Derivatization of Papyrus Reeds for Use as a Super Absorbance Mulch Substrate

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Abstract: ***Water is vital for the life and survival of plants. It is essential for transportation of plant nutrients from the soil; it maintains the plant posture and serves as a raw material for various chemical processes like photosynthesis, transpiration and buffer the plant against wide temperature fluctuations. Lack of enough water to crops may lead to wilting and eventually death, these may result to dependence on relief food or irrigation. Irrigation is a tedious task, which requires a lot of water, and so some farmers have resulted to mulching. Naturally occurring materials have been used as mulches for improvement of agricultural production since time immemorial. Plant remains and inorganic materials alike have been used traditionally but they lose water quickly. There are few studies on application of hydrogel in agriculture in India and North America but not much has been done in Africa. Papyrus reeds have been found to have the ability to absorb and retain substantial amount of water and the present study hypothesized that when modified, they could retain even more. This study therefore sought to enhance water retention of papyrus reed fibers through appropriate functionalization and cross-linking for use as a mulching agent. The mulch was functionalized and characterized by the use of FTIR, SEM, the swelling ratio was also calculated, and the mulch was applied in the field for the growing of kales and spinach. The FTIR peaks were observed for P-H at 2356.95 cm^{-1}, P-OH at 820 cm-^{1}, N-H at 3342 cm-^{1}, C=O at 1660 cm^{-1}, C-N at 1154.42 cm-^{1} and C-O at 1111.98 cm^{-1}. The SEM images showed increase in the number of crevices and pores on the surface of the functionalized and cross-linked papyrus reed. The phosphate derivative absorbed more than 12 times its weight. The derivatized mulch gave the best results of kales and spinach in terms of weight, which had a mean of 2kg, a mean length of 27.8 cm, mean width of 9.96 cm and a mean of 4 leaves. The mulch preserves water; it is non-toxic, biodegradable, leads to high yield and helps to save labor and water by reducing frequency of irrigation.***

Keywords: Absorbance, FTIR, Mulch, Papyrus reeds, SEM

1. Introduction

Mulching is the process of covering the top soil with plant material such as leaves, grass, twigs, crop residues, straw etc. The utilization of natural (organic) plants, wood or inorganic materials like stone chippings, plastic sheets for mulching is not a new concept in agriculture [29]. The use of grass clippings is perhaps the most widely recognized example for its use as a natural mulch in nurseries [32]. Different grass species occur naturally, wild or grown. Other plants, including bark and wood chippings, newspapers and leaves have also been used as mulches for improving soil moisture, weed control, beautification and soil improvement [29]. The use of naturally occurring materials as mulches for improvement of agricultural production has been studied before; and plant remains and inorganic materials like plastics and stones have been used traditionally in many countries [35, 36, 37].

Moisture conservation, reduced evaporation, reduced scalding and erosion, decreased splashing due to heavy rainfall, minimal weed growth and improved appearance of the farm are among the benefits of mulching [1, 4, 8, 17, 29]. Mulching also ensures fruits, vegetables and plants are unsoiled Organic types of mulches also advance the state of the soil as they provide organic matter when they decompose; this helps keep the soil loose. This encourages root development, improves the percolation of water, and also advances the soil water-holding capacity [35]. Decomposed plant organic matter provides fortification of plant nutrients and delivers a paramount atmosphere for important mutual soil micro-organisms.

Regional droughts carry the seeds of catastrophe. The immediate risk is famine; the long-term risk is destitution. In general, drought affects the crop planting seasons of March to May and September to November, and leads to increased food imports in the years following the drought. If the present trends persist, the whole country generally will face not only more severe drought events, but also significant reductions in food security [6, 18]. Seasonal rainfall patterns in Kenya are also very complex due to the presence of complex geography and large inland water bodies [7, 16].

Extended dry periods can cause wilting or drooping of leaves and weakening of the root system making the plants more susceptible to insects and diseases. Interrupted rainfall patterns has continually caused severe drought in Kenya, leaving behind serious consequences such as harvest failure, deteriorating pasture conditions, decrease in water availability and livestock losses leading to dependence on relief food and irrigation. Several studies have been done towards the application of hydrogels to plants as mulch but there is limited information on mitigation of water stress in plants through the application of hydrogel super-absorbents. This research investigated derivatization of cut *C. papyrus* by incorporation of cellulose acetate and reduction of cross-linking to increase water retention and improve swelling after water absorption.

2. Literature Survey

Cyperus papyrus, generally called papyrus, belongs to the family called *Cyperaceae* and is a very promising abundant macrophyte found in the tropical and subtropical African wetlands. Plant research has revealed that stacks of papyrus are able to build up great quantities of nutrients and possess a high standing phytomass. The papyrus plants take 6–9 months to be completely established with high and reliable normal re-growth and renewal even after harvesting [5, 26].

The ability of *C. papyrus* as plant stems to avoid soil erosion and trap adulterated soil sediments, utilize wastewater nutrients like Phosphorus and Nitrogen and integrate heavy metals and other organics into its biomass; very stress-free management which is just periodic harvesting, informs its suitability for use in tropical areas.

Use of ionic liquids (IL) has been reported several times for functionalization of cellulose [11, 15, 20, 31]. This research investigated derivatization of cut *C. papyrus* by incorporation of acetate within the polymer chains and reduction of cross-linking to increase water retention and improve swelling after water absorption.

