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PULP AND PAPER MILL SLUDGE; A SOIL AMENDMENT AND COMPOST OPTION FOR LANDFILL DIVERSION FOR SOUTH-AFRICA

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ABSTRACT

In South-Africa, approximately 30% of all recycled paper is being disposed into landfill sites or incinerated. Using this type of hazardous and industrial waste as a resource is essential to reduce landfilling of organic waste. In this study, Pulp and Paper-Mill Sludge (PPMS) has been evaluated under two possible pathways contributing to landfill diversion and secondary use: compostability and the use of PPMS as a soil amendment. A short review of existing studies on PPMS using these two pathways as alternative for secondary use and within the South-African context have been undertaken. This investigation showed that the addition of PPMS to soil as an amendment does not negatively affect soil fertility. The potential of PPMS as a soil amendment or compost contribute to improving factors allowing for increased soil fertility resulting in a better soil structure. Such effects from either using PPMS as an amendment or compost will directly increase resistance of soils to degradation ultimately allowing for reduced erosion potential of soils.

1. INTRODUCTION

The Pulp and Paper Industry (PPI) is considered to be one of the greatest water intensive and polluter industries, globally. In South-Africa, PPI's contribute significantly towards growth of the global economy (Makgae, 2011). In the manufacturing of pulp and paper products, virgin materials and recycled fibres are processed, subsequently generating large quantities of wastes requiring sustainable waste management (Makgae, 2011).

Different paper grade requirements allow for specific production processes which varies between mills, as a consequence, residuals vary in amounts and composition (Poykioa et al., 2018). Composition of solid wastes generated i.e., Pulp and Paper Mill Sludge (PPMS), is majorly affected by the type of materials processed, the manufacturing process utilised and technologies used in wastewater treatment.

PPMS are complex mixtures of chemically modified wood fibres, inorganic solids and chemicals added during manufacturing processes (Ghinea et al., 2014). PPMS generated from wastewater treatment processes accounts for the largest volume waste stream in a pulp and paper mill plant (Ghinea et al., 2014). The Recently, the PPI has adopted the concept of sustainability, cleaner production and circularity, globally. However, in South-Africa, PPMS is still landfilled. In most countries of the global south, efficient waste management plays a critical role not only in reducing the impact of wastes generated from an economic standing, but also from an environmental sustainability and social development point of view (Gibril et al., 2018). Therefore, for PPMS, landfill diversion and valorisation are urgent concerns.

The case of PPMS is the perfect example of the failure of the perfect circle of the Circular Economy. Residues from the recycling sector are unavoidable and they needs a final sink for closing the loops of the material, whether it is a sustainable landfill or the soil after proper stabilisation (e.g. compost back to the soil) (Cossu, 2020). Current waste management practices include incineration and landfilling. These practices can be unsustainable, since incineration can lead to net energy losses and GHG emissions, and landfilling of organic materials is a direct contributor to GHG emissions responsible to global warming. Furthermore, in South-Africa, additional parameters such as transportation of waste, associated disposal gate-fees and the associated negative impacts on social and environmental health are issues to attend urgently. South Africa bans landfilling of wastes of moisture contents greater than 40% (Lundqvist, 2020), sustainable methods must be considered in the case of waste management of effluents

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from the PPI. Moreover, the lack of appropriate landfill designs including sustainable technologies, that could benefit countries of the Global South has resulted in a series of accumulative critical hurdles in traditional non-sustainable landfills that prevents sustainable landfilling of organic materials such as PPMS (Grossule, 2020).

A rapidly increasing world population led to increased demands on paper and related products, with demands projected to significantly increase over the next 50 years by between 46% to 78% above existing levels (Desmond and Asamba, 2019). This has led to heightened focus on alternate uses of PPMS through valorisation approaches which will not only eradicate challenges associated with disposal, but will redirect the waste stream towards the manufacturing of value added products. Such waste management approaches enable the transition towards a circular economic model whilst simultaneously increasing sustainability of the industry.

PPMS is an active organic material classified as hazardous (Ghinea et al., 2014), posing advantages and disadvantages. It is vital in characterising their physical and chemical properties allowing accurate assessing of impacts towards finding alternative waste management practices. Through a sustainable utilisation, this waste material will counter-balance demands placed on limited natural resources.

