous outgrowths that partially or completely block the vessel lumen (*Figure 3*). Thus, this can limit RW from retaining more nutrient fertiliser (urea) compared to OPF.

Impregnation process plays an important role in attaining higher salt retention. The application of external pressure would assist the system to push more urea to fill up the void structure of the materials in a shorter time. This system has been proven successful to impregnate preservative or chemicals into impermeable wood. A study by Robinson *et al*. (2011) revealed that southern yellow pine was successfully impregnated with a pyrolysis oil-based penetrant using both high pressure and vacuum impregnation systems. Zaidon (1995) found that boron compound could penetrate the silicous epidermal layer of rattan by a treatment method employing a combination of vacuum and pressure process.

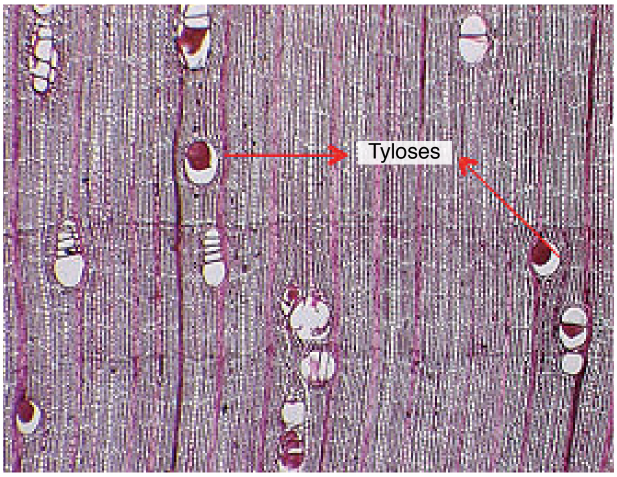
Nutrient Content

The mean values of carbon and nitrogen content for OPF and RW samples treated with different treatment conditions are shown in *Figures 4* and *5*. Based on *Figure 4*, RW samples showed slightly higher carbon content than OPF sample which were 40.57% and 38.11%, respectively. This result was in line with that of Sian-Meng *et al*. (2011) that RW is high in carbon content. However, the carbon content found in the urea-treated OPF was relatively lower compared to the carbon content in fresh OPF sample of a previous study. Zahari *et al*. (2012) found that the carbon content in a fresh OPF was



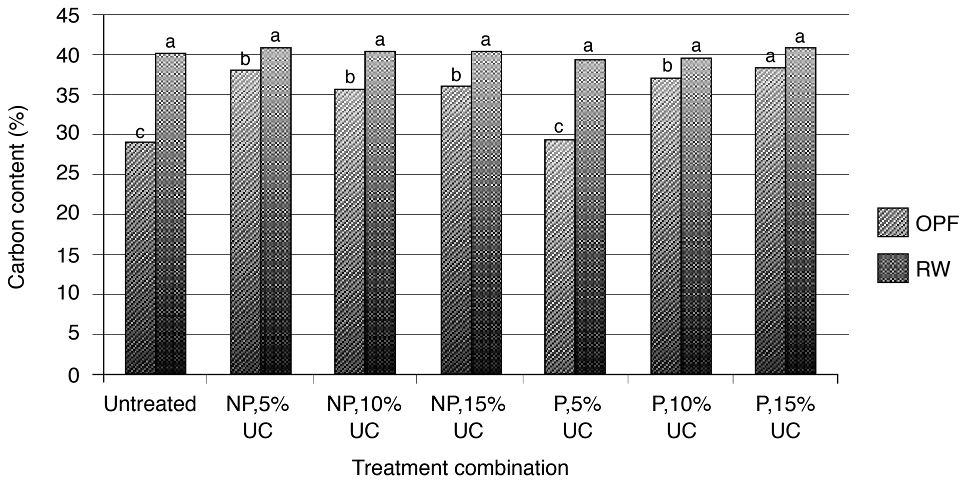
Note: Mx - metaxylem, Px - protoxylem, Ph - phloem, P - parencyhma, F - fibre.

Figure 2. Anatomical structure of oil palm frond.



Source: Richter and Dallwitz (2000).

Figure 3. Transverse section of rubber wood (RW) showing the existence of tyloses in the vessels.