Cellulose is a disperse linear single monomer polymer encompassing of regio- and enantioselective *beta*-1,4-glycosidic bond interconnected Dextro-glucose entities (**Fig 2.1**).The polymer has three chemically active –OH groups at the C–2, C–3, and C–6 atoms, which are accessible to the characteristic transformations of 1^0 and 2^0 alcoholic –OH entities. Because of this molecular structure, that is, the uniform arrangement of the –OH moeities, the organization of glucose moieties, systematic H-bond arrangements form severalkinds of semi-crystalline macro-molecular assemblies [15]. The H-bonding system also affects the entire biochemical conduct of cellulose [23]. A significant result of the macro-molecular construction is the insolubility of the supra-molecule in water and in common organic liquids, which still motivates the research on the solvents suitable for same phase chemical reactions.

Figure 2.1: Structure of cellulose

Cellulose functionalization has been employed to adjust the properties of macromolecule for different purposes, particularly, as a chemical feedstock for production of cellulose derivatives for a variety of industrial applications.

A new type of macro molecular synthetic water absorbing polymer material is super absorbent hydrogel. It has a water uptake potential as high as 100,000% of its own weight in a short period of time by osmosis and forms granules in soil to enhance soil properties [39]. Super absorbent hydrogel are generally white sugar-like hygroscopic materials that swell in water to form a clear gel made of separate individual particles and can retain moisture even under pressure without risk of conflagration or rupturing/blasting.

Super Absorbent hydrogel used in agriculture are mostly prepared from acrylic acids and a cross-linking agent like potassium by solution or suspension polymerization [22]. The polymer so formed is called a polyacrylate whose swelling capacity and gel modulus depends greatly on the quantity and type of cross-linker used. Polyacrylates are non-toxic, non-irritating and non-corrosive in nature and tested to be biodegradable with a degradation rate of 10%-15% per year. They demonstrate high water absorbance potential and can freely release 95% of the same under suction pressure by plant roots. They improve soil quality, preserves water and resists drought stress Increases seed sprouting and seedling development leading to better farm success [12]. They have advantage of being non-pollutant and biodegradable, as well as helping in reducing irrigation frequency and water consumption and creates a simple cyclic process to provide water directly to roots and prevent soil [2] compaction. Super Absorbent Hydrogel acts as micro water reservoirs at plant roots and as soil matter flocculants which closely bind loose soil thus forming loams that can help better root latching, in agriculture.

3. Materials and Methods

Sampling of Reed and Pre – Treatment

Reeds were collected from Tola dam in Thika, Kahaini in Muranga and Sobot in Olojolorok, all in Kenya. They were washed three times to remove impurities, half split and oven dried at 80^0C until there was no change in weight. They were then ground to reduce the size.

Reed Functionalization

Functionalization of Cellulose with Ethylene Diamine

Functionalization was done according to [9] guidelines. A sample of 10 g of pretreated papyrus reed was activated at 80 ^{0}C for 12 hours and cooled in a desiccator for three hours. It was then suspended in a 200 mL *N*,*N*-dimethylformamide (DMF) followed by addition of 35 mL of thionyl chloride at 80 ^{o}C (**Figure 3.1**), while stirring for 2 hours. The resulting solution was washed with dilute ammonium hydroxide solution and filtered under a vacuum at room temperature. 5 g portions of the chlorinated sample refluxed with 25 mL of ethylene-1, 2-diamine for three hours, filtered through sintered glass crucible and the solid dried in a vacuum at room temperature for 24 hours. The presence of anchored functional groups were confirmed using FTIR and SEM.

Cross-linking (Carboxylation)

100 g of the derivatized cellulose was placed in a beaker with 2,000 mL of 0.1M sodium hydroxide solution, stirred

for an hour and the liquid discarded. The mixture was washed twice with distilled water for 20 minutes and 30 minutes respectively, dried on a porcelain tray in open air, before adding 600 mL of 0.6M citric acid solution (Figure 3.1). The mixture was stirred for 30 minutes and the remaining supernatant discarded. The acid treated cellulose was washed with warm water until the effluent turned non-turbid with lead (II) nitrate in buffer solution at pH 4.8. Nitrogen gas was blown into a desiccator to create an inert environment and kept in a fume chamber with the sample until it was dry. The sample was then analyzed using SEM and FTIR.

Figure 3.1: Fuctionalization of cellulose using Ethylene Diamine

Preparation of Phosphorylated Cellulose

This was done according to protocol highlighted in [21]. The cellulose reaction with phosphoric acid in aqueous medium was performed by adding H_3PO_4 (85%) to pre-treated cellulose reeds medium at 30 ^oC. The temperature was raised to 100 ^oC and maintained for 30 min while stirring at 10 minute intervals. The reaction was then cooled in an ice bath, reeds decanted from the resulting suspension and washed at least three times. Urea was added and the temperature to adjusted to 152 ^oC. The entire reaction scheme is summarized in figure 3.2. The crosslinked functionalized cellulose fibres were then analysed using scanning electron microscope (SEM) and Fourier transform Infrared spectroscopy (FTIR).