PPMS is considered to be an organic waste with high potential for valorisation into bio-products, hence, this paper reports on research undertaken at UKZN to develop viable alternative methods adapted to the South-African context. This study aims to explore viable alternate end of life pathways for pulp and paper mill sludge based on its composition allowing for optimisation and valorisation, facilitating landfill diversion of this waste. In particular, it explores the use of PPMS as a soil amendment and the compostability potential of PPMS in South-Africa.

2. BACKGROUND AND CONTEXT

Severe effects and consequence of climate change have visibly affected South Africa. Weather-related natural disasters cause parts of the country to experience drought regimes whereas other parts contrastingly experience severe storms with changes in rainfall patterns. These effects, if not mitigated through urgent adaptation measures has the potential in causing environmental, social and economic losses in cities and towns in South Africa, affecting millions. People will now become vulnerable and exposed to ramifications of climate change.

Increased frequency of such events allows effects of climate to grow with time. This is evident in South Africa, where the events recorded between 1996 to 2016 increased by 57% compared to the period of 1976 to 1996. Currently, in the 8th month of 2021 and all 9 provinces have experienced flooding events.

Compounding the effects of climate change is the ENSO (El Nino Southern Oscillation), a recurring weather pattern involving changes in ocean temperature in the Indian and Pacific Ocean with effects felt throughout South Africa. Within ENSO, there are three distinct stages i.e. El Nino (drought phase), neutral phase and La Nina (wet phase). ENSO is characterised in alternating of different phases every 3 to 7 years.

El Nino phase is characterised by below average climatic events being observed, such as reduced rainfall resultant of decreased ocean surface temperatures causing less water becoming available for cloud formation. The major drought facing South Africa from early 2016 up until late 2020's is attributed as an effect of the EL Nino phase of ENSO. Neutral phase can be described with normal climatic conditions. La Nina, contrastingly to EL Nino results through increased ocean surface temperatures allowing larger amounts of water becoming available for cloud formation. Effects of La Nina are characterised by an increased frequency in rainfall and storm events with subsequent higher rainfall intensities.

Climate change coupled with ENSO results in detrimental and in many cases catastrophic effects in the Southern African region. A simple example on such an effect having one of the largest contributing industries to the South African GDP, being agriculture. EL Nino phase resulted in the largest recorded drought crippling the agricultural sector with thousands of animals dying due to malnutrition and minimal water available with millions of hectares of crops, flora and fauna destroyed due to this drought. La Nina phase followed between the end of 2020 into 2021 subsequently bringing excessive amounts of rain to the region, such rainfall described as destructive and not beneficial.

Effects were severe and ramifications still being felt and others yet to manifest themselves. A significant proportion of these effects could have been avoided by early mitigation and adaptation strategies. Employing such strategies are of a proactive approach prior to such effects, then following a reactive approach in the wake and aftermath of such events. This would allow factors with risks such as soils having an increased resilience in the face of uncertainty (Hao-an et al., 2020).

With much of the climatic conditions attributed to ENSO with literature supporting it, it does not rule out the possibility of such events or a proportion of these events caused by climate change as it causes the severity of climatic events to increase. Examples of such events are increased rates of melting of polar ice caps, changes in ocean currents, rising sea levels, changes in climate and vegetation, desertification and increased global temperatures.

Climate change is not a new climatic occurrence effecting earth, previously, many historic global cooling and warming events occurred. A huge differentiating factor between past and current events and subsequent conditions are due to anthropogenic activities accelerating changes at unprecedented rates combined with an increased magnitude of effects (Simpson, 2010). Effects of these changes at such rapid rates are at the forefront of research still being investigated.

In determining mitigation strategies in the aim of increasing our adaptability to uncertainty, it would be logical in focussing on renewable resources produced as a result of climatic conditions especially in the face of uncertain climatic conditions, examples of such is soil and freshwater.

Formation of soil found on the earth's surface takes millions of years (Rasa et al., 2020, Durigan et al., 2017a, Hao-an et al., 2020). Numerous literature agrees that formation of approximately 1 cm of soil takes between 80 and 400 years, and between 3000 and 12000 years in building soil reserves adequate in formation of productive land (Simpson, 2010). Soil, a fragile foundation anchoring all life on earth either directly or indirectly (Hao-an et al., 2020). It is one of the most valuable resources available to humans comprising of countless species in creating a dynamic and complex ecosystem (Reddy and Pillay, 2005). Therefore, although soil technically is a renewable resource, the renewability is not on a human time scale implicating the need to regard and treat it as a vital non-renewable resource.