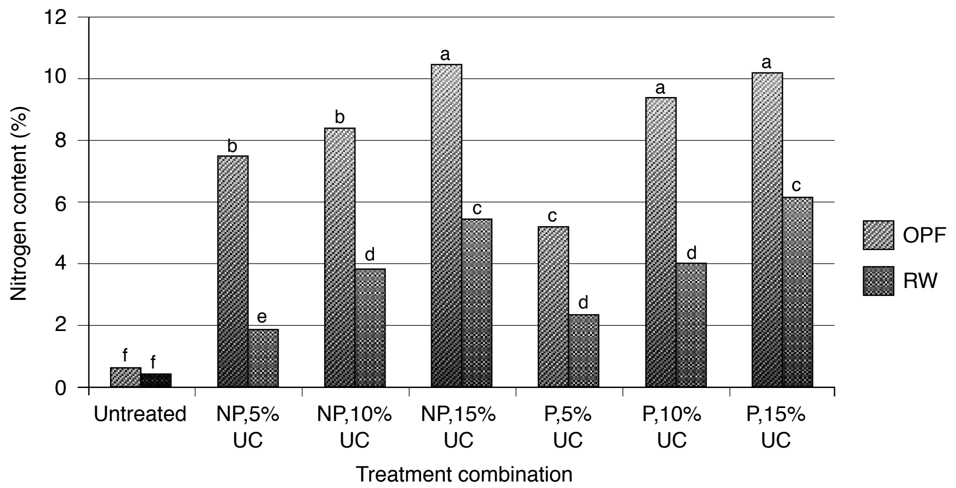
Note: *Mean values with same letter (a,b,c,d,e,f) are not significantly different at P≤0.05.
**P – pressurised, NP - non-pressurised, UC - urea concentration.

Figure 4. Carbon content of oil palm frond (OPF) and rubber wood (RW) samples on different treatment combination.

49%. This phenomenon was probably attributed to the disintegration of the cellulose during oven drying process of the OPF and as a result, some of the carbons might have been lost during drying.

The results also showed that the impregnation process did not give significant effect on the carbon (C) content of RW samples treated with all the three levels of urea concentration. On the contrary, the impregnation process significantly affected the C content of the OPF in which the C content of pressure-treated OPF chips increased with increasing urea concentration. As compared to the untreated chips (control), *i.e.* 28.78%, pressure-treated and soaked treated OPF chips showed higher C content in the range of 29.19% to 38.11% and 35.22% to 37.64%, respectively. Addition of urea, [CO $(NH_2)_2$] during impregnation treatment was believed to be the reason for this C content increment. This is because urea composition itself consists of 20.00% of C, 26.64% of oxygen (O), 46.65% of nitrogen (N) and 6.71% of hydrogen (H).

From *Figure 5*, one can see that N content was significantly affected by the material used. Both treated and untreated OPF generally showed higher percentage of N content than RW. This might be related to the WPG of the material in which OPF had higher urea retention than RW (*Figure 1*). Moreover, nutrient content, including that of nitrogen, vary between wood species (Ahmed *et al*., 2011). *Table 2* shows the N retention of several different woodchips from a previous study and this current work. The release patterns of nutrient from the woodchips are also expected to vary due to these anatomical and porosity factors of the materials. Ahmed *et al*. (2011) suggested that even though the impregnated oak woodchip retained



*Note: Mean values with same letter (a,b,c,d,e,f) are not significantly different at P≤0.05.
**P - pressurised, NP - non-pressurised, UC - urea concentration.

Figure 5. Nitrogen content of oil palm frond (OPF) and rubber wood (RW) samples treated with different treatment combination.

TABLE 2. NITROGEN RETENTION OF DIFFERENT WOODCHIPS MATERIAL FOR DEVELOPMENT OF SLOW RELEASE FERTILISER

Study	Material	N content (%)	
		Untreated woodchip	Treated woodchip
Ahmed *et al*. (2011)	Pine	0.10	22.70
	Poplar	0.10	25.70
	Oak	0.30	16.50
Current study	OPF	0.60	10.44
	RW	0.41	6.13

Note: OPF - oil palm frond. RW – rubber wood.

the lowest amount of N due to low porosity, oak showed the slowest N release of the three wood species studied.