Figure 3.2: Phosphorylation of Cellulose

Mulch Sample Analysis

Degree of Cross linking

Cross linking was determined by swelling experiment as described by Merle and others in [27]. 5g of the cross linked sample and 5 g of the non-derivatized sample were placed in 80 mL water in different beakers at the farm temperature. The two samples were left in the water for 24 hours, filtered and variation in weight determined. Depending on the grade of swelling, the Flory Interaction Parameter, the specific gravity of the liquid, and the hypothetical grade of cross-linking was determined following Flory's Network Theory [27, 24]. The mass of sample after drying, rate of swelling, cross-linking compactness and the soluble part were also determined.

Measuring the degree of water retention under farm conditions

Samples of both the control, derivatized, and non-derivatized papyrus reeds were subjected to ordinary farm condition temperatures and water retention was examined by weighing the mulched soil samples and the non-mulched soil sample. 500 mL of water was each added into three perforated containers, the first one had 1kg of soil only, and the second had 200g of non-derivatized mulch and 800g of soil while the third container had 200g of derivatized mulch and 800g of soil. The mass was determined three times per day; at 6.00am, noon and at 6.00 pm.

Field Experiments

The field experiments were carried out in Kiambu County, Kenya. In this area, *Brassica oleracia* (kales), *spinacia oleracea* (spinach) and other vegetables are normally grown under irrigation, where watering is done at least once per day.

The field experiments were done on a total of nine different plots of one by one meters in a green house. Three plots had no mulch; another three had plain papyrus reeds without derivatization or functionalization and the other three had derivatized and crosslinked mulch. The nine plots were subjected to the same conditions like the number of seedlings, soil type, amount of manure and fertilizer.

Watering intervals was not constant as watering was done in the first two weeks, then four weeks and lastly in five weeks to mimic random rainfall patterns. The mulch was applied during transplantation at the base of every plant, mixed with the soil. The amount of applied mulch was the same for the mulched plots. Equal amounts of water of 500 mL were used for watering each plant per watering session. The plants stayed for two weeks until the next phase of watering.

Optimum conditions for fiber water retention were established for derivatized and crosslinked papyrus reeds. Harvesting was done once per week and the produce was weighed for each plot and recorded. The height of the plants were measured after every two weeks and recorded.

4. Results and Discussion

FTIR spectra of the PAPYRUS REED mulches

The FT-IR revealed the existence of several fingerprints for different functional groups within the papyrus reed structure as shown in **Figure 4.1** and **4.2**

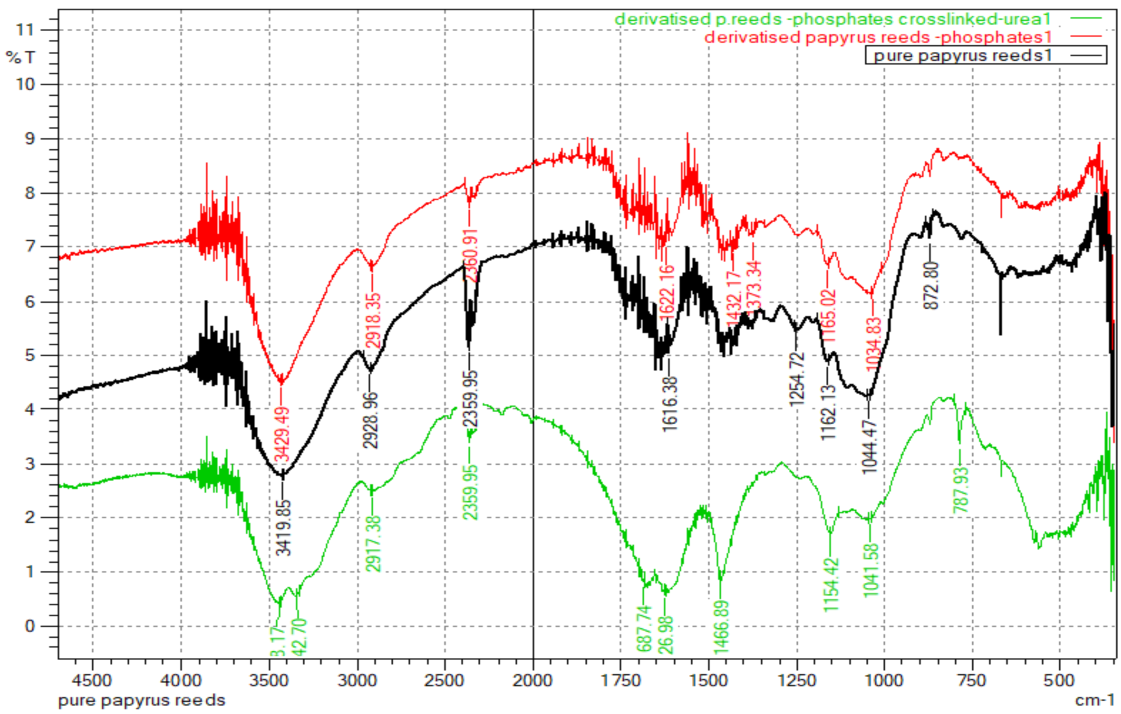

Figure 4.1: FTIR spectra overlay of non derivatized papyrus (black), phosphate derivatized papyrus (red) and a urea crosslinked phosphate derivatized papyrus (green)

The broad and strong band at about 3423.71- 3443.00 cm^{-1} could be assigned to either –OH or –NH groups [33]. The band at 2928.28 cm^{-1} was ascribed to C-H stretches while the band at 1600.0–1700.0 cm^{-1}, though with a lot of noise, was attributed to stretching –OH, C=O or N=C [32]. The band at 1373.3–1480 cm^{-1} confirmed the presence of an amide (Kapoor and Viraraghavan, 1997). The material in figure 4.1, (black and green), were phosphate modified with urea crosslink (green) while that of figure 4.2, (green and red), were modified with ethylene diamine and crosslinked with citric acid (green).