Soil erosion occurs when erosion is greater than the rate of soil formation (Canadian Ministry of Agriculture Food and Rural Affairs, 2021). Anthropogenic accelerated effects in climate change lead to in massive quantities of soil becoming lost through erosion. Erosion is a natural process, but anthropogenic activity caused rapid acceleration of this process. Globally, half of all topsoil was lost over the past 150 years (Canadian Ministry of Agriculture Food and Rural Affairs, 2021). Soil erosion is a major problem confronting South African land and water resources (Singh, 2014).

Prolonged erosion results in soil loss becoming irreversible (Hao-an et al., 2020). Major effects are reductions in ecological functions such as biomass production, and hydrological functions such as infiltration and water holding capacities (Hao-an et al., 2020). Other pertinent issues facing soil erosion in South Africa is loss in productivity of soils and increased mobilisation of soil sediments causing mobilisation resulting in clogging of waterways and siltation of dams putting massive strains on water resources especially as this country can be classified in having water scarcity (Makgae, 2011).

Soil erosion is naturally occurring affecting all landforms. Often referred to as wearing away of topsoil due to natural forces acting on it such as water, wind and anthropogenic activity (Lawaal, 2009). Three distinct actions occur resulting in soil erosion. These are soil detachment, movement and deposition (Lawaal, 2009). Generally, via the means of natural forces, soil erosion is a slow process yet, contrastingly, it can occur swiftly and rapidly at alarming rates. Soil degradation accelerates erosion process with factors increasing rates of soil degradation are soils with low organic matter content, soil structure, poor drainage, soil pH and compaction (Hao-an et al., 2020, Lal, 2015, Rasa et al., 2020, Johns, 2015). There are many factors controlling the rate and magnitude of soil is erosion via natural forces of water and wind. The following factors are pertinent to keeping in line of this research. These factors are rainfall and runoff, soil erodability, vegetative cover and climatic conditions.

Rainfall is directly related to soil erosion, increased intensity and duration of a rainstorm results in higher erosion potential. Rain drops hit the soil surface, causing breaking and dispersing of soil aggregates (Lawaal, 2009). Lighter aggregates in the case of fine sands, silt, clay and organic material easily break down and removed through the splash caused by rain drops and runoff (Lawaal, 2009). Increased rainfall intensity and runoff allow for removal of larger particles of sand and gravel. Soil movement is greatest in short high intensity rainfall and thunderstorms, but erosion occurring over time with reduced intensity rainfalls may not be as noticeable compared with high intensity rainfalls, although effects off soil erosion compounded through time results in substantial losses of soil (Lawaal, 2009). When excess water is present and cannot infiltrate or absorb in to the soil, this results in surface runoff (Hao-an et al., 2020). Factors reducing amounts of waters ability to infiltrate soils are compaction, crusting and freezing of soils, causing increasing runoff.

Estimation of soils resistance to erosion is referred to as 'erodability' of soil, based on its physical characteristics (Kemner and Adams, 2021). Primary factors affecting erodability are soil texture, organic matter content, structure and permeability. Greater infiltration, organic matter and structure improve soils resistance to erosion (Kemner and Adams, 2021, Lawaal, 2009, Lal, 2015).

During wind erosion, small particles are lifted into the air and transported over large distances, medium particles are lifted for short distances but fall back to the surface, and upon impact damage vegetation, breaking down and dispersing soil aggregates, Large particles unable to lift are dragged along the surface (Lawaal, 2009). A major effect from wind erosion is abrasion caused by wind-blown particles breaking down surface aggregates increasing erodability of soils (Lawaal, 2009).

Vegetative cover directly relates to soil erosion. Vegetative cover that's minimal or absent have increased potential to erosion (Lawaal, 2009, Kemner and Adams, 2021). Vegetative cover allow for a degree of protection from rain drops and splashes, reduces speed of consequent runoff generated simultaneously allowing for greater infiltration (Lawaal, 2009). This is effective in controlling potential of wind erosion as vegetation cover acts as a wind break. Vegetation completely covering soils has the highest efficiencies controlling erosion through intercepting all rain drops. Whereas vegetation partially covering soil is effective, but at reduced efficiencies since they provide channels for infiltration of surface water and runoff (Lawaal, 2009).