The levels of urea concentration also give significant effect on N content. As expected, all the treatment combination showed increasing trend with the increase in urea concentration. Both OPF and RW chips treated with 15% urea concentration obtained the highest N content, followed by 10%, 5% and untreated chips (control). The results were probably due to the reaction mechanism of urea with the structure of woodchips. Khan *et al*. (2008) stated that during treatment, N fertiliser was impregnated into the cell wall structure of the chips where large numbers of hydroxyl groups are present as part of the cellulose. With higher concentration of urea, this will contribute to the possibility of more H bonding between urea and the hydroxyl groups of cellulose. Therefore, increase in the level of urea concentration will result in increase of N content of treated chips.

Nitrogen Release Pattern from OPF and RW Impregnated Chips

The release pattern of OPF and RW is different due to their micro-structural differences and N retention. The rate of N release from RW is lower than OPF as exhibited in *Figure 6*. The nitrogen released from OPF was 34% and 65% at 12 hr and 384 hr, respectively. Meanwhile, the nitrogen released from RW at 12 hr and 384 hr was recorded as 27% and 61%, respectively. In other words, OPF and RW released only 65% and 61% N, respectively, after 384 hr of incubation which proved that both OPF and RW are suitable for the development of SRF. Moreover, *Figure 6* suggests that the release patterns of both OPF and RW were similar to the conventional SRF as they gradually slowed down after a rapid release in the beginning stage.

Variation in wood material, nutrient solutions as well as exposure conditions are crucial factors

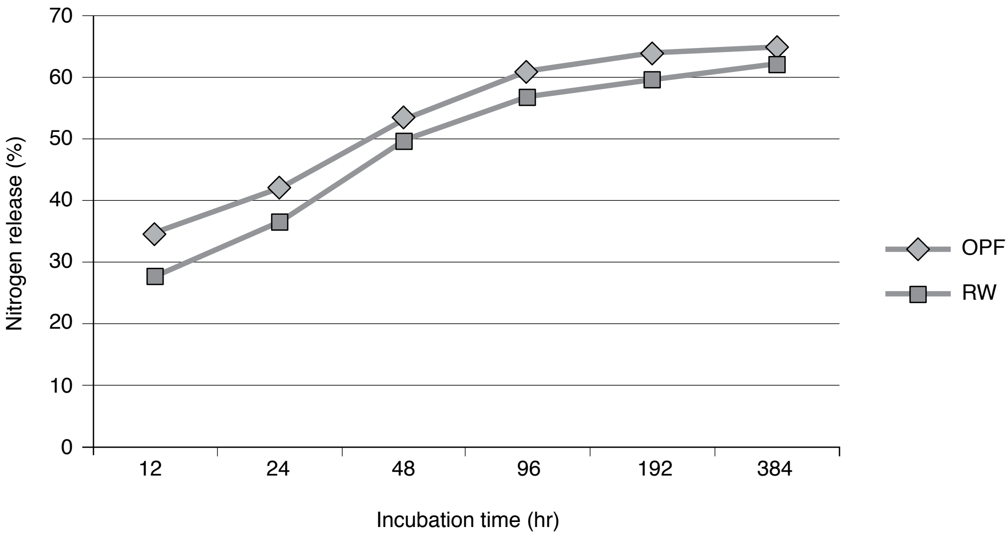


Figure 6. Nitrogen release pattern from oil palm frond (OPF) and rubber wood (RW) chips to distilled water.

affecting the release of nitrogen (Waldron *et al*., 2006). In this study, N release from OPF and RW varied depending on the wood species and the impregnation technique. Different release patterns are targeted for different applications. Therefore, the woodchips fertiliser can be recommended according to their nutrient release pattern, based on the nutrient demands of the cultivated crops. For instance, short duration plants like corn and vegetables can be fertilised with OPF impregnated chips that showed higher N release, whereas RW impregnated chips with slower release pattern can be used for plants that need nutrients over a long period of time.

CONCLUSION

Based on the above findings, it can be concluded that types of material, impregnation process and urea concentration did influence the treatability of oil palm frond and RW chips with urea solution. Among the two materials, OPF was found to have the higher WPG and retention of N compared to RW. Impregnation of OPF or RW chips using vacuum followed by soaking under pressure for 30 min attained higher dry salt retention compared to soaking the materials in the solution for 24 hr. Within the range of the urea concentration studied, treatment with 15% urea concentration using vacuum-pressure process was found to be the most efficient treatment combination in the development of wood waste SRF. Considering that Malaysia has high potential and sustainable supply of wood wastes, OPF and RW biomass have promising future to be used as carriers for new formulation of SRF.

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