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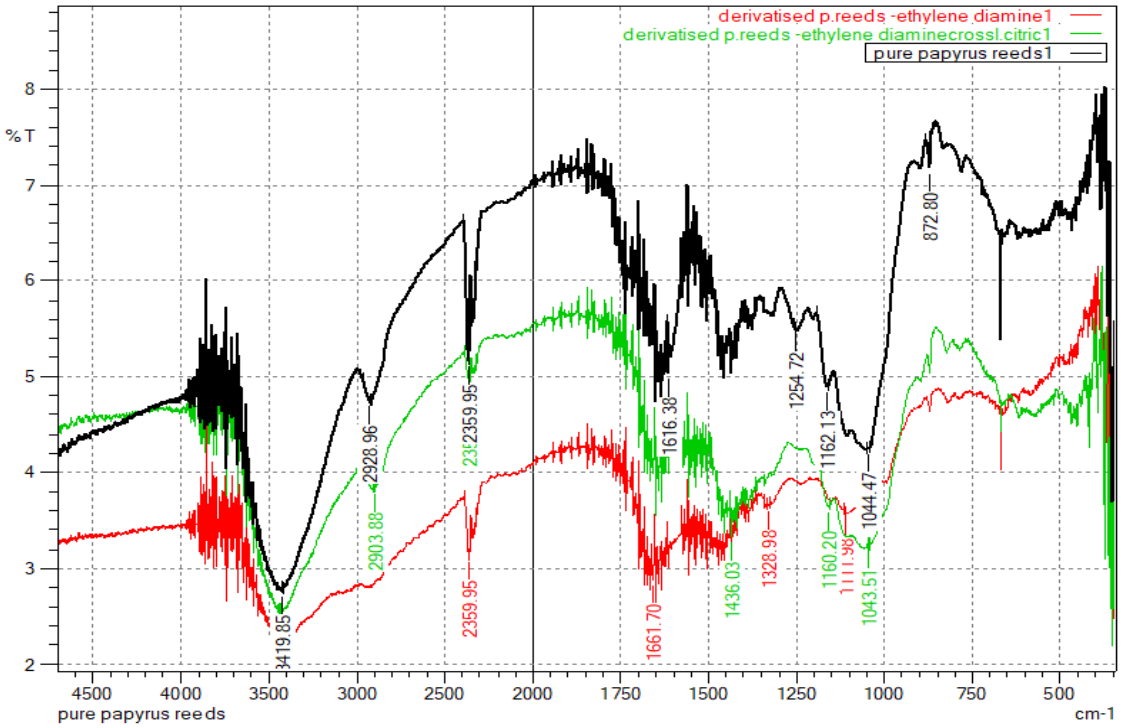

Figure 4.2: FTIR spectra overlay of non derivatized papyrus (black), ethylene diamine linked papyrus (red) and citric acid ethylene diamine cross-linked papyrus (green)

These FTIR spectra show where the typical absorption bands for cellulose can be observed: $v(OH\cdots O)$ at 3600–3100 cm^{-1}, $v(CH_2)$ and $v(CH_3)$ at 2980–2850 cm^{-1}, $v(OHO)$ at 1615–1665 cm^{-1}, $v(CH_2)$ and $v(CH_3)$ at1436 cm^{-1}, $v(CH)$, $v(CH_2)$ and $v(CH_3)$ at 1373 cm^{-1}, $v(CO)$ and $v(OH)$ at 1336 cm^{-1}, and $v(CH_2)$ at 1328 cm^{-1}, v(C OH) and v(C CH) at 1250-1255 cm^{-1}, v(C C) at1154–1163 cm^{-1}, v(C O C) at 1111 cm^{-1}, and asymmetrical stretching of a glucosidic ring within the plane at 1043–1045 cm^{-1}.

Figure 4.1 indicates a band at approximately 2359 cm^{-1} corresponding to the P–H stretching vibration mode [34], a band at approximately 1240 cm^{-1} corresponding to the P=O stretching mode (Aoki and Nishio, 2010) and the peaks between 820 and 900 cm^{-1} attributable to the P–OH stretching vibration mode of the phosphoric group [34]. For homogenously phosphorylated fibrous papyrus cellulose a highly increased band between 1500 and1700 cm^{-1} was observed with the four maxima occurring at 1616, 1622 1626 and 1687.7 cm^{-1}. The trace vibrations at 1616, 1622 and 1626 cm^{-1}in both figure 4.1 and 4.2, had most evidently originated from the same carbonyl groups, whilst vibrations at 1687 cm^{-1} were assigned to an enolic group, being in equilibrium with its tautomer, a conjugated carbonyl group [25]. In the case of homogenously phosphorylated crystalline cellulose increased broad and smooth bands between 1500 and 1750 cm^{-1} were detected.