Eroded soils cause exposing of the subsurface layer that has a poorer structure and reduced organic matter content than surface layers, allowing for an increased erodability potential compared to surface layer of soils (Durigan et al., 2017a).

Soil structural properties are of the same importance as chemical and biological properties in defining soils fertility (Durigan et al., 2017a). Primary soil particles combine and arrange themselves with other solid components in soils influencing their abilities in retaining and transmitting air, water, organic and inorganic substances, resulting in the formation of lumps known as aggregates.

Resistance of soil to degradation is known as aggregate stability (Turgut and Kose, 2015), which directly influences the physical behaviour of soils including infiltration, permeability and erosion at a macro scale. Organic matter present in soil is a major factor affecting aggregate stability, due to soil organic carbon acting as a binding agent, allows for aggregate formation where acts as a nucleus, and increasing the resistance offered by aggregates against dispersive and dissolution actions of water through formations of strong intra-aggregate bonds (Turgut and Kose, 2015).

Aggregates can be differentiated into two groupings i.e. micro- and macro-aggregates. Micro-aggregates are particles of silt and clay bound together, collections of micro-aggregates together with organic matter and other particles are known as macro-aggregates (Turgut and Kose, 2015). Secretions from microbial activity, plant roots and mycorrhizae are major factors in the formation of macro-aggregates (Kemner and Adams, 2021).

Declining soil structure is form of land degradation (Makgae, 2011). Soil structure is majorly influenced by changes in biological activity and climate. Improving of soil structure through management where increasing amounts of carbon and decreasing the rate of carbon loss through soil management through decomposition and erosion (Lawaal, 2009). Management of soil structure and aggregates improve productiveness, porosity and decreases erosion potential (Turgut and Kose, 2015, Rasa et al., 2020).

Such management practices include tillage, addition of manures, composts, fertilisers and nutrients to the soil. Addition of fertilisers and nutrients have variable effects on aggregation, but when applied correctly, allow for increased soil productivity, soil organic carbon and microbial activity, resulting in an increased amount of aggregation (Turgut and Kose, 2015). Application of composts improves the structure whilst lowering density of soil. Composting materials have high potential in increasing aggregation and aggregate stability (Turgut and Kose, 2015). Use of composting practices face limitations such as environmental conditions like drought and effects of composts generally are short lived.

South Africa, a country with primary GDP contributing industries involving the agricultural sector, but only 9.9% of its total land area is arable land. Soil erosion has potential in causing detrimental effects to the environment, social and economic wellbeing of the nation. In the face of climatic extremities been felt, with more effects yet to manifest themselves directly, as a result of climate change coupled with ENSO, existing situations of erosion could only be predicted with increased frequencies and magnification in future effects. Special attention, adaptation and proactive mitigation strategies need to be implemented in areas where soils face a higher risk and vulnerability to erosion.

Therefore, the use of PPMS as a soil amendment and / or as a compost is solution to consider to mitigate the effect of the climate change phenomenon while diverting organic waste from landfill within a circular economy ethos.

3. RESULTS AND DISCUSSION

3.1 Relevance of using PPMS as soil amendment

In the past decade, climate change coupled with El Nino Southern Oscillation (ENSO) resulted in detrimental and often catastrophic effects on the Southern African region. The devastating impacts of climate change and weather-related hazards cause parts of South Africa to increasingly experience drought regimes whereas other parts contrastingly experience severe storms with continuos changes in rainfall patterns. The combined effect of the El Nino hurricane phase (2016 to 2020) followed by La Nina phase (2020-2021) resulted in the largest recorded drought in Southern Africa, subsequently followed by excessive rainfalls and destructive flooding events, responsible for massive soil erosion that is crippling the agricultural sector.

Special attention, adaptation and proactive mitigation strategies need to be implemented in areas where soils face higher risk and vulnerability to erosion.

The primary focus of this investigation is assessing the suitability of composting of PPMS as an alternative organic waste management solution that maximises its diversion from landfills while producing a viable product for land applications. The suitability of PPMS for composting was investigated, as well as the effects of mining PPMS for reuse as compost or soil amendant, in terms of parameters such as pH, salinity, organic content, heavy metals concentration, as well as properties such as nitrogen immobilisation and mineralisation, ion-cation exchange capacity and exchange acidity.

A review of previous studies on land application of PPMS was pragmatically undertaken. The studies reviewed focussed on the medium to long term effects of treated PPMS on soil properties. The next section emphasizes the optimisation of PPMS, the suitability and viability in the direct application to land, the effects on the fertility of soils and the outcome of toxic and harmful elements present when applied to soils.