The broadening of the peaks in the cross linked fibers of papyrus suggested that, for crystalline papyrus cellulose, the contribution of the residual water was more strongly bonded to the crystals than to the fibers, which could not be removed by lyophilization or oven drying and shielded the carbonyl/carboxyl bands. The intensities of the crystalline-sensitive peaks at 3000 cm^{-1} (C–H) and1300 cm^{-1} (CH_2) in both figures 4.1 and 4.2**,** were greatly increased for both homogenous phosphate derivatized papyrus cellulose, whilst the amorphous band at 872 cm^{-1} almost disappeared, indicating that its crystalline components were increased after phosphate derivatization.

Scanning Electron Microscope (SEM) Analysis

SEM analysis was done on the papyrus reed before and after derivatisation to determine SEM micrographs, and results were as indicated in Plate 4.1 and 4.2

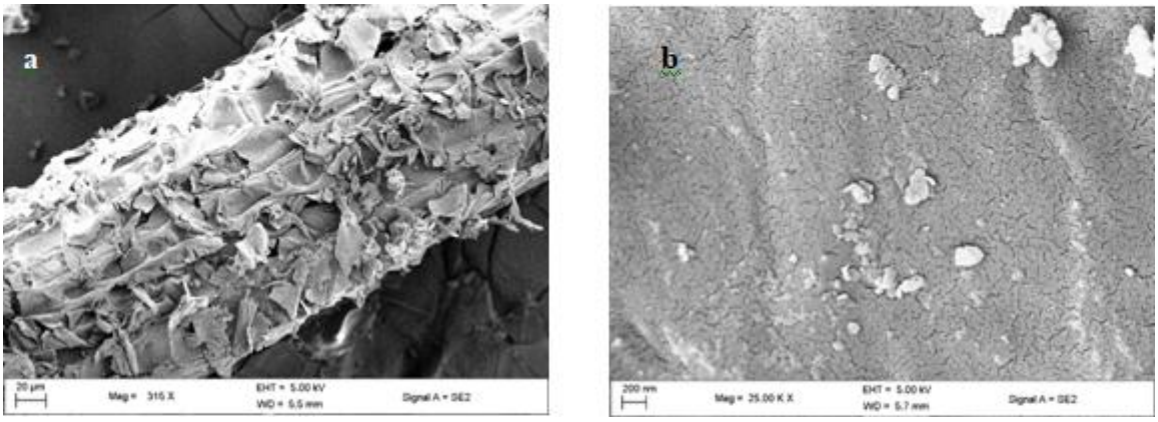

Plate 4.1: Non-derivatized papyrus SEM image, **a,** at x315 magnification showing just one reed fiber and, **b**, at x2500000 showing a section within a reed fiber

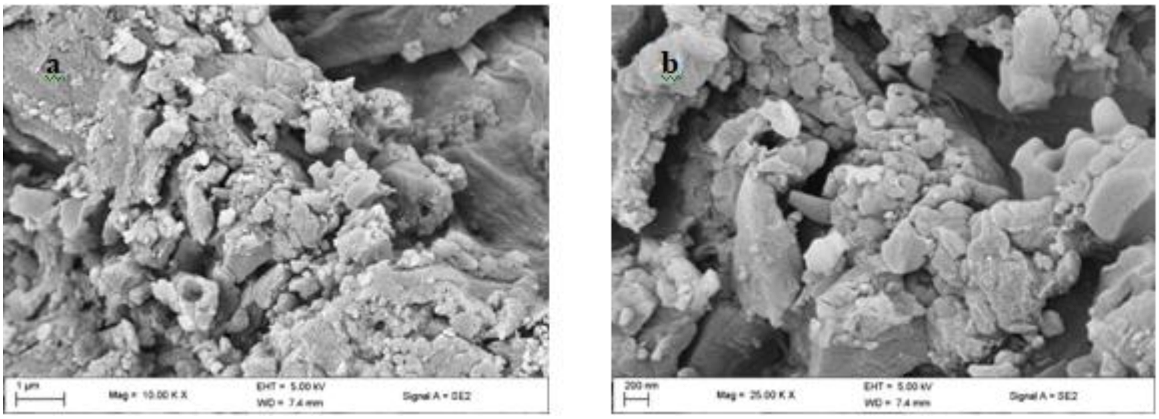

Plate 4.2: Derivatized papyrus reed with urea cross-link showing a section within a reed fiber, **a**, at x1000000 magnification and **b**, at x2600000 magnification

Plate 4.1 (a) is a single fiber within the papyrus reed powder while 4.1 (b) is the pure papyrus reeds powder before derivatization and cross-linking. The image shows a surface that is smooth with no pores. Plate 4.2 (a) is an image after cross-linking with phosphate, while 4.2 (b) is after an x 2600000 magnification. There is presence of crevices and pores on surface of the cross-linked papyrus reed in plate 4.2 (b), which are absent on the initial papyrus reeds in plate 4.1 (b). The pores are responsible for the more than 12 times water retention characteristics, which is comparable with that of a baby diaper which absorbs 15 times its weight [14].

5. Determination of Swelling Capacity

Swelling is a consequence of interaction between a solvent and a matrix. It is the first step before total solvation occurs (if possible). It is an increment in 3D geometry of the hydrogel's molecular structure. This expresses the affinity and exchange of enthalpy between the two phases. Sometimes and for partially cross-linked systems, swelling is a tool that measures the free volume (average) between knots. In other words, it measures the crosslink density [24]. Extent of swelling in polymers can be determined through changes in linear dimensions or through volumetric changes. The latter was considered in this study, and the results were as shown in **Table 4.1 and 4.2**

From the results, the swelling percentage was determined using the formula:

$$\text{Swelling (\%)} = \frac{(W_s - W_d)}{W_d} \times 100 \ldots\ldots 4.1$$

Where W_d= Weight of dry polymer and
W_s = weight of swollen polymer

Table 4.1: Data from swelling experiment for the determination of the water absorption capacity of the respective mulches with Urea cross-link

Experiment	Weights (Grams)	Net Weight (grams) after excess solvent filtration
Non-Derivatized Mulch +water + Beaker	115.447	
Beaker	99.36	11.54
Derivatized Mulch + Water+ Beaker	164.32	
Beaker	114.13	45.27
Weights after Drying (Grams)		
Non-derivatized fibers		4.73
Derivatized fibers		3.44

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Table 4.2: Data from swelling experiment for the determination of the water absorption capacity of the respective mulches with Citric Acid cross-link

Experiment	Weights (Grams)	Net Weight (grams) after excess solvent filtration
Non-Derivatized Mulch +water + Beaker	115.35	
Beaker	99.20	11.44
Derivatized Mulch + Water+ Beaker	155.67	
Beaker	114.26	30.23
Weights after Drying (Grams)		
Non-derivatized fibers		4.63
Derivatized fibers		3.98

Swelling percentage for the non-derivatized and the derivatized with urea cross-link were found to be **143.97 %** and **1215.99 %** respectively. This means that, the non-derivatized mulch absorbed water 1.43 times its weight whereas the derivatized mulch with urea cross-link absorbed 12.15 times its weight; a desirable property for the latter. This represents more than eightfold water absorption increment for the phosphate-cross linked mulch derivative compared to the non-derivatized one.

The swelling percentage for citric acid cross-linked derivatize and non-derivatize was found to be **659.548%** and **147.08%.** The implication that, the derivatized one absorbs 6.6 times its weight, representing more than a fourfold increment compared to the non-derivatized one. It was also realized that, some parts of the polymer dissolved during the swelling experiment and this was evident by the reduction in the weight of the dried polymer obtained at the end of the swelling experiment. Dissolution was more pronounced in the derivatized mulch than in the non-derivatized mulch. This is a desired property, as it will eventually lead to release of the phosphate fertilizer for the phosphate type. This will also enrich the soil with nutrients in the form of dissolved organic matter.

According to Flory's interaction theory and equation, when the volume fraction of polymer in the swollen gel is used. The swelling ratio is defined as

$$Q = \frac{1}{V} = \frac{1}{45.27} = 0.02209 \ldots\ldots\ldots\ 4.2$$

If this equation is used, the Q value is correlated to the polymer-solvent interaction parameter, $\chi^{3/5}$ [30]

Water Retention

The results from the soil sample water retention are presented in **tables 4.2 and 4.3,** as arithmetic mean for the triplicate measurements together with their respective standard errors. **Table 4.2** data involved the use of half a liter water for all the soil types while **Table 4.3** involved the use of enough water, depending on the capacity of the soil-mulch sample ,i.e., half a liter for non-mulch soil sample, a liter for pure mulched-soil sample and two liters for the derivatized mulch-soil sample.

Table 4.2: Water retention for the different soil samples over a period of seven days. The values are averages for the triple repeated experiments together with the standard error

Day	Soil Samples		
	No Mulch	Non-Derivatized Mulch	Derivatized Mulch
1	1.470±0.000^{k}	1.500±0.000^{j}	1.500±0.000^{j}
2	1.330±0.006^{f}	1.437±0.006^{g}	1.483±0.003^{c}
3	1.137±0.014^{c}	1.237±0.006^{e}	1.437±0.003^{g}
4	1.030±0.005^{b}	1.203±0.006^{d}	1.327±0.003^{f}
5	1.010±0.000^{a}	1.140±0.000^{c}	1.230±0.006e
6	1.000±0.000^{a}	1.000±0.000^{a}	1.140±0.000^{c}
7	1.000±0.000^{a}	1.000±0.000^{a}	1.130±0.000^{c}

It was clear, from tables 4.2 and figure4.3, that derivatized mulch-soil sample retained water even when the other two types of samples had lost all their water. This is attributed to its improved structure for water retention. There was a significant difference between the non-derivatized mulch and the derivatized mulch. The curve for derivatized mulch was also smoother, implying reliability in its water content and release as opposed to the other curves that have sharp turns.