3.1.1 The effects of using PPMS on soil properties

PPMS is an active organic material that can offer potential benefits in waste management practices. It is regarded as a source of nutrients for soil and plants especially in degraded lands extending its potential uses to the agricultural sector (Larney and Angers, 2011). The potential negative side effects of active organic materials' application to land is the reduction of soil fertility, crop yields, loss of topsoil with nutrients leaching out the soils profile causing soil loss, creating potential vulnerability to natural elements proning erosion (Canadian Ministry of Agriculture Food and Rural Affairs, 2021). In the case of use of PPMS as an active organic material, a crucial requirement in soil protection is ensuring soil fertility is not negatively impacted by contamination by heavy metals. Table 1 and 2 present data from a study conducted by Singh (2014) on changes in soil's properties when using active organic waste (including PPMS for farm C) as fertiliser in three sugar cane farms in South Africa.

3.1.2 Effects on Cation Exchange Capacity

The cation exchange capacity (CEC) is an indication of the soil's capacity in holding cations present in nutrients, a high CEC is desirable (Singh, 2014). Untreated soils of farm A and B have a low CEC, an indication of decreased soil fertility and a low resistance to changes in the soil's chemistry resulting from intense land use (Singh, 2014).

Conversely, soils treated with PPMS had increased CEC capacity, with farm C increasing three times that of untreated soil (Abu Bakar et al., 2015). An increased CEC allows for greater buffering capabilities against adverse effects relating to changes in the pH, availability of nutrients, levels of calcium and structural changes (Durigan et al., 2017b). Many investigations have shown CEC increasing following application of PPMS to soil (Durigan et al., 2017b, Reddy and Pillay, 2005, Gavrilescu et al., 2012).

3.1.3 Effects on pH

The addition of PPMS to soils increases the organic content and pH in the soil due to the alkaline nature of PPMS (Singh, 2014). pH is an important chemical characteristic in plants' growth affecting nutrient availability, nutrient toxicity and microbial activity in the soil (Lal, 2015). Many studies have shown the calcium carbonate content in PPMS, when added to land increased the soils pH with significant positive responses and impacts on a diverse range of crops found on acidic soils (Lal, 2015, Singh, 2014, Abdullah et al., 2015).

In the study by Singh (2014) the pH levels increased following additions of PPMS (Singh, 2014). However, for farm C the increase of pH was not sustained over time, following the fast decomposition of PPMS that resulted in pH levels becoming similar to those detected in untreated soils (Singh, 2014).

3.1.4 Effects on Nutrient and Organic Carbon Availibility

Nutrient availability depends on pH (Lal, 2015). Micro- and macronutrients become less available at pH lower than 4.5 and 5 respectively (Lal, 2015, Singh, 2014). In Table 2, farm A (treated soil) had a pH of 3.89 that is highly acidic. Nutrients from soil analysis at farm A were lower than farm B and C (Singh, 2014). Low pH levels facilitate some nutrients to bind with soil and other nutrients like phosphorous, and undergoing chemical structural changes, becoming unavailable to plants (Simpson, 2010).

Soil Organic Carbon (SOC) has effects on the chemical, physical and biological properties of nutrient availability and organic matter in soils (Abdullah et al., 2015). Studies have shown applications of PPMS increased the SOC and soil organic matter showing positive accumulations of SOC with the addition of PPMS. (Abdullah et al., 2015, Singh, 2014).

Increased SOC causes improved water-holding capacity of the soil, whilst reducing water loss and erosion, it also increases the supply of micro- and macronutrients and organic matter content, creating a better root environment for the plant (Lal, 2015, Singh, 2014, Abdullah et al., 2015).

3.1.5 Effects on the C:N ratio

Land application of PPMS with a high C:N ratio results in a net immobilisation of Nitrogen, it is an indication that PPMS undergoes microbial decomposition, which highlights competition with plants in securing the available N present prior to releasing a portion of its own N content to N-depleted environments (Jackson and Line, 1997). In thery, C:N thresholds are as follow; C:N greater than 30:1 results in immobilisation of Nitrogen and less than 20:1 results in mineralisation where the micro-organisms decompose the sludge releasing nitrogen (Gavrilescu et al., 2012). In this study, PPMS increased the C:N ratio when added to the soils. In Singh (2014), Farm C, during 2010 had C:N ratio of 10:1 and increased after one application of PPMS to C:N ratio of 48:1 due to N immobilisation, followed by mineralisation.

Fertilisers are added to soils as a way of mitigating effects of nutrients immobilisation and nitrogen losses (Singh, 2014). The rate at which the immobilised N is released is a function of the soil turnover and available biomass that constitutes a greater fraction of immobilised Nitrogen. The decomposition of plant organic residues of different bio-degradability may result in a non-uniform mineralisation of the substrate (Johns, 2015).

3.1.6 Effects on Heavy metals

Investigations have shown that the application of PPMS to agricultural land did not lead to high heavy metal bioaccumulation in plants and soils (Abdullah et al., 2015, Abu Bakar et al., 2015, Reddy and Pillay, 2005, Jackson and Line, 1997, Singh, 2014). Increased levels of copper and zinc on all farms following the application of PPMS (Singh, 2014) could be due to using deinking PPMS containing dyes and pigments from recycling processes

Elevated levels of copper due to deinking PPMS was investigated (Turgut and Kose, 2015) and found no sign of increased levels of copper in plant leaves, stems and roots, and concluded that copper was immobilised resultant of complexing with organic matter present or through ion-exchange.

Table 3 above shows the minimum number of PPMS applications raising soils to the limits put in place for heavy metals by the United Kingdom (Aitken et al., 1998). In the case of this study (Singh, 2014), considering the low concentration of copper found in comparison the United Kingdom study, long term application of PPMS for the most limiting metal found (copper) would require 55 applications at 250 kg N/ha to reach the maximum threshold found in the United Kingdom.

3.2 Composting of PPMS

PPMS contains organic and inorganic materials, with potential nutritional value to soils. Application to soils may potentially rectify the organic and nutrient status of poor soils, improve fertility and reduce disposal costs . Composting is advantageous as it successfully diverts waste from landfills, reducing the environmental impacts of organic wastes in landfills while contributing to the reduction of GHG emissions.

In this research, previous studies on composting of pulp and paper mill sludge which were done on three scales i.e. lab experiments, 50 kg and 1 ton were considered. In this study, the effects of composting on process parameters such as micro/macro nutrients, heavy metals, soluble salts, C:N ratio, oxygen, moisture content and temperature were carefully considered.

The investigation also underlined the optimisation of PPMS, the assessment of the potential of composting, the safe application of the composted material to lands and the applicability in composting PPMS as a waste management strategy for landfill diversion.

TABLE 1: Soil property changes for samples obtained from farm A, farm B and farm C cultivating *Saccharum officinarum* (sugar cane).

	Sample	Years since application	Sample density (g/mL)	Exchange acidity (cmol/L)	Cation exchange capacity (cmol/L)	Acid saturation (%)	pH
Farm A	Control	-	1.34	0.05	2.67	1.87	4.81
	2010	1	1.26	0.82	3.01	27.24	3.89
Farm B	2010	1	1.25	0.06	5.16	1.16	6.4
	2009	2	1.14	0.03	6.21	0.48	6.57
Farm C	Control	-	1.29	0.02	3.86	0.52	5.94
	2010	1	0.77	0.09	11.82	0.76	7.09
	2008	3	0.98	0.08	11.6	0.69	5.24

Adapted from (Singh, 2014)

TABLE 2: Results and analysis of soils nutrients, organic carbon and carbon:nitrogen ratios (C:N) from farms A, B, and C cultivating *Saccharum officinarum* (sugar cane).

	Sample	Years since application	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Zn (mg/L)	Mn (mg/L)	Cu (mg/L)	Soil organic carbon (%)	C/N (%)
Farm A	Control	-	40	60	422	44	1.1	1	1.6	1	20
	2010	1	19	68	276	78	1.1	5	0.7	1.5	18.75
Farm B	2010	1	48	191	648	167	1.6	4	2.1	0.5	10
	2009	2	136	170	824	199	5.3	8	2.7	0.7	14
Farm C	Control	-	31	79	451	169	1.8	1	2.4	0.5	10
	2010	1	350	598	1642	244	9.9	16	4.5	2.4	48
	2008	3	55	409	1691	247	10	7	6.7	4.3	14.33

Adapted from (Singh, 2014)

3.2.1 Temperature

Temperatures around the centre of the heap generated most heat resultant of microbial activity, and decreased with increasing distances from the centre(Jackson and Line, 1997). The main process indicator of composting is temperature, where the process is gauged by monitoring temperature changes (Jackson and Line, 1997). Temperatures are predicted to rapidly raise once the thermophilic range is reached.