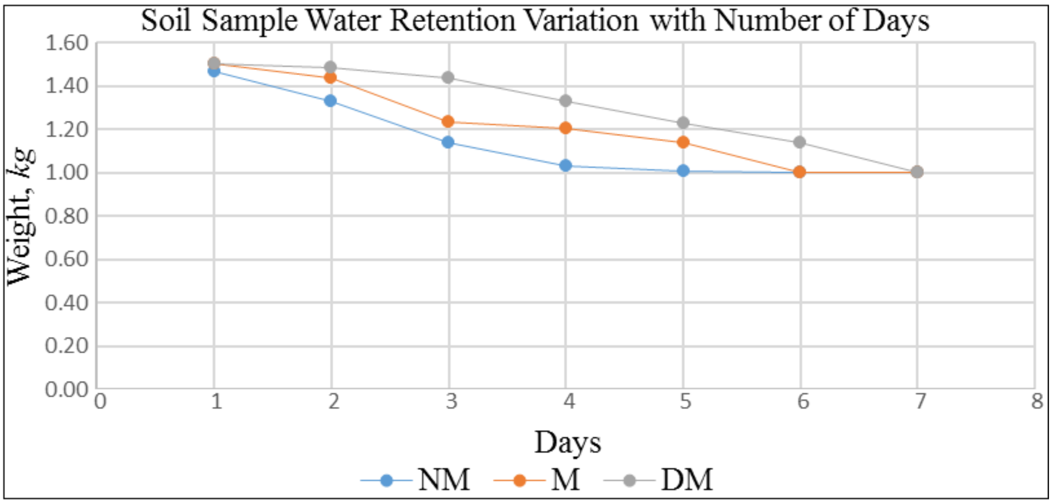

Figure 4.3: Soil sample water retention versus time for the water retention experiment. NM–No Mulch-soil sample (1kg soil), M–Non-derivatized papyrus mulch-soil sample (200g mulch and 800g soil), DM Derivatized papyrus mulch-soil sample (200g mulch and 800g soil)

Table 4.3: Soil samples masses water retention at maximum water holding capacity and their temporal variation

Day	Soil Samples Masses (*kgs*)		
	No Mulch (0.5 *l* H_2O)	Non-Derivatized (1 *l* H_2O)	Derivatized (2 *l* H_2O)
1	1.450 ± 0.017^{i}	2.000 ± 0.000^{i}	3.000 ± 0.000^{u}
2	1.377 ± 0.003^{l}	1.833 ± 0.003^{k}	2.910 ± 0.006^{t}
3	1.243 ± 0.009^{e}	1.600 ± 0.006^{w}	2.800 ± 0.010^{b}
4	1.030 ± 0.006^{c}	1.393 ± 0.009^{g}	2.630 ± 0.006^{r}
5	1.000 ± 0.000^{a}	1.317 ± 0.009^{f}	2.507 ± 0.009^{q}
6	1.000 ± 0.000^{a}	1.220 ± 0.012^{e}	2.333 ± 0.003^{p}
7	1.000 ± 0.000^{a}	1.123 ± 0.003^{d}	2.127 ± 0.009^{o}
8	1.000 ± 0.000^{a}	1.013 ± 0.007^{b}	2.077 ± 0.003^{n}
15	1.000 ± 0.000^{a}	1.000 ± 0.000^{a}	2.013 ± 0.003^{m}
27	1.000 ± 0.000^{a}	1.000 ± 0.001^{a}	1.11 ± 0.002^{m}

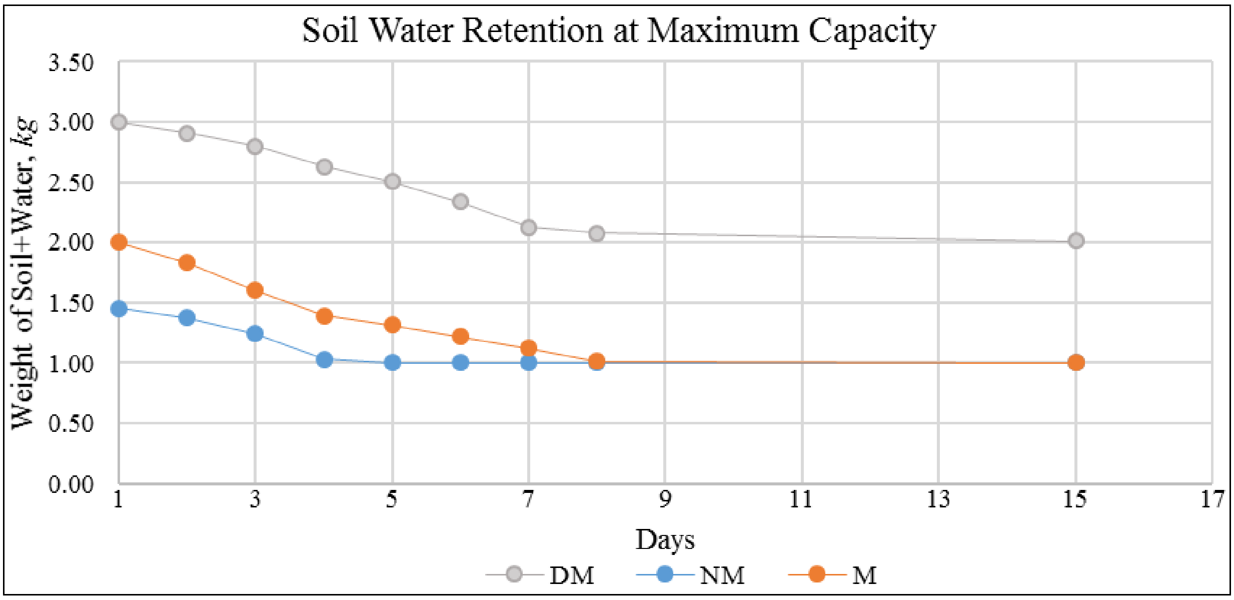

Figure 4.4: Variation in water retention with time at maximum water absorption capacity for the three types of soil samples (DM- derivatized mulch-soil sample (200g mulch and 800g of soil), NM-no mulch (1kg) soil sample and M- non-derivatized mulch-soil sample (200g mulch and 800g soil)