(Singh, 2014) on small scale composting of PPMS, temperature peaked at 4 weeks, longer than predicted. Resultant of the moisture content being high, disrupting the flow of oxygen and limiting activity of organisms. Rapid heat loss following the peak is not an indication of completed composting. If the process had completed following the peak, it would be due to moisture content being close to the upper limits of the available range, inhibiting oxygen flow resulting in limited or ceased microbial activity, ending the process early.

(Singh, 2014) on the large scale composting, max temperature reached 38 degrees Celsius, below the predicted temperature range of 60-70 degrees Celsius. The low maximum temperature was resultant of disrupted microbial activity by unnecessary turning heaps in efforts to ensure adequate aeration and avoid anaerobic conditions.

(Jackson and Line, 1997) showed addition of nutrients in day 1 caused the mean windrow temperature (temper-

TABLE 3: The average heavy metal contents found in soils, sewage sludge and PPMS, as well as the minimum amount of wastes applications required towards reaching the limits for soil metal contents in the United Kingdom at a pH range of between (pH 6.0 – 7.0).

	Zn	Cu	Ni	Cd	Pb	Hg	Cr
PPMS – Cumulative metal concentrations (mg/kg)	93	103	10.7	<0.25	21.4	0.07	23.8
Sewage sludge – Average concentration of metals (mg/kg)	922	574	65	5	201	3.5	208
Soils - Normal total concentration (mg/kg)	80	18	24	0.5	37	0.09	54
Soil limits (mg/kg) in soils amended with sludge in the United Kingdom	200	135	75	3	300	1	400
Amount of application required to reach the limit if applications are done at 250kg N/ha							
PPMS	62	55	227	>508	589	592	698
Sewage sludge	51	80	307	198	511	99	650

Adapted from (Aitken et al., 1998)

ature at centre of heap) increasing from 15 to 52 degrees Celsius due to nutrients stimulating microbial activity.

3.2.2 pH

During the thermophilic stage, proteolytic bacteria and temperature directly affects acetic acid formation and ammonium content changing the pH, and expected dropping to anoxic conditions before stabilising (Singh, 2014). Prior to completion, pH is expected to decline and representative of the degradation of recalcitrant compounds such as cellulose, hemicellulose and lignin. An increase in pH thereafter indicates maturity of the final product (Jackson and Line, 1997). pH varies over time and an optimum pH range is (6.5 to 7.5).

This can be seen on small scale compostability by (Singh, 2014) initially pH dropped to anoxic conditions resultant of acetic acid formation by microbial activity. Maturity of the compost is indicated by the pH reaching neutral levels. Large scale composting showed similar results, initially dropping to anoxic conditions followed by stabilisation to neutral levels. The initial decline is resultant of organic acid formation by degrading easily degradable carbon sources. The pH thereafter stabilises through liberation of ammonia and the depletion of carbon sources.

(Jackson and Line, 1997) determined that without adequately managing the pH, between 54-62% of the nitrogen pool could be lost resulting from ammonia volatisation. (Jackson and Line, 1997) absence of ammonia volatisation was evident and confirmed with a C:N ratio 23:1 and pH 5.4 at 21 weeks.

3.2.3 Moisture Content

Moisture content at high levels occupy most porous spaces, limiting oxygen circulation, and mitigated with additions of bulking agents (Lal, 2015). At low levels, microbial activity limits as they require wet environments for survival. Below 10%, microbial activity ceases.

Aeration was a limiting factor on the small scale compostability due to a high moisture content. A vital parameter, as porous spaces are required for air circulation. A high moisture content hinders the circulation of air (Singh, 2014).

Large scale composting showed deviations in moisture content during the first 6 weeks, as PPMS is clumpy and retains water in pockets, deviations decreased after 7 weeks resulting in moisture content becoming uniform (Singh, 2014). A desirable moisture content is between 40 and 60% (Jackson and Line, 1997).

3.2.4 Heavy Metals

Decreasing trends of heavy metals is resultant of oxidation and formation of organo-mineral complexes during the thermophilic stage, reducing soluble contents of metals (Jackson and Line, 1997, Singh, 2014). Humic substances are found to bind with metals exchangeable and carbonate fractions (Lal, 2015).

All heavy metals in small scale and large scale composting are shown to be within an acceptable limit (Environmental limits on compost quality)(Singh, 2014). Trends in both small and large scale experiments showed decreasing levels of copper and zinc (Singh, 2014) Another cause of disparity between PPMS and compost analysis is because of the bulk mass reducing during composting resultant of a concentrating effect. Reducing the volume increases the bulk density of compost.

3.2.5 Soluble Salts

Determining the soluble salt content provides an indication of deficiencies and excess regarding nutrient status of soil. The soluble salt contents of a growth medium receives contributions from all ionic compounds present (Johns, 2015). Nutrients do not damage plants, but effects water by reducing its potential, resulting in less water being available (Johns, 2015). Higher amounts of salts causes more energy being required to take up water (Singh, 2014).

Soluble salts normal range is between (0.35 to 0.64 dSm-1) (Jackson and Line, 1997), if below the normal range indicates the need for fertilization, and if above the range for extended periods result in root injury, leaf chlorosis, marginal burn and physiological drought (Jackson and Line, 1997). (Jackson and Line, 1997) obtained an electrical conductivity of 2.78dSm-1, and due to it falling significantly higher than the normal range, it would require reduction prior to soil application. Reductions can be achieved by leaching the composts with water in reducing the salt concentration.

Mineral nutrients are utilised as sources of nitrogen, phosphorous and potassium combined with volume reduction causes increases in the bulk density and ash content (Jackson and Line, 1997). Increased bulk density results in increased elemental concentrations, consequently increasing electrical conductivity.

3.2.6 C:N ratio

Carbon, an energy source, nitrogen necessary for plant growth and function, and microorganisms for protein and cellular synthesis, therefore achieving an optimal C:N ratio is a critical parameter in composting (Lal, 2015). An initial C:N ratio 30:1 is recommended and an optimal C:N ratio is between 20:1 & 25:1 (Reddy and Pillay, 2005), depends on bioavailability of carbon and nitrogen.

PPMS undergone small scale composting had an initial C:N (54.14:1) (Singh, 2014). Such a high ratio will cause composting process not to heat up due to insufficient nitrogen for organism's growth. In mitigating this nitrogen deficiency, urea pellets were added to achieve C:N 30:1 (Singh, 2014).

Large scale composting by (Singh, 2014) had shown C:N ratios drop to 13:1, an indication of increased carbon removal through decomposition.

Studies done on PPMS composting by (Jackson and Line, 1997) showed the C:N ratio decrease from 218:1 to 23:1 after 147 days with the supplementation of nutrient, indicating that the composted material will not immobilise nitrogen if applied to soils.

4. CONCLUSIONS

From literature reviewed, the addition of PPMS to soil as an amendment does not negatively affect fertility of soil. Addition of PPMS as a soil amendment increases soil organic carbon directly improving water holding capacity, supply of macro- and micro-nutrients, root environment and cation exchange capacity. Changes due to PPMS on pH affected nutrient availability but stabilised allowing for increased plant nutrient uptake and C:N ratio increased indicating beneficial use with more applications.

Composting PPMS show it becoming stable upon curing. Heavy metals present were reduced to acceptable levels during the thermophilic phase. Oxidation and organo-mineral complexes reduced the soluble contents of metals, therefore facilitating its transformation to an environmentally friendly product.

This has implications for waste management practices of pulp and paper industries. Potential of PPMS as a soil amendment or compost in improving factors allowing for increased soil fertility that in turn improves probability of aggregation overall resulting in a better structure. Such effects from either using PPMS as an amendment or compost will directly increase resistance of soils to degradation ultimately allowing for reduced erosion potential of soils.

Costs associated with purchasing of manures, composts and fertilisers can become exponentially high when determining amounts needed to remediate large tracks of lands requiring a proactive adaptability and mitigating approach prove unfeasible. Through utilisation of PPMS as an amendment or compost allow for substantial amounts of landfill diversion and the transformation of PPMS into a non-hazardous environmentally friendly product. Resource recovery is facilitated through such a practice. An important factor in such practices allow for carbon sequestering, substantially lowering the carbon footprint of PPI's. This is possible as PPMS will no longer be incinerated and landfilled saving the environment from emissions of harmful gasses released from combustion and landfill gasses such as methane.

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