From table 4.3 and figure 4.4, the water retention at maximum capacity for the soil-mulch samples and unmulched revealed higher capacity for the derivatized mulch. This confirmed the higher amount of water results witnessed, and the capacity to hold such vast amounts of water is illustrated by the SEM images in plates 4.1 and 4.2

Plant Growth and Yield Analysis

Kales (*Brassica oleracia*) and Spinach (*Spinaciaoleracea*) were each transplanted into greenhouse in four different sections, 1 m by 1 m, in a 1 x 1 randomized block design each with a replica, and four weekly harvests between 28 and 57 days after trans-plantation. Each block had 4 plants along each side totalling to 20 plants on each section for each plant. Kales were grown on their own section, and the same was applied for spinach. Another section was mixed just to see the effect of mixing the food crops in a mulched environment, although, this was not studied further than just visually seeing if some noticeable effect was present. Each row was harvested at a time during harvest. At each harvest, leaf length and width were measured. Number of leaves and their weights were also determined and recorded. This data is presented in *table 4.4*.

Plots that had no mulch were observed to lose water quickly and the crops wilted leading to poor yield and reduced number of plants. Plots that had non-derivatized mulch had good yield but the crops did not look as healthy as the crops grown in plots with derivatized mulch. This is because on top of the derivatized mulch having a higher water retention and release capacity, bits of it dissolved into the soil enriching it via organic matter and phosphate fertilizer release. Images of the plant health differences in the three plots are as shown in *plate 4.3 a, b* and *c*.

Plate 4.3: Plant health assessment **a,** withering/wilting of vegetable for non-mulched soil, **b**, mulched soil but unhealthy plants shown by decolourization on the leaves, **c** mulched soil with derivatized papyrus and healthy vegetables, the derivatized papyrus on top of having the organic fertilizer supplies phosphate fertilizer to the plants

Table 4.4: Analysis of Mean and standard error for the number of leaves, length, Width and the weight of produce

Descriptive Analysis				
		Mean	Std. Error	95% confidence limits
No of weeks	Derivatized	2.5±1.17	0.34	1.7580
	non derivatized	2.50±1.17	0.34	1.7580
	no mulch	2.50±1.17	.34	1.7580
The plot identity	Derivatized	2.00±0.85	.25	1.4582
	non derivatized	2.00±0.85	.25	1.4582
	no mulch	2.00±0.85	.25	1.4582
Weight of the leaves	Derivatized	2.00±0.35	.10	1.7799
	non derivatized	1.72±0.33	.09	1.5184
	no mulch	0.97±0.17	.05	.8696
Number of leaves	derivatized	4.17±0.39	.11	3.9193
	non derivatized	3.58±0.51	.15	3.2562
	no mulch	3.50±0.52	.15	3.1682
Length of the plant	derivatized	27.82±5.10	1.54	24.3950
	non derivatized	25.16±4.52	1.31	22.2920
	no mulch	16.54±4.11	1.19	13.9309
	Total	23.04±6.60	1.12	20.7744
Width of the leaves	derivatized	9.96±2.10	.61	8.6210
	non derivatized	8.33±1.44	.41	7.4213
	no mulch	5.33±1.23	.36	4.5512

Table 4.4 shows a comparison between growing of kales using derivatized mulch, non derivatized mulch and no mulch at all. The weight of leaves on plots with derivatized mulch was 2.00kg which was higher than 1.72kg on plots with non derivatized mulch. The width of leaves was also different whereby the plots with derivatized mulch had 9.96cm, non derivatized had 8.33cm while plots which had no mulch was the least having 5.33cm. There was also a significant difference on the length of leaves on different types of mulches as shown in the table. The differences in the results was attributed to the fact that the derivatized mulch was able to retain a lot of water which it released to the plant roots during the long spell of not watering. The results were also confirmed by Ahmed.et. al., [2], who worked on preparation and applications of hydrogels. He stated that hydrogels creates a simple cyclic process to provide water directly to the plant roots.

It is worth noting that phosphates and urea were used during the functionalization and cross-linking which could have also contributed to the health growth of the plants. This results were also confirmed by Milani. et. al., [28], who worked on polymer and its application in agriculture. He pointed out that the super absorbent hydrogel can reduce overuse of fertilizers and pesticides in the field.

6. Conclusions

Ethylene diamine and phosphate derivatives of the derivatized papyrus reed mulch were cross-linked with citric acid and urea respectfully. This cross-linking increased the porosity of the fibers and the overall swelling capacity to absorb and retain water more than 12 times its weight for the phosphate derivative, and more than 6.6 times for the ethylene diamine derivative.

The derivatized mulch held water for about 27 days, while the non-derivatized held it for only 8 days. Derivatized mulch registered the highest growth and yield non-derivatized mulch. Growth was comparatively low in the plots without any mulch. Therefore, the use of mulch in areas with inadequate agricultural water is highly encouraged so as to boost agricultura yield.

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